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NUREG-2184

Supplement to the U.S. Department of Energy's Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada

Draft Report for Comment

Office of Nuclear Material Safety and Safeguards

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Draft Report for Comment

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ABSTRACT

This “Supplement to the Department of Energy’s Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada” (supplement) evaluates the potential environmental impacts on groundwater and impacts associated with the discharge of any contaminated groundwater to the ground surface due to potential releases from a geologic repository for spent nuclear fuel and high-level radioactive waste at Yucca Mountain, Nye County, Nevada. This supplements the U.S. Department of Energy’s (DOE’s) 2002 “Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada” and 2008 “Final Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada,” in accordance with the findings and scope outlined in the U.S. Nuclear Regulatory Commission (NRC) staff’s 2008 “Adoption Determination Report for the U.S. Department of Energy’s Environmental Impact Statements for the Proposed Geologic Repository at Yucca Mountain.”

This supplement describes the affected environment and assesses the potential environmental impacts with respect to potential contaminant releases from the repository that could be transported through the volcanic-alluvial aquifer in Fortymile Wash and the Amargosa Desert, and to the Furnace Creek/Middle Basin area of Death Valley. This supplement evaluates the potential radiological and nonradiological impacts—over a one million year period—on the aquifer environment, soils, ecology, and public health, as well as the potential for disproportionate impacts on minority or low-income populations. In addition, this supplement assesses the potential for cumulative impacts associated with other past, present, or reasonably foreseeable future actions. The NRC staff finds that all of the potential direct, indirect, and cumulative impacts on the resources evaluated in this supplement would be SMALL.

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This supplement evaluates the potential environmental impacts on groundwater and impacts associated with the discharge of any contaminated groundwater to the ground surface due to potential releases from a geologic repository for spent nuclear fuel and high-level radioactive waste at Yucca Mountain, Nye County, Nevada. This supplements the U.S. Department of Energy's (DOE's) 2002 "Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada" and 2008 "Final Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada," in accordance with the findings and scope outlined in the U.S. Nuclear Regulatory Commission (NRC) staff's 2008 "Adoption Determination Report for the U.S. Department of Energy's Environmental Impact Statements for the Proposed Geologic Repository at Yucca Mountain."

In Section 3.2.1.4.2 of the Adoption Determination Report (ADR), the NRC staff found that DOE's environmental impact statements (EISs) did not adequately characterize impacts from potential contaminant releases to groundwater and from surface discharges of groundwater. Specifically, DOE's analysis does not provide adequate discussion of the cumulative amounts of radiological and nonradiological contaminants that may enter the groundwater over time and how these contaminants would behave in the aquifer and surrounding environments. This supplement provides the information the NRC staff identified as necessary in its ADR. Two distinct but related aspects of potential impacts on the groundwater system are addressed in this supplement. These are (i) the nature and extent of the repository's impacts on groundwater in the aquifer (beyond the regulatory compliance location) and (ii) the potential impacts of the discharge of potentially contaminated groundwater to the ground surface.

This supplement describes the affected environment with respect to the groundwater flow path for potential contaminant releases from the repository that could be transported beyond the regulatory compliance location through the volcanic-alluvial aquifer in Fortymile Wash and the Amargosa Desert, and to the Furnace Creek/Middle Basin area of Death Valley. The analysis in this supplement considers both radiological and nonradiological contaminants. Using groundwater modeling, the NRC staff finds that contaminants from the repository would be captured by groundwater withdrawal along the flow path, such as the current pumping in the Amargosa Farms area, or would continue to Death Valley in the absence of such pumping. Thus, this supplement provides a description of the flow path from the regulatory compliance location to Death Valley, the locations of current groundwater withdrawal, and locations of potential natural discharge along the groundwater flow path. The supplement evaluates the potential groundwater-related environmental impacts at these locations over a one-million year period following repository closure.

To evaluate the environmental impacts, this supplement assumes the repository and performance characteristics in the DOE license application, as evaluated in the NRC staff's Safety Evaluation Report. This supplement describes the potential impacts that could occur under different climate conditions and under different assumptions for groundwater withdrawal. The analysis in this supplement encompasses the range of credible future climates and human activities affecting groundwater in the Yucca Mountain region, and includes conservative assumptions for future conditions and processes. Future climates are projected to include periods that are relatively hot and dry (similar to present-day conditions) and periods that are relatively cooler and wetter over the one-million-year time period. These climate states are based on geologic evidence of past climate change cycles in the region. They are also consistent with DOE's model of repository performance, in that they capture the rates of contaminant release and transport through the groundwater system. Projected human-induced climate change (a future climate that is warmer and drier than present, or the longer persistence of the present-day climate conditions) is represented within the range of potential climate conditions, repository performance, and water use considered in this supplement.

This supplement evaluates the potential impacts on the aquifer environment, soils, ecology, and public health, as well as the potential for disproportionate impacts on minority or low-income populations. In addition, this supplement assesses the potential for cumulative impacts that may be associated with other past, present, or reasonably foreseeable future actions. Cumulative impacts on groundwater and from surface discharges of groundwater are the potential impacts of the proposed repository when added to the aggregate effects of other past, present, and reasonably foreseeable future actions.

The NRC staff finds that all of the impacts on the resources evaluated in this supplement would be SMALL. The NRC staff's analysis includes the impact of potential radiological and nonradiological releases from the repository on the aquifer and at surface discharge locations of groundwater beyond the regulatory compliance location. The peak estimated annual individual radiological dose over the one-million-year period at any of the evaluated locations is 1.3 mrem [0.013 mSv]. This maximum dose is associated with pumping and irrigation at the Amargosa Farms area, and the estimated radiological dose at any other potential surface discharge location is lower. The NRC staff concludes that the estimated radiological doses are SMALL because they are a small fraction of the background radiation dose of 300 mrem/yr [3.0 mSv/yr] (including radon), and much less than the NRC annual dose standards for a Yucca Mountain repository in 10 CFR Part 63 {15 mrem [0.15 mSv] for the first 10,000 years, and 100 mrem [1 mSv] for one million years, after permanent closure}. Based on conservative assumptions about the potential for health effects from exposure to low doses of radiation, the NRC staff expects that the estimated radiation dose would contribute only a negligible increase in the risk of cancer or severe hereditary effects in the potentially exposed population. Impacts to other resources at all of the affected environments beyond the regulatory compliance location from radiological and nonradiological material from the repository would also be SMALL. The cumulative impact analysis concludes that, when considered in addition to the incremental impacts of the proposed action, the potential impacts of other past, present, or reasonably foreseeable future actions would be SMALL.

ACRONYMS AND ABBREVIATIONS

ACHP	Advisory Council on Historic Preservation
ADR	Adoption Determination Report
BLM	Bureau of Land Management
CCD	Census County Division
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*Code of Federal Regulations*
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DVRFS	Death Valley Regional Flow System
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
FR	*Federal Register*
HLW	high-level radioactive waste
IAEA	International Atomic Energy Agency
I	iodine
ICRP	International Committee on Radiological Protection
LLRW	low-level radioactive waste
MCL	mean concentration limit
Mo	molybdenum
mrem	millirem
mSv	milliSieverts
NDWR	Nevada Division of Water Resources
NEDP	National External Diploma Program
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act
Ni	nickel
NNSA	National Nuclear Security Administration
NNSS	Nevada National Security Site
Np	neptunium
NRC	U.S. Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act
NWRPO	Nuclear Waste Repository Project Office
Pu	plutonium
RFFAs	reasonably foreseeable future actions
RMEI	reasonably maximally exposed individual
ROD	record of decision

ACRONYMS AND ABBREVIATIONS (continued)

SAR	Safety Analysis Report
Se	selenium
SEIS	supplemental environmental impact statement
SER	Safety Evaluation Report
SEZ	solar energy zone
SHPO	State Historic Preservation Office
SNF	spent nuclear fuel
SNWA	Southern Nevada Water Authority
SNDWR	State of Nevada Division of Water Resources
SWEIS	Site-Wide Environmental Impact Statement
Tc	technetium
TDS	total dissolved solids
Th	thorium
TSPA	Total System Performance Assessment
U	uranium
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
V	vanadium

1 INTRODUCTION

This "Supplement to the Department of Energy's Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada" (supplement) evaluates the potential environmental impacts on groundwater and impacts associated with the discharge of any contaminated groundwater to the surface due to potential releases from a geologic repository for spent nuclear fuel (SNF) and high-level radioactive waste (HLW) at Yucca Mountain, Nye County, Nevada. This supplements the U.S. Department of Energy's (DOE's) 2002 "Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada" (DOE, 2002) and 2008 "Final Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada" (DOE, 2008a), in accordance with the findings and scope outlined in the U.S. Nuclear Regulatory Commission (NRC) staff's 2008 "Adoption Determination Report for the U.S. Department of Energy's Environmental Impact Statements for the Proposed Geologic Repository at Yucca Mountain" (NRC, 2008a).

The NRC staff has prepared this supplement pursuant to the National Environmental Policy Act of 1969, as amended (NEPA) and the Nuclear Waste Policy Act of 1982, as amended (NWPA), as implemented in NRC's regulations in Title 10 of the *Code of Federal Regulations* (CFR) Part 51.

1.1 Background—License Application and EIS Adoption Review Process

The NWPA specifies that in the United States, SNF and HLW will be disposed of in a deep geologic repository. Amendments to the NWPA in 1987 identified Yucca Mountain, Nevada, as the single candidate site for characterization as a potential geologic repository. DOE prepared a final environmental impact statement (EIS) related to the construction, operation, and closure of a potential geologic repository for HLW at Yucca Mountain, Nevada, in February 2002. The EIS accompanied the Secretary of Energy's site recommendation to the President on February 14, 2002, pursuant to NWPA Section 114(f). In July 2002, Congress passed and the President signed a joint resolution designating Yucca Mountain as the site for development of a geologic repository. In October 2006, DOE announced its intent to prepare a supplemental EIS to update the 2002 EIS (71 FR 60490).

DOE published a final supplemental EIS (SEIS) in June 2008. Also that June, DOE submitted its license application (DOE, 2008b), including the 2002 EIS and 2008 SEIS to NRC seeking authorization to construct a geologic repository at Yucca Mountain. In accordance with NWPA Section 114(f)(5) and NRC's regulations in 10 CFR 51.109, NRC is to adopt DOE's EIS to "the extent practicable." The NRC staff reviewed DOE's EISs and found, as stated in its Adoption Determination Report (ADR), that it is practicable for NRC to adopt the EISs, with further supplementation (NRC, 2008a). Specifically, the NRC staff determined that a supplement was needed because the NRC staff concluded that DOE's EISs did not adequately address potential repository-related impacts on groundwater and from surface discharges of groundwater.

After docketing the DOE license application and issuing the ADR in September 2008, the NRC staff began its licensing review and development of its Safety Evaluation Report (SER). In

October 2008, the Commission issued a Notice of Hearing and Opportunity to Petition to Intervene, which began the adjudicatory process (NRC, 2008b).

In February 2010, the Secretary of Energy stated that the “Administration has determined that developing a repository at Yucca Mountain, Nevada is not a workable option.” (DOE, 2010) DOE filed a motion with the Atomic Safety and Licensing Board presiding over the adjudication seeking permission to withdraw its license application. The Board denied that request in June 2010, and the Commission did not overturn the Board’s decision. After Congress reduced funding for the NRC’s review of the license application, NRC began an orderly closure of its Yucca Mountain activities. On September 30, 2011, the Board suspended the adjudicatory proceeding, and the NRC staff’s Yucca Mountain license application review activities ceased.

In August 2013, the U.S. Court of Appeals for the District of Columbia Circuit issued a decision directing the NRC to resume the licensing process for DOE’s license application. In November 2013, the Commission directed the NRC staff to complete the SER and requested that DOE prepare the EIS supplement that the NRC staff had determined to be necessary in the ADR. DOE informed the NRC that it would update a 2009 technical analysis it provided to NRC (DOE, 2014a; 2009a), but that it would not prepare a supplement to its EISs (DOE, 2014b).

In January 2015, the NRC staff completed the five-volume SER (NRC, 2015a,b; 2014b; 2010). In February 2015, the Commission directed the NRC staff to prepare the EIS supplement. The adjudicatory proceeding remains suspended.

1.2 Scope and Assumptions

The NRC staff’s general approach in this supplement for evaluating the potential impacts to groundwater and from the surface discharge of groundwater is identified in the NRC staff’s 2008 ADR and follows the guidance in NUREG–1748, “Environmental Review Guidance for Licensing Actions Associated with NMSS Programs: Final Report” (NRC, 2003).

1.2.1 Need for Supplementation and Scope of the Analysis

Section 3.2.1.4 of the ADR describes the NRC staff’s evaluation of the adequacy of the analyses in DOE’s 2002 and 2008 EISs. Since the ADR was prepared (in 2008), the NRC staff has not identified new information that would change the NRC staff’s position described in detail in the ADR.

Section 3.2.1.4.2 of the ADR, “Impacts on Groundwater and from Surface Discharge of Groundwater,” provides the NRC’s staff’s assessment of the groundwater and surface discharge impact analyses in DOE’s EISs. As described in the ADR, the NRC staff finds that the EISs did not adequately characterize potential contaminant release to groundwater and from surface discharges of groundwater. While DOE’s analysis of the postclosure behavior of the repository recognizes that the release of contaminants to groundwater can be expected over the long term, the analysis does not provide adequate discussion of the cumulative amounts of radiological and nonradiological contaminants that may enter the groundwater over time, and how these contaminants would behave in the aquifer and surrounding environments.

This supplement provides the information the NRC staff identified as necessary in its ADR. Two distinct but related aspects of potential impacts on the groundwater system are addressed in this supplement. These are (i) the nature and extent of the repository’s impacts on groundwater in the aquifer and (ii) the potential impacts of the discharge of potentially contaminated groundwater to the ground surface. These two aspects are described further below:

Impacts on Groundwater

- A description of the full extent of the volcanic-alluvial aquifer, particularly those parts that could become contaminated, and how water (and potential contaminants) can leave the flow system.

- An analysis of the cumulative amount of radiological and nonradiological contaminants that can be reasonably expected to enter the aquifer from the repository, and the amount that could reasonably remain over time.

- Estimates of contamination in the groundwater, given potential accumulation of radiological and nonradiological contaminants.

Impacts from Surface Discharges of Groundwater

- A description of the locations of potential natural discharge of contaminated groundwater for present and expected future wetter periods.

- A description of the physical processes at potential surface discharge locations that could affect accumulation, concentration, and potential remobilization of contaminants carried by groundwater.

- Estimates of the amount of contaminants that could be deposited at or near the surface, including estimates of the amount of discharged groundwater and near-surface evaporation; the amounts of radiological and nonradiological contaminants in that groundwater; contaminant concentrations in resulting deposits; and potential environmental impacts.

This supplement assesses the potential groundwater and surface discharge impacts over a period of approximately one million years after repository closure.

1.2.2 Analysis Assumptions

The analyses in this supplement make the following assumptions:

- Repository characteristics and performance are consistent with the information DOE provided in its license application, as well as the conclusions in the NRC staff’s SER. The NRC staff found (i) the analytic models in DOE’s performance assessment for the repository to be technically sound and to provide an acceptable representation of repository performance; and (ii) DOE’s technical basis for excluding certain features, events, and processes from the performance assessment was acceptable (NRC, 2014a; Section 2.2.1.4.1). Information from DOE’s application, supporting documents, and the NRC staff’s SER, is referenced in this supplement where appropriate.

- The current population in the area near Yucca Mountain and its distribution (as discussed in NRC, 2015a; Section 2.1.1.1.3.2, Regional Demography) will continue for the period analyzed in the supplement (approximately one million years). The supplement assumes the current range of human activities will also continue for this period. This is consistent with 10 CFR Part 63, Subpart L.

- With the exception of assumptions concerning groundwater pumping (described below), the NRC staff did not speculate about the types of future human activities that could occur far in the future. Unsupportable assumptions about human activities far in the future would result in correspondingly unsupportable conclusions about the potential impacts. This is consistent with NRC regulations in 10 CFR 63.305(b) and EPA regulations in 40 CFR 197.15, which direct the DOE not to project changes in society, the biosphere (other than climate), human biology, or increases or decreases of human knowledge or technology.

This supplement describes the potential impacts that could occur under different climate conditions and different groundwater-use rates. These conditions are described as analysis cases that provide a representative range of credible future climates and human activities affecting groundwater in the Yucca Mountain area. These cases are discussed in more detail in Section 2.3. Based on data from past climates in the Yucca Mountain region, future climates are projected to include interglacial periods that are relatively hot and dry (similar to present conditions) and periods that are relatively cooler and wetter. The present-day climate is an interglacial period. The analysis in this supplement makes no assumptions about the timing of these potential future climate states, only that such conditions can be expected to occur sometime during the approximately one-million-year period evaluated in this supplement.

In addition, the supplement considers two scenarios concerning potential groundwater withdrawal to encompass uncertainty in predicting future human activity that may affect the groundwater. These scenarios, considered in the analysis cases in Chapter 2 of this document, include the scenario where significant pumping for irrigation purposes (i.e., substantial removal of groundwater) will occur, as well as the scenario where limited or no pumping (i.e., no substantial removal of groundwater) will occur. Both of these pumping scenarios are considered for both the dry and wet climate states described above to create the analysis cases evaluated in this supplement. The NRC staff is addressing different pumping cases and different climate states because the amount of groundwater pumping affects where groundwater ultimately reaches the surface, while a wetter climate affects the amount of groundwater flow, and thus the concentrations of contaminants in the groundwater. As discussed in Chapter 2 of this document, changes in climate are not expected to significantly affect the groundwater flow paths in the area.

Presently available information about human-induced climate change from the release of greenhouse gases indicates that for this region, the most potentially significant long-term effect is that the present-day interglacial climate (hot and dry) would persist longer than it would in the absence of human-induced change (NRC, 2014a; Section 2.2.1.3.5). Projected human-induced climate change is represented within the range of potential climate conditions (i.e., both dry and wet climate states) and water use (i.e., both substantial and no substantial removal of groundwater from the system) considered in this supplement.

1.2.3 Significance of Environmental Impacts

The NRC has established standards of significance for assessing environmental impacts. In NRC environmental reviews, significance indicates the importance of potential environmental impacts and is determined by considering two variables: (i) context and (ii) intensity. Context is the geographic, biophysical, and social setting in which effects are expected to occur. Intensity refers to the severity of the impact. The NRC uses a three-level standard of significance based upon the President's Council on Environmental Quality guidelines in 40 CFR 1508.27 and as provided in the NRC's environmental review guidance in NUREG–1748 (NRC, 2003):

> **SMALL**: The environmental effects are not detectable or are so minor that they will neither destabilize nor noticeably alter any important attribute of the resource.
>
> **MODERATE**: The environmental effects are sufficient to alter noticeably, but not to destabilize, important attributes of the resource.
>
> **LARGE**: The environmental effects are clearly noticeable and are sufficient to destabilize important attributes of the resource.

1.3 Public and Agency Involvement

The NRC staff announced its intent to develop this supplement in the *Federal Register* (FR) on March 12, 2015 (80 FR 13029). The NRC staff also issued a press release, and notified the hearing participants and other stakeholders.

Pursuant to 10 CFR 51.26(d), the NRC staff did not conduct scoping for this supplement, the scope of which was established by the ADR. The NRC staff did not identify any cooperating agencies for this supplement, nor did the NRC staff receive any formal requests for cooperating agency status.

The NRC staff is providing a 60-day public comment period for this draft supplement. The comment period begins on the date of publication of NRC's Notice of Availability of this draft supplement and the U.S. Environmental Protection Agency's (EPA's) concurrent notice in the FR. During the comment period, the NRC staff will conduct public meetings to describe the results of the analysis in this supplement and accept comments. Comments received on the draft supplement will be addressed in the final supplement.

1.4 Document Format

This supplement does not reflect a change to DOE's proposed action or to DOE's purpose of or need for the proposed action. DOE's proposed action, as described in Chapter 2 of the 2002 EIS and 2008 SEIS, is the construction, operation, monitoring, and closure of a repository for the disposal of SNF and HLW at Yucca Mountain, Nevada. The NRC's proposed action would be the issuance of an authorization to DOE for the construction of a repository at Yucca Mountain. This supplement also does not reflect a change in the alternatives DOE presented in Chapter 2 of its EISs, which are the proposed action and the no action alternative of not constructing a repository. As discussed in the ADR, these aspects of DOE's NEPA analysis are not affected by this supplement, and they are not addressed further.

This supplement presents additional information about the impacts of potential repository contamination of groundwater, as well as the potential impacts associated with the discharge of contaminated groundwater to the surface. As such, the supplement affects the information presented in DOE's analyses of affected environment, impacts after repository closure, and cumulative impacts in its EISs.

Chapter 2 of this supplement describes the potentially affected groundwater and surface environments and the potentially affected resource areas for each environment. Chapter 3 describes the potential impacts of repository contamination of groundwater and from the surface discharge of groundwater. Chapter 4 describes cumulative impacts associated with potential repository contamination of groundwater and the surface discharge of that groundwater. Chapter 5 provides a summary of the NRC staff's impact findings.

2 AFFECTED ENVIRONMENT

2.1 Introduction

The U.S. Department of Energy's (DOE's) Environmental Impact Statement (EIS) (DOE, 2002, Chapter 5) and Supplemental Environmental Impact Statement (SEIS) (DOE, 2008a, Chapter 5) described the affected environment from the Yucca Mountain repository site to the location of the reasonably maximally exposed individual (RMEI), or regulatory compliance location,[1] in the Amargosa Desert using information from a model that DOE developed for its license application (DOE, 2008b). The RMEI location is characterized using features of present-day conditions and activities at Amargosa Farms (the south-central portion of Amargosa Desert, as shown in Figure 2-1). Using these conditions, the location of the RMEI is approximately 18 km [11 mi] from Yucca Mountain, along the flow path of the predominant groundwater flow, and approximately at the southern boundary of the Nevada National Security Site (NNSS) (NRC, 2014a). For locations beyond the regulatory compliance location, the analysis in DOE's 2002 EIS and 2008 SEIS scaled the results calculated for the regulatory compliance location to generic locations at 30 km [19 mi] and 60 km [37 mi] from the repository in the predominant direction of groundwater flow.

The U.S. Nuclear Regulatory Commission (NRC) staff's review of DOE's EISs found that it was practicable for the NRC to adopt the 2002 EIS and 2008 SEIS, but with further supplementation (NRC, 2008a). The NRC staff concluded that a supplement was needed to describe the full spatial extent of the volcanic-alluvial aquifer beyond the regulatory compliance location, particularly those parts that could become contaminated by potential releases from the repository, and how water (and potential contaminants) could leave the flow system. Specifically, the NRC staff's review of the EISs concluded that the affected groundwater environments, and any impacts, were not adequately identified and described by DOE's analyses for areas beyond the regulatory compliance location.

This chapter provides a description of the affected environment with respect to the groundwater flow path for potential releases from the repository that could be transported beyond the regulatory compliance location through the volcanic-alluvial aquifer in Fortymile Wash and Amargosa Desert. Groundwater flow and potential releases traveling beyond the regulatory compliance location, if uninterrupted, would discharge in Death Valley. Death Valley is the ultimate discharge area for groundwater flow in the Death Valley Regional Groundwater Flow System (DVRFS) (Figure 2-1). Importantly, discharge to the surface (e.g., springs) and the pumping of groundwater along the flow path towards Death Valley reduces the amounts of groundwater (and therefore, the amount of any contaminants) that discharge in Death Valley. This chapter provides a description of the flow path towards Death Valley, and the locations of potential natural discharge along the groundwater flow path for present and expected future cooler and wetter periods. It also evaluates current and potential future water use that might affect the groundwater flow paths and natural discharge for present and future wetter periods.

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[1] This point is defined and specified at 10 CFR 63.312(a) as the point of compliance for calculating dose with respect to postclosure individual protection, human intrusion, and groundwater protection standards. This location is based on the definition of the controlled area in 10 CFR 63.302. The model DOE used to support its license application calculates radiological dose to a reasonably maximally exposed individual located at a point on the NNSS boundary that is approximately 18 km [11 mi] south of the analyzed repository footprint in the predominant direction of groundwater flow.

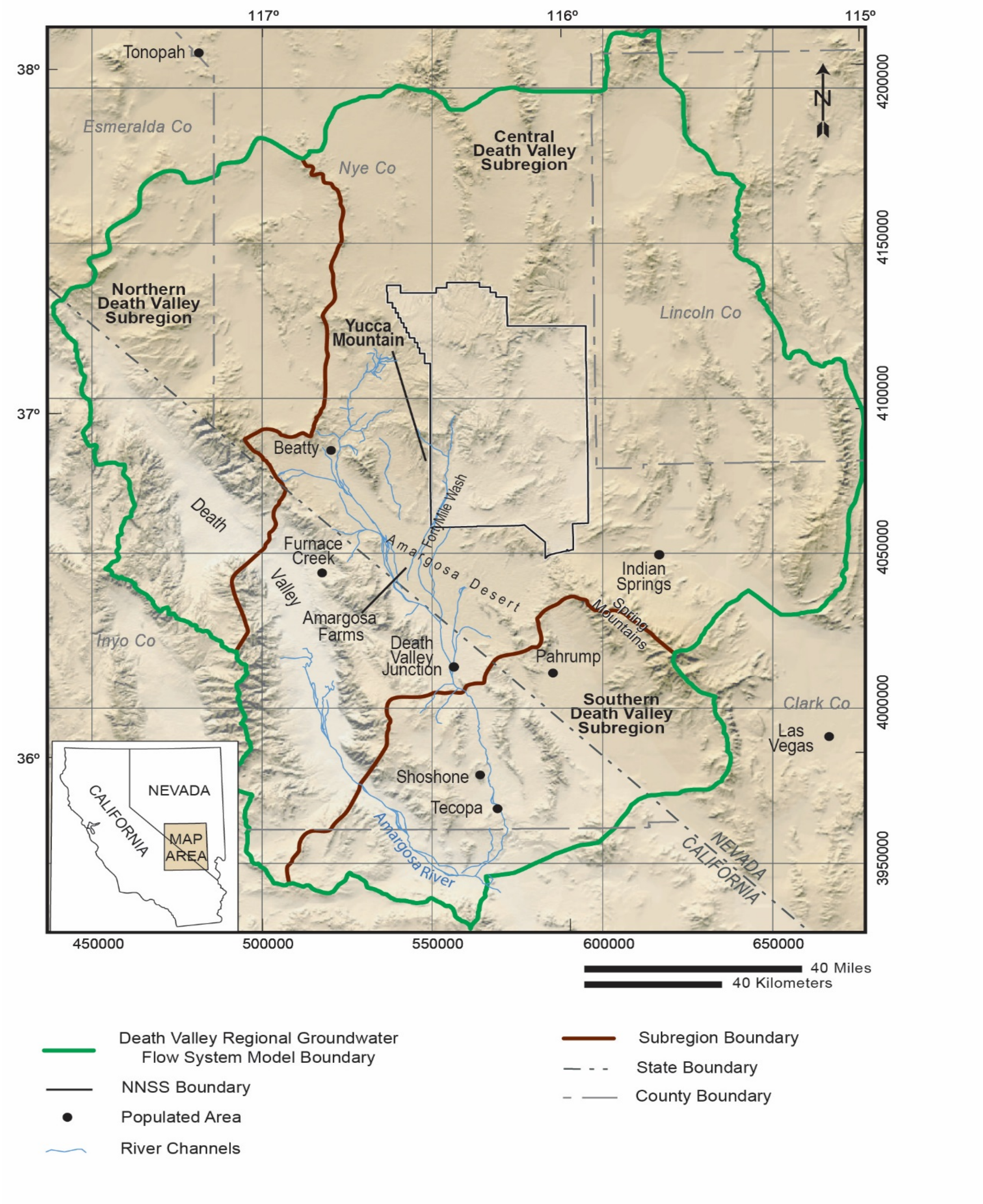


Figure 2-1. Location of Selected Geographical Features Within Death Valley Regional Groundwater Flow System. NNSS Is the Nevada National Security Site (Previously Called the Nevada Test Site). Modified From Belcher and Sweetkind (2010).

The affected environment for contaminants released from the repository, therefore, includes the aquifer itself as well as the sites where groundwater could discharge to the surface, either through pumping or natural processes.

In particular, this chapter describes:

(i) Groundwater Environment (Section 2.2)

- Aquifers in the region potentially affected by releases from Yucca Mountain, including aquifers along the flow path from Yucca Mountain to Death Valley
- Effects of groundwater pumping on groundwater flow
- Effects of the present and possible future climates on groundwater flow

(ii) Surface Discharge Environment (Section 2.3)

- Present-day discharge sites for releases from Yucca Mountain along potential flow paths beyond the regulatory compliance location
- Paleodischarge sites (areas of prehistorical, but not current surface discharge) during wetter and cooler climates as indicators of potential future discharge

(iii) Groundwater Modeling (Section 2.4)

- Effects of pumping on groundwater conditions
- Effects of climate on future flow paths

(iv) Water Use and Quality (Section 2.5)

- Water use along potential flow paths
- Groundwater quality in the Yucca Mountain region

(v) Analysis Cases for Assessing Impacts (Section 2.6)

- Present-day pumping levels (all potential contaminant releases are assumed to be captured by pumping wells at the regulatory compliance location)
- No future pumping (surface discharges downstream of the regulatory compliance location under present and possible future climates)

The descriptions of groundwater flow and surface discharges in this chapter are drawn from sources including the U.S. Geological Survey (USGS) (e.g., Belcher and Sweetkind, 2010), Nye County (Nye County NWRPO, 2009), and Inyo County (e.g., Bredehoeft and King, 2010; Bredehoeft et al., 2008; Inyo County, 2007), as well as independent NRC staff analyses (e.g., NRC, 2014a). The descriptions in this chapter also incorporate further work by DOE on the flow system beyond the regulatory compliance location (DOE, 2014a; 2009a).

2.1.1 Regional Demography

As discussed in Chapter 1, the NRC staff assumes the current population and its distribution, as well as the current range of human activities, will continue for the entire period analyzed in the supplement. This is consistent with NRC regulations in 10 CFR 63.305(b) and EPA regulations in 40 CFR 197.15, which direct DOE not to project changes in society, the biosphere (other than climate), human biology, or increases or decreases in human knowledge or technology.

Using data from the 2010 U.S. census, the NRC staff found in its Safety Evaluation Report (SER) (NRC, 2015a; Section 2.1.1.1.3.2) that DOE's assessment of the demographic characteristics of the area surrounding Yucca Mountain was accurate. In its license application, DOE described population locations, regional population centers, and provided population projections for a 50-year period (2017-2067) (DOE, 2008b; Section 1.1.2). DOE's assessment encompassed an 84-km [52-mi] radial area, centered on the repository site. The area comprises parts of Clark, Esmeralda, Lincoln, and Nye Counties in Nevada, and Inyo County in California. DOE provided a baseline population distribution within the 84-km [52-mi] radius for the 50-year period. DOE did not identify any permanent residents closer than about 22 km [13.7 mi] to the repository site. The nearest resident population was located in the town of Amargosa Valley, Nevada.

For its SER, the NRC staff performed independent confirmatory calculations for DOE's baseline 2003 population distribution within 84 km [52 mi] of the repository. The NRC staff's results are consistent with DOE's information. The NRC staff also compared the U.S. Census Bureau data for the 2010 population distribution within 84 km [52 mi] of the repository location with that of DOE's projected population distribution data and found that DOE's estimate is generally higher, and therefore conservative in terms of potential impacts. The NRC staff further found in the SER that DOE identified all significant population centers within an appropriate demographic study area {within 84 km [52 mi]} and used population data consistent with other acceptable evaluations of demography and population centers in the repository area (NRC, 2015a).

The NRC staff incorporates by reference its SER assessment (NRC, 2015a; Section 2.1.1.1.3.2) and DOE's license application description of regional demography (DOE, 2008b; Section 1.1.2) because the NRC staff has determined that groundwater could discharge to the surface in or near population centers. These population centers are the town of Amargosa Valley and Death Valley National Park (NRC, 2015a; Section 2.1.1.1.3.2., Population Centers). The population in Death Valley includes the Timbisha Shoshone Tribe community located on a 314-acre [1.27-km^2] parcel of land in the Furnace Creek area. The Tribe has federally appropriated rights to 92 acre-feet per year [0.113 million m^3/yr] of surface and groundwater to support this community (DOE, 2014a; 16 U.S.C. 410aaa).

2.2 Groundwater Environment

2.2.1 Aquifers in the Death Valley Region

The DVRFS lies within the southern portion of the arid, internally drained region known as the Great Basin. The principal groundwater-bearing units in the DVRFS can be classified as volcanic, alluvial, or carbonate aquifers (DOE, 2014a; 2008a), depending on the types of rock or sediment through which the groundwater flows. The mountainous areas in the north-central portion of the DVRFS are mostly of volcanic origin and contain associated volcanic aquifers (i.e., aquifers composed principally of fractured tuff and other volcanic rocks). In the lower elevations and in portions of the southern area, the volcanic aquifer in some areas connects with relatively young permeable basin fill sediments (mostly deposited by streams, also called alluvium or alluvial deposits) in valleys across the DVRFS. These sediments comprise the affected alluvial aquifer. The lowermost aquifer is a deep regional groundwater system formed of thick sequences of older, highly permeable carbonate rocks that foster interbasinal groundwater flow between basins that are topographically closed (Belcher and Sweetkind, 2010), as illustrated schematically in Figure 2-2. Regional groundwater flow in the DVRFS through the carbonate rock sequence is affected by complex geologic structures caused by regional faulting and fracturing. These geological structures can enhance or impede flow (DOE, 2008b, Section 2.3.9). Although the carbonate aquifer is generally regionally connected and fast flowing (Sweetkind et al., 2010; Winograd and Thordarson, 1975), there is also some evidence from geochemical and temperature data that it may be locally compartmentalized (e.g., Bushman, et al., 2010; Nye County NWRPO, 2009). The compartmentalized areas are a possible consequence of a complex geological structure in the DVRFS, where local faulting may intersperse less-permeable units.

The basin fill sediments and fractured volcanic rocks form local aquifers, and in some areas they are well connected such that groundwater can flow easily from volcanic to alluvial sections. The volcanic and alluvial aquifers interact with the regional carbonate aquifer either through (i) vertical flow if the carbonate aquifer underlies the volcanic-alluvial aquifer, or (ii) lateral flow, where the carbonate aquifer, due to faulting, juxtaposes alluvial-volcanic aquifers (Belcher and Sweetkind, 2010). At any one location, confining layers between the aquifers at different depths allow varying degrees of water exchange between aquifers.

The NRC staff’s description of the entire regional flow system derives from the integration of geologic data (rock units and structures), hydrologic data (potentiometric and hydrologic properties of the rock), water chemistry data, and temperature data for each aquifer in the flow system (e.g., Belcher and Sweetkind, 2010; DOE, 2014a). For example, water levels in wells across the DVRFS provide data regarding the hydraulic gradient, and thus, the potential directions of water flow. These include indications of the potential for vertical flow between aquifers and differing horizontal flow directions of shallow and deep aquifers. Also, water temperature can provide indications of deeper groundwater interacting with shallower aquifers, or of deeper water discharging to the ground surface.

Groundwater chemical compositions are used to understand groundwater flow paths and identify areas in which groundwater mixing occurs. Groundwater chemistry is influenced by interactions with the rock through which it flows. Interactions may include dissolution of minerals, ion-exchange between the water and minerals, chemical alteration of mineral phases, and precipitation of new mineral phases. Through these interactions, the groundwater develops a chemical composition that is characteristic of a particular aquifer system. For example, groundwater in the volcanic tuff aquifer system typically has relatively low ionic strength and has higher concentrations of sodium, potassium, and silica derived from the volcanic source rocks. In contrast, groundwater in the carbonate aquifer is dominated by dissolved calcium, magnesium, and bicarbonate.

Groundwater Subregions, Basins, and Sections

To simplify modeling of the entire DVRFS and support modeling at different scales, the USGS created a hierarchy of subregions, basins, and sections, from largest to smallest, respectively (most recently described in Belcher and Sweetkind, 2010). DOE used earlier versions of the

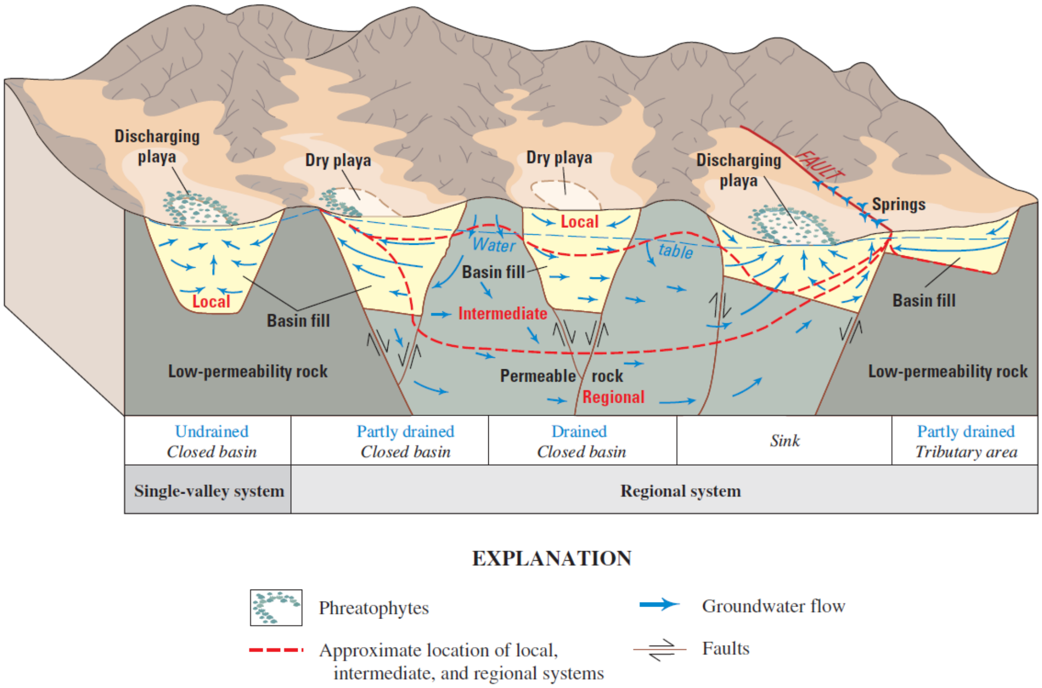
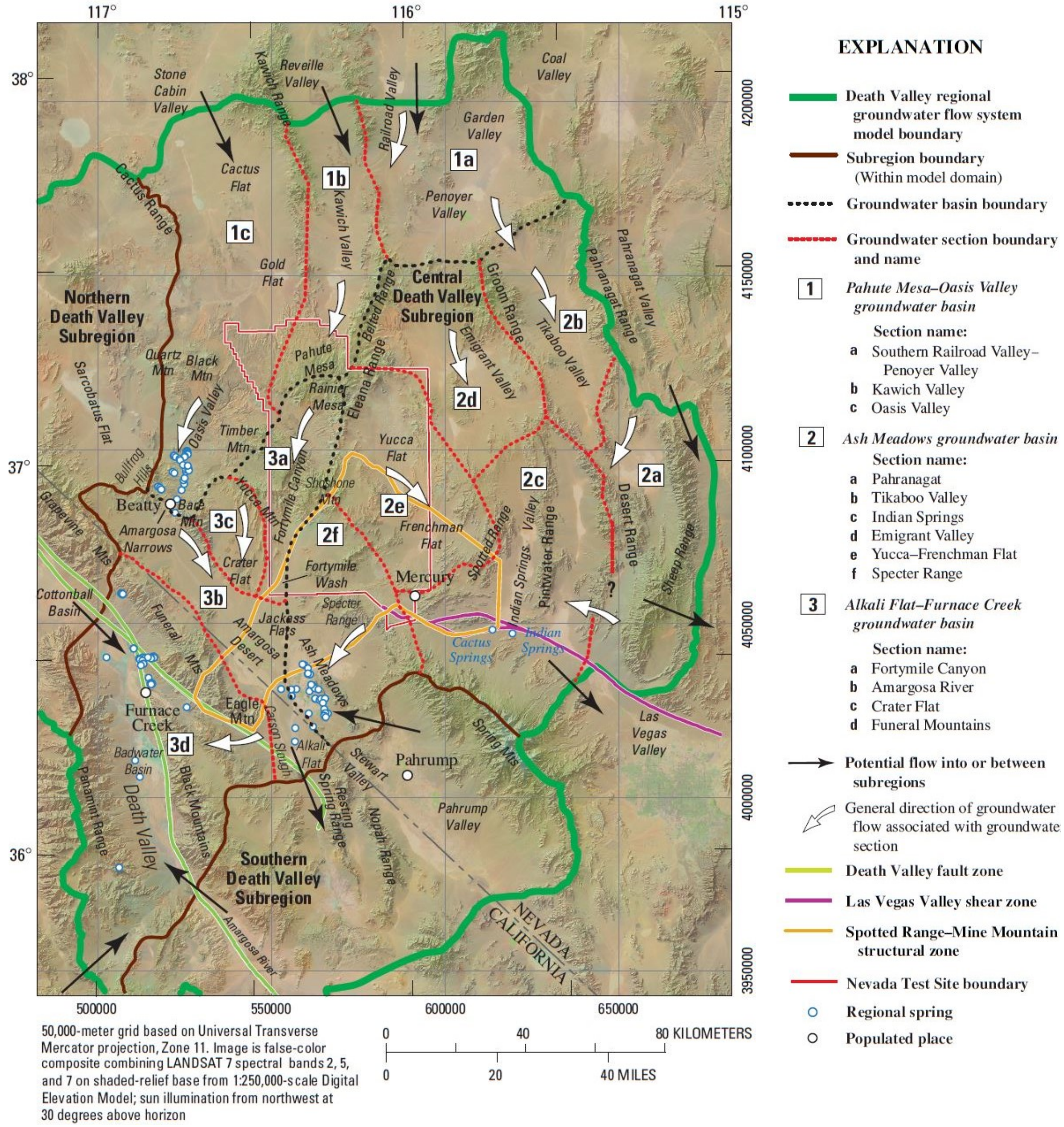


Figure 2-2. Schematic Block Diagram Illustrating the Structural Relations Among Mountain Blocks, Valleys, and Groundwater Flow in the Region (Modified from Eakin, et al., 1976). Taken From Belcher and Sweetkind (2010; Figure D-1).

USGS delineation of these groundwater flow areas (e.g., Belcher, 2004; Belcher, et al., 2002;) at different scales in its EIS (DOE, 2002) and SEIS (DOE, 2008a). This delineation is a reasonable method for conceptualizing the DVRFS, and this supplement utilizes the same terminology. The delineation is reasonable because it is based on (i) an understanding of the geology, including the rock units and structures that may influence groundwater flow; (ii) observations or estimates of hydrologic information, including potentiometric surface (for unconfined aquifers, the water table elevation is the potentiometric surface) and hydrological properties of hydrogeological units; (iii) hydrogeochemical and thermal information; and (iv) groundwater modeling that integrates all the hydrogeological information together. Modeling the groundwater system involves characterizing the inflows and outflows for each section, basin, and subregion. The inflows and outflows include recharge, lateral inflow and outflow between areas, pumping, discharge related to springs, and evapotranspiration (movement of water directly to air from ground surface and from plants).

Following the hierarchical delineation by the USGS, the DVRFS is divided at the largest scale level into three subregions (Belcher and Sweetkind, 2010). The proposed repository site at Yucca Mountain is in volcanic tuff and lies above part of the large volcanic aquifer in the Central Death Valley Subregion (Figures 2-1 and 2-3). As discussed in the subsequent sections, this Subregion contains the aquifers likely to be affected by contaminants released from the repository. Some small portion of groundwater flow from beneath Yucca Mountain may enter the Southern Death Valley Subregion to the south and east. The third subregion, to the west and north of the Central Death Valley Subregion, is the Northern Death Valley Subregion,



50,000-meter grid based on Universal Transverse Mercator projection, Zone 11. Image is false-color composite combining LANDSAT 7 spectral bands 2, 5, and 7 on shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon

Figure 2-3. Death Valley Regional Groundwater Flow System (Outline in Green) with Further Delineations of Central Death Valley Subregion (Brown Line) Showing Basins (Black Dotted Lines), Numbered Sections (Numbered and Red Lines), and Flow Directions. Taken From Belcher and Sweetkind (2010; Figure D–7).

and is not affected by flow from beneath Yucca Mountain. The subregions are further subdivided into basins, which themselves are subdivided into sections. Yucca Mountain falls in the Fortymile Canyon Section, which is part of the Alkali Flat-Furnace Creek Basin, which is part of the Central Death Valley Subregion, as shown in Figure 2-3.

The other two basins delineated in the Central Death Valley Subregion (Pahute Mesa-Oasis Valley and Ash Meadows Basins) contribute lateral water flow into the Alkali Flat-Furnace Creek Basin at its northern, eastern, and western boundaries.

The NRC staff next evaluates the principal groundwater flow path between Yucca Mountain and Death Valley, within the Alkali Flat-Furnace Creek Basin, and the potential minor flow into the Southern Death Valley Subregion.

2.2.2 Aquifers Along the Flow Path From Yucca Mountain

This section describes the expected flow path for groundwater from below the proposed repository. In the 2002 EIS and 2008 SEIS, DOE described the flow path from the repository to the area of pumping at the regulatory compliance location in the Amargosa Desert. DOE described the flow of water in the unsaturated zone through the repository and vertically downward to the underlying saturated volcanic rocks. This flow path is the same as that described in DOE's Safety Analysis Report (SAR) for performance of the repository (DOE, 2008b, Section 2.3.9). DOE found that such water flow is the principal means of release of contaminants from repository once the engineered barriers cease to contain the waste (DOE, 2008a,b). The NRC staff found the description of this flow path to the regulatory compliance location to be acceptable in its Adoption Determination Report (ADR) (NRC, 2008a); the NRC staff's review of repository performance is given in its SER (NRC, 2014a; Section 2.2.1.3.8).

The flow system that passes below Yucca Mountain trends southward along Fortymile Wash in the Fortymile Canyon Section (Figure 2-3). Beyond the regulatory compliance location, it merges with east-southeast flow in the Amargosa Desert and continues south towards Amargosa Farms. The next sections of this chapter provide descriptions of the groundwater flow path in the Amargosa Farms area of the southcentral portion of the Amargosa River Section, and between the Amargosa Farms area and Death Valley, predominantly westward through the carbonate aquifer at the eastern Funeral Mountains (the Funeral Mountain Section of the flow path). In addition, the potential, minor flow from Amargosa Farms to Alkali Flat is also described. As discussed in the sections below, particle tracking analysis using the DVRFS model indicates the possible pathways for contaminants from a repository at Yucca Mountain past the Amargosa Farms area are westward through the Funeral Mountains to Death Valley, or along the Amargosa River course to discharge at Alkali Flat.

Amargosa River

The Amargosa River is an intermittent waterway, 298 km [185 mi] long, in southern Nevada and eastern California. It drains the Amargosa Valley in the Amargosa Desert and other smaller valleys on its way to Death Valley. Except for a small portion of its route near Beatty, Nevada, and a portion in the Amargosa Canyon (near the towns of Shoshone and Tecopa) in California, the river flows above ground only after rare major rainstorm events in the region (see also Menges, 2008).

Fortymile Canyon Section

The first portion of the flow path is in the Fortymile Canyon Section (Figure 2-3; labeled 3a). As described in the 2008 SEIS, infiltrating water at Yucca Mountain passes through the unsaturated zone, reaches the uppermost volcanic aquifer, and then flows east to southeast to join the larger volume of groundwater flowing southward along Fortymile Wash towards Amargosa Desert. The first part of this flow path is within the volcanic aquifer. Flow in these volcanic rocks occurs predominantly in networks of fracture and fault zones. Along Fortymile Wash, the strata (layers) of the volcanic aquifer thin and transition into the sediments of the alluvial aquifer. The groundwater then exits the fractured volcanic tuffs and enters the relatively unconsolidated granular porous media of the alluvial aquifer. This transition occurs in the vicinity of the Highway 95 fault (a poorly-expressed west-northwest striking high-angle fault zone that occurs just south of the southern boundary of NNSS, as shown in Figures 2-1 and 2-3, near the label "Jackass Flats"). The Highway 95 fault appears to be the southern boundary of the volcanic aquifers, based on a fault zone geometry inferred from borehole and geophysical data (DOE, 2008a; Nye County NWRPO, 2009). The fault juxtaposes fractured volcanic rocks on the north side with less permeable alluvial sediments on the south side. Nye County investigators proposed that contact with the less permeable alluvial sediments causes the southward groundwater to flow up into an overlying alluvial aquifer system, which continues to the Amargosa Desert (Nye County NWRPO, 2009). Hydraulic measurements conducted by DOE and Nye County support a slight upward gradient in the alluvial aquifer (DOE, 2008a; p. 3-33), which, when combined with the stratified alluvial sediments, indicates that a groundwater plume emanating from Yucca Mountain would remain in the upper portion of the uppermost alluvial aquifer in the Amargosa Desert. The transition from the Fortymile Canyon Section to the Amargosa River Section coincides approximately with the regulatory compliance location {approximately 18 km [11 mi]} along the flow path from the proposed repository site. In this area, distributed recharge occurs in mountainous areas and focused recharge from intermittent streamflow occurs in smaller washes. Losses from the aquifer are predominantly by evapotranspiration.

Amargosa River Section

The next portion of the flow path is in the Amargosa River Section (Figure 2-3; labeled 3b). The groundwater flow path from Yucca Mountain goes southward from Fortymile Wash into the Amargosa Desert. Groundwater geochemical data indicate that the flow paths within the alluvial aquifer of Fortymile Wash are readily identifiable along the length of Fortymile Wash and southward across the Amargosa Desert (Figure 2-4) (Kilroy, 1991; SNL, 2007a). Amargosa Farms is a small farming community which occupies the area where the alluvial fan (a fan- or cone-shaped deposit of sediment built up by streams) from Fortymile Wash meets the broad, dry Amargosa River bed in the Amargosa Desert, south of the regulatory compliance location along the Yucca Mountain flow path (Figure 2-1). The Amargosa Farms area is not a hydrographic area defined on Figure 2-3; it lies within the southcentral portion of the Amargosa River Section. At present, extensive groundwater pumping for irrigation and drinking water occurs in Amargosa Farms. Groundwater withdrawal contributes more to losses within the Amargosa River Section than evapotranspiration. Groundwater pumping, mostly in the Amargosa Farms area, has been on the order of 17,600 acre-ft/yr [21.7 million m^3/yr] for the past several decades (DOE, 2014a, Table 2-1; NDWR , 2015). By comparison, evapotranspiration losses from the Amargosa River Section were estimated to be 1,350 acre-ft/yr [1.67 million m^3/yr] (DOE, 2014a, Table 2-1). Due to groundwater pumping from 1952 to 1987, the maximum drawdown of the water table was more than 9 m [30 ft] over a region more than 10 km [6 mi] across, east to west, centered on the irrigation wells distributed

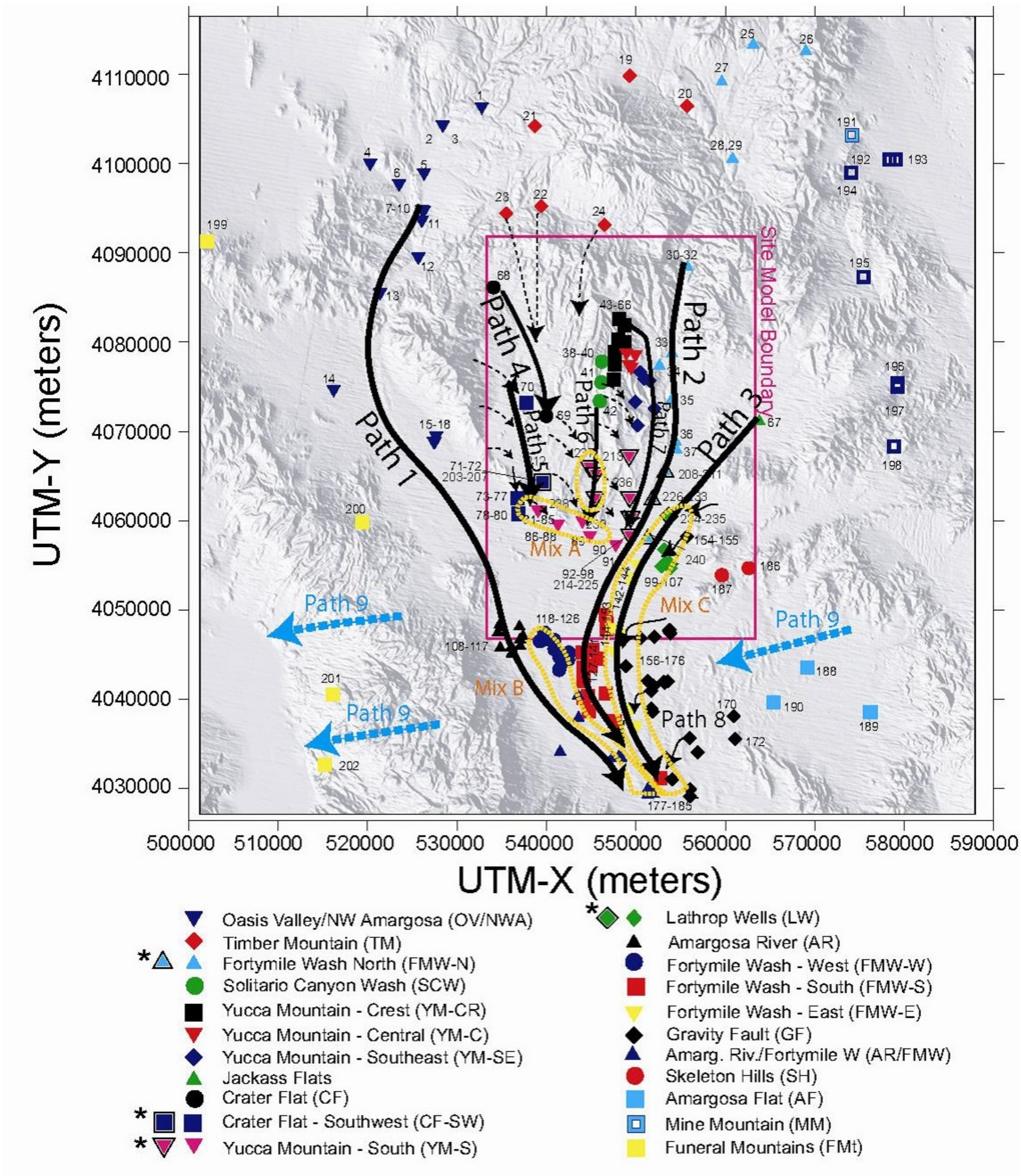


Figure 2-4. Groundwater Flow Paths Inferred From Groundwater Geochemical Analyses (From SNL, 2007a, Figure B6-15). Flow Path 2, Which Merges With Flow Path 7, Represents the Direction of Flow From Yucca Mountain. Flow Path 2 and Flow Path 1 (Amargosa River) Converge Near the Location of the State Line Deposits.

around the Amargosa Farms area (Kilroy, 1991). Studies by the Bureau of Land Management (BLM) (BLM, 2010) reported the maximum drawdown of the water table as being more than 90 ft [27 m] in 2003. At the southern end of the Amargosa Farms area, near the lower margin of the Fortymile Wash alluvial fan, are the State Line Deposits (also referred to as the Stateline deposits), fossil spring deposits that occur over an area 10–15 km [6–9 mi] long and approximately 5-km [3-mi] wide (Paces and Whelan, 2012). These deposits formed during past wetter climates; the youngest units date from more than 30,000 years ago. There are presently no springs near the State Line Deposits, although dense vegetation at nearby Franklin Well indicates a relatively shallow water table. The fossil deposits have a variety of complex geochemical compositions that represent the likely mixing of the Amargosa River and Fortymile Wash groundwater, with some inflow from the carbonate aquifer (Paces and Whelan, 2012). Within the State Line Deposits area, groundwater flow gradients in the vicinity of freshwater limestone deposits and bedrock structures indicate upward flow from the carbonate aquifer below the alluvial sediments of Amargosa Valley (Kilroy, 1991; Paces and Whelan, 2012). The groundwater flow direction in the regional carbonate aquifer in this area is west to southwest, in comparison to the southward flowing groundwater in the alluvial sediments of the Amargosa Farms area (Belcher and Sweetkind, 2010; DOE, 2014a).

East of the Amargosa Farms area are Ash Meadows and Devils Hole, which are part of the Ash Meadows Basin hydrographic area (Figure 2-3). Ash Meadows Basin is the largest in the Central Death Valley Subregion. Flow in the carbonate aquifer is southwesterly to westerly in the Ash Meadows Basin, approaching the north-south and northwest trending high-angle faults in the Ash Meadows area. The faults cause much of the carbonate groundwater to be discharged in Ash Meadows as spring flows and through evapotranspiration (Winograd and Thordarson, 1975). Groundwater that is not discharged in Ash Meadows mixes to the south with flow from the volcanic and alluvial aquifers of the Alkali Flat-Furnace Creek Basin (Levich, et al., 2000), as described below.

Ash Meadows and Devils Hole

Ash Meadows is a National Wildlife Refuge, a 40-acre detached unit of Death Valley National Park. It contains more than 30 seeps and springs, including Devils Hole, fed by water from the carbonate aquifer. The caves at Devils Hole provide habitat for the only naturally occurring population of the endangered Devils Hole Pupfish (Cyprinodon diabolis).

West of Ash Meadows, there is a steep hydraulic gradient coincident with the north-south trending high-angle fault between the alluvial sediments of Amargosa Farms and the carbonate rock exposed at the ground surface in Ash Meadows (Belcher and Sweetkind, 2010). All of the present-day springs in Ash Meadows are in the area of the carbonate rocks. The surface exposure of carbonate rocks in Ash Meadows is in sharp contrast to the hydrologic conditions in the central portion of Amargosa Desert, where the carbonates are present far below the thick sequence of alluvial sediments. The steep hydraulic gradient across the north-south trending fault indicates little mixing of carbonate waters to the east with alluvial aquifer waters to the west in the present-day climate. Given the direction of the hydraulic gradient, any connection between the uppermost and underlying aquifers in this area is likely to be flow from the carbonate aquifer of Ash Meadows to the alluvial aquifer in the Amargosa Farms area. Further south, the waters of the two aquifers likely mix in the area between the Nevada-California state line and Alkali Flat (Figure 2-3). This is because the north-south trending high-angle fault appears to end further south near the Nevada-California state line (Belcher and Sweetkind, 2010; Figure B-26).

South of Amargosa Farms, the groundwater from the alluvial aquifer under Amargosa Farms can flow either southwestward or southward. Flow to the southwest is through the fractured carbonate rock at the southeastern end of the Funeral Mountains to eventual discharge at Furnace Creek springs or evaporation in the Middle Basin of Death Valley (Figure 2-3). A possible alternative flow path southward from Amargosa Farms follows the dry bed of the Amargosa River. For this flow path, water moves in the thinning alluvial sediments along the Amargosa River towards Alkali Flat (also known as Franklin Lake Playa), where the groundwater intermittently discharges to the surface, or continues along the Amargosa River into the Shoshone-Tecopa Section of the Southern Death Valley Subregion. There is uncertainty in how the westward flowing carbonate aquifer interacts with the southward flowing alluvial aquifer of the Amargosa River Section, but geochemical data indicate that mixing occurs in the general area between the Nevada-California state line and Alkali Flat (Faunt, et al., 2010a).

Analysis of potential flow beyond Amargosa Farms, using a modification of the DVRFS model, indicates that in the absence of pumping in Amargosa Farms over the last century, the flow path would dominantly trend to the southwest under the eastern end of the Funeral Mountains (DOE, 2014a). The model used was based on Belcher and Sweetkind (2010), modified to include pumping data from 1913 to 2003 (SNL, 2014). Flow pathways can be identified in the model by releasing nominal “particles” at the regulatory compliance location and tracking their movement within the DVRFS. Adsorption, colloidal filtering, decay, or other mechanisms that would preclude the particles from moving with the water are not included in this analysis, so the particle tracking represents unrestrained movement of water-borne contaminants. In the model runs, 8,024 particles were released and tracked from the regulatory compliance location. The 8,024 particles were derived from the release of 10,000 particles at repository locations in the Yucca Mountain Site-Scale Flow Model (SNL, 2009). The NRC staff has found DOE’s model for saturated zone flow in the vicinity of the repository and its integration of the multiple models to be acceptable as part of its safety evaluation (NRC, 2014a; Section 2.2.1.3.8).

When historic data for pumping are considered in the DVRFS model, all particles are captured by the wells in Amargosa Farms. When no pumping is included (the prepumping model, representing groundwater conditions prior to 1913), two pathways were identified (DOE, 2014a). The predominant path identified was approximately southward through Amargosa Farms and turning southwestward to westward beneath the Funeral Mountains to the springs at Furnace Creek and on to Middle Basin in Death Valley (DOE, 2014a, Figure 3-1). A potential alternative, but less likely, path was identified by 2 particles (out of the 8,024 particles) that traveled southward to and discharged at Alkali Flat (DOE, 2014a, Figure 3-2). The flow path of the few particles tracked to Alkali Flat arises from the uncertainties in the model parameters, and may represent the possibility that a limited amount of water diverts from the predominant pathway. The particle tracking approach is a recognized method for understanding contaminant transport in hydrologic models (e.g., Faunt, et al., 2010b). The NRC staff concludes that the use of particle tracking in the DVRFS model is a reasonable means of defining the potential paths that contaminants may follow, consistent with the flow fields of the DVRFS. Further information on the particle tracking model is given in Appendix A to this supplement.

The groundwater flow path from Amargosa Farms southwest through the Funeral Mountains continues towards the springs near Furnace Creek and to Middle Basin in Death Valley. The likelihood of flow through the carbonate blocks at the southeastern end of the Funeral Mountains was identified through research conducted by the USGS (Belcher and Sweetkind, 2010) and Inyo County (2007); (Bredehoeft, et al., 2008), which defined the relatively permeable carbonate units within the Funeral Mountains.

The likelihood of this southwesterly flow path differs from that identified in earlier DOE analysis (2008 SEIS; p.3-31), which indicated that the majority of the water moved instead to the south from the Amargosa Farms area, generally following the trace of the Amargosa River and discharging at Alkali Flat, but did not include the presence of highly transmissive carbonate units beneath the Funeral Mountains. Flow conditions in the absence of pumping in Amargosa Farms are not well characterized, so some possible flow towards Alkali Flat cannot be excluded. This alternate flow path is described further in the subsection on Alkali Flat and the Southern Death Valley Subregion.

Funeral Mountain Section

As previously noted, in the absence of pumping in Amargosa Farms, the more likely path for groundwater originating from Yucca Mountain is predominantly to the Funeral Mountain Section (Figure 2-3; labeled 3d) through the fractured carbonate rock of the southeastern part of the Funeral Mountains (the main flow path shown in Figure 3-1 of DOE, 2014a). Flow southwestward beneath the Funeral Mountains is likely in the fast-flowing fractured carbonate aquifer (Bredehoeft and King, 2010). This groundwater would then feed the springs of the Furnace Creek area of Death Valley. Water from these springs is currently used to support activities in the Furnace Creek area of Death Valley National Park. In the absence of human activity, discharges at these springs could reinfiltrate into the Death Valley alluvial fans and evaporate or transpire further downstream in the fans, or evaporate from the Middle Basin playa at the floor of Death Valley (Belcher and Sweetkind, 2010).

The geochemistry of water at the Furnace Creek springs is similar to that at the springs of Ash Meadows, and to that of the regional carbonate aquifer generally (DOE, 2014a; 2008a). The chemistry of the water at the springs appears to have equilibrated (i.e., reflects the mineral content of) with the surrounding carbonate rock as indicated by the calcium, magnesium, and bicarbonate composition in the water. Further similarity of water discharging from the Furnace Creek springs to water discharging at Ash Meadows is shown in their content of rare earth elements (Johannesson, et al., 1997). In addition, strontium isotope measurements also indicate that the groundwater interacted with older metamorphic or igneous rocks (Levich, et al., 2000) in the central part of the Funeral Mountains. Furthermore, information from potentiometric and structural geology maps and water temperature measurements also support groundwater in the eastern regional carbonate aquifer flowing westward through Ash Meadows, under the southern part of the Amargosa Desert and the eastern end of the Funeral Mountains, to the springs at Furnace Creek. Geochemical and other data are consistent with the interpretation that under present pumping conditions at Amargosa Farms, the Furnace Creek springs do not include a significant component of water from the alluvial aquifer in that area. The data from the Furnace Creek springs are also consistent with water from the alluvial aquifer mixing with a larger volume of water flowing in the carbonate aquifer, or water that has equilibrated with the carbonate rocks of the Funeral Mountains.

Evapotranspiration causes a much larger amount of groundwater loss than spring discharge in the Funeral Mountain Section. Three large springs (Texas, Travertine, and Nevares) at Furnace Creek together have a discharge of 2,300 acre-ft/yr [2.8 million m^3/yr] (DOE, 2014a; Table 2-1). The annual estimate of evapotranspiration for the Funeral Mountain Section is approximately 10 times larger than this spring discharge (DOE, 2014a; Table 2-1). There is also a small amount of groundwater pumping in the Funeral Mountain Section, but this pumping does not occur near the groundwater flow path from Yucca Mountain, and thus does not impact the path for potential contaminants.

Alkali Flat and Southern Death Valley Subregion

An alternative flow path for groundwater from Yucca Mountain is along the trace of the Amargosa River to Alkali Flat (DOE, 2014a). As previously noted, flow to Alkali Flat was considered more likely prior to updated information on aquifer units in the Funeral Mountains. This path is now seen as much less likely, but some flow in this direction cannot be ruled out, and discharge in Alkali Flat is considered as a potentially affected environment in this supplement.

Based on the modeling results (DOE, 2014a), contaminant transport along the flow path beyond Alkali Flat is unlikely. Past Alkali Flat, the groundwater flow path follows the trace of the Amargosa River southward through the Shoshone-Tecopa Section and California Valley Section of the Southern Death Valley Subregion, and then continues along the Amargosa River as it turns westward through the Ibex Hills Section. Small, intermittent springs occur along the predominantly dry Amargosa River in this section, although portions of the river are perennially wet due to springs in the California Valley Section. Groundwater not lost to evapotranspiration, the springs along the river, or pumping from two wells near the town of Tecopa, continues to the flow path's endpoint at Badwater Basin, the lowest-elevation playa and salt pan in Death Valley.

The aquifer in Pahrump Valley, in the northeastern portion of the Southern Death Valley Subregion, does not directly interact with the alluvial-volcanic aquifer in the Amargosa River Section, but likely contributes groundwater flow to the lower (southern) part of the Amargosa River near Death Valley (Belcher and Sweetkind, 2010; Chapters C and D). The Pahrump Valley Section has extensive recharge in the surrounding mountainous areas as well as extensive pumping for agriculture in the Pahrump Valley. Under present and expected future wetter conditions, no contaminants from the repository would reach the aquifer in Pahrump Valley, based on the regional flow gradients (Belcher and Sweetkind, 2010).

In the Shoshone-Tecopa, California Valley, and Ibex Hills Sections, more groundwater is lost through evapotranspiration {12,350 acre-ft/yr [15.2 million m^3/yr]} than through pumping (DOE, 2014a; Table 2-1). Wells in these areas extract only on the order of 27 acre-ft/yr [0.033 million m^3/yr] of groundwater (DOE, 2014a; Table 2-1).

2.2.3 Effects of Groundwater Pumping on Flow

In the 2002 EIS and 2008 SEIS, DOE provided a discussion of pumping in the DVRFS with additional detail for the Amargosa Desert. In the 2008 SEIS, DOE reported pumping rates based on irrigation estimates generated by the Nevada Division of Water Resources [(NDWR), see LaCamera, et al., 2005)]. Analyses in this supplement use pumping rates from DOE (2014a), which were generated by the USGS using a different approach for estimating irrigation (Moreo and Justet, 2008) that led to somewhat higher estimates of pumping rates. For example, for the period from 1994 to 2003, the pumping rates in the Amargosa Desert estimated by the NDWR are 72 to 84 percent of those estimated by the USGS. The different methods are described further in Section 2.4 (Groundwater Modeling). This section of the supplement provides a brief description of pumping rates for all water uses in the DVRFS, including the updated rates provided in DOE (2014a).

Groundwater Pumping in DVRFS

Significant pumping in the region started in 1913 and increased from the 1940s to 1960s. The pumping rates varied at approximately the same levels from the 1970s to the present-day for the DVRFS (Moreo and Justet, 2008; Figure 2). There are three major groundwater pumping areas within the DVRFS: Amargosa Valley, Pahrump Valley, and Penoyer Valley. In Amargosa Valley, an average of 16,800 acre/ft [20.7 million m^3] of groundwater was withdrawn annually from 1994 to 2003, of which 85 percent was used for irrigation and 13 percent was used for mining, domestic, and commercial purposes. Annual pumping variations are generally a result of crop and irrigation cycles. In Pahrump Valley, the largest groundwater withdrawal area in the DVRFS, annual pumping estimates ranged from approximately 20,000 to 33,000 acre-ft [25 to 41 million m^3] from 1994 to 2003. Compared to Amargosa Valley, a larger fraction of the pumped water in Pahrump Valley was used for domestic purposes and the public water supply, rather than agriculture. Water used for irrigation ranged from approximately 50 percent to 75 percent during the period 1993 to 2003, and this fraction decreased over time. Groundwater withdrawal in the Penoyer Valley (northeastern portion of DVRFS, outside of the area that influences groundwater flow from beneath Yucca Mountain) was about 12,600 acre-ft/yr [15.5 million m^3/yr] and was used primarily for irrigation with the pumping rate holding relatively steady from 1994 through 2003. Over the entire DVRFS for 2003, about 55,700 acre-ft [68.7 million m^3] of groundwater was pumped, of which 69 percent was used for irrigation; 13 percent for domestic; and 18 percent for public supply, commercial, and mining activities (Moreo and Justet, 2008). Comparable data for the entire DVRFS for more recent years are not readily available, but the available records for the area from the State of Nevada Division of Water Resources suggest that these volumes and fractions have not changed significantly (NDWR, 2015).

Groundwater Pumping in Amargosa Valley

Historically, agricultural irrigation used 80 percent of annual groundwater withdrawal in Nye County, Nevada, which includes both Pahrump and Amargosa Valleys. Domestic and mining water supplies used the majority of the remaining 20 percent (DOE, 2014a). Outside of Pahrump Valley, the primary irrigation area is Amargosa Farms, in the south-central portion of Amargosa Valley. In the Amargosa Valley, total annual groundwater withdrawals averaged 16,800 acre-feet [20.7 million m^3] from 1994 through 2003, with a minimum and maximum of 14,100 and 21,100 acre-ft [17.4 and 26 million m^3] (Moreo and Justet, 2008). Estimates of pumping rates since 2003 are available from the State of Nevada's Division of Water Resources (NDWR, 2015). For Amargosa Valley[2], the State of Nevada estimates of groundwater withdrawal rates from 2006 to 2012 range from 15,400 to 18,000 acre-ft/yr [19 million to 22.2 million m^3/yr] with an average of 16,700 acre-ft/yr [20.6 million m^3/yr].

In its 2008 SEIS and in DOE (2014a), DOE suggested that present-day pumping rates for the Amargosa Farms areas may not be sustainable due to proximity to Devils Hole and the potential impact of pumping on water levels there. As DOE described in its 2002 EIS and 2008 SEIS, strict limits on groundwater withdrawal in the Ash Meadows area have been instituted to protect the water level in Devils Hole and the endangered Devils Hole pupfish. Withdrawals from within Ash Meadows are a very small portion (less than 1 percent) of the total withdrawals from the Amargosa Desert Hydrographic Basin (DOE, 2008a). Information provided at a State of Nevada administrative hearing in 2007 (Taylor, 2008) showed that the water level in Devils Hole was within 0.7 ft [0.2 m] of the minimum threshold. Accordingly, the Nevada State Engineer issued an order (Taylor, 2008) that would deny any water rights applications within 25 mi

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[2] Amargosa Valley is referred to as the Amargosa Desert Hydrographic Basin (#230) in the State of Nevada Division of Water Resources designation system (NDWR, 2015). The DVRFS includes multiple hydrographic basins in the State of Nevada classification system, as well as groundwater basins in California.

[40 km] of Devils Hole, and any change applications that place the point of diversion to within 25 mi [40 km] of Devils Hole (with some exceptions). This 25-mi [40 km] radius encompasses the Amargosa Farms area. The State Engineer's order essentially limits future pumping rates in areas beyond Ash Meadows that may impact Devils Hole. These restrictions may also render the present-day pumping rates at the Amargosa Farms area unsustainable, as further analysis (SNL, 2009) indicates that the protected water level at Devils Hole could be reached by 2016, assuming only the continuation of current groundwater pumping.

2.2.4 Past and Future Climates

Understanding of possible future climates is important for the affected environment, as a climate that is cooler and/or wetter than the present-day climate can affect several aspects of groundwater flow, particularly groundwater levels, flow rates, and potential surface discharges. Recharge of the aquifers in the DVRFS by infiltrating water occurs predominantly at higher elevations on mountains and ridges where soils are thin, and along washes and riverbeds when water is flowing (DOE, 2008b, Section 2.3.1). Recharge is not evenly distributed over the DVRFS, and would change in a wetter climate. An increase in recharge (from increased precipitation and increased infiltration) would raise water levels in aquifers, which can cause surface discharge where the water table reaches the ground surface.

In the southern Great Basin, precipitation and temperature are the two most important climate variables affecting groundwater conditions (e.g., Garfin, et al., 2014). DOE developed projections that consider potential cooler/wetter future climates as part of its assessment of repository performance (DOE, 2008b). The climate projection developed by DOE for the Yucca Mountain site can be appropriately applied to the entire DVRFS because it is based on regional information on past climates and a general understanding of how similar conditions can be expected to occur in the future.

Reconstructions of regional past climates in the southern Great Basin, including the Yucca Mountain region, show patterns of periods that are relatively hot and dry (similar to present conditions) and periods that are relatively cooler and wetter (e.g., Reheis, et al., 2008). Wetter phases in the region, represented by high stands of paleolakes, do not necessarily correspond to the full glacial conditions known from global reconstructions, but have occurred during glacial transition periods (e.g., Smith and Street-Perrott, 1983).

These reconstructions of past climate states are the best indicators of expected future climates. Using paleoclimate reconstructions as a basis, DOE has defined three climate states in addition to the present-day interglacial climate that are expected to occur over the next million years (DOE, 2008b, Section 2.3.1). These are (i) a monsoonal climate that is warm and wetter compared to the present-day interglacial climate, with a shift in the seasonality of precipitation; (ii) a glacial-transition climate with cooler and wetter conditions compared to the present-day climate; and (iii) a full-glacial climate, which represents the maximum extent of cool conditions recorded in paleorecords. DOE included the interglacial, monsoonal, and glacial-transition climate states in its performance assessment for the repository over the first 10,000 years following permanent closure, and used a prescribed deep percolation rate (the amount of water reaching the repository) for the remainder of the one million year period, as provided in 10 CFR 63.342 (DOE, 2008b, Section 2.3.1.2). The NRC staff found DOE's model for future climate states to be acceptable as part of its safety evaluation (NRC, 2014a; Section 2.2.1.3.5).

For this supplement, the most significant considerations for groundwater are the overall flow paths and flow rates, and potential changes in the water table that could affect locations of surface discharge, as these can affect contaminants from the repository in the aquifer and at surface discharge locations. For these effects, the present day interglacial (hot and dry) and glacial or glacial-transition (cooler and wetter) climates represent the range of potential climate effects on groundwater in the DVRFS. A monsoonal climate is not considered further in this supplement because the effects on groundwater of that climate state fall between those of the present-day and cooler/wetter climate states (i.e., a warm, wet climate would have less impact on groundwater than a cooler/wetter climate). The effects of the cooler/wetter climate on the impacts addressed in this supplement are included in several aspects of the NRC staff's analysis. The potential climate impacts on repository releases are captured through the use of the DOE performance assessment outputs for contaminants reaching the regulatory compliance location (which includes the effects of increased water flow reaching the repository). Adjustments to groundwater velocity are used to incorporate the higher groundwater flow rates expected in a cooler/wetter climate. Potential changes in surface discharge locations are included by considering the fossil deposits that formed during past cooler and wetter periods. Appendix A provides details on the methods used to evaluate the effects of different climate states.

The analysis in this supplement makes no assumptions about the timing of the potential future climate states, only that such conditions can be expected to occur during the one-million-year period considered in this supplement. Notably, key indicators of past wetter climates, such as deposits from former high lake levels and past surface discharges of groundwater (paleodischarge sites), provide useful insight into changes in groundwater conditions regardless of when they occurred. The analysis in this supplement assumes that potential releases of contaminants from the repository can occur independently of the climate state, so the timing of changes in climate has no effect on the impact analysis.

The principal changes to groundwater in the Yucca Mountain region from cooler and wetter climates in the future are potentiometric surfaces (water table in the unconfined, upper aquifer) that are higher than present day conditions, changes in the flow paths, and changes to flow rates. One consequence of a shift to a cooler/wetter climate is that elevated water tables could lead to discharge at new locations. Present-day types of natural discharge are described in Section 2.3, including potential locations of discharge under a cooler/wetter climate state (Section 2.3.4). A second consequence is the possible alteration of pumping rates and irrigation strategies; in a cooler/wetter climate, less irrigation water would be needed to maintain the same set of crops. A third consequence is that the local or regional groundwater quantity, flow rates, and flow distributions may change due to changes in hydraulic gradients and the water table position. The consequences of this uncertainty in pumping rates is considered in Section 2.5 and in Chapter 3. Potential changes to groundwater flow in future climates are also discussed in Section 2.4.

Presently available information about human-induced climate change from the release of greenhouse gases indicates that, for this region, the most notable effects on groundwater would be increased heat and aridity in the near term, and over longer term, potentially extending the duration of the present-day interglacial climate (hot and dry) for longer than it would persist in the absence of human-induced change (e.g., Garfin, et al., 2014). The principal effects of a climate that is warmer and drier than the present-day climate is to delay the release and transport of contaminants from a repository. This is because releases depend on water entering the repository by infiltration and percolation, and transport depends on the amount and rate of water flow through the unsaturated and saturated zones (DOE, 2008b, Enclosure 8; NRC, 2014a, Section 2.2.1.3.5). Therefore, the impacts from potential human-induced climate change are captured within the range of conditions for climate and water use considered in this supplement.

2.3 Surface Discharge Environments

Present-day natural surface discharge sites from the groundwater system in the desert of the southern Great Basin cover a spectrum of types, from seeps onto the ground surface (springs) to wet or dry playas. Groundwater discharges as springs where the water table reaches the ground surface. Wet playas occur in low areas where the water table is below the ground surface to depths of less than 5 m [16 ft] (Reynolds, et al., 2007). Dry playas occur where the water table is at greater depths {greater than 5 m [16 ft]}; though at much greater depths, and depending on the soil type, evaporation becomes minimal. Springs discharging to the ground surface may reinfiltrate downstream. Surface discharges in desert environments can vary seasonally and year to year, depending on precipitation and other factors. Springs or streams in desert environments where water is always flowing are referred to as perennial. Those that vary between wet and dry periods are referred to as ephemeral.

In a wet playa, capillary action (water moving through pores in the soil, or wicking) brings water to the surface or near-surface, where evaporation causes dissolved material in the water to precipitate as mineral deposits within or on existing sediments. Texturally, soils found at wet playas differ from those at dry playas (Reynolds, et al., 2007). Mineral deposits near the surface in wet playas are described as fluffy, puffy, and soft. Wind erosion can redistribute the finer-grained minerals. Soils at dry playas, however, are described as generally compact and hard. The potential for wind erosion, and thus wind redistribution of deposited minerals, is relatively low at dry playas (Reynolds, et al., 2007). Spatial and temporal variations add complexity to classifying discharge locations. For example, low-lying areas may have springs and a complex distribution of wet and dry playas. Seasonally or from year to year, features at a discharge location may change between dry or wet playas, or to springs or standing water. The distinction between wet and dry playas is important for the analysis of impacts in Chapter 3 of this supplement because the wind-driven redistribution of surface material that could contain contaminants deposited from groundwater depends on the nature of the deposits. As noted above, redistribution of precipitated material by wind is more likely from wet playas than from dry playas.

Geographically, locations of natural discharge sites fall into two categories. The first type is seeps (springs) and focused evapotranspiration along alluvial fans or faults. The second type occurs where there is a confluence of the water table with low-lying areas, such as the bottom of a valley. At the first type, water may either evapotranspirate or flow downslope and infiltrate back into the ground. At the second type, water evaporates, or transpires if plants are present.

As previously noted, the chemistry of spring water reflects the rock through which the water has flowed. Water equilibrated with carbonate rock is of a calcium-magnesium-bicarbonate composition and generally contains more dissolved chemicals than water equilibrated with volcanic rock or volcanic-derived sediments, which has higher concentrations of sodium, potassium, and silica. This water chemistry plays a role in what minerals precipitate as the groundwater evaporates at a discharge site, which in turn can affect what contaminants could be present in surface deposits.

2.3.1 Ecology at Surface Discharge Sites

The region south of Yucca Mountain, where the surface water discharge locations discussed in this supplement are located, is within the Mojave Basin and Range ecoregion (Bryce, et al., 2003; Griffith, et al., 2011;). The Mojave Basin and Range ecoregion is composed of broad basins and scattered mountains that are generally lower, warmer, and drier than those of the Central Basin and Range located north of the Mojave Basin and Range ecoregion (north of Beatty, Nevada). The broader Mojave Basin and Range ecoregion is further subdivided into smaller ecoregions: State Line/Franklin Well, Ash Meadows, and Alkali Flat, which are located within the Amargosa Desert ecoregion, and Furnace Creek Springs and Middle Basin, which are located within the Death Valley/Mojave Central Trough ecoregion (Bryce, et al., 2003; Griffith, et al., 2011).

The landscape in this region consists of north-south trending mountains separated by valleys. The creosotebush (Larrea tridentata)—white bursage (Ambrosia dumosa) association covers approximately 70 percent of the Mojave Desert, especially on lower valley floors (MacMahon, 2000; p. 292). These two desert scrub plants dominate much of the lower slopes and alluvial fans at the base of the mountain ranges and extend down into many of the inter-mountain basins. Plant species typically found with creosotebush—white bursage association in the Mojave Desert include Shockley's goldenhead (Acamptopappus shockleyi), Anderson's wolfberry (Lycium andersonii), range ratany (Krameria parvifolia), Mojave yucca (Yucca schidigera), California jointfir (Ephedra funerea), spiny hopsage (Grayia spinosa), and winterfat (Krascheninnikovia lanata). Blackbrush (Coleogyne ramosissima) and Joshua tree (Yucca brevifolia)–dominated vegetation series are present on mid-elevation mountains and hillsides. On alkaline flats, vegetation transitions to species dominated by saltbush (Atriplex ssp.), saltgrass (Distichlis stricta), alkali sacaton grass (Sporobolus airoides), and iodine bush (Allenrolfea occidentalis) or pickleweed (Salicornia spp.) (Bryce, et al., 2003). The mixed saltbush-greasewood (Sarcobatus vermiculatus)-dominated vegetation series is common on the basin floor in Death Valley (MacMahon, 2000; p. 267). Iodine bush and pickleweed-dominated vegetation series and saltgrass-dominated vegetation series are present on wet basin-fill and lacustrine deposits.

Wildlife species often use multiple habitat types throughout their life cycle and move within corridors or between patches that contain acceptable habitat. As an example, riparian areas and wetlands are key features for a large number of wildlife species throughout the Mojave Basin and Range ecoregion. Some animals, endemic species, survive only in a particular area such as within the subdivided Amargosa Desert ecoregion. Other animals live throughout the region, while others pass through the region during migration. Common terrestrial wildlife found in the Amargosa Desert and Death Valley/Mojave Central Trough ecoregions include mammals such as the desert bighorn sheep (Ovis canadensis), desert kit fox (Vulpes macrotis), coyote (Canis latrans), ground squirrels [e.g., white-tailed antelope squirrel (Ammospermophilus leucurus), bats (e.g., California myotis (Myotis californicus) and the western pipistrelle (Parastrellus Hesperus)], desert cottontails (Sylvilagus audobonii), black-tailed jackrabbit (Lepus californicus), and rodents (e.g., kangaroo rat (Dipodmys spp.) (Digital Desert, 2015). Birds found in these areas include a number of species of eagles, hawks, owls, quail, roadrunners, finches, warblers and orioles. Reptiles include the desert tortoise (Gopherus agassizii) and several species of rattlesnake and lizard. Insects (e.g., butterflies and moths, tarantula hawk wasps, beetles, ants, grasshoppers), and arachnids (e.g., scorpions, tarantulas, wolf spiders, crab spiders) are also an important part of the desert ecosystem.

Significant landscape changes may occur within the Mojave Basin and Range ecoregion in the short term and long term in response to climate change. Modeling the next five decades suggests that in response to possible near-term climate change, the lowest-elevation basins throughout the ecoregion, where surface water discharge locations are currently or are expected to occur, could transition from warm desert scrub into relatively barren areas, the expansion of some desert playas, and the slow expansion/transformation of the mixed salt-desert scrub vegetation type (Comer, et al., 2013). Areas currently dominated by Joshua tree and blackbrush-scrub type vegetation could transition to a creosotebush-dominated scrub vegetation type. In a similar manner, a future cooler/wetter climate will lead to changes in the type and abundance of vegetation. Changes in species composition, community types, and distribution ranges can be expected, with pinyon-juniper woodlands and other less-arid Great Basin species likely to become more prevalent in the region during this climate state (DOE, 2008b, Section 2.3.1.3.2.1.5; NRC, 2014a, Section 2.2.1.3.5). The exact mechanisms for these transformative vegetation changes will likely vary by type and location with varying speed and intensity.

The linkages between key climate variables and ecosystem dynamics across the Mojave Basin and Range are not well understood. While the long-term climate-related trends are highly unpredictable, and the resulting ecosystem dynamics are speculative (Comer, et al., 2013), the details of particular ecological changes are not necessary for assessing the impacts considered in this supplement. As discussed in Chapter 3, the impacts at the discharge locations are not dependent on the specific nature of the vegetation that is present, but are instead driven by the amount of surface discharge, the concentration of potential contaminants, and the type of discharge environment (e.g., springs, playa, or salt pan).

Ecological characteristics of specific sites are discussed in the subsequent sections.

2.3.2 Cultural Resources at Surface Discharge Sites

The NRC staff has determined that historic and cultural resources may be located in or around current surface discharge areas, described in Section 2.3.3, or in paleodischarge areas (which are also potential future discharge locations), described in Section 2.3.4. Previous analysis of cultural resources by DOE in its EISs for the repository at Yucca Mountain focused on the repository site and the surrounding controlled area. In its 2002 EIS, DOE identified as its region of influence for cultural resources “the land areas that would be disturbed by the proposed repository activities (as described in Chapter 2) and areas in the analyzed land withdrawal area where impacts could occur” (DOE, 2002; Section 3.1.6). DOE updated this information in Section 3.1.6 of the 2008 SEIS, which states that DOE widened the region of influence to include land that DOE had proposed for an access road from U.S. Highway 95, and land where DOE would construct offsite facilities. Section 3.1.6 of the 2008 SEIS also notes that DOE had developed a draft programmatic agreement among DOE, the Advisory Council on Historic Preservation, and the Nevada State Historic Preservation Office for cultural resources management related to activities that would be associated with development of the proposed repository (DOE, 2008a). In February 2009, DOE finalized its programmatic agreement (DOE, 2009b). The area covered by the agreement “includes all site activities conducted by [DOE] and its contractors for the licensing and development of Yucca Mountain as a repository for disposal of spent nuclear fuel and high-level radioactive waste that have the potential to affect historic properties, and that are located within the boundaries of the Yucca Mountain Project Operator-Controlled Area.”

The affected environments considered in this supplement are outside of the nominally controlled area considered by DOE in its previous assessments, and could include historic and cultural resources. For example, members of the Timbisha Shoshone Tribe reside on a 314-acre [1.27-km^2] parcel of trust land located in the Furnace Creek area of Death Valley, near Furnace Creek springs. As previously noted, the tribe has federally appropriated rights to 92 acre-feet per year [0.113 million m^3/yr] of surface and groundwater in the area (DOE, 2014a; 16 U.S.C. 410aaa). Section 3.3 is the NRC staff's consideration of impacts on cultural resources.

2.3.3 Present-Day Discharge Sites

This section describes present-day sites of natural surface discharge near or along the flow path from Yucca Mountain to Death Valley in terms of the groundwater flow pathways discussed in Section 2.2. Table 2-1 provides annual estimates of surface discharge for six different areas discussed in the text. Figure 2-5 shows the locations discussed in the text.

As described in Section 2.2.2, the predominant flow path is southwestward from Amargosa Farms, beneath the eastern end of the Funeral Mountains. Another path is southward from Amargosa Farms towards Alkali Flat. In addition to these, other sites of minor discharge in the Amargosa Farms area and areas immediately south are discussed in this section.

Discharge Locations along the Flow Path Southwest from Amargosa Farms

The springs at Furnace Creek in Death Valley (Figure 2-5) discharge groundwater that has flowed under the Funeral Mountains. The springs in the Furnace Creek area appear to be controlled by major structural features (Fridrich, et al., 2012). The Texas, Travertine, and Nevares Springs at Furnace Creek are surrounded by shrubs and grasses. The discharge is predominantly a calcium-magnesium-bicarbonate water reflective of the regional carbonate aquifer. Engineered structures have been built at several of the Furnace Creek springs to manage the water for use in Death Valley. Section 2.5.1 provides more information on water use.

Middle Basin (Figure 2-5) is a local low point in Death Valley that is down gradient from Furnace Creek. Groundwater that does not discharge at the three Furnace Creek springs, or that re-infiltrates after discharging from the springs, flows down an alluvial fan to the salt pan at Middle Basin. Along the alluvial fan, there are numerous small springs surrounded by a variety of desert shrubs, trees, and grasses. Direct evaporation occurs in the salt pan at the bottom of the alluvial fan. As a salt pan, Middle Basin is a low point or depression in the ground in which saline water has evaporated, leaving salt deposits.

Discharge Locations along the Flow Path South from Amargosa Farms

Alkali Flat, also known as the Franklin Lake Playa, is a broad area south of Amargosa Farms along the dry bed of the Amargosa River (Figure 2-5). Deposits at the site reflect intermittent spring discharge and wet and dry playas (Reynolds, et al., 2007). Salt pan, soft and fluffy wet playa deposits, and hard and compacted dry playa deposits are distributed near or intermixed with channel deposits at the confluence of Carson Slough (an ephemeral stream that intermittently flows south from Ash Meadows) and the Amargosa River. The present-day water table at Alkali Flat varies from 0 to 4 m [0 to 13 ft] below the ground surface. Water is supplied

Table 2-1. Annual Discharge Estimates for Natural Discharge Locations. In Most of the Areas, Estimates of Discharge Rates Could Not Readily Separate Contributions From Evapotranspiration and Spring Flow. Ash Meadows Data Is Provided for Comparison. [Data From Belcher and Sweetkind (2010), Tables C–1 and C–2.]

Discharge Area	Prominent Springs Present?	Evapotranspiration plus Spring Flow (millions of m^3)	Spring Flow (millions of m^3)
Alkali Flat-Franklin Lake	—	1.23	—
Shoshone-Tecopa	Yes	10.5	
Furnace Creek	Yes	—	2.83
Middle Basin of Death Valley	—	2.42	—
Franklin Well	—	0.43	—
Ash Meadows	Yes	22.2	—

to the flat from Ash Meadows along Carson Slough and from the Amargosa River. Surface discharge is dominated by loss to evaporation and, to some extent, transpiration by scattered low scrub vegetation, although intermittent surface flow can occur during brief wetter periods such as major rainfall events (e.g., Beck and Glancy,1995; Tanko and Glancy, 2001). Surface water in the wet playa portion primarily flows off the playa and continues along the Amargosa River bed (Reynolds, et al., 2007); little standing water has been observed in this area. Chemistry of the water varies widely, from dilute to highly saline. Water in the thin alluvial sediments is confined to those sediments. Two springs in the northern part of the flat have relatively dilute water; water emanating from a well and from a spring have 1,000 mg/l [ppm] and <5,000 mg/l [ppm], respectively, of total dissolved solids. By contrast, total dissolved solids reaches 80,000 mg/l [ppm] in water from the wet playa portions of the flat. The water at Alkali Flat is of insufficient quantity and too saline to be of beneficial human use (Czarnecki and Stannard, 1997).

Most of the surface of Alkali Flat is not vegetated (Czarnecki and Stannard, 1997). Vegetated areas are limited mainly to along the braided river channel with relatively lower salt content. About 1 to 5 percent of the total surface area of the playa {total area roughly 16 km^2 [6 mi^2]} consists of sparsely distributed mounds primarily covered with greasewood, seep weed (Suaeda fruticosd), and saltbush. Small quantities of saltgrass are concentrated near the few springs and seeps at the northern and eastern playa margins.

The Shoshone and Tecopa portions of the Amargosa River, south of Alkali Flat, are perennial under the present-day climate (Menges, 2008). Water that does not discharge at Alkali Flat flows in the alluvial sediments of the Amargosa River valley. The quantity of groundwater discharge is sufficient to maintain a flowing river year-round for a short stretch near Shoshone and a longer stretch {about 8 km [5 mi]} south of Tecopa.

Other Discharge Locations in the Amargosa Farms Area

Evidence of paleosprings in the Amargosa Farms area is found in the State Line Deposits, which extend southward from the Amargosa Farms area and span a section of the dry Amargosa River bed. The surface exposures of these deposits consist of a complex distribution of Holocene playa sediments and older freshwater limestone rocks interspersed with channel and alluvial fan deposits (Kilroy, 1991). At present, this area is not likely to have significant water loss by evapotranspiration, as described in Belcher and Sweetkind (2010, Chapter C),

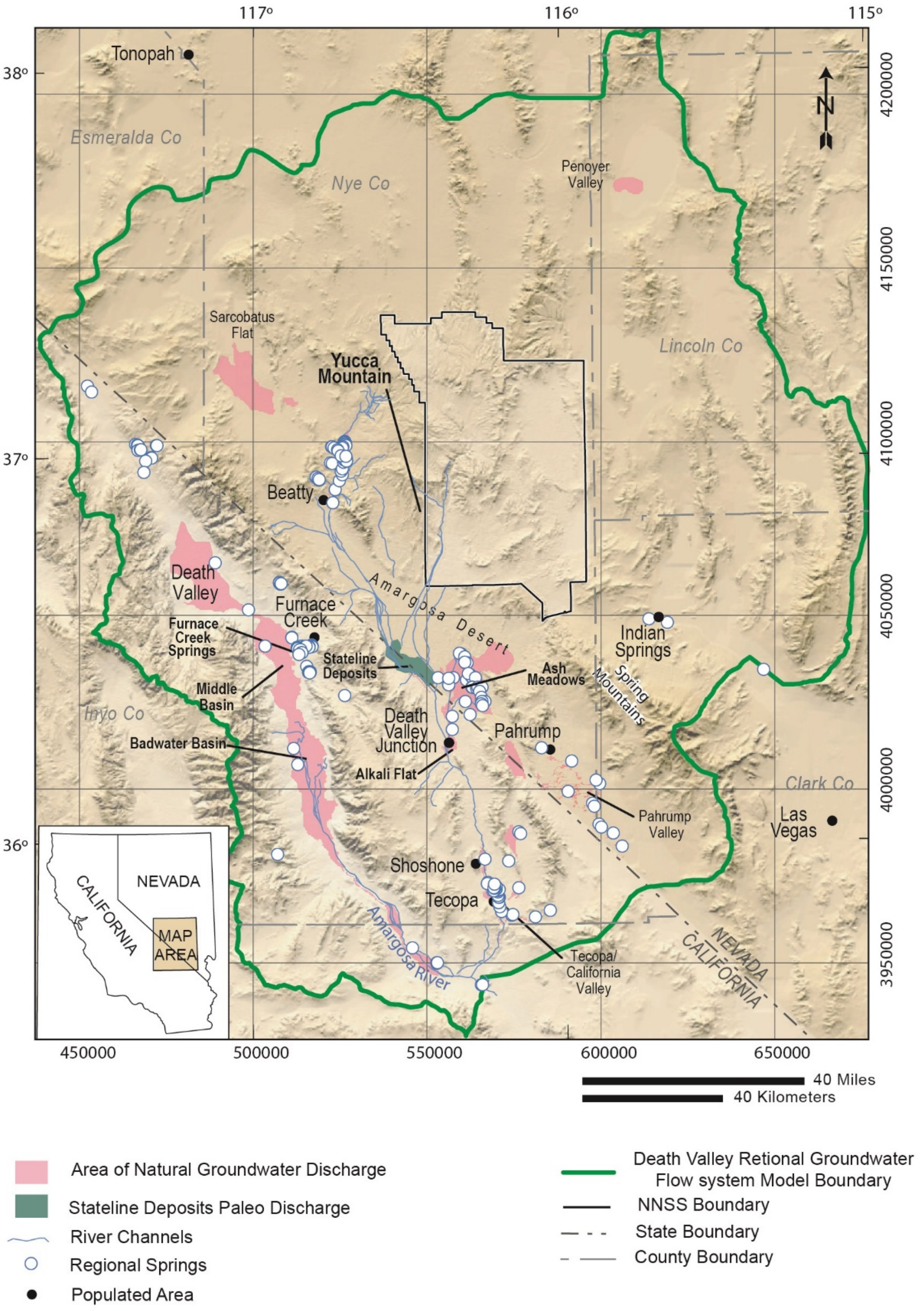

Figure 2-5. Location of Natural Groundwater Discharge Areas, Including Springs and Playas, in the Death Valley Regional Groundwater Flow System. Modified From Belcher and Sweetkind (2010).

except for the limited Franklin Well area, as discussed below. The water table in the State Line Deposits area varies from 1.8 to 10 m [6 to 33 ft] below the surface, based on well measurements from the 1980s (Kilroy, 1991; Paces and Whelan, 2012). The water table is closest to the ground surface immediately to the southwest of the deposits, in the vegetated Franklin Well area. In the area of the State Line Deposits, the water table depth is within the range of a potential wet playa environment. Groundwater drawdown from pumping in the Amargosa Farms area over the last century may have extended to parts of the State Line Deposits area, and thus, in the absence of pumping at Amargosa Farms, evaporation may occur over a larger area in the State Line Deposits wherever the water table is within 5 m [16 ft] of the ground surface (following the delineation by Reynolds, et al., 2007). The State Line Deposits area could be a potential minor discharge location for water flowing from Yucca Mountain under the present-day climate (or in a future cooler/wetter climate), but only if pumping in the Amargosa Farms area is significantly reduced. However, there is no evidence of recent springs in the State Line area, and the youngest dated State Line spring deposits formed approximately 30,000 years ago (Paces and Whelan, 2012).

The Franklin Well area is a small linear band along the base of the alluvial fan from the southern end of Funeral Mountains and the Amargosa River bed. Adjacent to the State Line Deposits, the Franklin Well area includes an approximately 8 km [5 mi] section with locally dense vegetation and associated evapotranspiration. Belcher and Sweetkind (2010) estimated a small amount of evapotranspiration discharge for this area (Table 2-1), but gave no further description. The specific source of the water in this narrow zone is not well defined. Possible sources include northward flowing groundwater in the alluvial fan bordering the Funeral Mountains, eastward flowing groundwater along the Amargosa River channel, and southward flowing groundwater in the alluvial aquifer under the Amargosa Farms area (Belcher and Sweetkind, 2010; Figure C–2). The southward flowing groundwater in the alluvial aquifer under Amargosa Farms includes groundwater from beneath Yucca Mountain.

The woodland vegetation of the Franklin Well area is comprised mostly of mesquite (Prosopis spp.), saltcedar (Tamarix spp.), and desert willow trees (Chilopsis linearis), with some meadow grasses and shrubs. The dense to moderately dense grassland vegetation in the area is primarily saltgrass and/or short rushes with an occasional tree or shrub (Laczniak, et al., 2001).

Ash Meadows

Ash Meadows is in the neighboring basin to the east of Amargosa Farms and, as such, is not a discharge location for groundwater flowing from Yucca Mountain. Ash Meadows is a large area of wetlands and pools fed by springs. The springs are surrounded by a broad area of grass meadows interspersed with moderately dense to sparse stands of trees and shrubs. The source of water to the springs is the regional carbonate aquifer, which is fed by recharge from the Spring Mountains, which flows from the east and northeast towards Ash Meadows (Belcher, et al., 2012). The groundwater flowing from the Ash Meadows area mixes with the Amargosa River flow path, well south of Yucca Mountain, along Carson Slough and Alkali Flat, as described above.

Ash Meadows is a well-studied desert wetland ecosystem encompassing over 23,000 acres [93 km^2] of spring-fed wetlands surrounded by sparse, relatively dry grassland interspersed with sparse to moderately dense stands of trees and shrubs (Belcher, et al., 2012). According to Laczniak, et al. (1999, pp. 7–8):

> Areas influenced by local springflow include groves of ash (Fraxinus velutina var. coriacea), cottonwood (Populus fremontii), willow (Salix exigua), and mesquite (Prosopis glandulosa torreyana and P. pubescens); thick stands of saltcedar (Tamarix aphylla, T. parviflora, and T. ramosissima); expansive meadows of saltgrass, wire-grass (Juncus balticus, J. cooperi, and J. nodosus), and bunch grass (Sporobolus airoides); and open marshland of cattails (Typha domingensis), reeds (Phragmites australis), and bulrush (Scirpus robustus). More typical Mojave Desert flora, primarily sparse covers of healthy creosote bush (Larrea tridentata), saltbush and desert holly (Atriplex hymemelytra), dominate upland areas not influenced by local spring discharge.

In summary, the principal natural discharge site under present conditions for groundwater potentially contaminated by releases from a repository at Yucca Mountain is in the Furnace Creek/Middle Basin of Death Valley. Minor discharge sites for contaminants include Alkali Flat and the area of the State Line Deposits. The present-day extensive surface discharge in nearby Ash Meadows is fed from a separate basin in the DVRFS, and is not a discharge location for potential repository contaminant releases.

2.3.4 Paleodischarge Sites

During cooler/wetter climates, groundwater would continue to discharge at the present-day sites, and potentially, at additional sites in Amargosa Valley and along the flow path from Yucca Mountain to Death Valley. The volume of future groundwater discharges at present-day sites would likely increase, as would the area of wet playas. Evaporation may decrease due to cooler temperatures. New discharge sites would likely form as the water table rises.

Evidence of paleodischarge sites found in Amargosa Desert and across the DVRFS serve both to identify possible future discharge locations and to constrain the potential increases in the elevation of the water table. These sites provide calibration targets[3] for groundwater flow models and are useful in identifying or precluding other potential discharge sites. Notably, results of numerical groundwater modeling, as discussed in Section 2.4, suggest that even though flow rates and discharge locations may vary, the flow path does not significantly change between drier and wetter periods.

Amargosa Desert Sites

Data derived from fossils, rock types, mineralogy, and chemistry at discharge sites across the Amargosa Desert provide consistent indicators of the timing, flow history, and characteristics of these discharge sites (Paces and Whelan, 2012; Paces, et al., 1997). The State Line Deposits and several Crater Flat area deposits were discharge sites under past cooler/wetter climates. These are representative of potential discharge sites along the present-day and potential future groundwater path from Yucca Mountain under a cooler/wetter future climate.

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[3] Calibration targets are known information used to constrain other less well-known inputs in a groundwater model

As described in Section 2.2.2, the State Line Deposits area (Figure 2-5) falls directly along the path of groundwater flowing from Yucca Mountain (DOE, 2014a). Observations from the discharge deposits show a complex interplay of surface flow and spring discharge in the southern part of the Amargosa Desert (Belcher and Sweetkind, 2010). The discharge deposits indicate that the groundwater generally reflects the mineral content of the volcanic-derived alluvial sediments of Amargosa Valley. The deposits also indicate contributions from (i) the lower carbonate aquifer, as indicated by the freshwater limestone deposits and (ii) older metamorphic rocks to the south in the Funeral Mountains, as indicated by the strontium isotopic composition (Paces and Whelan, 2012; Paces, et al., 1997). Based on the areal distribution of discharge deposits at the ground surface and at depth, and the present-day topography, the water table rise in a cooler/wetter climate would likely be no more than 30 m [98 ft] in this part of the southern Amargosa Desert (Paces and Whelan, 2012). Information from the fossils, mineralogy, and stratigraphy (relative relations of the rock layers) indicates that these ancient discharge sites existed in a diverse wetland environment fed by springs and perennial or seasonal flow along the Amargosa River (Paces and Whelan, 2012). This wetland environment included wet ground, seeps, marshes, flowing channels, and open pools. Surrounding areas supported phreatophyte (deep-rooted) vegetation with associated discharge by evapotranspiration. Isotopic dating of the deposits indicates that the springs were active at several times during the transition into the last glacial maximum, with measured ages of roughly 100,000 and 40,000 years before present.

Several small areas of paleodischarge deposits, marked in Figure 2-5, occur northeast of the State Line Deposits, but west of Ash Meadows. These are much more limited in extent and have not been studied in as much detail as the State Line Deposits. Given their locations, these deposits are more likely related to groundwater from Ash Meadows during past wetter climates, rather than the southward flowing volcanic-alluvial aquifer system in Fortymile Wash. The present depth-to-water table at this location is greater than the possible water table rise in the alluvial aquifer during wetter climate conditions (Paces and Whelan, 2012). For these reasons, these locations are not likely to represent potential future discharge sites for groundwater from the Yucca Mountain flow system.

Three paleodischarge deposits are present at the southern end of Crater Flat (Figure 2-5), on a smaller scale and with much less carbonate deposition compared to the State Line Deposits (Paces and Whelan, 2012). All three deposits have geochemical signatures of water equilibrated with alluvial sediments derived from tuff (volcanic rock) and a lesser amount of carbonate rock (Paces, et al., 1997). Differences in the stratigraphy at the three sites, together with those in the State Line Deposits area, suggest that these deposits formed in local ponds and marshes, rather than in a large lake across the Amargosa Desert (Paces, et al., 1997). Diatomites (deposits composed of fossil diatoms, microscopic organisms with a silica shell) are present at all the Amargosa discharge sites, though only the Lathrop Wells site has a thick sequence. The presence of diatomites, along with other fossils (shells of ostracodes and mollusks) indicate a paleoenvironment of open water such as flowing springs, pools, and wetlands (Paces and Whelan, 2012). The three Crater Flat deposits occur at elevations of 790 to 835 m [2,591 to 2,739 ft] (Paces and Whelan, 2012). These elevations indicate the water table elevation exiting Crater Flat during the wetter periods. Nye County research wells indicate that the present-day depth to the water table ranges from 8 to 31 m [2.4 to 9.5 ft] at the three paleodischarge sites (Paces and Whelan, 2012). Importantly, geochemical data and age determinations indicate flow at the Crater Flat paleodischarge locations was active during roughly the same time periods as at the State Line location (Paces and Whelan, 2012; Paces, et al., 1997), indicating that the discharge was likely related to regional climate effects. However, none of the three Crater Flat sites is located along a present or past flow path from

Yucca Mountain, based on an analysis of the elevations and potential extent of water table rise at Yucca Mountain (Paces, et al., 1997; SNL, 2007a). Instead, particle tracking model results for future wetter climates indicate that flow from the northwest below Crater Flat was the likely source for the Crater Flat discharge deposits (Winterle, 2005).

Alkali Flat to Death Valley

The Carson Slough and Amargosa River flow systems (groundwater and surface water) feed Alkali Flat (Franklin Lake Playa). Evidence from Devils Hole shows that the water table fluctuated between 5 and 9 m [16 and 30 ft] higher at Ash Meadows during the glacial periods of the last 116,000 years (DOE, 2014a). This rise, along with possible perennial flow in the Amargosa River, suggests that in future wetter climates, a larger amount of groundwater and surface flow would reach Alkali Flat than under the present-day climate. Today, Alkali Flat is mostly a flow-through system (Reynolds, et al., 2007). The very low topographic gradient suggests that greater flow will not lead to extensive standing water, and that the area would remain an assemblage of variable extents of wet and dry playas in future climates. Additional flow in the river bed continues down to Death Valley, where potentially standing water (and during some periods, an extensive lake) remained year-around during wetter climates, based on paleorecords (e.g., paleo-Lake Manly; Paces and Whelan, 2012; Smith and Street-Perrott, 1983).

2.3.5 Summary of Surface Discharge Environments

Surface discharge environments along the Yucca Mountain flow path fall into three generic types: (i) pumping for irrigation and other uses, as at Amargosa Farms; (ii) discharge at springs, such as at Furnace Creek or the paleo-State Line Deposits; and (iii) discharge at wet and dry playas and salt pans, such as at Alkali Flat or Middle Basin. These types encompass the range of discharge environments expected under current and future climate conditions.

2.4 Groundwater Modeling

In the 2008 SEIS, DOE provided a description of the two groundwater flow models of different scales that were used to quantify flow in and around the DVRFS. The small-scale model covers Yucca Mountain and southward to Amargosa Desert (the Yucca Mountain Site Scale model). This model remains unchanged since 2008 in DOE (2014a). The Yucca Mountain Site Scale model provides flow information for groundwater conditions near Yucca Mountain, which DOE used to support its evaluation of repository performance in its SAR (DOE, 2008b). The DVRFS model is the larger scale model used by DOE in its SAR; it provides information about areas beyond those in the Yucca Mountain Site Scale model. As previously noted, the NRC staff has found DOE’s integration of the multiple models for saturated zone flow to be acceptable as part of the NRC’s safety evaluation (NRC, 2014a; Section 2.2.1.3.8). For its 2002 EIS and 2008 SEIS analysis, DOE used the DVRFS model and its representation of groundwater flow beyond the regulatory compliance location and along the flow path to Death Valley. The 2008 SEIS describes the DVRFS model, as documented by the USGS in Belcher (2004). The USGS has since updated the documentation of the DVRFS model (Belcher and Sweetkind, 2010), but the information about the model in the updated report is substantively unchanged (Belcher and Sweetkind, 2010).

DOE used a slight modification of the Belcher and Sweetkind (2010) model in its 2014 analyses (DOE, 2014a). DOE used the 2004 DVRFS model to calculate the groundwater conditions (e.g., water table position) present before extensive pumping in Amargosa Farms (nominally for conditions in 1913). The model input parameters were then adjusted to match the transient (changing) conditions that account for groundwater pumping from the period of 1913 to 1998 (Belcher and Sweetkind, 2010). DOE (2014a) incorporated an expanded pumping data set from Moreo and Justet (2008) that accounted for the period 1913 to 2003, to further update the DVRFS model. As previously noted in Section 2.2.3, pumping records since 2003 indicate little change in the past decade, so this update and analysis capture current pumping rates (NDWR, 2015). This update and DOE's observations from modeling several scenarios are described below, especially as they pertain to the affected environment beyond the regulatory compliance location.

Effects of Pumping on Groundwater Conditions

As described in Section 2.2.3 (Groundwater Pumping), substantial pumping in the area began in 1913 and has increased markedly in the past several decades. Evaluation of groundwater conditions without pumping is an important starting point for comparisons with paleorecords for calibrations to account for transient conditions caused by pumping, and for analyzing the groundwater impacts if no pumping were to occur in the future.

Estimates of pumping rates changed as the DVRFS model evolved from its early version (e.g., D'Agnese, et al., 1999), to that used in the 2002 EIS, the 2008 SEIS, and in DOE (2014a). Pumping rates for irrigation, the primary use of groundwater in the Amargosa Farms area, are typically not directly measured. Model groundwater pumping, therefore, is from indirect estimates. Not only does irrigation usage vary from year to year, but techniques differ for estimating the pumping rates for irrigation (DOE, 2014a). The methods used by the USGS and the NDWR are both based on reliable data for the amount of land under irrigation, but use different water application rates (amount per acre) to generate estimates of pumping rates. Groundwater pumping estimates for the DVRFS in the 2002 EIS and the 2008 SEIS are different from those used by the USGS in developing its updated model (Belcher and Sweetkind, 2010). The 2002 EIS and 2008 SEIS used estimates from the State of Nevada, whereas Belcher and Sweetkind (2010) used estimates developed by the USGS that were slightly greater (by about 20–30 percent) than those of the State of Nevada. Use of greater pumping rates may lead to over-estimates of flow rates and potentiometric elevations (e.g., water table for unconfined aquifers) in the absence of pumping.

The Belcher (2004) model was first calibrated to account for steady-state groundwater levels prior to 1913, before significant pumping occurred in the area of the DVRFS. This no-pumping condition provides an estimate of the water table position and flow path directions in the Amargosa Farms area without the water table decrease caused by pumping. The model was then calibrated for transient conditions using values for water level, spring flows, evapotranspiration, and pumping as they changed over time from 1913 to 1998 (DOE, 2014a). The results of these calibrations were compared with measured water table positions as they changed until 1998.

Uncertainties in future pumping rates were considered in DOE (2014a), especially concerning the effect on the water level in Devils Hole and on the positive vertical gradient from the regional carbonate aquifer to the overlying alluvial aquifer in the Amargosa Farms area. Using the USGS DVRFS model, DOE conducted simulations of long-term pumping, up to 500 years, at the 2003 groundwater pumping rates. These simulations were done both with and without an additional 10,600 acre-ft/yr [13.1 million m^3/yr] of withdrawal from the lower carbonate and alluvial aquifers, as proposed by the Southern Nevada Water Authority for additional supply wells east of the NNSS (SNL, 2009). The modeling results suggested that the upward hydraulic gradient in the lower carbonate aquifer would be maintained after 500 years of additional pumping and would be within 3 percent of that predicted for no-pumping steady-state conditions. Simulation results with the additional annual withdrawal quantity proposed by the SNWA indicated little additional impact on water levels beyond that calculated without the SNWA-proposed withdrawal (SNL, 2009). In any case, continued heavy pumping from the shallow alluvial aquifers would result in an increase in the upward vertical gradient of the lower carbonate aquifer in the Amargosa Desert (SNL, 2009), at least until the pumping rate triggered the restrictions discussed in Section 2.2.3 regarding impacts on the water levels at Devils Hole.

For the analyses of impacts in this supplement, the NRC staff used results based on the updated DVRFS model (Belcher and Sweetkind, 2010; DOE, 2014a), which included expanded pumping data for 1913 to 2003. Consistent with its previous evaluation of saturated zone flow in the area (NRC, 2014a, Section 2.2.1.3.8), the NRC staff has concluded that the updated DVRFS model is a reasonable representation of the regional groundwater system. Values of groundwater flow velocity derived from the updated DVRFS model were used as inputs to groundwater transport calculations (DOE, 2014a). The NRC staff used the result of these calculations to determine the potential impacts when groundwater pumping is assumed to occur (Section 3.3.1) and when no pumping is assumed to occur (Section 3.3.3).

Effects of Climate on Future Flow Paths

D'Agnese, et al. (1999) simulated the future groundwater environment by using increased recharge to reflect expected future climate conditions and assessing the impact on groundwater conditions. The different distribution and increased values of recharge were intended to reflect cooler and wetter conditions comparable to the glacial climate of 21,000 years ago. The model used by D'Agnese, et al. (1999) was a predecessor to the current version of the DVRFS model (Belcher and Sweetkind, 2010), but the models are sufficiently alike to expect similar conclusions for the effect of climate change. D'Agnese, et al. (1999) found that the elevated water table calculated for the cooler/wetter climate had generally the same shape as the present day water table. This means that the directions of flow along the path from Yucca Mountain would not likely differ between present-day conditions and a future cooler/wetter climate. This analysis also found that the extent of water table rise for this cooler/wetter climate was consistent with the observed locations of paleodischarge deposits. The D'Agnese, et al. (1999) model predicted that the confluence of Fortymile Wash and the Amargosa River would be a discharge location under future wetter conditions, consistent with discharge at the State Line Deposits area. Furthermore, the model results suggested that long stretches of both channels would become perennial streams. D'Agnese, et al. (1999) noted that flow in the rivers, along with the increased discharge of groundwater, in a cooler/wetter climate state would be sufficient to supply the water in paleo-Lake Manly in Death Valley.

2.5 Water Use and Quality

This section provides a brief description of water use and quality for areas south of Amargosa Farms, along the flow path to Death Valley.

In the 2002 EIS and 2008 SEIS, DOE provided a description of water use and the biosphere for the Yucca Mountain area and south to the regulatory compliance location, approximately 18 km [11 mi] along the flow path. Beyond the regulatory compliance location, water from wells or springs is used in Amargosa Farms, and Furnace Creek. Amargosa Farms and Furnace Creek are along the primary flow path for groundwater from Yucca Mountain. The 2002 EIS and 2008 SEIS list water uses in the Amargosa Valley as irrigation, mining (mostly in western Amargosa

Valley), livestock, and for quasi-municipal, commercial, or domestic water supply. DOE (2014a) states that water from the Furnace Creek springs (Texas, Travertine, and Nevares) is used to support Death Valley National Park and the Timbisha Shoshone Tribe, which occupies several hundred acres within Death Valley National Park. The springs support the commercial and domestic water supplies, including a small commercial date farm.

The 2002 EIS and 2008 SEIS provide descriptions of regional groundwater quality, including for the area of pumping in Amargosa Farms. Generally, the quality of the groundwater in Amargosa Farms is good, and the tested groundwater sources met the EPA's primary drinking-water standards (DOE, 2014a; 2008a). Some groundwater samples from the Amargosa Farms area contained concentrations of naturally occurring arsenic above EPA primary drinking water standards; as noted in DOE (2014a), these samples were not collected from drinking water systems, so the EPA standards are not directly applicable. Water from Texas Spring at Furnace Creek (again, not collected from a drinking water system) had similar high arsenic levels, and also had naturally occurring lead and fluoride concentrations above drinking-water standards (DOE, 2014a). Concentrations of selected groundwater constituents are given in Table 2-2, for potential contaminants released from the proposed repository.

The quality of water discharged to playas, either as intermittent seeps, standing water, or runoff, is variable but is often highly saline. Because of the low amount of water, lack of reliability, and poor quality of this water, it is not of practical use by humans and has not been developed for use.

2.6 Analysis Cases for Assessing Impacts

Any potential changes in the affected groundwater environment would be due to changes to the regional and local groundwater system that affect flow paths, amount of flow, or discharge locations. As discussed above, changes to the groundwater system over the one-million-year period depend primarily on two factors that will likely vary in the future: climate state (through changes in the amount of groundwater recharge and losses through evapotranspiration) and the amount of regional pumping (through the lowering of the water table and possible capture of contaminants). To address these two factors, two analysis cases are considered that provide a reasonable range of conditions to assess the affected environment and potential impacts.

- Analysis Case 1: Pumping in Amargosa Farms for current uses at current rates

- Analysis Case 2: Natural surface discharge at and downstream from Amargosa Farms with limited or no pumping in Amargosa Farms

The analysis cases address both pumping in the Amargosa Farms area (substantial removal of groundwater from the system) and no pumping, and thus account for uncertainty in future pumping levels. Analysis Case 1 considers present-day rates of pumping in Amargosa Farms. At present-day extraction rates, all the contaminant releases from a repository at Yucca Mountain are assumed to be captured by the pumping wells, consistent with the analysis assumption for water extraction at the regulatory compliance location (DOE, 2008b; NRC, 2014a).

Analysis Case 2 accounts for surface discharges beyond the regulatory compliance location in the case of limited or no pumping in Amargosa Farms. In this case, contaminants could reach locations further along the flow path, as far as Death Valley. With little or no pumping in Amargosa Farms, contaminants from a repository could discharge to the surface at areas

Table 2-2. Concentrations of Naturally-Occurring Constituents in Groundwater From Amargosa Farms and Furnace Creek Springs, for Potential Contaminants Contributing to Impacts Discussed in Chapter 3

Constituent	Groundwater Amargosa Farms	Discharges from Furnace Creek Springs	Federal Drinking Water Standard (40 CFR 141)
Total Uranium (µg/L)	2.55	5.1	30
Molybdenum (mg/L)	0.007	(0.03)	None
Vanadium (mg/L)	(0.01)	(0.01)	None
Nickel (mg/L)	—	—	None

Data from highest value given in DOE, 2008a, Table 3-19, or DOE, 2014a, Table 2-2. Parentheses indicate concentration below detection; value in parentheses is detection limit.

similar to the State Line Deposits or Alkali Flat, or to Furnace Creek Springs and Middle Basin in Death Valley.

As discussed in Section 2.3.2, paleodischarge sites from water flowing beneath Yucca Mountain have not been identified along the flow path upgradient from Amargosa Farms. Although the future flow path is subject to some uncertainty, analyses suggest that it would not change appreciably (Section 2.4). For this reason, natural discharge of contaminated water is not expected between Yucca Mountain and Amargosa Farms, even under future cooler and wetter climates, thus possible impacts from natural discharge are not considered for that area.

Therefore, these analysis cases reasonably capture the credible range of future conditions, encompassing future climate change and potential changes in groundwater extraction in Amargosa Farms. Two important factors related to future pumping rates further support this conclusion. The first is the restriction on groundwater pumping due to basin withdrawal related to impacts on water levels at Devils Hole (Section 2.2.3). Because of this restriction, the pumping rate is not likely to be greater than that over the past several decades, and may be less in the future. The second factor is that in a future cooler/wetter climate, the demand for groundwater for irrigation could lessen and pumping could decrease. In such a climate of lower evaporation and increased precipitation, less irrigation would be required to support present-day farming. If pumping decreases substantially, groundwater withdrawal may not capture all of the contaminants from a repository. In this case, potential impacts could occur at downstream discharge locations. These are addressed in Analysis Case 2, which assumes most contaminants reach discharge locations downstream of Amargosa Farms.

Thus, potential impacts at Amargosa Farms under the present climate and pumping rates, or a cooler/wetter climate and somewhat reduced pumping rates, are addressed by Analysis Case 1 (which assumes all contaminants are captured at Amargosa Farms). Potential impacts downstream of Amargosa Farms under both climate states with limited or no pumping are addressed by Analysis Case 2. The impacts for these two analysis cases are discussed in Chapter 3.

3 ENVIRONMENTAL IMPACTS

The affected environment described in Chapter 2 includes the aquifer and the surface discharge sites beyond the regulatory compliance location at approximately 18 km [11 mi] along the groundwater flow path from Yucca Mountain. This chapter assesses the potential impacts for these environments from contaminants released from the proposed repository.

In Chapter 5 of its Final Environmental Impact Statement (EIS) (DOE, 2002), the U.S. Department of Energy (DOE) described its approach and analyses for estimating potential impacts on human health, other biological impacts, and environmental impacts from releases of radioactive and nonradioactive materials to the environment after closure of the proposed repository at Yucca Mountain. Using a similar approach and analysis for its 2008 Supplemental Environmental Impact Statement (SEIS) (DOE, 2008a), DOE summarized, incorporated by reference, and updated information presented in Chapter 5 of the 2002 EIS. In the 2002 EIS and 2008 SEIS, DOE described the affected environment and impacts up to the regulatory compliance location at approximately 18-km [11-mi] distance along the flow path from the repository. At the regulatory compliance location, the impacts were estimated for the reasonably maximally exposed individual (RMEI), consistent with the RMEI characteristics in 10 CFR Part 63. In its 2008 SEIS, DOE stated that the environmental impacts beyond the regulatory compliance location would be less than those at the regulatory compliance location. In its Adoption Determination Report (ADR) (NRC, 2008a), the NRC staff determined that it could adopt the general approach used by DOE in estimating releases from the repository and the impacts at the regulatory compliance location, but concluded that the affected environment and any impacts for areas *beyond* the regulatory compliance location were not adequately described in the 2002 EIS and 2008 SEIS for potential releases of radiological and nonradiological contaminants from the repository.

In this NRC staff-prepared supplement, impacts on water and soil, ecology, cultural resources, and environmental justice are provided for locations beyond the regulatory compliance location, drawing on the previous work by DOE and its subsequent analyses in DOE (2014a). The affected environment is described in Chapter 2, including potential locations for groundwater pumping and types of natural surface discharge in the Yucca Mountain groundwater flow path beyond the regulatory compliance location, downstream to Death Valley.

The description of water and soil impacts is in Section 3.1, ecological impacts in Section 3.2, cultural resources in Section 3.3, and environmental justice in Section 3.4. A summary of impacts is provided in Section 3.5.

3.1 Impacts on the Aquifer, Water and Soil

In the 2002 EIS and 2008 SEIS, DOE provided radiological impacts for the RMEI at the regulatory compliance location (also called the RMEI location) for the 10,000-year and one million-year periods following repository closure for a stylized scenario of groundwater pumping for irrigation of limited local food cultivation. The scenarios analyzed by DOE follow the characteristics of the RMEI in 10 CFR 63.312.

DOE’s analysis of radiological impacts for the RMEI in its 2002 EIS and 2008 SEIS is based on results from its Total System Performance Assessment (TSPA) model for performance of the repository after permanent closure (DOE, 2008b, Chapter 2). The development of the model involved a systematic assessment of potential features, events, and processes that could affect the release of radioactive material from the repository, transport of that material beyond the site boundary, and radiological exposure to the RMEI. The regulatory compliance location is defined in 10 CFR 63.312 as the point where the RMEI would receive the greatest dose. Doses beyond this location along the groundwater flow path are lower due to dispersion and sorption of contaminants in the aquifer, along with radioactive decay during longer transport times. The NRC staff found DOE's TSPA methodology to be acceptable as part of its safety evaluation (NRC, 2014a, Section 2.2.1.4.1).

In the 2002 EIS, but not in the 2008 SEIS, DOE scaled results from the regulatory compliance location to account for dispersion in the groundwater system to estimate impacts 30 and 60 km [19 and 37 mi] downstream from the repository. These distances from Yucca Mountain approximate the distances to Amargosa Farms and to Alkali Flat, respectively. In the 2002 EIS and 2008 SEIS, DOE provided chemical toxicity impacts in terms of a bounding analysis at the RMEI location only for the first 10,000 years after repository closure.

This supplement provides updated impact information for groundwater pumping in the Amargosa Farms area, and provides impacts at sites of natural surface discharge along the flow path between the regulatory compliance location and Death Valley along the Yucca Mountain groundwater flow path. The impacts include those from both radiological and nonradiological contaminants at pumping locations (Amargosa Farms) and at natural discharge locations for one million years; results at earlier times are also provided. Impacts from groundwater contamination prior to this timeframe are not expected, as described in the NRC's Safety Evaluation Report (SER) and in DOE's EISs (DOE, 2008a, 2002; NRC, 2014a;).

As discussed in Chapter 2, impacts are analyzed accounting for uncertainty in both future pumping rates and climate using two analysis cases. Consideration of the type of discharge site (pumping from wells or natural surface discharge), uncertainties in future pumping rates in Amargosa Farms, and potential future climate states leads to delineation of two cases for the analysis of impacts. These cases encompass the reasonable range of future conditions and activities. These analysis cases are as follows:

Analysis Case 1: Pumping at Amargosa Farms

- Present-day and future cooler and wetter climate states

Analysis Case 2: Surface Discharge Downstream of Amargosa Farms

- Assumes limited or no pumping in Amargosa Farms
- Present-day and future cooler and wetter climate states

The first analysis case assumes that the pumping rate and well distribution in Amargosa Farms is comparable to the present-day and is sufficient to extract any contaminants released from the repository to the groundwater system. It also assumes that the present-day pumping rates will continue into the future. Both present-day climate and a future cooler/wetter climate are considered in the pumping scenario of Analysis Case 1 (Section 3.1.1). The second analysis case assumes that limited or no pumping occurs in Amargosa Farms and, thus, all contaminants would migrate to natural discharge locations along the path from Amargosa Desert to Death Valley (Section 3.1.2). Downstream natural surface discharge locations considered in Analysis Case 2 include natural spring discharges in the State Line Deposits/Franklin Well area, Furnace Creek, and the playa/salt pan of Middle Basin of Death Valley. An additional potential flow path to surface discharge to a playa/salt pan environment at Alkali Flat is also considered (see Section 2.3.3). Analysis Case 2 also addresses both present-day and future cooler/wetter climates. The methods used in this analysis are summarized in the next section, and described in more detail in Appendix A.

Considering the uncertainty in future pumping projections, it is likely that future conditions would lie somewhere between the two analysis cases. Thus, these two analysis cases are not additive. They represent, instead, the endpoints of the spectrum of future scenarios addressing the uncertainty of pumping in Amargosa Farms. Possible future scenarios could fall at (in an extreme case) or between these endpoints. For example, some reduced amount of pumping in Amargosa Farms would extract some fraction of a contaminant plume, and the remainder would be transported down the flow path. In this case, the impacts at Amargosa Farms would be less than those described in Analysis Case 1, and the impacts downstream would be less than those described in Analysis Case 2. As discussed below, the magnitude of the environmental impacts in a given setting is generally proportional to the amount of contaminants present in that setting. Uncertainty in climate is addressed by determining the peak impact from either the present-day or a future cooler/wetter climate for each impacted environment.

The next three sections summarize the methods used in analyzing impacts, the mass balance approach for contaminants in the aquifer, and information on typical human radiation exposure from all sources, as well as applicable regulatory standards for radiation and other potential contaminants. The subsequent sections then describe the results for each of the two Analysis Cases.

Analysis Method

The impact analysis in this supplement builds off the DOE results for the regulatory compliance location (DOE, 2008a; 2002), which the NRC staff found acceptable in its ADR (NRC, 2008a), as well as DOE's assessment of overall repository performance (DOE, 2008b; NRC, 2014a). From this basis, an analytical solution is then used to calculate the transport of radiological and nonradiological material beyond the regulatory compliance location to affected environments along the groundwater flow path to Death Valley. This analytical solution is part of an analysis framework that includes source term development, transport, and impact calculations. This framework is described in detail in Appendix A, which includes descriptions of (i) source terms (i.e., calculated releases from the repository) for radiological and nonradiological contaminants, (ii) models of contaminant transport from the repository to the regulatory compliance location, (iii) models of contaminant transport beyond the regulatory compliance location along the flow path to discharge locations, and (iv) processes that may occur at discharge locations that may affect concentrations and exposures at different types of affected environments.

The results of these calculations and impacts at each location for the analysis cases are provided for 10,000 and one million years in tables and plots in the following sections. In some cases, the peak values for contaminants at a given location do not occur at the 10,000- or one-million-year times, due to the pattern of the releases from the repository over time and the effects of sorption during transport. This is particularly apparent for some of the nonradiological contaminants (e.g., nickel), where conservative assumptions in the model for release from the repository and significant sorption during transport strongly affect the peak values (see Figure A–1 and Appendix A for further details). Specific cases for times of peak contaminant concentrations at each location are discussed in the following sections.

Mass Balance Description

The NRC staff concluded in the ADR (NRC, 2008a) that a description was needed of the accumulated amounts of radiological and nonradiological contaminants from the repository that may enter the groundwater over time, as well as a description of where those contaminants would travel along the flow path.

Sections 3.1.1 and 3.1.2 of this chapter consider impacts to groundwater and surface discharge using mass flux (the amount of a contaminant moving through the system), accumulation, exposure pathways, and dose. As part of the impacts described in these sections, the amount of radiological and nonradiological material from the repository is estimated that will (i) discharge to the surface at specific locations and accumulate in soils and (ii) reside in the aquifer environment (dissolved in water and sorbed to rock) between those locations. In Sections 3.1.1 and 3.1.2, subsections for Aquifer Environment and Soils include descriptions of where contamination may occur along the path between the regulatory compliance location and Death Valley for present-day and wetter climates for two time frames: 10,000 and one million years.

Impacts of Calculated Contaminant Levels

This section provides context for the calculated radiological and nonradiological concentrations, radiological dose, and nonradiological body intake used to determine the level of impact from releases at Yucca Mountain to different areas of the affected environment.

On average, Americans receive a radiation dose of approximately 620 mrem/yr [6.2 mSv/yr] (NRC, 2015c). Half {310 mrem/yr [3.1 mSv/yr]} comes from man-made sources of radiation, including medical, commercial, and industrial sources. The other half of this dose comes from natural background radiation, which is predominantly due to exposure to radon in air.[1] In general, a yearly dose of 620 mrem [6.2 mSv] has not been shown to cause humans any harm (NRC, 2015c). The natural background radiation, excluding radon, for a resident of Amargosa Valley is 96 mrem/yr [0.96 mSv/yr] (DOE 2002, Table 3-30). For this supplement, a total natural background radiation exposure at Amargosa Farms of approximately 300 mrem/yr [3.0 mSv/yr] (including radon) is used as a comparison to the estimated doses for populations at affected environments along the flow path from Amargosa Farms to Death Valley.

Radiation Exposure and Cancer Risk

Public health data do not absolutely establish the occurrence of cancer following exposure to low doses and dose rates of radiation below about 10,000 mrem [100 mSv]. Studies of occupational workers who are chronically exposed to low levels of radiation above normal background have shown no adverse biological effects. Even so, the radiation protection community conservatively assumes that any amount of radiation may pose some risk for causing cancer and hereditary effect, and that the risk is higher for higher radiation exposures. The linear no-threshold (LNT) dose-response relationship is used to describe the relationship between radiation dose and the occurrence of cancer. This dose-response model suggests that any increase in dose, no matter how small, results in an incremental increase in risk. The NRC accepts the LNT hypothesis as a conservative model for estimating radiation risk.

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[1] Radon exposure varies depending on several factors, including geographic location, housing type, ventilation, and local geology. On average in the U.S., radon exposure accounts for a dose of approximately 200 mrem/yr [2.0 mSv/yr] (NRC, 2015c).

Further context for the dose values provided in this supplement is the average annual dose estimated for the regulatory compliance location from the 2008 SEIS. DOE calculated maximum average annual dose for the RMEI at the regulatory compliance location to be 0.24 mrem/yr [0.0024 mSv/yr] for the initial 10,000 years after repository closure, and the maximum average annual dose one million years after closure to be 2.0 mrem/yr [0.02 mSv/yr] (DOE, 2008a, Section 2.4.1). The NRC staff has found DOE's calculations to be acceptable as part of its safety evaluation (NRC, 2014a, Section 2.2.1.4.1). The regulatory safety standards in 40 CFR Part 197 and 10 CFR Part 63 for the RMEI are 15 and 100 mrem/yr [0.15 and 1.0 mSv/yr] for the 10,000 and one million year periods, respectively.

One way to understand the impact of radiological dose is in terms of a risk of causing cancer or a severe hereditary effect. This can be done through a conversion factor, which assumes a simple linear relationship between the dose and the risk of these health effects. Using the conversion factor for members of the public recommended by the International Committee on Radiological Protection (ICRP) (ICRP, 2007), the probability of a latent cancer fatality, nonfatal cancer, or severe hereditary effect from a 1.0 mrem/yr [0.01 mSv/yr] dose is 5.7×10^{-7}, or less than one in one million.

For nonradiological chemical contaminants, impacts to human health are compared to the U.S. Environmental Protection Agency (EPA) Oral Reference Dose (EPA, 1999a,b; 1997a,b; 1994), which is the chemical level below which no detectable human health effects would occur. In this supplement, uranium (U) is evaluated for both radiological and nonradiological contaminants, because in addition to being radioactive, it has a notable toxicity as a heavy metal. For nonradiological analysis, U concentrations are given as a sum of the U isotopes from the radionuclide calculations, since the chemical risk of U does not depend on the particular isotope.

EPA Oral Reference Dose

The Oral Reference Dose is an estimate of a daily oral exposure of a chemical to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. In the U.S., the EPA establishes the Oral Reference Dose after a thorough review of the health effects data for individual chemicals.

Additional comparisons provide context on the quantities and concentrations of potential repository contaminants that may be present in groundwater or discharge to the surface and accumulate in soil. Calculated concentrations of nonradiological materials in water and soils are compared to natural background levels from water and soil analyses, where available. Reference values for soil concentration impacts are the soil screening levels used in determining the need for further evaluation or remediation during cleanup of contaminated land. The EPA has established generic soil screening levels for many chemicals, including nickel (Ni), molybdenum (Mo), vanadium (V) and U (EPA, 2015). These screening levels are not cleanup standards, but are used a guidelines for determining the need for further action. The screening levels for specific contaminants are included in the subsequent sections, as appropriate.

3.1.1 Analysis Case 1: Pumping at Amargosa Farms

In the 2002 EIS and 2008 SEIS, DOE provided estimates of impacts for the RMEI at the regulatory compliance location. In its ADR, the NRC staff found this impact assessment for the RMEI location to be acceptable for adoption (NRC, 2008a). In this supplement, impacts are estimated at the nearest population center to the repository location, Amargosa Farms, which is approximately 17 km [10.5 mi] beyond the regulatory compliance location, or approximately

35 km [22 mi] along the flow path from Yucca Mountain. Because the RMEI dose pathways identified by DOE in its EISs were based on activities and lifestyles of residents in Amargosa Farms, the same pathways are appropriate for the analysis of impacts at Amargosa Farms in this supplement. Amargosa Farms is a community that uses groundwater pumping for irrigation and for its commercial and domestic water supply. The dose pathways for a resident of Amargosa Farms are external (body) exposure, inhalation, and ingestion of crops, meat, and soil. Details of these pathways are described in Appendix A and in DOE (2014a, Table B-2).

Impacts in this section are described in terms of (i) the amount of contaminants from the repository in the groundwater system between the regulatory compliance location and Amargosa Farms, (ii) the concentration of contaminants in the groundwater at the Amargosa Farms area, (iii) the concentration of contaminants in soils at the Amargosa Farms area due to irrigation, and (iv) the radiological dose and body intake of contaminants for the identified exposure pathways. Together, these items provide a description of the distribution of contaminants present in the aquifer and the impact of radiological and nonradiological contaminants on the affected environment. This section addresses the impacts under both the present day and the cooler/wetter climate states.

The transport model uses a path length of 17 km [11 mi; the distance from the RMEI location to Amargosa Farms] and transport properties that are distance-weighted from each segment of the pathway (see Appendix A, Section A.1.2). Transport segments are the different hydrogeological model units in the Death Valley Regional Flow System (DVRFS) model that predict the groundwater flow from Yucca Mountain along the path from the regulatory compliance location to (in this case) Amargosa Farms. For items (ii) to (iv) in the previous paragraph, several other parameter values are required:

- The mass flux of radiological and nonradiological material from the repository reaching wells at Amargosa Farms is calculated using the 2003 pumping rate of 16,828 acre-feet/year [20.7 million m^3/year] taken from Moreo and Justet (2008). This pumping rate is more than five times larger than the value used in the 2008 SEIS for the RMEI, which calculated contaminant concentrations based on a withdrawal rate of 3,000 acre-feet/year [3.7 million m^3/year].

- Transport in the aquifer to Amargosa Farms is calculated using a value of 0.00613 m/day [0.020 ft/day] for the specific discharge (flow rate) along the 17 km [11 mi] path in the present-day climate (see Appendix A, Section A.1.2). For the wetter climate, the specific discharge is multiplied by a factor of 3.9 (DOE, 2014a; 2008b, Section 2.3.9). An average porosity in the aquifer of 0.16 is used for both climate states.

- Contaminated water extracted by pumping can be recycled into the aquifer through irrigation and other uses, as water pumped to the surface can infiltrate, reach the water table, and be pumped again (see Appendix A, Section A.2.1 for details of the irrigation recycling model). The analysis in this supplement uses a value of 86 percent for the recycling fraction (the amount of water pumped to the surface that reaches the water table), and a value of 100 percent for the recapture fraction (the fraction of that water which is then captured by pumping and returned to the surface). These values are conservative in that they assume that contaminants are brought to the affected environment with high efficiency. These values result in an overall factor of 0.86 for contaminant recycling through well pumping, compared to the value of 0.11 used in previous recycling analyses (DOE, 2014a; Kalinina and Arnold, 2013; SNL, 2007b).

A larger value for this factor leads to greater calculated contaminant concentrations in the exposure pathways, greater estimates of dose and body intake, and greater calculated values of contaminants accumulating in soils.

- Dose conversion factors used in this analysis are derived from DOE (2008b, Table 2.3.10-12) with adjustments for potential secular disequilibrium of decay chain radionuclides (see Appendix A, Section A.1.2). The NRC staff has found these dose conversion factors to be acceptable as part of its safety evaluation (NRC, 2014a, Section 2.2.1.3.14)

All radiological and nonradiological contaminants in the releases from the repository (which becomes the source term for this evaluation) are analyzed in the transport and accumulation models. Only those radionuclides that (i) reach the affected environment, beyond the regulatory compliance location and to the Amargosa Farms area, and (ii) are major contributors to the calculated dose, are described in the sections that follow. Calculated concentrations of other radionuclides are extremely low and do not contribute to estimates of dose or other environmental impacts. For Analysis Case 1 (Pumping in Amargosa Farms), the radionuclides that are significant contributors to dose at Amargosa Farms area are technetium (Tc)-99, iodine (I)-129, selenium (Se)-79, uranium (U)-233, thorium (Th)-230, neptunium (Np)-237, and uranium (U)-234 for both the present-day and wetter climates, in their approximate order of significance. The relative significance of radionuclides varies with time due to the timing of release from the repository and due to sorption, decay, and radionuclide ingrowth during transport. Nonsorbing species (e.g., Tc and I) are not delayed during transport and reach the affected environment faster than sorbing species (such as U or Th). All four of the nonradiological chemical species in the source term from the repository (Mo, Ni, V, and U) reach the Amargosa Farms area.

Aquifer Environment

This section describes the total amount of contaminants from the repository in the aquifer environment between the regulatory compliance location and the Amargosa Farms area. This amount changes over time, as contaminants are released from the repository and are transported by water to the aquifer and then downstream along the flow path. The concentration of these contaminants in the groundwater at Amargosa Farms is then calculated from the amount of contaminants present in the groundwater, and the volume of water affected by the pumping. The amount of contaminants in the aquifer, and the contaminant concentration in the groundwater, represent the impacts on the aquifer.

The term “aquifer environment” includes both the subsurface rock (porous media, predominantly alluvial sediments) and water within the pores of the rock, and is used here to include the contaminants both dissolved in the water and sorbed onto the rock. The amount of the contaminants in the aquifer environment between the regulatory compliance location and the Amargosa Farms area, based on mass balance calculations, is provided in Table 3-1a. The values in Table 3-1a result from calculating the difference between the mass of the contaminants that reach the regulatory compliance location and the contaminants that accumulate in the Amargosa Farms area, using values from DOE (2014a, Tables B-6 and B-7). These values were calculated from the releases from the repository over time, the amounts transported downstream, and the amounts retained within the aquifer by sorption on rock surfaces, following the methodology used in DOE’s TSPA for repository performance (DOE, 2008b, Section 2.4.1). The NRC staff has found DOE’s TSPA methodology to be acceptable as part of its safety evaluation (NRC, 2014a, Section 2.2.1.4.1). For U and Th, a combined value is reported that includes all the identified isotopes in the source term and daughter products. The mass of contaminants includes the effects of radioactive decay over time.

These results show how different contaminants behave in the aquifer environment. At a given time, the nonsorbing species Tc-99, I-129, and Mo show much greater accumulation at Amargosa Farms (Table 3-1b) than in the aquifer environment between the regulatory compliance location and Amargosa Farms (Table 3-1a). This is because these species migrate more readily than sorbing species, and are not retained in the aquifer (except as dissolved in the groundwater). In contrast, sorbing species such as U, Th, Np, Ni, and V are present in the aquifer both sorbed onto the rock surfaces and dissolved in the groundwater.

They therefore accumulate in the aquifer environment between the regulatory compliance location and Amargosa Farms. At 10,000 years after permanent closure, these sorbing species are present in the aquifer upstream from Amargosa Farms, but have a very small (or no) presence at Amargosa Farms (Table 3-1b), as they are held back on the rock surfaces within the aquifer. Over the one million year period, these species reach Amargosa Farms in greater abundance, but still show appreciable accumulation within the aquifer.

The amounts of the six predominant radionuclides listed in Table 3-1a (by activity, in Curies) and nonradiological material (by mass, in grams) are used to calculate the average concentration of each contaminant in the aquifer environment between the regulatory compliance location and Amargosa Farms. This calculation requires an estimate of the volume occupied by the contaminant plume. These geometric assumptions give an affected aquifer volume of 5.1 km^3 [1.2 mi^3]. For an average porosity of 0.16 (DOE, 2014a), this volume contains 0.82 km^3 [0.2 mi^3] of water. Appendix A provides more detail on this calculation and its inputs.

As noted above, the average concentration of a contaminant in the aquifer includes both the contaminants in the groundwater and those sorbed onto the rock surface. For a sorbing species, only some fraction of the contaminant will be dissolved in the groundwater. The groundwater concentrations are calculated using the amounts in the groundwater (not sorbed to the rock), and the appropriate volume of water (see Appendix A, Section A.2.1).

Table 3-2 provides concentrations of radiological and nonradiological material calculated for the groundwater in the vicinity of Amargosa Farms. The concentrations are calculated by dividing the mass flux to the Amargosa Farms area by the pumping rate from all wells in the area. Consistent with their behavior in the overall repository performance assessment, Tc-99 and I-129 are present in relatively higher quantities than other radiological contaminants because of their transport characteristics (i.e., they do not sorb). The amount of U reflects its high abundance in the repository waste inventory. As shown in Table 3-2, a cooler/wetter climate has variable effects on the calculated groundwater concentrations at Amargosa Valley. For some contaminants, a wetter climate leads to slightly higher concentrations compared to the drier climate (e.g., I-129 and Tc-99 at 10,000 years), as these nonsorbing contaminants move more rapidly along the flow path. In others, the calculated concentrations show little or no difference (e.g., Mo, V, and Ni), as the amount of contaminant moving through the system (the mass flux) is not strongly affected by the groundwater flow rates.

Table 3-1a. Amount of Selected Radiological and Nonradiological Material From the Repository in the Aquifer Environment Between the Regulatory Compliance Location and Amargosa Farms. [1 kg = 2.2 lbs]

	Present-Day Climate		Cooler/Wetter Climate	
	10,000 years	1 million years	10,000 years	1 million years
U isotopes (Ci)	1.5	316	1.5	90
Th isotopes (Ci)	0.18	178	0.18	51
Np-237 (Ci)	1.4	147	1.4	42
I-129 (Ci)	0.0042	0.23	0.0038	0.021
Tc-99 (Ci)	7.6	105	1.4	26
Se-79 (Ci)	5.8	83	5.8	22
Mo (kg)	1.3×10^{5}	2.6×10^{5}	1.1×10^{5}	2.7×10^{5}
Ni (kg)	1.7×10^{7}	1.7×10^{7}	1.7×10^{7}	1.2×10^{7}
V (kg)	2.2×10^{3}	9.7×10^{3}	2.2×10^{3}	5.7×10^{3}

U = uranium, Th = thorium, Np = neptunium, I = iodine, Tc = technetium, Se = selenium, Mo = molybdenum, Ni = nickel, V = vanadium
See Appendix A, Section A.2, for the methods of calculation.

Table 3-1b. Amount of Selected Radiological and Nonradiological Material From the Repository Accumulated at the Amargosa Farms Area. [1 kg = 2.2 lbs]

	Present-Day Climate		Cooler/Wetter Climate	
	10,000 years	1 million years	10,000 years	1 million years
U isotopes (Ci)	1.6×10^{-15}	101	1.5×10^{-10}	123
Th isotopes (Ci)	2.3×10^{-14}	61	1.2×10^{-11}	74
Np-237 (Ci)	7.1×10^{-17}	43	7.1×10^{-17}	54
I-129 (Ci)	2.4	134	2.5	134
Tc-99 (Ci)	125	2,270	126	2,280
Se-79 (Ci)	1.6×10^{-15}	121	1.6×10^{-15}	182
Mo (kg)	1.3×10^{6}	2.1×10^{7}	1.3×10^{6}	2.1×10^{7}
Ni (kg)	0	1.3×10^{8}	0	1.3×10^{8}
V (kg)	0	4.7×10^{5}	0	4.1×10^{5}

U = uranium, Th = thorium, Np = neptunium, I = iodine, Tc = technetium, Se = selenium, Mo = molybdenum, Ni = nickel, V = vanadium
See Appendix A, Section A.2, for the methods of calculation.

Table 3-2. Average Groundwater Concentrations of Radiological and Nonradiological Material from the Repository in the Aquifer at Amargosa Farms

	Present-Day Climate		Cooler/Wetter Climate	
	10,000 years	1 million years	10,000 years	1 million years
U isotopes (pCi/L)	0	0.063	7.1×10^{-12}	0.073
Th isotopes (pCi/L)	0	0.005	4.2×10^{-13}	0.002
Np-237 (pCi/L)	0	0.051	0	0.007
I-129 (pCi/L)	0.007	0.088	0.013	0.088
Tc-99 (pCi/L)	4.3	2.1	5.3	2.1
Se-79 (pCi/L)	0	0.016	0.009	0.017
Mo (mg/L)	7.3×10^{-3}	1.9×10^{-4}	7.1×10^{-3}	1.9×10^{-4}
Ni (mg/L)*	0	1.4×10^{-3}	0	1.3×10^{-3}
V (mg/L)	0	2.1×10^{-9}	0	2.1×10^{-9}

*calculated peak concentration value of 0.02 mg/L for Ni occurs at 74,000 years after repository closure.
U = uranium, Th = thorium, Np = neptunium, I = iodine, Tc = technetium, Se = selenium, Mo = molybdenum, Ni = nickel, V = vanadium

Overall, the concentrations of radionuclides and other contaminants from the repository for groundwater at Amargosa Farms are uniformly very low. For example, the EPA Maximum Contaminant Level (MCL)[2] for alpha-particle emitting radionuclides in drinking water is 15 pCi/L, compared to the calculated total for all alpha-emitting radionuclides in Table 3-2 of less than 0.1 pCi/L.

The highest calculated total uranium concentration in the groundwater at Amargosa Farms corresponds to less than 1 μ/L; for comparison, the EPA MCL for U in drinking water is 30 μ/L. While no MCLs have been established for the metals Mo and V, the calculated groundwater concentrations for these potential contaminants are all much lower than one part per million, which is comparable to the levels occurring naturally at present (Table 2-2). The calculated peak concentration of Ni in groundwater at Amargosa Farms, for each climate state, does not occur at 10,000 years or one million years after repository closure. The peak concentration for Ni in groundwater at this location is 0.02 mg/L, and is estimated to occur at 74,000 years for the cooler/wetter climate. This concentration is much lower than the EPA National Recommended Water Quality Criteria level for Ni of 0.61 mg/L (EPA, 2014).

Based on the analysis described above, the NRC staff concludes that the accumulation of radiological and nonradiological material released from the repository to the aquifer environment between the regulatory compliance location and Amargosa Farms would be minimal and not noticeably affect the quality of the aquifer environment. Thus, the NRC staff concludes that the impact on the aquifer environment beyond the regulatory compliance location would be SMALL.

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[2] MCLs are EPA standards for drinking water quality that are established under the Safe Drinking Water Act. An MCL is the highest level of a contaminant that is allowed in public drinking water systems.

Soil

This section describes the accumulation of contaminants in soils at Amargosa Farms. As described in Chapter 2, pumping is the dominant means of groundwater discharge to the surface at Amargosa Farms (the only other discharge is by very limited evapotranspiration along the Amargosa River Section of the flow system; Section 2.2.2). Thus, any potential accumulation of contaminants in soils in this area would be from irrigation. The NRC staff calculated soil contaminant concentrations using the irrigation recycling model described in Appendix A, Section A.2.1. The model accounts for accumulation in soil of both radiological and nonradiological contaminants. Calculated values of contaminants from the repository in the soils at Amargosa Farms are given in Table 3-3.

For both the present-day and potential future cooler/wetter climate, the primary radionuclides that would accumulate in the soil are U-238, U-235, Np-237, Pu-242, U-233, and Th-230 (Table 3–3). Note that the nonsorbing radionuclides (I-129 and Tc-99) do not accumulate in soil as they remain dissolved in groundwater. The calculated soil concentrations for all of these radionuclides are very low for both climate states. The calculated soil concentration for the radionuclides in Table 3-3 correspond to a total activity of less than 1 pCi/g, and would not appreciably contribute to dose or other environmental impacts.

Nonradiological contaminants show the greatest calculated concentrations at one million years (Table 3-3). For comparison, also shown in Table 3-3 are concentrations of some elements measured in sediment samples in well cuttings from Fortymile Wash, just north of the Amargosa Farms area (Bertetti and Prikryl, 2003). The cuttings are samples of alluvial sediments that are geochemically and mineralogically similar to those found in the upper part of the sediment column at the Amargosa Farms area. Also included in Table 3-3 are the generic soil screening levels for residential soil for the nonradiological contaminants (EPA, 2015).

None of the nonradiological contaminants show any appreciable accumulation in the soil at Amargosa Farms, and all are well below soil screening levels or the natural abundance in local sediments. The estimated highest concentration of Ni in the soil at Amargosa Farms for both climate states occurs approximately 270,000 years after repository closure. The calculated peak soil concentration at that time is 4 ppm. After that time, the levels of Ni from the repository in the groundwater decrease, and Ni is leached from the soil by continued irrigation, leading to a lower concentration at one million years.

Based on the analysis described previously, the NRC staff concludes that the accumulation in soils at Amargosa Farms of radiological and nonradiological material released from the repository would be minimal and either not result in a difference from background levels or otherwise not noticeably affect soil. Thus, the NRC staff finds that the impact on soils at Amargosa Farms would be SMALL.

Public Health

The biosphere dose pathways used for this supplement for Amargosa Farms are the same as those identified in DOE’s 2008 EIS and for the RMEI in DOE’s Safety Analysis Report: (i) external exposure; (ii) inhalation of soil particles and from use of evaporative coolers; and (iii) ingestion from water, crops, animal products, fish, and soil. The NRC staff has found these exposure pathways for the RMEI to be acceptable as part of its safety evaluation (NRC, 2014a, Section 2.2.1.3.14). As further discussed in Sections A.1.3 and A.2.2 of Appendix A, the values for the dose conversion factors have not changed from those in the 2008 SEIS, except for

Table 3-3. Estimates of Peak Concentrations of Radionuclides and Chemical Materials in Soils at Amargosa Farms Area for Analysis Case 1 (Pumping).

Peak Soil Concentration (ppm)	Present-Day Climate		Cooler/Wetter Climate		Local Natural Sediments*	Soil Screening Level†
	10,000 years	1 million years	10,000 years	1 million years		
Np-237	0	1.5×10^{-3}	0	1.0×10^{-4}	—	—
Pu-242	0	1.9×10^{-11}	0	2.8×10^{-5}	—	—
U-235	0	9.6×10^{-4}	4.7×10^{-14}	5.8×10^{-4}	—	—
Th-230	0	7.2×10^{-6}	3.2×10^{-16}	1.4×10^{-6}	—	—
U-238	0	0.042	2.0×10^{-12}	0.025	—	—
U-233	0	1.1×10^{-5}	4.6×10^{-16}	6.5×10^{-6}	—	—
Mo	0.007	1.9×10^{-4}	0.007	1.9×10^{-4}	—	390
Ni	0	0.29	0	0.27	17.8	1500
V	0	1.2×10^{-4}	0	1.2×10^{-4}	22.4	390
U (all isotopes)	0	0.043	2.0×10^{-12}	0.026	3.9	230

Np = neptunium, Pu = plutonium, U = uranium, Th = thorium, Mo = molybdenum, Ni = nickel, V = vanadium
Peak soil radionuclide concentrations are derived from estimates in DOE (2014a, Tables B-13 and B-14), assuming the contamination is in the top 0.25 m [0.82 ft] of soil and the soil bulk density is 1,500 kg/m^3 [94 lb/ft^3]
*ppm, from Bertetti and Prikryl (2003)
†ppm, values shown are for total Mo and V, and for soluble salts of Ni and U in residential soil (EPA, 2015)

adjustments for secular disequilibrium. Dose conversion factors for the present-day climate were used for both the present-day and future cooler/wetter climate. This approach is conservative because dose conversion factors for cooler and wetter climates would be expected to be lower than those for the present-day climate (Appendix A, Section A.2.3).

The largest contributors to dose for both the present-day and wetter climate at Amargosa Farms are I-129, Tc-99, Np-237, and Th-230 (Figure 3-1). At 10,000 years, I-129 and Tc-99 are the primary contributors to dose. They do not sorb onto rock grains, but rather remain dissolved in water. The other radionuclides shown in Figure 3-1 sorb to various degrees, and thus arrive at Amargosa Farms later. The dose curves in Figure 3-1 also illustrate the effect of a wetter climate on transport and, consequently, dose. The higher specific discharge rate for the wetter climate leads to the more rapid transport of several radionuclides, and thus relatively earlier steady-state contributions to dose (expressed in Figure 3-1 as a shift of the dose curves to the left for the wetter climate, as compared to the curves for the present-day climate).

Peak doses, considering all radionuclides, are shown in Table 3-4 for 10,000 and one million years for both climate states. The peak dose of 1.3 mrem/yr [0.013 mSv/yr] in Table 3-4 is lower than the dose from natural background levels of approximately 300 mrem/yr [3.0 mSv/yr] (including radon) for Amargosa Valley, and lower than that calculated for the RMEI at the regulatory compliance location closer to the repository (DOE, 2008b). Furthermore, the peak values estimated for 10,000 and one million years for the present-day and cooler/wetter climate are much lower than the NRC annual dose standards for a Yucca Mountain repository in 10 CFR Part 63 {15 mrem [0.15 mSv] for the first 10,000 years, and 100 mrem [1 mSv] for one million years, after permanent closure}.

Potential health effects from the nonradiological contaminants are considered for a nominal body intake from ingestion of contaminated water, assuming daily intake for a 70-kilogram person drinking 2 liters of water daily. Human health impacts of the nonradiological

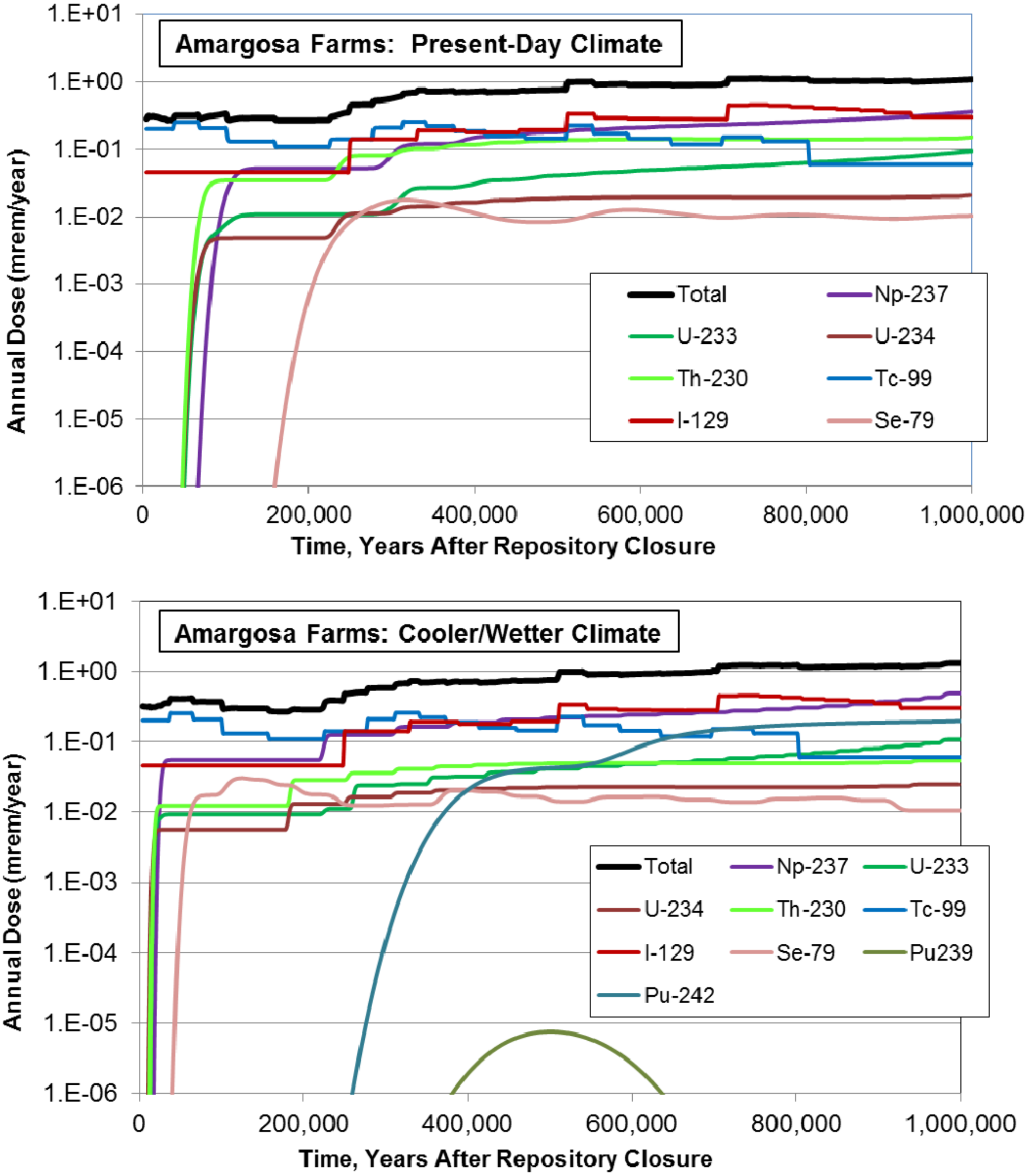

Figure 3-1. Dose History of Selected Radionuclides at Amargosa Farms for the Present-Day (Top) and Cooler/Wetter (Bottom) Climates. [Modified from DOE (2014a)].

contaminants are assessed by comparing daily intakes with EPA's Oral Reference Dose standard (EPA, 1999a,b; 1997a,b; 1994). Estimated values of peak daily intakes for each of the nonradiological contaminants are summarized in Table 3-5 for the one-million-year period. In accord with the calculations for the aquifer environment between the regulatory compliance location and Amargosa Farms, the peak daily intake for Ni is estimated to occur at 74,000 years. The peak value of 0.004 mg/kg body weight/day corresponds to the peak values

Table 3-4. Peak Annual Dose Estimates for the Amargosa Farms Area. Values From DOE (2014a, Table 3-1).

	Peak Annual Dose (mrem/yr)*	
	10,000 years	1 million years
Present-day Climate	0.21	1.1
Cooler/Wetter Climate	0.25	1.3

*Note: 1.0 mrem/yr = 0.01 mSv/yr

Table 3-5. Impact of Nonradiological Contaminants at Amargosa Farms Using Estimates of Body Intake

Peak Daily Intakes (mg/kg body-weight/day)	Present-Day Climate		Cooler/Wetter Climate		EPA Oral Reference Dose
	10,000 years	1 million years	10,000 years	1 million years	
Mo	1.5×10^{-3}	4.5×10^{-5}	1.5×10^{-3}	4.1×10^{-5}	5.0×10^{-3}
Ni*	0	2.9×10^{-4}	0	2.7×10^{-4}	2.0×10^{-2}
V	0	4.7×10^{-7}	0	4.5×10^{-7}	9.0×10^{-3}
U (all isotopes)	0	3.5×10^{-6}	0	3.8×10^{-6}	3.0×10^{-3}

*calculated peak daily intake of 0.004 mg/kg body weight/day for Ni occurs at 74,000 years after repository closure.
Mo = molybdenum, Ni = nickel, V = vanadium, U = uranium

in groundwater Ni concentration for the cooler/wetter climate. The calculated peak daily intake for Ni for the present-day climate is lower than that estimated for the cooler/wetter climate. The estimated values of daily intake are all much lower than the EPA Oral Reference Doses.

Based on the above analyses of radiological and nonradiological material released from the repository to the Amargosa Farms area, the NRC staff finds that the impact to public health beyond the regulatory compliance location would be SMALL, as the contribution from both radiological and nonradiological contaminants is generally nominal, and in all cases below applicable impact and reference standards and limits.

3.1.2 Analysis Case 2: Surface Discharge Downstream of Amargosa Farms

This section addresses impacts from surface discharge at downstream locations in the case of limited or no pumping at Amargosa Farms. For this case, contaminants from the repository would travel past the Amargosa Farms area and could reach the surface environment at the downstream locations discussed in Section 2.3. This Analysis Case considers both the present day and cooler/wetter climate states.

In the 2002 EIS, DOE scaled results from the RMEI location to account for groundwater dispersion to estimate impacts at 30 and 60 km [19 and 37 mi] from the repository, which are approximately the distances from the repository to Amargosa Farms and Alkali Flat, respectively. In the 2002 EIS and 2008 SEIS, DOE stated that the contaminants would discharge to the surface at Alkali Flat, but the DOE discussion of these impacts is limited to a statement that no detrimental radiological impacts on plants and animals are expected.

In this supplement, impacts at natural discharge sites along the groundwater pathway beyond the regulatory compliance location are analyzed. This Analysis Case addresses discharge of contaminants by springs or playas at the State Line Deposits/Franklin Well area (which would occur under a cooler/wetter climate only), the springs at Furnace Creek, and the playa/salt pan at Middle Basin of Death Valley. Results from the DVRFS groundwater model indicate that in the absence of pumping of the aquifer at Amargosa Farms, the predominant discharge site of contaminants transported from Yucca Mountain for the present-day climate would be Middle Basin in Death Valley (Chapter 2; see also Belcher and Sweetkind, 2010). Along the way to Middle Basin, some amount of groundwater contaminants may be discharged at the springs in the Furnace Creek area. In a future wetter climate, another potential location for natural discharge is springs in the State Line Deposits/Franklin Well area. In addition, groundwater modeling indicates that beyond the State Line area, a very small fraction (2 out of 8,024 modeled particles, or 0.03 percent) of contaminants may move southward toward Alkali Flat, rather than Middle Basin (Chapter 2). This discharge location is considered as an alternative pathway to the expected pathway (State Line–Furnace Creek–Middle Basin).

Descriptions of potential impacts are provided for natural discharge at the State Line Deposits/Franklin Well area (Section 3.1.2.1), Furnace Creek and Middle Basin of Death Valley (Section 3.1.2.2), and Alkali Flat (Section 3.1.2.3). For each of the locations, the peak impact is estimated by conservatively assuming that the entire plume of potential contaminants discharges at that single location. This is conservative because it is likely that radiological and nonradiological contaminants in the plume would discharge at multiple surface locations that may be active at the same time.

3.1.2.1 State Line Deposits/Franklin Well Area

As discussed in Chapter 2, the State Line Deposits area is located approximately 21 km [13 mi] beyond the regulatory compliance location, or 39 km [24 mi] from the repository along the Yucca Mountain flow path. These paleospring deposits occur where the Amargosa River and Fortymile Wash join. The water table approaches the ground surface in the present-day climate, and reached the ground surface during past wetter climates to produce deposits that formed in playas, springs, marshes, and ponds (Section 2.3.4). The Franklin Well area refers to the narrow band of dense vegetation along the Amargosa River channel at the southern extent of the State Line Deposits area. In the present-day climate, the Amargosa River only flows after significant precipitation events in most of Amargosa Desert, including in the Franklin Well area. For the present-day climate, a small amount of natural discharge occurs at the Franklin Well area as evapotranspiration from a dominantly mesquite thicket along the river channel.

To estimate impacts in the State Line/Franklin Well area, the transport and biosphere model inputs and assumptions are derived from the present hydrologic characteristics and environmental inferences from the paleospring deposits observed in the region. In the present-day climate, discharge occurs at the Franklin Well area only as evapotranspiration in the Amargosa River channel. For a cooler/wetter climate, discharge is projected to occur in the entire State Line Deposits/Franklin Well area in a combination of springs, pools, marshes, and wet and dry playas. The discharge rate during a future cooler/wetter climate can be estimated based on the extent of the deposits and similar modern springs in the region. One modern analog, albeit on a larger scale, may be Ash Meadows. The present-day Ash Meadows area of springs, marshes, pools and playas is approximately twice the area of the State Line deposits, and has similar types of discharge to that indicated for the State Line Deposits area. Present day discharge at Ash Meadows is estimated to be 60,372 m^3/day [17,865 acre-ft/yr] (Belcher and Sweetkind, 2010, Table F-4). Prior to water use restrictions related to Devils Hole, water was diverted from pools and ponds, and was pumped from the ground for agriculture in Ash Meadows. Whereas limited water diversion for agriculture at a future, wetter State Line Deposits area is possible, extensive agriculture in the area of the State Line Deposits is unlikely due to the high concentrations of salts in the soils. Therefore, biosphere and dose pathway modeling for a cooler/wetter climate at the State Line Deposits/Franklin Well area includes (i) inhalation of resuspended dust from wet and dry playas, (ii) ingestion of water and soil, and (iii) subsistence farming using water diverted from less saline pools and springs. Recycling and recapture of irrigated water are not applicable for water diverted from pools and springs for agriculture because unlike the case of well-pumping irrigation, any irrigation water diverted from springs or pools is typically used downstream from its source, and thus the contaminants pass only once through the local soil. Transport properties for the State Line Deposits/Franklin Well area, except for the distance, are the same as used for the calculations for Amargosa Farms, as the characteristics of the aquifer are the same. For the estimated impacts at the State Line area, the NRC staff conservatively assumes that the entire plume discharges to that location.

Aquifer Environment

Several features of the aquifer environment at the State Line Deposits/Franklin Well area indicate that groundwater concentrations and accumulations of sorbed material onto sediments would be lower than in the aquifer environment at Amargosa Farms:

- The area is a short distance further downstream from the Amargosa Farms area. The amount of radiological and nonradiological material expected in the aquifer environment, both sorbed to alluvial sediment grains and dissolved in the groundwater would therefore be slightly less than at Amargosa Farms due to additional dispersion and decay. Except for the additional distance, the transport processes to Amargosa Farms and to the State Line Deposits/Franklin Well area are similar.

- No additional concentrating mechanisms occur in State Line Deposits/Franklin Well area, such as the recycling/infiltration of water used for agriculture, compared to those at the aquifer environment at Amargosa Farms.

- Whereas there are indications that water from the carbonate aquifer contributed to the paleospring deposits at the State Line Deposits/Franklin Well area (discussed in Section 2.3.4), the groundwater is still dominantly derived from an alluvial/volcanic aquifer, based on its chemical characteristics. Any amount of water from the underlying uncontaminated carbonate aquifer would dilute the contaminants in the groundwater at this location, and lower their concentrations in the aquifer.

- Groundwater from the northwest (Amargosa Desert) and south (Funeral Mountain alluvial fan) contribute to the groundwater flow in the area. These uncontaminated sources would similarly reduce aquifer contaminant concentrations.

As noted above, the NRC staff found the impacts to the aquifer environment in the Amargosa Farms area to be SMALL. As the impacts at the State Line Deposits/Franklin Well area would be less than those at Amargosa Farms, the NRC staff finds that the impacts on the aquifer environment at the State Line Deposits/Franklin Well area would be SMALL.

Soil

This section describes the accumulation of repository materials in soils at the State Line Deposits/Franklin Well area for the wetter climate. Because of the very limited area where the water table is potentially close enough to the ground surface for contaminants to enter the soil in present-day climate conditions, an insignificant amount of precipitation of radiological and nonradiological contamination from the repository is expected to occur. However, in a cooler/wetter climate state where the water table could rise approximately 20 to 30 m [66 to 98 ft] (Section 2.3.4), a larger area would be affected and soil concentrations of contaminants could be greater.

The NRC staff uses two approaches to estimate the soil concentration of contaminants for the cooler/wetter climate to account for the range of processes that occur in this type of environment. These approaches are for contaminants in evaporite minerals at a wet playa-type discharge setting, and for contaminants in sediments collecting in a salt marsh-type discharge setting. These are the environments inferred from the paleospring deposits in this location (Section 2.3.4). In the first approach, evaporation from a wet playa-type of discharge site is conservatively assumed for the entire State Line Deposits/Franklin Well area. This approach leads to the greatest calculated contaminant concentration in soils at the State Line Deposits/Franklin Well area, as it assumes extensive formation of evaporite minerals in playa-type areas, which strongly concentrates contaminants from groundwater. The concentrations of contaminants in soil and evaporite deposits within the wet playa are calculated using the estimated concentrations of the contaminant and total dissolved solids (TDS) content of the groundwater. This model for soil concentration assumes that as water is lost by evaporation, contaminants in groundwater are incorporated into newly formed evaporite minerals. The contaminant concentration is higher in evaporites formed from relatively dilute water (low TDS) than from water with the same concentration of contaminants but a greater initial content of (noncontaminant) dissolved material, as a greater amount of evaporation is needed to form evaporites from water with a low amount of TDS. These calculations conservatively use water with a relatively low TDS [257 ppm, as measured in groundwater from well J-13 in Fortymile Wash (DOE, 2014a)]. An additional conservatism is that the model assumes that the “soil” is composed entirely of minerals formed by evaporation of the groundwater. While this can be observed in some local areas of extreme aridity (for example, in salt pans in Death Valley), wet and dry playas typically contain significant amounts of nonevaporite material, with mineral grains transported to the playa by wind or running water (like the playa environments indicated by the paleospring deposits in the State Line area; Section 2.3.4). This assumption thus represents a conservative means of estimating contaminant concentrations in the soil.

The second approach assumes accumulation of contaminants in soils formed from sediments in spring-fed marshes and pools. Unlike the first approach, this method does not assume complete evaporation of the groundwater. Instead, this approach assumes that contaminants accumulate on sediment that forms soils in a marsh/pool environment like that seen in nearby wet areas, such as Ash Meadows. The calculation of soil contaminant concentration used in this approach is similar to that described for the Amargosa Farms area (Section 3.1.1), except that no recapture and recycling is included. Table 3-6 provides the estimated radiological and nonradiological contaminant soil concentrations for both approaches.

The calculated soil concentrations in Table 3-6 show similar patterns to Amargosa Farms for sorbing and nonsorbing radionuclides and metals. Estimates of sorbing radionuclide (Np-227 and U isotopes) and metal (Ni and V) contaminants are essentially zero at the State Line

Table 3-6. Soil Concentrations of Radiological and Nonradiological Contaminants at the State Line/Franklin Well Area in a Cooler/Wetter Climate State, Calculated Using the Evaporite and Salt Marsh Soil Models

Concentration (ppm)	Evaporite Soil Model (Playa)		Salt Marsh Soil Model	
	10,000 years	1 million years	10,000 years	1 million years
Np-237	0	7.1×10^{-4}	0	5.2×10^{-5}
U-235	0	3.1×10^{-3}	0	2.9×10^{-4}
U-238	0	0.13	0	0.013
U-233	0	3.4×10^{-4}	0	3.3×10^{-6}
Tc-99	3.0×10^{-3}	8.9×10^{-4}	2.5×10^{-6}	7.5×10^{-7}
I-129	5.5×10^{-4}	3.6×10^{-3}	7.8×10^{-6}	5.1×10^{-5}
Mo	52	1.4	3.6×10^{-3}	4.9×10^{-5}
Ni	0	9.6	0	0.069
V	0	0.016	3.2×10^{-5}	3.2×10^{-5}
U (all isotopes)	0	0.14	0	0.013

*calculated peak concentration value of 1 ppm for Ni occurs at 88,000 years after repository closure.
U = uranium, Th = thorium, Np = neptunium, I = iodine, Tc = technetium, Se = selenium, Mo = molybdenum, Ni = nickel, V = vanadium

Deposits/Franklin Well area at 10,000 years, for both calculation models. The nonsorbing contaminants (I-129, Tc-99, and Mo) are estimated to be present in low concentrations at 10,000 years. As expected, the calculated concentrations are significantly greater for the more-conservative evaporite model, particularly for the nonsorbing contaminants, but are still very low.

At one million years, the calculations show all of the contaminants from the repository present in the soils at the State Line Deposits/Franklin Well area, with most concentrations still very low. As expected, the more conservative evaporite model gives a greater calculated concentration than the salt marsh model for those contaminants estimated to occur in the soil. Even using the evaporite model, the values calculated for all contaminants are all very low for both time periods. As was the case for Amargosa Farms, the estimated peak soil concentration for Ni at this location for either climate state occurs between 10,000 and one million years after repository closure, at approximately 88,000 years, and reaches a maximum of 1 ppm for a short period of time before decreasing. The estimated concentrations for all of the nonradiological contaminants are lower than the EPA generic soil screening levels (Table 3-3).

Based on the analysis above for the accumulation in soils of radiological and nonradiological contaminants from the repository and the associated conservative assumptions used in the analysis, the NRC staff finds that the impact on soils at State Line Deposits/Franklin Well area would be SMALL.

Public Health

Combined radionuclide peak dose (considering all radionuclides) and body intake for nonradiological contaminants are given in Table 3-7 for 10,000 and one million years for the cooler/wetter climate, and the contributors to radiological dose are shown in Figure 3-2. The largest contributors to radiological dose for both the present-day and the wetter climate at the State Line Deposits area are I-129, Tc-99, Np-237, and Pu-242 (Figure 3-2). At 10,000 years,

Table 3-7. Peak Annual Dose and Body Intake Estimates for the Cooler/Wetter Climate at the State Line Deposits/Franklin Well Area

	10,000 years	1 million years
Peak Dose (mrem/yr)*	0.034	0.28

	Body Intake Estimates		Oral Reference Dose
	10,000 years	1 million years	
Mo (mg/kg body-weight/day)	3.8×10^{-4}	1.0×10^{-5}	5.0×10^{-3}
Ni (mg/kg body-weight/day)[†]	0	7.0×10^{-5}	2.0×10^{-2}
V (mg/kg body-weight/day)	0	1.6×10^{-7}	9.0×10^{-3}
U (mg/kg body-weight/day)	0	1.0×10^{-6}	3.0×10^{-3}

*Note: 1.0 mrem/yr = 0.01 mSv/yr

[†] calculated peak daily intake of 0.001 mg/kg body weight/day for Ni occurs at 88,000 years after repository closure

Mo = molybdenum, Ni = nickel, V vanadium, U = uranium

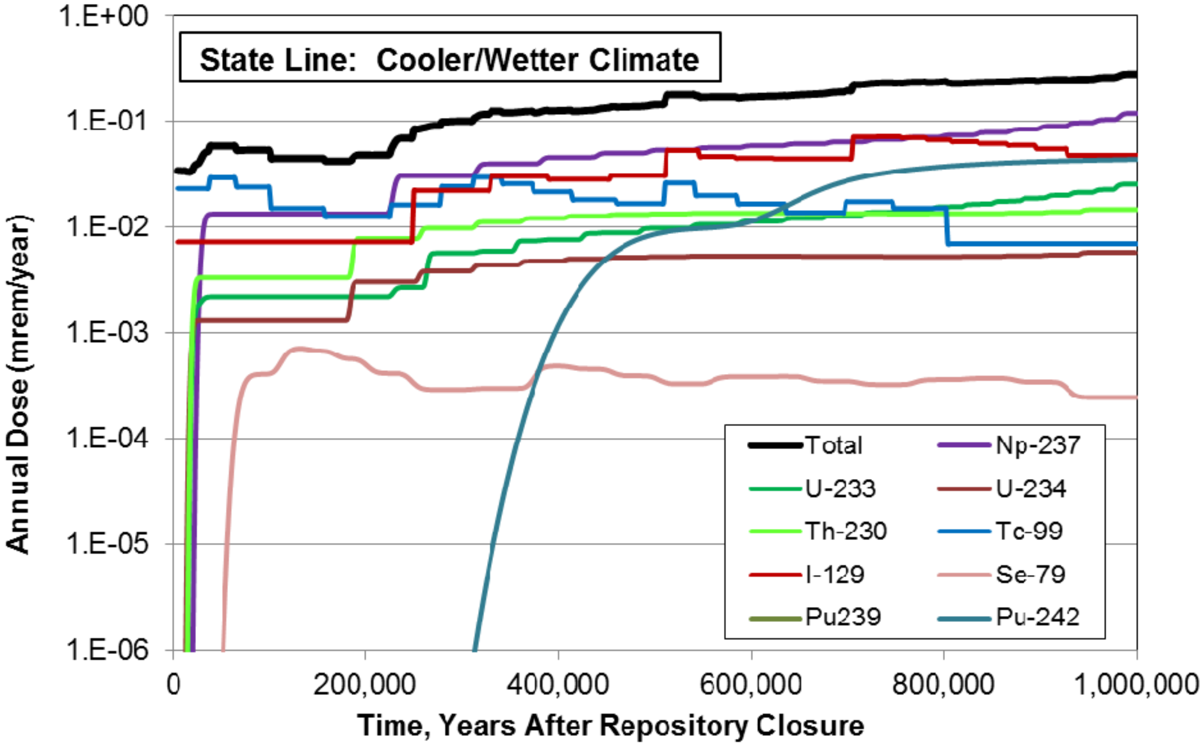

Figure 3-2. Dose History of Selected Radionuclides at State Line Deposits/Franklin Well Area for the Cooler/Wetter Climate

I-129 and Tc-99 are the primary contributors to dose. They do not sorb onto rock grains, but rather remain dissolved in water. The other radionuclides in Figure 3-2 sorb to various degrees, and thus arrive later.

Estimates of dose and body intake for the present-day climate are extremely small because of the small area affected (Franklin Well area) and limited amount of evapotranspiration. For the cooler/wetter climate, the peak dose of 0.28 mrem/yr [0.0028 mSv/yr] is substantially lower than the dose from natural background levels {approximately 300 mrem/yr [3.0 mSv/yr], including radon} for Amargosa Valley. Peak values estimated for 10,000 and one million years for the cooler/wetter climate are much lower than the NRC annual dose standards for a Yucca Mountain repository in 10 CFR Part 63 {15 mrem [0.15 mSv] for the first 10,000 years, and 100 mrem [1 mSv] for one million years, after permanent closure}.

The peak daily intake value for Ni at the State Line Deposits/Franklin Well area corresponds to its maximum groundwater and soil concentration at this location. The maximum of 0.001 mg/kg body weight/day occurs at approximately 88,000 years after repository closure. For all of the nonradiological contaminants at this location, the estimates of body intake are significantly lower than the EPA Oral Reference Dose.

Based on the analyses above of radiological and nonradiological material potentially released from the repository to the State Line Deposits/Franklin Well area, the NRC staff finds that the impact to public health would be SMALL.

3.1.2.2 Furnace Creek and Middle Basin

The Furnace Creek area and Middle Basin of Death Valley are located approximately 56 km [35 mi] beyond the regulatory compliance location. As discussed in Section 2.2.2, under scenarios in which there is no pumping at the Amargosa Farms area, groundwater modeling indicates that the majority of contaminants transported from Yucca Mountain would be discharged in Middle Basin of Death Valley (Belcher and Sweetkind, 2010). Contaminated groundwater could also discharge at the springs in the Furnace Creek area, a short distance upgradient from Middle Basin (Belcher and Sweetkind, 2010; DOE, 2014a). For the estimated impacts at Furnace Creek or Middle Basin, the NRC staff conservatively assumes that the entire plume discharges at that location. For these locations, the impact types are the same as for Amargosa Farms (Section 3.1.1): (i) the amount of contaminants from the repository in the groundwater system, (ii) the concentration of contaminants in the groundwater, (ii) the concentration of contaminants in soils, and (iv) the radiological dose and body intake of contaminants for the relevant exposure pathways. Biosphere dose conversion factors for the Furnace Creek and Middle Basin areas are based on exposures to full-time residents in the local environments (see Appendix A, Section A.2.2).

The transport model uses a path length of 56 km [35 mi] and transport properties that are distance-weighted for each segment of the pathway (see Appendix A, Section A.1.2). The specific inputs and assumptions used to determine the impacts are:

- The mass flux of radiological and nonradiological material reaching the potential discharge locations at Furnace Creek or Middle Basin is calculated using observations of spring discharge and evaporation losses. Total discharge from the springs at Furnace Creek is 2,294 acre-ft/yr [2.83 million m^3/yr]. Discharge in the playa environment at Middle Basin occurs through evaporation, and observed evaporation losses were 1,962 acre-ft/yr [2.4 million m^3/yr] at that location (Belcher and Sweetkind, 2010; Table F-4).

- Transport in the aquifer to Furnace Creek is calculated using a value of 0.00046 m/day [0.0015 ft/day] for the specific discharge (flow rate) along the 56 km [35 mi] path in the present-day climate (see Appendix A, Section A.1.2). For the wetter climate, the specific discharge is multiplied by a factor of 3.9 (DOE, 2014a; 2008b, Section 2.3.9). An average porosity in the aquifer of 0.11 is used for both climate states.

- A value of 257 ppm is used for the groundwater TDS content. This is the same conservative value used in the State Line Deposits area analysis, and lower than values typically observed at discharges from springs at Furnace Creek. As discussed in Section 3.1.2.1, using a lower TDS value is conservative. The TDS value is used to determine the total mass of evaporite deposits that could form. This affects the calculated concentration of contaminants in evaporite deposits.

- Dose conversion factors used in the analyses are derived from DOE (2008b, Table 2.3.10-12) with adjustments for secular disequilibrium (see Appendix A, Section A.1.2).

All radiological and nonradiological contaminants in the source term are analyzed in the transport models, but only the predominant elements reaching the affected environment of Furnace Creek or Middle Basin are described in detail below. Estimates for other contaminants produce extremely low concentration values, and they do not contribute to estimates of dose or toxic exposure. For this Analysis Case 2 (Discharge at Furnace Creek or Middle Basin), the radionuclides that are significant contributors to dose are Tc-99 and I-129 for both the present day and wetter climates. Because of sorption (and to a lesser degree, radioactive decay) along the long transport path, none of the other analyzed radionuclides reach the Death Valley locations and contribute to dose within the one-million-year analysis period for either climate scenario. Similar to the radionuclides, only the nonsorbing nonradiological contaminant, Mo, reaches the discharge locations in Death Valley over the one-million-year analysis period.

Aquifer Environment

This section describes (i) the amount of material from the repository that could be deposited in the aquifer environment between the regulatory compliance location at 18 km [11 mi] and the Death Valley discharge locations 56 km [35 mi] down the flow path, and (ii) the concentration of contaminants in the groundwater at the Death Valley discharge locations.

The amount of radiological and nonradiological contaminants in the aquifer environment between the regulatory compliance location and the potential Death Valley discharge locations, based on mass balance calculations, is provided in Table 3-8. The term “aquifer environment” includes both the rock and water along the groundwater flow path from Yucca Mountain. Thus, the contaminants are both dissolved in the water and sorbed onto the porous media of the aquifer matrix, which includes the alluvial fill of the Amargosa Desert and the carbonate rocks underlying the Funeral Mountains. The values in Table 3-8 are calculated by subtracting the mass of material accumulated at the discharge locations from the cumulative mass released to the regulatory compliance location.

Many of the contaminants shown in Table 3-8 (U, Th, Np, Se, Ni, and V; all but Tc-99, I-129, and Mo) do not discharge to the surface in Death Valley within one million years due to the decay of radionuclides and sorption effects. For these contaminants, all of the material that is released beyond the regulatory compliance location (which would have been discharged at Amargosa Farms at the present pumping rates for Analysis Case 1) is retained within the aquifer system and does not discharge to the surface.

Table 3-8. Amount of Radiological and Nonradiological Material (From the Repository) in the Aquifer Environment Between the Regulatory Compliance Location and Death Valley

	Present-Day Climate		Cooler/Wetter Climate	
	10,000 years	1 million years	10,000 years	1 million years
U isotopes (Ci)	1.5	1,320	1.5	1,320
Th isotopes (Ci)	0.18	791	0.18	791
Np-237 (Ci)	1.4	581	1.4	581
I-129 (Ci)	2.5	65	2.2	15
Tc-99 (Ci)	1,260	1,520	1,160	435
Se-79 (Ci)	5.8	204	5.8	204
Mo (kg)	1.4×10^{6}	4.6×10^{5}	1.4×10^{6}	3.0×10^{5}
V (kg)	2.2×10^{3}	4.2×10^{5}	2.2×10^{3}	4.2×10^{5}
Ni (kg)	1.7×10^{7}	1.3×10^{8}	1.7×10^{7}	1.3×10^{8}

U = uranium, Th = thorium, Np = neptunium, I = iodine, Tc = technetium, Se = selenium, Mo = molybdenum, Ni = nickel,

Table 3-9 presents the estimated average concentrations of the radiological and nonradiological contaminants in groundwater discharging to the surface at the Furnace Creek area for this Analysis Case (limited or no pumping at Amargosa Farms). The concentrations are calculated by dividing the mass flux to Death Valley by the discharge rate at Furnace Creek. Under the lower flow volumes associated with the present-day climate, no contaminants reach the Furnace Creek area before 10,000 years after repository closure. Estimated contaminant concentrations at one million years are greater for the present-day climate state because there is less dilution of the contaminants in the groundwater. Although the contaminants arrive at Furnace Creek earlier in the cooler/wetter climate state, the contaminant concentration is lower.

Groundwater at Middle Basin would have similar concentrations, but as described in Section 2.3.3, there is presently no spring discharge at Middle Basin, and it is unlikely that free-flowing water would appear in that wet playa environment (see discussion in Appendix A, Section A.2.2). Because sorption and decay processes significantly impact transport over the long transport pathway to Death Valley, only nonsorbing contaminants (I-129, Tc-99, and Mo) are found in groundwater discharging to the surface in Death Valley.

At Furnace Creek, the maximum concentration of Mo in the groundwater occurs approximately 58,000 years after repository closure for the present-day climate (under the cooler/wetter climate, the peak arrives at 20,000 years after closure, at a lower concentration). The major release of this contaminant from the repository occurs fairly early after repository closure (see Appendix A), and as a nonsorbing element, transport of Mo is not significantly delayed in the aquifer. The estimate of the maximum Mo concentration in the groundwater is 0.04 mg/L and declines after this time. As noted previously, EPA has not set an MCL or National Recommended Water Quality Criteria level for Mo, but the peak concentration is much lower than 1 ppm and near the detection limit for Mo for the levels given in Table 2-1.

Because the only radiological and nonradiological material reaching Furnace Creek and Middle Basin are small amounts of Tc-99, I-129, and Mo, the NRC staff finds that the impact on the aquifer environment at Furnace Creek and Middle Basin would be SMALL.

Table 3-9. Average Concentrations of Radiological and Nonradiological Material From the Repository Discharging in Groundwater at Furnace Creek, Death Valley

	Present-Day Climate		Cooler/Wetter Climate	
	10,000 years	1 million years	10,000 years	1 million years
U isotopes (pCi/L)	0	0	0	0
Th isotopes (pCi/L)	0	0	0	0
Np-237 (pCi/L)	0	0	0	0
I-129 (pCi/L)	0	0.65	0.02	0.17
Tc-99 (pCi/L)	0	13.5	9.3	3.8
Se-79 (pCi/L)	0	0	0	0
Mo (mg/L)*	0	0.001	0	3.7×10^{-4}
V (mg/L)	0	0	0	0
Ni (mg/L)	0	0	0	0

*calculated peak concentration of 0.04 mg/L for Mo occurs at 58,000 years after repository closure
U = uranium, Th = thorium, Np = neptunium, I = iodine, Tc = technetium, Se = selenium, Mo = molybdenum, V = vanadium, Ni = nickel

Soil

This section describes the accumulation of potential contaminants from the repository in soils at Middle Basin or Furnace Creek. The concentrations of contaminants in soil and evaporite deposits within the wet playa are calculated using the estimated concentrations of the contaminant and TDS content of the groundwater, as in the evaporite model calculation for the State Line Deposits area (Section 3.1.2.1). Essentially, as water is lost due to evaporation, forming evaporites and other minerals, the contaminants in groundwater are incorporated into the newly formed solids. The concentration of the contaminant in the resulting solid is calculated by dividing the contaminant concentration in the groundwater by the TDS of the groundwater. The same conservative low value of TDS (257 ppm) is used here as in the previous evaporite model calculations (Section 3.1.2.1). The measured values of spring discharge waters at Furnace Creek are approximately 600 ppm TDS (Steinkampf and Werrell, 1998). Using this value for TDS in the evaporite model would decrease the calculated concentration in the soil to less than half that of the present estimate. Table 3-10 provides the calculated concentrations of radiological and nonradiological contaminants in soil and evaporite at Middle Basin. These values are derived from estimates in DOE (2014a, Table B-15) and the observed evaporation-driven discharge rates at Middle Basin (Belcher and Sweetkind, 2010). The values calculated for Middle Basin are limiting for possible soil accumulations at Furnace Creek. This is because any potential soil contamination from natural spring discharge at Furnace Creek would likely occur in a marsh/pool environment, rather than the wet playa environment in the topographic low at Middle Basin. As discussed in Section 3.1.2.1, modeling contaminant accumulation as a process that forms evaporites is very conservative, and results in greater concentrations than would form in an environment with less extreme evaporation. Potential accumulations of contaminants in soil at Furnace Creek are therefore expected to be less than those shown in Table 3-10 for the Middle Basin playa.

No radionuclide contaminants reach Middle Basin within 10,000 years in the present-day climate state, even with no pumping in Amargosa Farms. In the cooler/wetter climate state, I-129 and Tc-99 are present in Death Valley groundwater at 10,000 years, and therefore would

Table 3-10. Soil/Evaporite Contaminant Concentrations for Middle Basin, Death Valley				
	Present-Day Climate		Cooler/Wetter Climate	
	10,000 years	1 million years	10,000 years	1 million years
I-129 (ppm)	0	0.017	0.0005	0.004
Tc-99 (ppm)	0	0.004	0.002	0.001
Mo (ppm)*	0	6.5	2.1×10^{-6}	1.6

*calculated peak concentration of 208 ppm for Mo occurs at 58,000 years after repository closure
I = Iodine, Tc = technetium, Mo = molybdenum

be found in Middle Basin soils, although at very low levels. Due to radioactive decay, maximum Tc-99 soil/evaporite concentration is reached at about 500,000 years for the present-day climate and at about 100,000 years in the cooler/wetter climate. The I-129 concentration continues to increase slowly over the one-million-year period in both climate states.

For nonradiological contaminants, only the nonsorbing element Mo reaches Middle Basin. Under both climate scenarios, Mo reaches a maximum soil/evaporite concentration at about 58,000 years. The estimated maximum value is 208 ppm under the present-day climate state. The maximum value occurs slightly earlier for the cooler/wetter climate, but is lower. The maximum value decreases in the soil as the groundwater concentration decreases over time. This maximum is lower than the EPA soil screening level of 390 ppm for Mo in residential soils (Table 3-3). Studies of evaporation pits collecting irrigation water in the San Joaquin Valley have measured similar amounts of natural Mo concentrations (up to 94 ppm in soil/evaporite) as observed in the wetter climate scenario (Tanji, et al., 1992). As discussed for the evaporite model results at the State Line Deposits area (Section 3.1.2.1), the environments where evaporites form are generally inhospitable due to the high salt concentrations and lack of potable water.

Because there is very little accumulation of radiological contaminants (only Tc-99 and I-129, and at very low levels) in soils at Middle Basin or Furnace Creek, and because accumulations of the one nonradiological contaminant present (Mo) is likely to be elevated only in barren and uninhabitable portions of these areas, the NRC staff finds that soil impacts from radiological and nonradiological contaminants associated with natural groundwater discharges at Middle Basin and Furnace Creek would be SMALL.

Public Health

Biosphere dose pathways used in DOE’s 2008 SEIS are very similar to those used for the regulatory compliance location, as the latter are based on the diet and living style of the people who now reside in the Town of Amargosa Valley, Nevada (as prescribed in 10 CFR 63.312). However, there are some significant modifications necessary for the application of these pathways to residents in areas of natural surface discharge, like Death Valley, as compared to the groundwater pumping areas of Amargosa Farms. These include, in the absence of extensive agriculture, the lack of significant irrigation and groundwater recycling. In Death Valley, most discharge is by evapotranspiration (DOE, 2014a). In the Furnace Creek area, much of the natural spring discharge is captured in engineered structures for use in local facilities (tourist lodgings and housing for National Park service personnel). And as previously noted (Section 2.1.1), the Timbisha Shoshone tribal community near Furnace Creek has federally appropriated rights to 92 acre-feet per year [0.113 million m3/yr] of surface and groundwater.

The biosphere dose pathways used in this supplement for the Death Valley locations include (i) external exposure, (ii) inhalation of soil/evaporite particulates and water vapor from evaporative coolers, and (iii) ingestion of water and soil/evaporite particulates. Ingestion of locally-grown crops, animal products, and fish was not included as a pathway for the natural discharge areas of Death Valley because there is very little current agricultural production in the Furnace Creek area (only a small commercial date farm) and wet playas such as Middle Basin are not suited for future agricultural production due to the salt content of the soil and water. Likewise, for wet playa-type discharges (such as Middle Basin), ingestion of water and exposure from evaporative coolers were also excluded as pathways because the saline water in the wet playa is not potable. Even in a cooler/wetter climate, the wet playa water would be unsuitable for use as drinking water or for use in agriculture.

For assessing impacts at the natural discharge locations in Death Valley, this supplement uses biosphere dose conversion factors similar to those developed based on exposure rates for full-time residents of the Amargosa Farms area and used in the 2008 SEIS. The factors are modified for the different exposure pathways in Death Valley compared to Amargosa Farms, and they include corrections to account for secular disequilibrium. Dose conversion factors for the present-day climate are used for both present-day and future wetter climate scenarios because the dose conversion factors for cooler and wetter climates would be lower than those used for the present-day climate. Appendix A, Section A.2.3 provides more information on the biosphere dose pathways and dose conversion factors used in this supplement.

Furnace Creek Radiological Contaminants

Peak annual dose estimates for Furnace Creek are given in Table 3-11 for both climate states. As discussed in the previous sections on impacts on the aquifer and soil, only a limited amount of radionuclides reach the natural discharge locations in Death Valley. The principal radionuclides that contribute to dose at Furnace Creek are Tc-99 and I-129 (Figure 3-3). The contribution from Tc-99 begins to decrease at about 400,000 years after repository closure due to its shorter half-life than I-129 (~200,000 years compared to 15.7 million years). Under the lower flow volumes associated with the present-day climate, no radiological contaminants reach the Furnace Creek area before 10,000 years after repository closure. Estimated peak annual doses at one million years are slightly greater for the present-day climate state because there is less dilution of the contaminants in the groundwater. Although the contaminants arrive at Furnace Creek earlier in the cooler/wetter climate state, the peak dose is lower due to the lower groundwater contaminant concentrations. The estimated peak annual doses are much lower than the NRC annual dose standards for a Yucca Mountain repository in 10 CFR Part 63 {15 mrem [0.15 mSv] for the first 10,000 years, and 100 mrem [1 mSv] for one million years, after permanent closure}.

Furnace Creek Nonradiological Contaminants

Peak daily intakes of the nonradiological contaminant Mo at Furnace Creek are given in Table 3-12 for both climate states. As discussed in the previous sections on impacts on the aquifer and soil, Mo is the only nonradiological contaminant present in groundwater discharging from springs at Furnace Creek, and only at the one million year period. The calculated peak daily intake at Furnace Creek correlates with the maximum peak concentration in groundwater and soil approximately 58,000 years after repository closure for the present-day climate state and is 1.3×10^{-3} mg/kg body-weight/day (as with the groundwater, the maximum for the cooler/wetter climate occurs slightly earlier and is a lower value). Human health impacts of the nonradiological contaminants are assessed by comparing daily intakes with EPA's Oral

Table 3-11. Peak Annual Dose Estimates for the Furnace Creek Area

	Peak Annual Dose (mrem/yr)*	
	10,000 years	1 million years
Present-day Climate	0.0	3.4×10^{-1}
Cooler/Wetter Climate	2.3×10^{-2}	8.9×10^{-2}

* Note: 1.0 mrem/yr = 0.01 mSv/yr

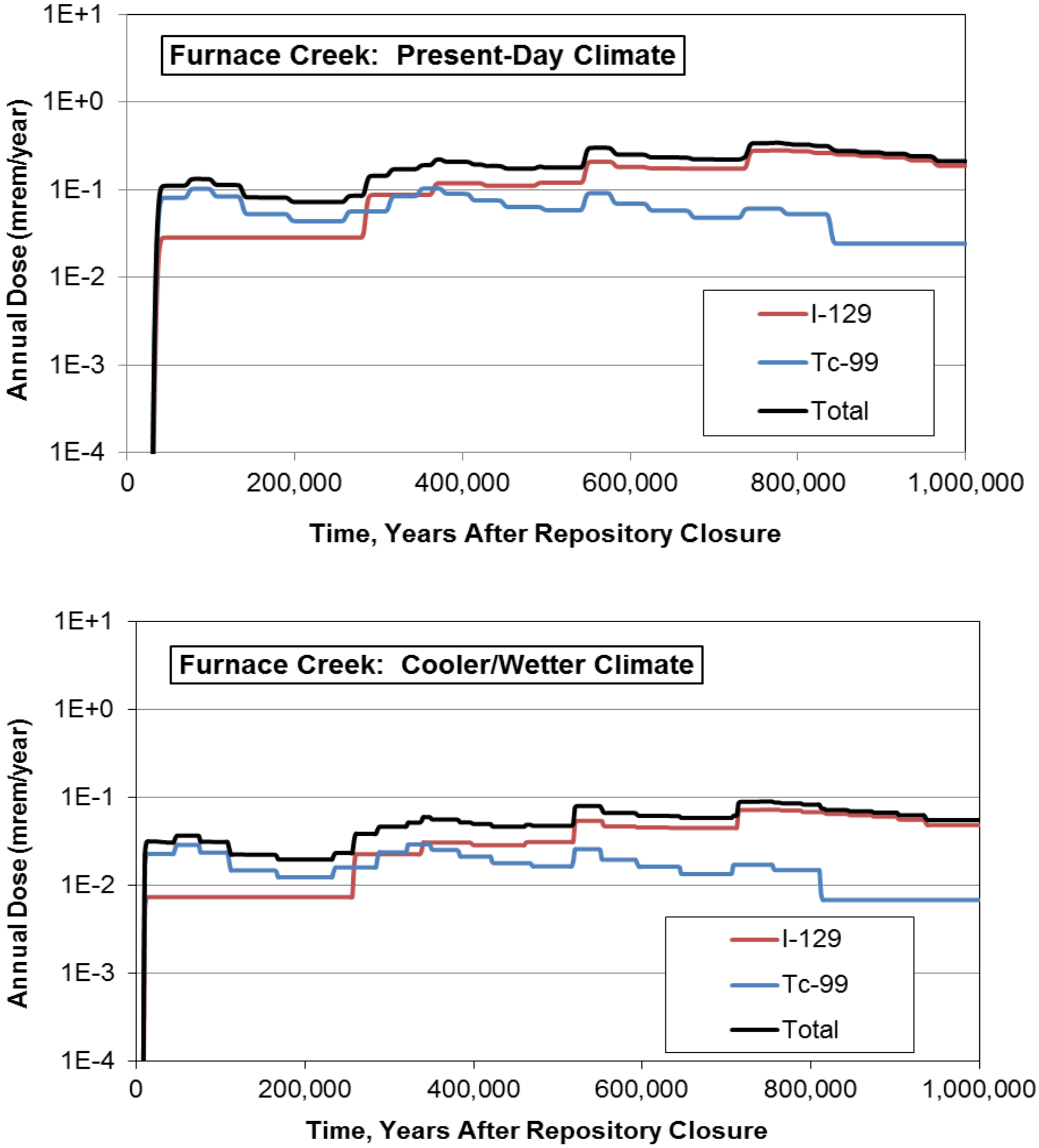

Figure 3-3. Dose History for Selected Radionuclides and Total Dose at the Furnace Creek Area for the Present-Day (Top) and the Cooler/Wetter (Bottom) Climate States.

Table 3-12. Peak Daily Intake for Mo at Furnace Creek			
Peak Daily Intake* (mg/kg body-weight/day)	**Present-Day Climate**	**Cooler/Wetter Climate**	**Oral Reference Dose**
Mo	1.3×10^{-3}	3.8×10^{-4}	5.0×10^{-3}
*calculated peak daily intake for Mo occurs at 58,000 years after repository closure for the present-day climate, and at 20,000 years for the cooler/wetter climate. Mo = molybdenum			

Reference Dose standard (EPA, 1999a,b; 1997a,b; 1994). For ingestion of potentially contaminated water, daily intake is estimated for a 70-kg person drinking 2 L [0.53 gal] of water daily. The estimated maximum value of daily intake is lower than the EPA Oral Reference Dose.

Middle Basin Radiological Contaminants

Peak annual dose estimates for Middle Basin are given in Table 3-13 for both climate states. As at the Furnace Creek area, the radiological contaminants that contribute to estimated dose in Middle Basin of Death Valley are limited to those elements whose transport in groundwater is not delayed due to sorption processes. As groundwater flows to Middle Basin and evaporates, these elements are incorporated into the resulting evaporite mineral deposits. Again, Tc-99 and I-129 are the primary contributors to dose (Figure 3-4). As at the Furnace Creek area (Figure 3-3), the contribution from Tc-99 decreases beginning at about 400,000 years after repository closure due to its shorter half-life than that of I-129. Similar to the results at the Furnace Creek area, dose estimates are greatest at one million years under the present-day climate scenario because of the dilution of the radiological contaminants in the larger groundwater flow volume under the cooler/wetter climate state, although the contaminants arrive sooner under the cooler/wetter conditions.

The peak annual dose estimates for Middle Basin are lower for both climate states than those for the Furnace Creek area. The low dose estimates are primarily due to the absence of a drinking water pathway at Middle Basin, given the high salinity of any standing water on the wet playa. As with the Furnace Creek results, estimated peak annual doses are much lower than the NRC dose standards for a Yucca Mountain repository in 10 CFR Part 63 {15 mrem [0.15 mSv] for the first 10,000 years, and 100 mrem [1 mSv] for one million years, after permanent closure}.

Middle Basin Nonradiological Contaminants

Peak daily intakes of nonradiological contaminants at Middle Basin are given in Table 3-14 for both climate states. As at Furnace Creek, Mo is the only nonradiological contaminant present in groundwater discharging at Middle Basin. At this location, Mo is present only at one million years under the present-day climate state, but is seen both at 10,000 and one million years under the cooler/wetter climate state.

Human health impacts of nonradiological contaminants are assessed by comparing daily intakes with EPA's Oral Reference Dose standard (EPA, 1999a,b; 1997a,b; 1994). At this location, the principal pathway is ingestion and inhalation of contaminated soil, as the water at this location is not potable. As previously noted, the peak concentration for molybdenum occurs approximately 58,000 years after repository closure for the present-day climate (the peak is lower for the cooler/wetter climate, but occurs earlier). The peak Mo daily intake at Middle

Table 3-13. Peak Annual Dose Estimates for Middle Basin

	Peak Annual Dose (mrem/yr)*	
	10,000 years	1 million years
Present-day Climate	0.0	1.6×10^{-1}
Cooler/Wetter Climate	1.5×10^{-2}	4.2×10^{-2}

* Note: 1.0 mrem/yr = 0.01 mSv/yr

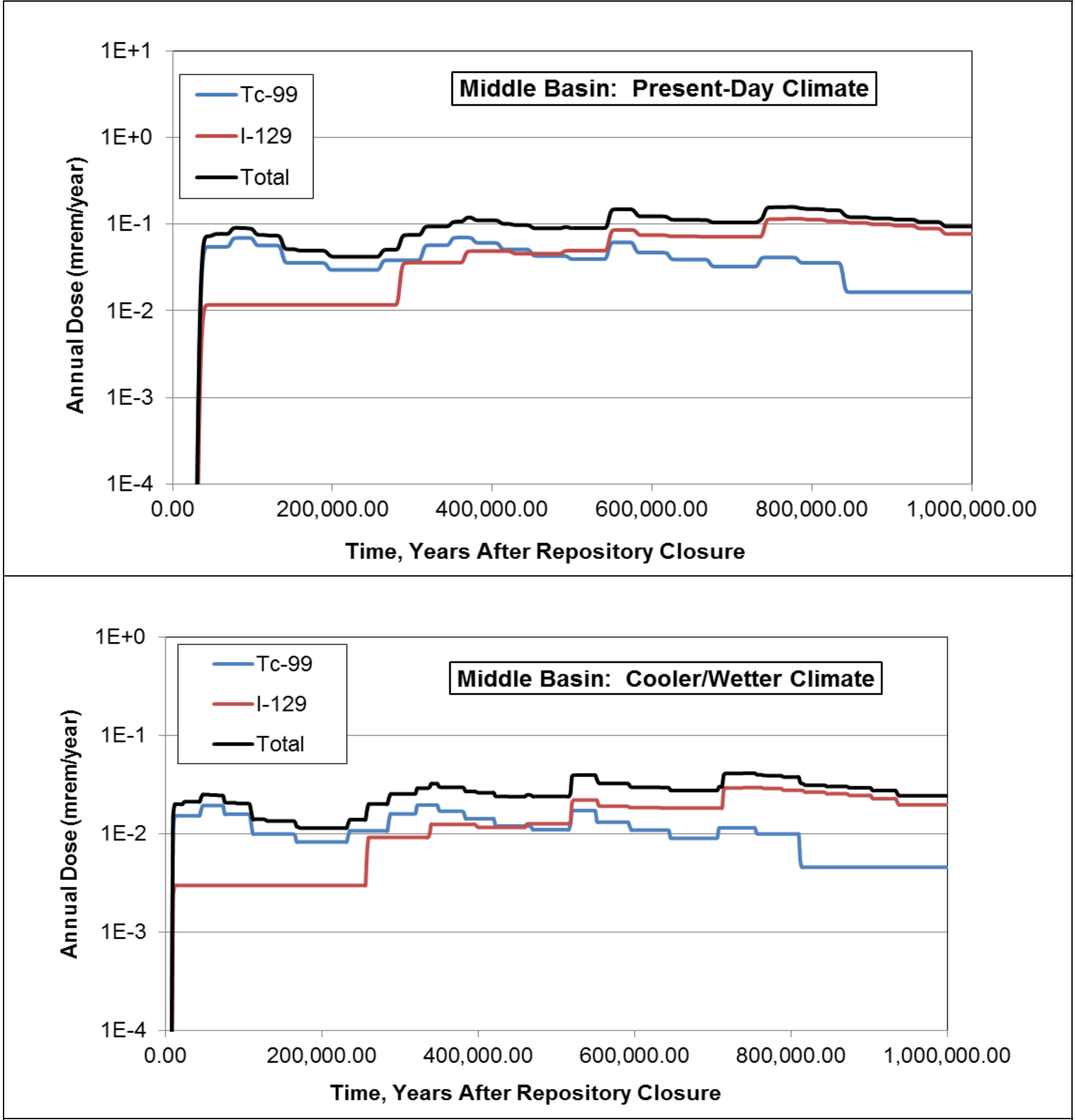

Figure 3-4. Dose History for Selected Radionuclides and Total Dose at Middle Basin for the Present-Day (Top) and Cooler/Wetter (Bottom) Climate States

Table 3-14. Peak Daily Intake for Mo at Middle Basin

Peak Daily Intake* (mg/kg body-weight/day)	Present-Day Climate	Cooler/Wetter Climate	Oral Reference Dose
Mo	3.0×10^{-4}	1.8×10^{-5}	5.0×10^{-3}

*calculated peak daily intake for Mo occurs at 58,000 years after repository closure for the present-day climate, and at 20,000 years for the cooler/wetter climate.
Mo = molybdenum

Basin is estimated to be 3×10^{-4} mg/kg body weight/day. The estimated values of daily intake in Table 3-14 and the peak value are both lower than the EPA Oral Reference Dose.

Based on the above, estimated doses from radiological contaminants at Furnace Creek and Middle Basin would be very low for both climate states {less than 1 mrem/year [0.01 mSv/yr]}, and the peak daily intakes of nonradiological contaminants would also be very low (below the EPA Oral Reference Dose). Therefore, the NRC staff finds that impacts to public health from radiological and nonradiological contaminants associated with natural groundwater discharges at Furnace Creek and Middle Basin of Death Valley would be SMALL.

3.1.2.3 Alkali Flat

Alkali Flat is located approximately 45 km [28 mi] from the regulatory compliance location, or 63 km [39 mi] from the proposed repository. The groundwater at Alkali Flat is a combination of groundwater flowing from Ash Meadows and groundwater from western Amargosa Desert and Fortymile Wash. As discussed in Section 2.2.2, under scenarios in which there is no pumping in the Amargosa Farms area, groundwater modeling indicates that the majority of contaminants transported from Yucca Mountain will be discharged in Middle Basin, and to a lesser extent, at Furnace Creek (or the State Line Deposits area in a wetter climate) prior to reaching Middle Basin (Belcher and Sweetkind, 2010; DOE, 2014a). DVRFS modeling indicated that only a small fraction of contaminants could be directed southward toward the Alkali Flat area (Belcher and Sweetkind, 2010; DOE, 2014a).

There are no people living at Alkali Flat. The water composition is highly variable, from saline to relatively dilute (low TDS), with the more-dilute water found in the small springs on the upstream side of the playa. Due to the lack of residents and the very limited amount of potable water at the site, potential exposure pathways are limited to inhalation and exposure to resuspended dust from evaporites in which radiological and nonradiological contaminants may have precipitated from evaporation of groundwater discharge.

Estimates of groundwater, soil, and surface discharge mass and concentration at Alkali Flat were not explicitly calculated for this supplement, as the impacts can be estimated from the estimates for the other, more-likely discharge areas. Alkali Flat is similar to Middle Basin in its dominantly playa environment, and in its inhospitable conditions and lack of habitation. But Alkali Flat is more distant from present population centers, and is less likely to have visitors or temporary occupants. The exposure pathways and biological dose conversion factors used for a playa at Middle Basin are therefore applicable (and conservative) for Alkali Flat. The fraction of the contaminant plume reaching Alkali Flat is expected to be very small (less than one percent of the potential release reaching the regulatory compliance location, based on DVRFS modeling). Thus, the results in Section 3.1.2.2 for release of the entire plume at Middle Basin are likely to overestimate the contaminants in the groundwater or accumulated in soil at Alkali Flat (even though the transport path is marginally shorter from the repository to Alkali Flat). For these reasons, the NRC staff finds that the impacts at Alkali Flat would be a small fraction of those calculated for Middle Basin under both climate states, which were found to be SMALL, above. Therefore, the aquifer environment, soil, and public health (radiation dose and body intake of chemicals) impacts for Alkali Flat would be SMALL.

3.2 Ecological Impacts

The NRC staff evaluated the potential for ecological impacts from radionuclides and chemical constituents at the potential locations for surface discharges of groundwater to the environment by considering the estimated radiation doses to humans (as a general indicator of the magnitude of radiological exposure), the concentrations of chemical constituents in various environmental media, and available information about how nonhuman biota could be impacted by radiological and chemical exposures. Relatively few studies have established impact levels for nonhuman biota exposed to radionuclides. Data on the impacts of nonradiological contaminants are more abundant but still limited (Hinck, et al., 2010; Poston, et al., 2011; Sample, et al., 1996). Most available data on both radiological and nonradiological contaminants are from laboratory animal toxicity studies that do not address chronic exposure or ecosystem-level impacts. Nonhuman biota exhibit varying levels of sensitivity to radiation and chemical exposures (Poston, et al., 2011; Sample, et al., 1996), although some biological receptors are potentially more or less susceptible than others. For example, the more highly developed phylogenetic classes of organisms (plants and animals) tend to be more susceptible to radiation effects than less developed ones (Poston, et al., 2011).

Given the very low doses estimated for Amargosa Farms, the State Line Deposits/Franklin Well area, and for Furnace Creek/Middle Basin in the previous sections, the NRC did not specifically calculate doses to nonhuman biota from radiological contaminants at these locations. The NRC staff considers it unlikely that nonhuman biota would receive doses significantly greater than the human dose estimates when the latter are a small fraction of the background exposure level. Based on this analysis, the NRC staff concludes that the potential for ecological impacts from radiological contaminants at these locations would be SMALL.

The NRC staff evaluated the potential for nonhuman biota to be exposed to potentially harmful levels of chemical constituents at Amargosa Farms, State Line Deposits/Franklin Well area, and Furnace Creek/Middle Basin based on the aquifer and soil concentrations in Sections 3.1.1 and 3.1.2 for present-day and cooler/wetter climates and for both the 10,000 year and one-million-year time-frames. Comparisons of the estimated groundwater and soil concentrations for the nonradiological contaminants to ecological impact concentrations are given for the three areas in Tables 3-15, 3-16, and 3-17. The water and soil concentrations shown in these tables are for the climate state showing the greatest concentration over the one million year time period for each area. Two approaches are used in Section 3.1.2.1 to estimate contaminant concentrations in surficial material: the evaporite model for playas and the salt marsh model for areas near and downstream from springs and pools. The values in Table 3-16 are derived from the salt marsh model because biota would dominantly be associated with springs and pools; and would be sparse on the saline playas.

The ecological impact values shown in Tables 3-15, 3-16, and 3-17 are derived from various data, depending on the applicability and availability of information and considering the wildlife that are representative of the region. Water concentration values are based on EPA aquatic life criteria (EPA, 2014) (available only for Ni) or the reported ranges of adverse ecological effect concentrations in scientific literature compilations. The threshold range for U in water is the

Table 3-15. Comparison of Estimated Groundwater and Soil Concentrations* of Contaminants at Amargosa Farms With Ecological Impact Concentrations (ppm)

Constituent	Estimated Water Concentration	Ecological Impact Concentration[†]	Estimated Soil Concentration	Ecological Impact Concentration[†]
Mo	7.3×10^{-3}	0.6–107	0.007	100–500
Ni	0.02	0.052	4.0	38–280
V	2.1×10^{-9}	0.835–200	1.2×10^{-4}	7.8–280
U (all isotopes)	1.9×10^{-4}[‡]	0.0026–69	0.043	5–200

Mo = molybdenum, Ni = nickel, V = vanadium, U = uranium

*Concentrations in ppm (mg/L or mg/kg) are peak values that consider both the present-day and cooler/wetter climates.

[†] The ecological impact values are from various sources, based on applicability and availability of information including EPA (2014; 2007; 2005), Hinck, et al. (2010), and Eisler (1989), as described in Section 3.2.

[‡] Concentration in ppm (mg/L) calculated from total uranium activity per liter from Table 3-2.

Table 3-16. Comparison of Estimated Groundwater and Soil Concentrations* of Contaminants at State Line/Franklin Well with Ecological Impact Concentrations (ppm)

Constituent	Estimated Water Concentration[†]	Ecological Impact Concentration[‡]	Estimated Soil Concentration[#]	Ecological Impact Concentration[‡]
Mo	$<7.3 \times 10^{-3}$	0.6–107	3.6×10^{-4}	100–500
Ni	<0.02	0.052	0.99	38–280
V	$<2.1 \times 10^{-9}$	0.835–200	3.6×10^{-5}	7.8–280
U (all isotopes)	$<1.9 \times 10^{-4}$[‡]	0.0026–69	0.013	5–200

Mo = molybdenum, Ni = nickel, V = vanadium, U = uranium

*Concentrations in ppm (mg/L or mg/kg) are peak values that consider both the present-day and cooler/wetter climates.

[†] Estimated aquifer concentration at State Line/Franklin Well is down gradient from Amargosa Farms and would, therefore, be less than the Amargosa Farms estimate.

Soil concentrations are based on values from the irrigation recycling model approach, Section 3.1.2.1

[†] Sources as in Table 3-15.

[‡] Concentration of U in water calculated from total uranium activity per liter from Table 3-2.

Table 3-17. Comparison of Estimated Groundwater and Soil Concentrations* of Contaminants at Death Valley Middle Basin[†] with Ecological Impact Concentrations (ppm)

Constituent	Estimated Water Concentration	Ecological Impact Concentration[‡]	Estimated Soil Concentration	Ecological Impact Concentration[‡]
Mo	0.13	0.6–107	208	100–500
Ni	0.0	0.052	0.0	38–280
V	0.0	0.835–200	0.0	7.8–280
U (all isotopes)	0.0	0.0026–69	0.0	5–200

Mo = molybdenum, Ni = nickel, V = vanadium, U = uranium

*Concentrations in ppm (mg/L or mg/kg) are peak values that consider both the present-day and cooler/wetter climates

[†] Furnace Creek groundwater concentrations would be similar, but there would be no accumulation of constituents in soil, as described in Section 3.1.2.1.

[‡] Sources as in Table 3-15.

range of reported guideline values in Hinck, et al. (2010). The ranges for Mo and V in water are from Sample, et al. (1996). The ecological impact values for soil concentrations of Ni and V are the EPA ecological soil screening levels (EPA, 2007; 2005). These EPA levels were developed to support screening analyses to identify potential ecological concerns at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites that may need further, more detailed, evaluation (e.g., ecological risk assessment). EPA stated that it expected that any federal, state, tribal or private environmental assessment could use the values to screen soil contaminants (EPA, 2003). The soil range for Mo is based on dietary concentrations where adverse effects have been observed in the most sensitive applicable organisms (rabbits and birds) (Eisler, 1989). This dietary concentration is compared with the estimated soil concentration, based on the assumption that the plants consumed by the organisms would be in equilibrium with the estimated soil concentration. The U range is the soil concentration-based guidance levels reported by Hinck, et al., 2010).

The results of the NRC staff's comparison of the estimated aquifer and soil concentrations with the ecological impact concentrations are provided in Tables 3-15 through 3-17. The estimated water and soil concentrations of Mo, Ni, V, and U at Amargosa Farms, the State Line Deposits/Franklin Well area, and at Furnace Creek/Middle Basin are generally below the ecological impact concentrations. The only exception is for Mo in the evaporite soil at Middle Basin. As previously discussed, this conservative value is for a highly saline soil which can support only sparse, if any, vegetation, and thus could not be the principal support for nonhuman biota. Therefore, the NRC staff concludes that environmental impacts to nonhuman biota from these chemical constituents would be SMALL.

Because the NRC staff finds that only a very small fraction of the contaminants are expected to reach Alkali Flat (Section 3.1.2.3), impacts to nonhuman biota at Alkali Flat would be much less than at the areas evaluated above. In addition, Alkali Flat is expected to remain dominantly a playa environment with sparse amounts of salt-tolerant vegetation growing in highly saline surficial material. Based on this analysis, the NRC staff concludes that the potential for ecological impacts from radiological and nonradiological contaminants at Alkali Flat would be SMALL.

In summary, based on the analyses in this section, the NRC staff concludes that the potential for ecological impacts from radiological and nonradiological contaminants at all of the surface discharge locations would be SMALL.

3.3 Historic and Cultural Resources

As stated in Section 2.3.2, historic and cultural resources may be located in or around current surface discharge areas, described in Section 2.3.3, or in paleospring discharge areas (and potential future discharge locations), described in Section 2.3.4. This section briefly describes DOE's analysis of impacts on cultural resources in its EISs, summarizes the NRC staff conclusions in its 2008 ADR, describes the scope of DOE's programmatic agreement with the Nevada State Historic Preservation Office (SHPO) and the Advisory Council on Historic Preservation (ACHP) under the National Historic Preservation Act (NHPA) (see Section 3.3.3), describes more recent work by DOE to evaluate impacts on historic and cultural resources, and provides the NRC staff's conclusions regarding impacts to historic and cultural resources at surface discharge locations.

3.3.1 Assessments in the DOE Environmental Impact Statements

DOE's historic and cultural resource analyses in its EISs for the proposed repository at Yucca Mountain focused on the repository site and the surrounding controlled area. Section 4.1.5 of the 2002 EIS contains DOE's evaluation of the potential environmental impacts of the proposed repository on historic and cultural resources. DOE updated its historic and cultural resources impact assessment in Sections 4.1.5 and 4.3.2.5 of the 2008 SEIS. Section 4.1.5 of the 2008 SEIS provides an update to the expected historic and cultural resources impacts, accounting for new information and an expanded region of influence, including land that DOE had proposed for an access road from U.S. Highway 95 and land where DOE would construct offsite facilities. Section 4.3.2.5 of the 2008 SEIS assesses the potential historic and cultural resource impacts of proposed infrastructure improvements, such as the construction or replacement of roads, the installation of transmission lines, and various on-site improvements.

In its 2002 EIS, DOE also noted that the "Native American view of resource management and preservation is holistic in its definition of 'cultural resource,' incorporating all elements of the natural and physical environment in an interrelated context. Moreover, this view includes little or no differentiation between types of impacts (direct versus indirect), but considers all impacts to be adverse and immune to mitigation." DOE also summarized the results of studies that delineated several Native American sites, areas, and resources in DOE's region of influence for cultural resources. DOE further stated that it would continue its Native American Interaction Program throughout the construction, operation, closure, and monitoring of the repository (DOE, 2002; Section 4.1.5.2).

3.3.2 Assessment in the NRC Staff's Adoption Determination Report (2008)

Section 3.2.1.4.1 of the ADR notes that DOE identified and described in its EISs the status of its NHPA consultation processes. The ADR states that some of the bases for EIS impact analyses and proposed mitigation measures include the anticipated results of these processes or other investigations that were ongoing, and that DOE committed in various sections of its EISs to resolving these ongoing activities. The ADR highlights two activities relevant to historic and cultural resources:

- DOE had been consulting with the Nevada SHPO and the ACHP to develop a programmatic agreement for the proposed repository.

- DOE indicated its intent to have continuing discussions with Native American tribes through its Native American Interaction Program and proposed establishing a "mitigation advisory board" to explore ways to address concerns about adverse impacts.

The ADR notes that, as indicated in NUREG–1748 (NRC, 2003; Section 5.1.4), an EIS should describe the current status of the required permit applications and consultations, but it is not necessary that all permitting and consultation activities be completed before publication of the final EIS. Additionally, the ADR notes that the Council on Environmental Quality (CEQ) regulations at 40 CFR 1502.22 state that an EIS may document incomplete or unavailable information provided the EIS clearly indicates such information is lacking. The NRC staff concluded in the ADR that the discussions of these ongoing activities in the DOE EISs meet NRC regulations and are consistent with NRC guidance.

The ADR also addresses how DOE assessed the impacts of the proposed repository on historic and cultural resources. As discussed further in the ADR, the two main components of DOE's analysis were (i) a description of DOE's efforts to assess effects on specific historic and cultural resources and (ii) a discussion of Native American viewpoints, which DOE characterizes as an opposing viewpoint. The ADR also notes that in its EISs, DOE further indicates its intent to continue its Native American Interaction Program to comply with the various laws that may affect Native American cultural practices, and to establish one or more mitigation advisory boards to address concerns about adverse impacts. The NRC staff concluded in the ADR that the consideration of Native American concerns and the impacts assessed on historic and cultural resources in the DOE EISs is adequate under the National Environmental Policy Act (NEPA).

3.3.3 DOE's Programmatic Agreement (2009)

As discussed in Section 2.3.2, in 2009 DOE finalized a programmatic agreement with the ACHP and the Nevada SHPO concerning the development of a repository at Yucca Mountain (DOE, 2009b). The area covered by the agreement "includes all site activities conducted by [DOE] and its contractors for the licensing and development of Yucca Mountain as a repository for disposal of spent nuclear fuel and high-level radioactive waste that have the potential to affect historic properties, and that are located within the boundaries of the Yucca Mountain Project Operator-Controlled Area… In the event the DOE is granted the proposed land withdrawal area depicted in Figure 1, this Agreement will be amended to expand the [Yucca Mountain Project Operator-Controlled Area]" to include the land withdrawal area (DOE, 2009a; Section A.1). The programmatic agreement further states that impacts from activities that support the repository, but which occur outside of the Operator-Controlled Area, are outside the scope of the agreement and would need to be considered separately. The agreement states that DOE would consult with the SHPO and appropriate State agencies, as necessary, regarding compliance with any applicable State and Federal laws or regulations (DOE, 2009a; Section A.1 and A.2). The agreement also states that should the NRC grant a construction authorization for the proposed repository, the NRC may use the agreement to fulfill its obligations under Section 106 of the NHPA.

3.3.4 Additional DOE Analysis (2014)

DOE's 2014 analysis of the potential impacts of the repository on groundwater and on surface discharges of groundwater (DOE, 2014a) includes a discussion of Native American concerns and provides an assessment of the potential impacts on Furnace Creek area residents of using and consuming groundwater that could contain contaminants from the repository. This assessment does not provide an accounting of any historic and cultural resources that may be present at or near surface discharge locations.

3.3.5 NRC Staff Evaluation

The NRC staff concluded in its ADR that DOE adequately addressed the potential impacts on historic and cultural resources in its EISs, given DOE's defined region of influence and given that some consultation processes were still ongoing at the time the final 2008 SEIS was published. Based on the region of influence DOE described in its EISs (DOE, 2008a; 2002), the NRC staff concludes that the affected environments considered in this supplement are outside the region DOE evaluated in its EISs' assessments of these impacts, and that the NRC staff found acceptable in its ADR. The NRC staff acknowledges that DOE has developed a programmatic agreement to specifically address impacts on historic properties under the NHPA.

However, the NRC staff notes that the agreement scope does not include areas outside the Operator-Controlled Area and that the agreement states that any impacts outside this area would need to be addressed separately. In addition, the DOE programmatic agreement focuses on proposed activities within the state of Nevada, and some of the affected areas identified in this supplement (and in DOE, 2014a) are in California. Thus, the NRC staff concludes that DOE would need to assess whether further consultation and investigation are necessary to account for potential impacts on cultural resources that may be located in areas where groundwater discharges to the surface.

3.4 Environmental Justice

Environmental justice refers to a Federal policy implemented to ensure that minority, low-income, and tribal communities historically excluded from environmental decision-making are given equal opportunities to participate in decision-making processes. This section discusses potential environmental justice issues related to the evaluations in this supplement for impacts on groundwater and the surface discharge of groundwater. Specifically, this section summarizes the environmental justice analysis in DOE's EISs, describes more recent work by DOE to evaluate environmental justice impacts, and provides the NRC staff's analysis and conclusions regarding environmental justice impacts from groundwater or surface discharges of groundwater.

Under Executive Order 12898 (59 FR 7629), Federal agencies are responsible for identifying and addressing potentially disproportionately high and adverse human health and environmental impacts on minority and low-income populations. In 2004, the NRC issued a Policy Statement on the Treatment of Environmental Justice Matters in NRC Regulatory and Licensing Actions (69 FR 52040), which states that "The Commission is committed to the general goals set forth in Executive Order 12898, and strives to meet those goals as part of its National Environmental Policy Act (NEPA) review process."

Disproportionately high and adverse human health effects occur when the risk or rate of exposure to an environmental hazard for a minority or low-income population is significant and exceeds the risk or exposure rate for the general population or for another appropriate comparison group. Disproportionately high environmental effects refer to impacts or risks of impacts on the natural or physical environment in a minority or low-income community that are significant and appreciably exceed the environmental impact on the larger community.

3.4.1 Assessments in DOE's Environmental Impact Statements

In its EISs, DOE provided an analysis of environmental justice impacts but did not identify groundwater as a resource area for which potential environmental justice impacts could occur. Because DOE did not provide an environmental justice analysis for impacts from groundwater or from surface discharges of groundwater, the NRC staff concludes that, consistent with the finding in the ADR with regard to the need for further supplementation, this discussion in the EISs is incomplete. The NRC staff's assessment is provided in the next section.

3.4.2 NRC Staff Assessment

This section assesses the potential for disproportionately high and adverse human health or environmental effects on minority and low-income populations that could result from groundwater containing contaminants from the repository. As stated in Section 2.1.1, the NRC staff incorporates by reference its SER assessment and DOE's license application description of regional demography. For this analysis, the affected area consists of population centers located along the groundwater flow path from Yucca Mountain. Section 2.1.1 describes population centers within an 84-km [52-mi] radius of Yucca Mountain, comprising parts of Clark, Esmeralda, Lincoln, and Nye Counties in Nevada, and Inyo County in California. Within that radius, there are two population centers that the NRC staff has determined are located along the groundwater flow path from Yucca Mountain. The potentially-affected population centers are the town of Amargosa Valley in Nye County, Nevada, and Death Valley National Park in Inyo County, California (NRC, 2015a; Section 2.1.1.1.3.2., Population Centers). The NRC staff's analysis of potential environmental justice impacts at these two locations is provided below.

Impacts on Minority and Low-Income Populations in the Amargosa Valley Area

The Amargosa Valley Census County Division (CCD) is a census area of Nye County, Nevada, located along the groundwater flow path from Yucca Mountain. Table 3-18 provides a summary of minority and low-income populations for this group.

NRC guidance states that minority populations with differences greater than 20 percentage points higher than the state or county percentages, or that exceed 50 percent of the census (typically at the block level) group, may be considered to be significant (NRC, 2003). Following this guidance, the NRC staff considers the low-income population in the Amargosa Valley CCD to be a significant environmental justice population (NRC, 2003). The NRC staff, therefore, evaluated whether the minority and low-income populations could experience disproportionately high and adverse human health and environmental effects from groundwater impacts. The groundwater impacts in the town of Amargosa Valley (which includes the Amargosa Farms area) would be from pumping potentially contaminated groundwater used primarily for irrigation (Section 2.3). Section 3.1.1 describes the potential groundwater impacts in Amargosa Farms. Amargosa Farms pumps groundwater for irrigation and for its commercial and domestic water supply. The dose pathways for a resident of Amargosa Farms are external (body) exposure, inhalation, and ingestion of water, crops, animal products, fish, and soil. Section 3.1.1 describes the concentration of contaminants in the groundwater at the Amargosa Farms area (see Table 3-2), the concentration of contaminants in soils in the Amargosa Farms area due to irrigation (see Table 3-3), and the dose and body intake values for radiological contaminants (see Table 3-4) and nonradiological contaminants (see Table 3-5).

In Section 3.1.1, the NRC staff finds that both for the present-day and wetter climates: (i) the impacts at Amargosa Farms from radiological and nonradiological contaminants to the aquifer environment would be SMALL; (ii) the impacts on soils at Amargosa Farms would be SMALL; and (iii) the impacts on public health at Amargosa Farms would be SMALL. Further, the peak dose of 1.3 mrem/yr [0.013 mSv/yr] in Table 3-4 is substantially smaller that the dose from natural background levels of approximately 300 mrem/yr [3.0 mSv/yr] (including radon) for Amargosa Valley.

Based on its conclusions in Section 3.1.1 concerning impacts on groundwater, soils, and public health, the NRC staff finds no environmental pathway that would affect minority or low-income populations differently from other segments of the general population. Therefore, the NRC staff concludes that no disproportionately high and adverse health or environmental impacts would occur to minority or low-income segments of the population in the Amargosa Valley area.

Table 3-18. 2010 Minority Populations and 2009-2013 5-Year Poverty Estimates for the Amargosa Valley Area

	Amargosa Valley Census County Division	Nye County	Nevada
Percent Minority (Including Hispanic and Latino Ethnicity)*	37	72	40
Percent of Persons Below the Poverty Level	38	19	15

Source: U.S. Census Bureau American Fact Finder <http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml> (accessed June 26, 2015)
Percentages are rounded to the nearest whole number.
*Minority population includes persons of Hispanic/Latino origin who are considered an ethnic minority and may be of any race (USCB, 2001).

Impacts on Minority and Low-Income Populations at Death Valley National Park

The Death Valley CCD, located in Inyo County, California, is a census population located along the groundwater flow path from Yucca Mountain. Table 3-19 provides a summary of minority and low-income populations for this group.

Consistent with NRC guidance, the NRC staff considers the minority population in the Death Valley CCD to be a significant environmental justice population (NRC, 2003). As noted in Section 2, the population in Death Valley includes the Timbisha Shoshone Tribe community located on a 314-acre [1.27-km^2] parcel of land in the Furnace Creek area, which is located within the Death Valley CCD. The Tribe has federally appropriated rights to 92 acre-ft/year [0.113 million m^3/yr] of surface and groundwater. The springs in the Furnace Creek area, including the Furnace Creek, Texas, Travertine, and Salt Springs, are of traditional and cultural importance to the Tribe (DOE, 2014a).

Section 3.1.2 describes the impacts of surface discharges, assuming no pumping at Amargosa Farms, for both the present-day and cooler/wetter climate states. The assumption of no pumping at Amargosa Farms models the maximum quantity of groundwater, and potential contaminants, to discharge at surface locations in Death Valley (as discussed in Chapter 2; with present pumping rates at Amargosa farms, no contaminants from the repository would reach Death Valley). The sites where discharges of radiological and nonradiological contaminants could occur are springs at the State Line Deposits/Franklin Well area (under a wetter climate only), springs at Furnace Creek, and the playa/salt pan at Middle Basin of Death Valley. The NRC staff estimated the peak impact at these two areas by conservatively assuming that the entire contaminant plume would discharge at each location. Biosphere dose conversion factors for these areas are based on exposures to full-time residents. As stated in Section 3.1.2.2, the dose pathways for a resident in these areas include external exposure, inhalation of soil/evaporite particulates and water vapor from evaporative coolers, and ingestion of water and soil/evaporite particulates. The NRC staff did not evaluate the ingestion of crops, animal products, and fish as pathways because there is little current agricultural production near the Furnace Creek area, and the NRC staff does not expect that wet playas would be used for agriculture. Likewise, for the Middle Basin wet playa, the NRC staff did not include the ingestion of water and exposure from evaporative coolers as pathways because the saline content of the water is unsuitable for such uses. Even in wetter climates, the wet playa water would be unsuitable for use as drinking water or in agriculture.

Table 3-19. 2010 Minority Populations and 2009-2013 5-Year Poverty Estimates for the Death Valley Area

	Death Valley Census County Division	Inyo County	California
Percent Minority (Including Hispanic and Latino Ethnicity)*	78	55	37
Percent of Persons Below the Poverty Level	12	13	16

Source: U.S. Census Bureau American Fact Finder http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml (accessed June 26, 2015)
Percentages are rounded to the nearest whole number
*Minority population includes persons of Hispanic/Latino origin who are considered an ethnic minority and may be of any race (USCB, 2001).

In Section 3.1.2.2, the NRC staff concludes that for the Furnace Creek area and for Middle Basin for the present-day and wetter climates: (i) the impact to the accessible environment for those locations would be SMALL; (ii) the soil impacts associated with groundwater discharges at Furnace Creek and Middle Basin would be SMALL; and (iii) the potential public health impacts from radiological and nonradiological contaminants associated with natural groundwater discharges at Furnace Creek and Middle Basin would be SMALL.

In Section 3.5 of its analysis of groundwater impacts (DOE, 2014a), DOE provided a discussion of potential impacts on members of the Timbisha Shoshone Tribe. This analysis is consistent with the NRC staff's conclusion. Based on its analysis, DOE states (DOE, 2014a; p.3-28):

> DOE has identified no high and adverse potential impacts to members of the general public associated with exposure to contaminants that may occur in groundwater following closure of a repository at Yucca Mountain. Further, DOE has not identified subsections of the population, including minority or low-income populations that would receive disproportionate impacts. Likewise, DOE has identified no unique exposure pathways that would expose minority or low-income populations to disproportionately high and adverse impacts. The Department acknowledges the sensitivities and cultural practices of the Timbisha Shoshone Tribe concerning the use and purity of springs in the [Furnace] Creek area; however, the information included in this Analysis of Postclosure Groundwater Impacts demonstrates that the potential concentrations of contaminants in those springs would be so low that there would be virtually no potential health effects associated with the use of those springs. Thus, this document supports the Department's previous conclusion that no disproportionately high and adverse impacts would result from a repository.

Based on its conclusions in Section 3.1.2 concerning impacts on groundwater, soils, and public health, the NRC staff finds no environmental pathway that would physiologically affect minority or low-income populations differently from other segments of the general population; therefore, the NRC staff concludes that no disproportionately high and adverse health or environmental impacts would occur to minority or low-income segments of the population in the Death Valley area.

3.4.3 NRC Staff Conclusion

The NRC staff acknowledges the sensitivities and cultural practices of the Timbisha Shoshone Tribe concerning the use and purity of springs in the Furnace Creek area. Based on the analysis above, the NRC staff determines that there would be no disproportionately high and adverse human health or environmental effects from uses or discharges of groundwater flowing from the repository on minority or low-income segments of the populations in the Amargosa Valley area and in Death Valley National Park.

3.5 Summary

In its 2008 SEIS, DOE determined that the waterborne pathway (groundwater flow to discharge locations downstream) would dominate potential postclosure impacts of a repository at Yucca Mountain. DOE found that its estimated mean annual individual dose at the regulatory compliance location was a small fraction of the 15 mrem/yr [0.15 mSv/yr] standard in 40 CFR Part 197 (for the first 10,000 years after closure). Similarly, DOE found that the estimated annual dose for the one–million-year period was a small fraction of the annual limit. DOE also found that significant human impacts from chemicals and anticipated adverse impacts to biological resources would be unlikely.

In this supplement, the NRC staff finds that the impacts to groundwater and from surface discharges of groundwater beyond the regulatory compliance location are SMALL.

The peak radiological dose from estimates for all locations evaluated in this supplement is 1.3 mrem/yr [0.013 mSv/yr], which occurs in the Amargosa Farms area for Analysis Case 1 (pumping). The NRC staff finds that the calculated radiological doses are SMALL because they are much lower than the NRC annual dose standards for a Yucca Mountain repository in 10 CFR Part 63 {15 mrem [0.15 mSv] for the first 10,000 years, and 100 mrem [1 mSv] for one million years, after permanent closure}. The peak dose estimates considered uncertainty in climate and pumping rates. Based on conservative assumptions about the potential for health effects from exposure to low doses of radiation, the estimated radiation dose is expected to contribute a negligible increase in the risk of cancer or severe hereditary effects in the potentially exposed population.

Impacts to all of the affected environments beyond the regulatory compliance location from nonradiological (chemicals) material from the repository were also found to be SMALL, as were radiological and nonradiological ecological impacts (Section 3.2).

4 CUMULATIVE IMPACTS

Chapter 3 of this supplement contains the U.S. Nuclear Regulatory Commission (NRC) staff's assessment of impacts on groundwater and on surface discharges of groundwater. In this chapter, the NRC staff evaluates the cumulative impacts of the direct and indirect impacts described in Chapter 3 when aggregated with the impacts of other actions that could affect the same resources. The NRC staff also evaluates how its findings in Chapter 3 and cumulative impact findings in this chapter affect the conclusions provided by U.S. Department of Energy (DOE) in its assessment of cumulative impacts on groundwater in Chapter 8 of its environmental impact statement (EIS) (DOE, 2002) and Chapter 8 of its supplemental EIS (SEIS) (DOE, 2008a).

A cumulative impact is "the impact on the environment that results from the incremental impact of [an] action when added to other past, present, and reasonably foreseeable future actions, regardless of what agency (Federal or non-Federal) or person undertakes such other actions" (NRC, 2003). Cumulative impacts can result from actions that are individually minor, but collectively significant, taking place over a period of time. A proposed project could contribute to cumulative impacts when its environmental impacts overlap with those of other past, present, or reasonably foreseeable future actions (RFFAs) in a given area. It is possible that a small impact from a proposed action could result in a larger cumulative impact when considered in combination with the impacts of other actions. The term "reasonably foreseeable" refers to future actions for which there is a reasonable expectation that the action could occur, such as a proposed action under analysis or a project that has already started.

This chapter is organized as follows: Section 4.1 describes the NRC staff's methodology in evaluating cumulative impacts; Section 4.2 describes the spatial and temporal boundaries for this cumulative impacts assessment; Section 4.3 describes the affected resource areas, consistent with the NRC staff's evaluation of impacts in Chapter 3; Section 4.4 identifies other related past, present, and reasonably foreseeable future actions that could contribute to cumulative impacts; and Section 4.5 presents the NRC staff's cumulative impacts analysis for the resource areas identified in Section 4.3 and Chapter 3. Sections 4.4 and 4.5 are each divided into two sections: the first section presents the information DOE provided in its 2002 and 2008 EISs; the second section presents the NRC staff's supplement to the 2002 and 2008 EISs, based upon the impacts evaluated in Chapter 3.

Because DOE's 2008 SEIS summarizes, incorporates by reference, and updates the information in the 2002 EIS, this chapter primarily refers to the 2008 SEIS. In addition, the NRC staff accepts the information in the 2002 EIS and the 2008 SEIS, unless otherwise noted in this chapter. As stated in the Adoption Determination Report (ADR), "[t]he NRC staff concludes that the 2002 EIS, the Repository Supplemental EIS, and the Rail Corridor SEIS meet NRC completeness and adequacy requirements in 10 CFR § 51.91 and in 10 CFR Part 51, Subpart A, Appendix A, and that the EISs are generally consistent with NRC's NEPA guidance in NUREG–1748."

4.1 Methodology for Supplementing DOE's Cumulative Groundwater Impacts Analysis

This cumulative impacts assessment examines the incremental groundwater impacts of the repository, as evaluated in this supplement, in combination with other past, present, and RFFAs. The general approach for assessing cumulative groundwater impacts is based on the principles and guidance described in NRC environmental review guidance (NRC, 2003), which incorporates by reference CEQ's *Considering Cumulative Effects under the National Environmental Policy Act* (CEQ, 1997) and EPA's *Consideration of Cumulative Impacts in EPA Review of NEPA Documents* (EPA, 1999c). Based on the review of applicable portions of these documents and the NRC's regulations for implementing NEPA in 10 CFR Part 51, the NRC staff used the following methodology for assessing cumulative impacts in this supplement:

1. The NRC staff reviewed the cumulative impacts analyses in DOE's EISs to determine how these analyses should be supplemented in light of the NRC staff's findings in Chapter 3 of this supplement. As noted in Chapter 1, the NRC staff did not conduct a scoping process for this supplement because the scope is already defined in the NRC staff's ADR.

2. The NRC staff identified several additional RFFAs that were not previously identified in DOE's EISs, but which could impact the relevant resource areas. The NRC staff evaluated these actions, along with the actions previously identified by DOE, in the cumulative impacts assessment in this supplement.

3. The affected environment for the cumulative impact analysis is described in Chapter 2. The direct and indirect impacts on particular resources, as described in Chapter 3, form the basis for the analysis in this chapter.

4.2 Spatial and Temporal Boundaries for Cumulative Groundwater Impacts

The spatial boundary for cumulative groundwater impacts consists of the area of the aquifer beneath Yucca Mountain and along the aquifer's flow path that could be affected by contaminant releases from the proposed repository (as described in detail in Section 2.2) or by other activities having the potential to affect groundwater. The spatial boundary also includes the types of areas aboveground where the groundwater from the Yucca Mountain flow path could naturally discharge to the surface (described in Section 2.3) or where groundwater is pumped, such as at Amargosa Farms (described in Section 2.2.2 and 2.2.3).

The temporal boundaries for cumulative impacts include impacts from past actions and extend to one million years after repository closure. The descriptions of the affected environment provided by DOE (2014a; 2008a; 2002), as supplemented by the NRC staff (Chapter 2), already encompasses the impacts of past human actions that may have previously affected groundwater. The affected area includes vast and remote areas of limited human activity in a predominantly naturally occurring state. Thus, the NRC staff concludes that the description of the affected environment in Chapter 2 provides a reasonable baseline for the assessment of cumulative groundwater impacts. The long duration of the temporal boundary is necessary because, as described in Section 3.1.2, DOE and the NRC staff's analyses indicate that contaminants released gradually from the repository would travel through the aquifer and potentially reach ground surface locations over a very long timeframe after repository closure. The analyses cover a period of one million years following repository closure, the nominal "period of geologic stability" used as a basis for defining the regulatory compliance period (70 FR 53,313). The NRC staff conducted a review to identify any near-term activities that could contribute to long-term cumulative groundwater impacts. However, the NRC staff concludes that using unsupportable assumptions about human activities occurring over the next one million years would result in correspondingly unsupportable conclusions about the potential impacts.[1]

4.3 Potentially Affected Resources

Chapter 2 provides descriptions of the resource areas that could be affected by potential groundwater contamination from the repository and surface discharges of contaminated groundwater. These areas and their location in Chapter 2 are listed as follows.

- Groundwater in the volcanic-alluvial aquifer, described in Section 2.2.
- Resources associated with pumping and irrigation at Amargosa Farms, described in Sections 2.2 and 2.3. The resources potentially affected at groundwater pumping locations include groundwater, soils, ecological resources, and public health (including environmental justice concerns).
- Resources at current natural surface discharge locations (springs and playas) and potential future sites of natural surface discharge under a reasonably foreseeable wetter climate state, described in Section 2.3. The resources potentially affected at surface discharge locations include groundwater, soils, ecological resources, public health (including environmental justice concerns), and cultural resources.

Other past, present, or reasonably foreseeable future actions could contribute to potential cumulative impacts on these resources, in addition to the impacts from the proposed repository. These other actions are discussed in Section 4.4, and their potential impacts, along with impacts from the proposed repository, on these resource areas are discussed in Section 4.5.

4.4 Other Past, Present, and Reasonably Foreseeable Future Actions

This section summarizes the other past, present, and future actions identified by DOE in the 2002 and 2008 EISs (Section 4.4.1) and by the NRC staff for this supplement (Section 4.4.2). As described by the Council on Environmental Quality (CEQ), identifying RFFAs is a critical component of a cumulative impacts analysis (CEQ, 1997). However, CEQ also recognizes that agencies should not engage in speculation in an effort to identify all actions that could contribute to overall potential cumulative effects. Given the long timeframes considered in this supplement, as described in Chapter 2, it is not possible to identify or reasonable to speculate about all potential public and private projects that could contribute to cumulative groundwater impacts over the course of the next one million years. Therefore, the NRC staff reviewed available information for the spatial boundary, including information in NEPA analyses and resource management plans, which together provide a reasonable picture of potential present or foreseeable future actions.

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[1] This is consistent with NRC regulations in 10 CFR 63.305(b) and EPA regulations in 40 CFR 197.15, which direct DOE not to project changes in society, the biosphere (other than climate), human biology, or increases or decreases of human knowledge or technology.

4.4.1 Actions Identified in DOE's EISs

Section 8.1 of the 2008 SEIS incorporates by reference and updates the information in the 2002 EIS. This section identifies past, present, and future actions that DOE considered to have the potential to affect the same resources as those that would be affected by the repository. In Section 8.1.1, DOE states that the description of the existing environmental conditions in Chapter 3 of DOE's 2008 SEIS accounts for the impacts of past and present actions on the environment that the repository would affect. In Chapter 3 of that document, DOE describes the results of groundwater sampling to support its description of regional groundwater quality. DOE also provides information about contaminants in groundwater from past activities at the Nevada National Security Site (NNSS; formerly the Nevada Test Site). DOE used the baseline information in Chapter 3 to develop its assessment of the incremental environmental impacts of the proposed repository and, thus, its assessment of cumulative impacts.

The region of influence (or spatial boundary) DOE defined for its groundwater impacts assessment and used for its cumulative impacts assessment, as described in Section 4.1.3 of the 2002 EIS and referenced in Section 4.1.3 of the 2008 SEIS, includes "aquifers under the areas of construction and operations that DOE could use to obtain water, and downstream aquifers that repository use or long-term releases from the repository could affect." In its description of the groundwater environment in Chapter 3 of the 2002 EIS, DOE included the volcanic-alluvial aquifer and the lower carbonate aquifer as the aquifers that could be affected by radionuclide releases from the repository and by other Federal, non-Federal, and private activities. The NRC staff concludes that DOE's spatial boundary is appropriate for the purpose of identifying other past, present, and reasonably foreseeable future actions that could contribute to cumulative groundwater impacts because this area encompasses the flow path from the repository to potential discharge points and is thus consistent with the spatial boundary for groundwater impacts defined by the NRC staff in Section 4.2 of this supplement.

Other Federal, non-Federal, or Private Activities Identified by DOE

This section describes the actions DOE identified in its EISs as potential contributors to cumulative groundwater impacts.

Section 8.3.2 of the 2008 SEIS examines the cumulative impacts from past, present, and reasonably foreseeable future actions that have the potential to affect resources after repository closure. The actions DOE identified that could have the potential to contribute to long-term cumulative groundwater impacts are (i) past, present, and reasonably future actions at the NNSS, including nuclear weapons testing and radioactive waste management; and (ii) past and present actions at a low-level radioactive waste disposal facility and hazardous waste disposal facility located about 16 km [10 mi] southeast of Beatty, Nevada, or 15 km [9.3 mi] west of the proposed repository.

In its EISs, DOE did not identify mining as a potential contributor to cumulative groundwater impacts. Because there is currently mining activity within the spatial boundary for this analysis, the NRC staff determines that further assessment of these activities is needed. Section 4.4.2 provides more information about regional mining activity.

Additional Inventory Modules

Under the Nuclear Waste Policy Act (NWPA), the proposed repository would be a permanent disposal facility for up to 70,000 metric tons of spent nuclear fuel (SNF) and high-level radioactive waste (HLW). The NWPA requires the NRC to include in any construction authorization a condition prohibiting the emplacement of more than 70,000 metric tons of heavy metal or a quantity of solidified high-level radioactive waste resulting from the reprocessing of such a quantity of spent fuel in the first repository until a second repository is in operation [NWPA, Section 114(d)]. DOE's proposed action, as described in its 2002 and 2008 EISs and in its Safety Analysis Report (SAR) (DOE, 2008b), is the construction of a repository and emplacement of up to 70,000 metric tons of spent nuclear fuel and high-level radioactive waste. In its 2002 EIS and 2008 SEIS analyses of cumulative impacts, DOE also included two RFFAs for the emplacement of waste beyond the 70,000-metric-ton limit, which DOE referred to as inventory modules. These modules accounted for the emplacement of additional SNF and other HLW, as well as Greater-Than-Class-C waste, at the Yucca Mountain repository. For this supplement, the NRC staff does not consider the inventory modules to be RFFAs because (i) DOE did not account for the additional waste inventories in its license application; and (ii) the NWPA prohibits both modules until such time as a second repository is in operation. Since no repository has been licensed, and no second repository is under consideration, the NRC staff concludes that a second repository is not reasonably foreseeable. The NRC staff further concludes that the modules are likewise speculative, therefore are not RFFAs, and are not considered further. If Congress enacts legislation that allows for the disposal of additional waste inventories at the Yucca Mountain repository before a second repository is in operation, any updated license application and associated environmental review would necessarily analyze the change in the proposed action.

NRC Staff Conclusions Regarding DOE's Identification of Other Actions

The NRC staff makes the following conclusions regarding the region of influence and identification of other actions in DOE's EISs:

- The NRC staff finds that the region of influence (spatial boundary) DOE used for identifying other actions that could affect groundwater is acceptable and reasonable because it extends throughout the area of the aquifer that could be affected by the repository or that would flow downstream to merge with groundwater flowing from the repository area, consistent with the description in Chapter 2 of the affected environment.

- The NRC staff has determined that in its EISs, DOE identified past, present, and reasonably foreseeable future actions that could affect groundwater along the flow path from the repository to the regulatory compliance location {18 km [11 mi] south of the repository site}. Specifically, the NRC staff finds that DOE appropriately identified the NNSS and the Beatty low-level waste site as potential contributors to cumulative groundwater impacts after repository closure. The NRC staff concludes that the actions identified by DOE are reasonable for the evaluation of cumulative impacts at the regulatory compliance location and are acceptable for evaluation of cumulative impacts in this supplement because the actions may affect the regional groundwater flow system that would be affected by the repository.

- The NRC staff finds that the DOE EISs did not identify regional mining activity as a past, present, and reasonably foreseeable future action that could affect groundwater along the flow path from the repository to the regulatory compliance location. Therefore, the NRC staff has included information about regional mining in Section 4.4.2.

- For the reasons given in the previous section, the NRC staff concludes that the additional inventory modules are not reasonably foreseeable actions and does not address them further in this supplement.

- Because this supplement assesses groundwater impacts along the predominant groundwater flow path to the pumping location in Amargosa Farms and to surface discharge locations in Death Valley, the NRC staff determines that further assessment is needed to determine whether there are (i) actions not identified by DOE, in addition to mining, that could affect groundwater downgradient from the regulatory compliance location and (ii) actions that could affect other resources at Amargosa Farms and at downgradient surface discharge locations, including those identified in DOE's EISs but not considered with the impacts identified in Chapter 3 of this supplement.

- DOE's analysis, as updated in the 2008 SEIS, is limited to actions already occurring or planned as of 2008. Thus, the NRC staff concludes that further supplementation is needed to describe actions planned or occurring since 2008 that could contribute to cumulative groundwater impacts, and to evaluate their potential cumulative impacts.

The results of the NRC staff's review are discussed in the next section.

4.4.2 NRC Staff Update and Supplementation of DOE EISs Identification of Other Actions

As discussed in the previous section, DOE's analysis included an assessment of impacts on groundwater at the regulatory compliance location. To address impacts on groundwater and from surface discharges of groundwater along the flow path beyond Amargosa Valley, the NRC staff supplements DOE's assessment by evaluating groundwater impacts at Amargosa Farms and at natural surface discharge locations in Death Valley. For this cumulative impacts assessment, the NRC staff has reviewed available information to determine whether other actions could affect the groundwater or resources at the surface discharge locations. In addition, the NRC staff has reviewed available information to determine whether actions planned or occurring after 2008 could have the potential to contribute to cumulative groundwater impacts.

The NRC staff consulted sources of publicly available information on existing and proposed activities, such as government websites, EISs, and resource management plans. The NRC staff also contacted Department of Interior (DOI), Bureau of Land Management (BLM) staff knowledgeable about RFFAs in the region.

Nevada National Security Site

DOE's National Nuclear Security Administration (NNSA) published its *Final Site-Wide Environmental Impact Statement for the Continued Operation of the Department of Energy/National Nuclear Security Administration Nevada National Security Site and Off-Site Locations in the State of Nevada (DOE/EIS-0426)* (NNSS SWEIS) in February 2013. The NNSS SWEIS assesses the potential environmental impacts of three alternatives for continued operations at the NNSS and operations at other DOE/NNSA-managed sites in southern Nevada. The sites in the spatial boundary are the NNSS, the Tonopah Test Range (about 19 km [12 mi] north of the NNSS northern boundary), and environmental restoration areas on the U.S. Air Force Nevada Test and Training Range (adjacent to the west, north, and east of the NNSS). The three alternatives include similar types of programs, capabilities, projects, and activities, but differ primarily in their levels of operations and facility requirements. The NRC staff reviewed the December 30, 2014 Record of Decision (ROD) (79 FR 78421) and the NNSS SWEIS to determine whether any proposed or continuing activities could contribute to cumulative groundwater impacts within the spatial boundary of this analysis. The ROD and the NNSS SWEIS (DOE, 2013; 2014c) state that DOE/NNSA would add new projects at the NNSS, including activities in the areas of nonproliferation and counterterrorism, high-hazard experiments involving explosives and nuclear materials, research and development, testing, renewable energy, and the disposal of a wide variety of wastes. Activities proposed for the Tonopah Test Range include the continuation of current activities (primarily weapons testing, experiments, and research and development) as well as improving infrastructure (such as communications, electrical transmission, and buildings) (DOE, 2013; Table 3-3).

In addition, DOE/NNSA would continue or start new projects on the NNSS to manage or dispose of low-level radioactive waste (LLRW), LLRW mixed with hazardous waste (mixed LLRW), hazardous waste, solid waste, explosives ordnance, and site remediation wastes. With the exception of a proposed solid waste management facility that would be located in Area 25 (adjacent to the east of the Yucca Mountain site), all of these waste management activities are or would be located in the easternmost areas of the NNSS, more than 30 km [19 mi] from the proposed repository site. The depth to the water table in these eastern areas of the NNSS ranges from over 500 ft [152 m] to nearly 2,000 ft [610 m] (Winograd and Thordarson, 1975; DOE, 2013; Section 4.1.6.2).

DOE/NNSA concludes that none of the proposed activities described in the NNSS SWEIS for the NNSS, the Tonopah Test Range, or the Nevada Test and Training Range would contribute to NNSS cumulative groundwater impacts (DOE, 2013; Tables 3-4, 3-7). The NRC staff finds the conclusions of the NNSS SWEIS for these proposed new and continuing activities to be reasonable and acceptable, based on the NRC staff’s understanding of the activities and that DOE/NNSS would continue managing the various types of wastes in compliance with applicable requirements, as described in Section 4.1.11 of the NNSS SWEIS.

Solar Energy Projects

DOI BLM has approved several renewable energy projects in Nevada and California in recent years as part of a larger, national effort to promote the growth of solar, wind, and geothermal energy generation. None of the approved solar, geothermal, or wind energy projects are located within the region of influence identified for this supplement (i.e., the geographic area overlying the area of the aquifer that could be affected by the repository or that would flow downstream to merge with groundwater flowing from the repository). However, three areas within the region of influence may be developed as solar energy facilities. Two of the areas could be developed as small (50-megawatt) photovoltaic energy facilities (Helseth, 2015). The third area is a larger zone designated recently by the BLM and DOE as a “solar energy zone” (SEZ), established as part of a BLM program to encourage solar energy development. This zone, named the Amargosa Valley SEZ, is located in the Amargosa Desert between the Funeral Mountains to the southwest and Yucca Mountain to the northeast. The SEZ is on BLM-administered land and the developable area within it is 8,479 acres [34.3 km^2]. There are no pending solar applications within the SEZ, but the BLM will encourage future interested parties to site projects within this zone (BLM, 2012a,b). Withdrawal of small amounts of water for construction {approximately 200 acre-ft [246,700 m^3] per photovoltaic facility} or operations {approximately 5 acre-ft [6,170 m^3] per photovoltaic facility per year} would be the principal impact on groundwater from the development of solar energy in this area (Helseth, 2015). The NRC staff concludes that these solar projects would not regularly produce liquid wastes, with the exception of sanitary wastewater and, depending on the type and size of the facility, blowdown water from a steam boiler. Such wastewaters would be retained (e.g., in septic systems or evaporative ponds) and would not be discharged to groundwater (BLM, 2010; Section 5.9). Therefore, the NRC staff concludes that these activities would not result in groundwater contamination and would not contribute to cumulative groundwater impacts.

Mining Activities

The BLM administers the mineral estate on public lands in Southern Nevada. The BLM *Las Vegas and Pahrump Field Offices Draft Resource Management Plan/Environmental Impact Statement* (BLM, 2014) describes historic, current, and future trends in mining activities in various regions of southern Nevada and evaluates the potential environmental impacts. The BLM EIS describes mining activities that have occurred in the vicinity of the town of Beatty and in Amargosa Valley, which are limited in the number of operations. These areas are within the region encompassed by the groundwater flow paths considered in this supplement, as described in Section 2.2.2. The mining activities include current gold and silver mining in the Bare Mountain district in the vicinity of Beatty, Nevada. Current conditions include one open pit and two underground mines. BLM indicates the level of precious metal mining activity is linked to market conditions, and future mining trends are, therefore, difficult to forecast. Amargosa Valley (in both Nevada and California) produces nonmetallic resources, including magnesium clays (used as binding agents, thickeners, gels, and in filtering) and zeolites (used in filtration systems, cat litter, and animal feed). Current conditions include ongoing production that has been limited by the recent economic recession. BLM projects that production would improve as the local, regional, or global economy improves. The BLM EIS impact analysis states that mineral extraction has the potential to impact surface water and groundwater quality due to increased sedimentation from surface disturbances and the potential for releases of wastewater. BLM concludes that the degree of impacts would depend on the level of preplanning and analysis, the provision of bonding to ensure sufficient funds would be available to mitigate potential impacts, and the regulatory stipulations aimed at protecting wildlife and other resource values, which would also protect water resources. BLM concludes impacts could be negligible to moderate but would be addressed through best management practices and other mitigation. Based on the information provided in the BLM EIS, the NRC staff concludes that the extent of mining activity in the region of the groundwater flow path is limited, and the existing permitting and associated regulatory protections would limit potential groundwater impacts to minimal levels. Based on this review, the NRC staff concludes that the omission of mining activities from the DOE cumulative impact analysis is not likely to have affected impact conclusions; however, these activities are included in the NRC supplement.

The NRC staff evaluated the description of other land uses for the repository site provided in DOE’s SAR (DOE, 2008b), and conducted an independent evaluation of the Yucca Mountain site description as part of its review (NRC, 2015a, Section 2.1.1.1.3.9; NRC 2014b, Sections 2.5.8 and 2.5.9). Based on the results of this review, the NRC staff has not identified other activities that would contribute to cumulative groundwater impacts.

4.5 Cumulative Impacts on Groundwater and from Surface Discharges

This section evaluates repository impacts on groundwater and from surface discharges when added to the aggregate effects of other past, present, and reasonably foreseeable future actions. As described in Chapter 3, the incremental impacts for all resource areas and locations would be SMALL. This section provides the NRC staff’s review of the cumulative impact assessment in DOE's EISs (Section 4.5.1) and the NRC staff's supplement to the cumulative impacts analyses in DOE's EISs for the impacts identified in Chapter 3 (Section 4.5.2).

4.5.1 Impact Assessment in DOE's EISs

In Section 8.3.2 of the 2002 EIS (as updated in Section 8.3.2 of DOE's 2008 SEIS), DOE assessed the potential cumulative impacts from other Federal, non-Federal, and private actions that could contribute to doses from modeled groundwater contamination at the regulatory compliance location, which is the location of the reasonably maximally exposed individual (RMEI), as defined in 40 CFR 197.21. DOE assessed the cumulative impacts associated with the NNSS and the Beatty waste management and disposal sites. A summary of DOE's assessments and the NRC staff's conclusions regarding DOE's assessments are provided in the sections that follow.

Nevada National Security Site

In the 2002 EIS, DOE made assumptions about the magnitude and timing of radiological releases from the NNSS (assuming, for example, that the peak groundwater concentrations of contaminants from the NNSS would coincide in time and space with the peak groundwater concentrations from repository contaminants). The NRC staff considers these assumptions to be conservative because the maximum concentrations of groundwater contaminants flowing from the repository and from multiple locations in the NNSS through a vast space for hundreds of thousands of years are unlikely to reach the same location at the same time. DOE also assumed that any contaminated groundwater from the NNSS would flow along the same paths as those for repository contaminants (DOE, 2002). The NRC staff also considers this to be a conservative assumption because the different groundwater flow paths for the NNSS contaminants are likely to cause dispersion of contaminants, depending on factors such as solubility, sorption rates, and the volume of groundwater flow. Based on available information about contamination migrating from the NNSS (DOE, 2013), the NRC staff concludes that DOE's assumptions as described previously are reasonable and conservative in considering the potential cumulative groundwater impacts from the NNSS.

In assessing potential impacts from future LLRW disposal activities in Areas 3 and 5 of the NNSS, DOE summarized various ongoing and proposed LLRW and mixed LLRW activities in its 2002 EIS (Section 8.3.2.1.3). DOE concluded that the only possible groundwater impacts from these activities would be from a few hazardous chemicals (1,2-dichloroethane, methylene chloride, and benzene), but that these chemicals are not within the inventory of chemicals from the repository. The NRC staff agrees that these chemicals are not among those that would be released from the repository. Further, the depth to the water table in Areas 3 and 5 ranges from over 500 ft [152 m] to nearly 2,000 ft [610 m] (DOE, 2013; Section 4.1.6.2; Winograd and Thordarson, 1975), and the NRC staff concludes that any small amount of contaminants leaking from these LLRW activities would be detected and remediated before they could affect groundwater. This conclusion is based on the NRC staff's assumption that DOE/NNSA would continue managing the LLRW and mixed LLRW wastes, in compliance with applicable requirements, as described in Section 4.1.11 of the NNSS SWEIS.

Beatty Low-Level Waste and Hazardous Waste Disposal Facilities

The Beatty LLRW facility, located on U.S. Highway 95 approximately 12 mi [19 km] south of the town of Beatty, stopped accepting radioactive waste in 1992 and is under the permanent custody of the Nevada Department of Health and Human Services Division of Public and

Behavioral Health. In Section 8.3.2 of the 2002 EIS, DOE provided an assessment of the quantity of radionuclides that could be available for groundwater transport and possibly contribute to cumulative groundwater impacts. DOE found the quantity of radionuclides at the Beatty site to be a small fraction of the quantity of radionuclides available for release and transport from initial failures of waste packages at the proposed Yucca Mountain repository. Therefore, DOE concluded that the Beatty LLRW site would be a small contributor to long-term cumulative impacts (DOE, 2002). The NRC staff finds DOE's conclusions about this site are supported by the available information and are therefore reasonable and acceptable.

Additionally, DOE noted that the co-located Beatty hazardous waste treatment, storage, and disposal facility is permitted under the Resource Conservation and Recovery Act and has engineered barriers and administrative controls that minimize the potential for offsite migration of hazardous constituents (DOE, 2002). This is consistent with the NRC staff's understanding of the management of these facilities. In particular, the Beatty facility is equipped with two liners, with leachate collection and removal systems placed between and above the liners; thus, any leakage from the facility would be collected and removed (NDEP, 2011; Section 7).

NRC Staff Conclusions Regarding DOE's Assessment

DOE's assumptions and analysis regarding the contribution to radiological and nonradiological groundwater contamination by the NNSS and the Beatty site are conservative for assessing the cumulative groundwater impacts at the regulatory compliance point. The NRC staff has determined that the groundwater flowing below Yucca Mountain is most likely to be impacted by those NNSS activities located in areas of the NNSS in the Alkali Flat-Furnace Creek Basin (Figure 2-3). Potential contaminants from NNSS activities in areas of the NNSS in the Pahute Mesa-Oasis Valley Basin (Figure 2-3) could also mix with groundwater from below Yucca Mountain in the Amargosa Desert area (see discussion in Section 2.2.1). Interactions of the Yucca Mountain flow path with water from the Ash Meadows Basin is much less likely (Section 2.2.2). Based on the potential contaminants that could be released from the NNSS and the Beatty waste disposal facilities and DOE's analysis, the NRC staff finds DOE's conclusions about the potential cumulative impact contribution of these sites to impacts at the regulatory compliance location to be reasonable. The NRC staff, therefore, concludes that DOE adequately addressed the possible contributions of radiological contaminants from the NNSS and the Beatty LLRW site to cumulative groundwater quality impacts. The NRC staff concludes that the NNSS and the Beatty LLRW and hazardous waste facilities are unlikely to contribute nonradiological contamination to groundwater. Further, the NRC staff concludes that while these sites could contribute to cumulative radiological impacts on groundwater along the flow path from the repository, the impacts would be reduced because of the attenuating effects of dispersion and radioactive decay as contaminants move through the groundwater flow path from the repository.

4.5.2 NRC Staff Supplementation of DOE EISs Cumulative Impacts Assessment

The following sections provide the NRC staff's supplementation to DOE's cumulative groundwater impacts analysis based on (i) the NRC staff's review of DOE's identification of past, present, and future actions in Section 4.4.1; (ii) the NRC staff's review of DOE's assessment of cumulative impacts in Section 4.5.1; and (iii) the NRC staff's updated identification of past, present, and reasonably foreseeable future actions in Section 4.4.2. Updates are included, as necessary, for cumulative groundwater impacts discussed in the groundwater subsections of Sections 4.5.2.1 (for the Amargosa Farms area) and 4.5.2.2

(for natural surface discharge locations). Supplementation is provided for cumulative impacts on other affected resources at Amargosa Farms area in Sections 4.5.2.1 (soils, ecological resources, public health, and environmental justice) and surface discharge locations in 4.5.2.2 (soils, ecological resources, public health, environmental justice, and cultural resources).

4.5.2.1 Cumulative Impacts on Affected Resources at Amargosa Farms

This section discusses cumulative impacts on groundwater and from pumping and irrigation in the affected environment described in Chapter 2. The impacts at Amargosa Farms are reported separately from the natural discharge locations because Amargosa Farms is not a natural discharge location and the evaluation of impacts involves a consideration of different environmental processes and pathways. As in Chapter 3, the analysis of impacts considers both the present-day and future cooler/wetter climates.

4.5.2.2 Groundwater at Amargosa Farms

Section 3.1.1 describes the incremental impacts on groundwater (the estimated concentrations of contaminants in the groundwater) at the Amargosa Farms area, which is approximately 17 km [10.5 mi] beyond the regulatory compliance location, or approximately 35 km [22 mi] along the flow path from Yucca Mountain. Tables 3-1a and 3-1b show the estimated levels of contaminants in the aquifer environment beyond the regulatory compliance location up to Amargosa Farms and at Amargosa Farms, respectively. Using the estimated concentrations in the Amargosa Farms area as representative of the aquifer that is subject to groundwater withdrawal in that area, Table 3-2 lists the average estimated groundwater concentrations of radiological and nonradiological material from the repository in the aquifer at Amargosa Farms for both the present-day and future wetter climates. As shown in Table 3-2, the estimated total concentration of all of the radionuclides in groundwater at Amargosa Farms from releases at the repository are lower than the applicable EPA standards for drinking water. No standards have been established for the nonradiological contaminants listed in the table, but the concentrations of each are much lower than one part per million, and are comparable to natural levels in the water (Table 2-2). As stated in the Aquifer Environment section of Section 3.1.1, based on the NRC staff's analysis of the potential future accumulation of radiological and nonradiological material released from the repository to the aquifer environment between the regulatory compliance location and Amargosa Farms, the NRC staff finds that the incremental impact on the aquifer environment beyond the regulatory compliance location would be SMALL.

Based on the information provided in Sections 4.4.1 and 4.4.2 concerning other actions and the NRC staff's conclusions about DOE's assessment in its EISs of cumulative groundwater impacts in Section 4.5.1, the NRC staff has identified only regional mining activity as an additional action that was not already identified by DOE as a potential contributor to cumulative groundwater impacts. As described in Section 4.4.1, the NRC staff concluded the extent of mining activity in the region of the groundwater flow path is limited and considering existing regulatory protections, the potential groundwater impacts would be minimal. The NRC staff has also identified new information concerning groundwater contamination resulting from past NNSS activities, discussed as follows.

As discussed in Section 4.5.1, in its EISs, DOE identified groundwater contamination from the NNSS as a possible contributor to cumulative groundwater impacts. Since the 2008 SEIS was published, DOE has detected and described contamination migrating off the NNSS. DOE provided information on this contamination in the NNSS SWEIS (discussed in Section 4.4.2) and it is summarized here. In its NNSS SWEIS description of affected groundwater at the

NNSS, DOE/NNSA reports that tritium was detected in two offsite wells. In 2009, DOE/NNSA detected tritium in Well ER-EC-11, which is less than one half-mile off the northwestern boundary of the NNSS on the Nevada Test and Training Range and about 23 km [14 mi] from the nearest public water source, a private well. The tritium concentration was 13,180 pCi/L, which is below the EPA's MCL of 20,000 pCi/L. In 2010, DOE/NNSA found low levels of tritium (48.3 pCi/L) in Well PM-3, located about 11,000 ft [3,353 m] west of the NNSS boundary on the Nevada Test and Training Range (DOE, 2013).

DOE/NNSA concluded that tritium releases in this area could eventually flow to the southwest, possibly discharging in the Amargosa River area or in Death Valley (DOE, 2013; Section 6.3.6.2). Based on the NRC staff's knowledge of groundwater flow, as described in Chapter 2, and the manner in which tritium moves through groundwater, the NRC staff finds the DOE/NNSA conclusion to be reasonable, but that the tritium releases are unlikely to lead to appreciable impacts. This is because the NNSS tritium releases would need to travel a long distance to the Amargosa Farms area, and because tritium migration identified to date is of limited extent. Additionally, as shown in Tables 3-1a, 3-1b, and 3-2, tritium is not a repository contaminant likely to reach the aquifer at this location due to the long delay for repository releases and the relatively short half-life of tritium (12.3 years). Therefore, the NRC staff concludes that tritium from the NNSS would likely decay to negligible levels before arriving at Amargosa Farms in conjunction with contaminants from the repository. Therefore, the NRC staff concludes that tritium contamination would not contribute cumulatively with the radionuclides from the repository.

Considering the information provided previously regarding regional mining activities, tritium releases from the NNSS, and the NRC staff's conclusions in Section 4.5.1 about DOE's analysis of cumulative groundwater impacts from the NNSS and the Beatty disposal sites, the NRC staff concludes that the cumulative impacts on groundwater at the Amargosa Farms area would be SMALL because any additional contaminants from these sites would likely not be detectable or would be so minor that they would not noticeably alter groundwater characteristics beyond the effects that could be attributed to the repository alone.

Soils at Amargosa Farms

Section 3.1.1 describes the potential accumulation from irrigation of radiological and nonradiological contaminants in irrigated soils at Amargosa Farms. Table 3-3 provides estimated concentrations in soils at 10,000 and one million years for the present-day and future wetter climates, as well as natural background concentrations and U.S. Environmental Protection Agency (EPA) screening levels for comparison purposes. As stated in Section 3.1.1, the calculated maximum soil concentrations for all of the contaminants are well below the EPA generic soil screening levels. Based on the NRC staff's analysis of the accumulation in soils at Amargosa Farms of radiological and nonradiological material released from the repository, the NRC staff finds that the incremental impact on soils at Amargosa Farms would be SMALL.

Based on the information provided in Sections 4.4.1 and 4.4.2 concerning other actions, the NRC staff has identified only regional mining activity impacts on groundwater and NNSS tritium releases as additional actions or impacts that could contribute to cumulative soils impacts at the irrigated Amargosa Farms area. Given the NRC staff's assessment of cumulative groundwater impacts provided in the previous section, which indicates that potential mining impacts would be mitigated by regulatory controls and would have minimal impacts on groundwater, and the NRC staff's conclusions in Section 4.5.1 about DOE's analysis of cumulative groundwater impacts from the NNSS and the Beatty disposal sites, the NRC staff concludes that the cumulative impacts on soils at the Amargosa Farms area from irrigation would be minimal and would not noticeably alter the soils beyond the potential impacts that could be attributed to the repository alone.

Public Health at Amargosa Farms

Section 3.1.1 provides the potential impacts at the Amargosa Farms area of groundwater contaminants on public health associated with external exposure, inhalation of soil particles and from evaporative coolers, and ingestion of water, crops, animal products, fish, and soil. As stated in that section, the largest contributors to dose for both the present-day and future wetter climates at Amargosa Farms are I-129, Tc-99, Np-237, and Th-230. At 10,000 years, I-129 and Tc-99 are the primary contributors to dose. Table 3-4 lists the peak annual dose estimates. The peak dose of 1.3 mrem/yr [0.013 mSv/yr] (occurring at one million years for the wetter climate) is a small fraction of the dose from natural background levels of approximately 300 mrem/yr [3.0 mSv/yr] (including radon) for Amargosa Valley, and is much lower than the NRC annual dose standards for a Yucca Mountain repository in 10 CFR Part 63 {15 mrem [0.15 mSv] for the first 10,000 years, and 100 mrem [1 mSv] for one million years, after permanent closure}.

The NRC staff assessed human health impacts from nonradiological contaminants by comparing daily intakes with EPA's Oral Reference Dose standard. Table 3-5 provides the estimated values of peak daily intakes for each of the nonradiological contaminants for the one-million-year period and shows that these values are lower than the EPA Oral Reference Doses. The Oral Reference Doses are the levels below which no detectable health effects would occur. As stated in Section 3.1.1, based on the NRC staff's analyses of radiological and nonradiological material released from the repository to the Amargosa Farms area, the NRC staff finds that the incremental impact of contaminants released from the repository on public health at the Amargosa Farms area would be SMALL.

Based on the information provided in Sections 4.4.1 and 4.4.2 concerning other actions, the NRC staff has identified only regional mining activity impacts on groundwater and NNSS tritium releases as additional actions or impacts that could contribute to cumulative public health impacts at the Amargosa Farms area. The NRC staff's assessment above of cumulative groundwater impacts at Amargosa Farms notes that, because tritium released from the NNSS would need to travel a long distance to the Amargosa Farms area, tritium from the NNSS would likely decay to negligible levels before arriving at Amargosa Farms in conjunction with contaminants from the repository. Given the NRC staff's assessment of cumulative groundwater and cumulative soils impacts at Amargosa Farms provided in the previous sections, and the NRC staff's conclusions in Section 4.5.1 about DOE's analysis of cumulative groundwater impacts from the NNSS and the Beatty disposal sites, the NRC staff concludes that the cumulative impacts on public health at the Amargosa Farms area would be minimal and would not noticeably affect public health beyond the potential public health impacts from the repository alone.

Ecological Resources at Amargosa Farms

Section 3.2 discusses the incremental impacts on ecological resources in the Amargosa Farms area. The NRC staff evaluated the potential for nonhuman biota to be exposed to radionuclides at the Amargosa Farms area, based on the estimated magnitude of radioactivity in the environment as quantified by the human dose estimates provided in Sections 3.1.1 and 3.1.2. Because the human dose estimates are a small fraction of background radiation exposure, the

NRC staff concludes in Section 3.2 that the estimated levels of radioactivity in the environment would be well below levels of concern for potential impacts to nonhuman biota.

The NRC staff also evaluated the potential for nonhuman biota to be exposed to potentially harmful levels of nonradiological chemicals at Amargosa Farms, based on the aquifer and soil concentrations in Sections 3.1.1 and 3.1.2 for present-day and future wetter climates and for both 10,000-year and one-million-year timeframes. The NRC staff compared the estimated aquifer and soil concentrations with ecological impact concentrations from available scientific data on the toxicity of the relevant chemicals. Table 3-15 compares estimated aquifer and soil concentrations at Amargosa Farms with ecological impact concentrations. The estimated water and soil concentrations of radiological and nonradiological contaminants at Amargosa Farms are below the ecological impact threshold concentrations; therefore, the NRC staff concludes that incremental environmental impacts to nonhuman biota from these constituents would be SMALL.

Based on the information provided in Sections 4.4.1 and 4.4.2 concerning other actions, the NRC staff has identified only regional mining activity and NNSS tritium releases as additional actions or impacts that could contribute to cumulative ecological resources impacts at the Amargosa Farms area. Given the NRC staff's assessment of cumulative groundwater, soil, and public health impacts at Amargosa Farms provided previously, and the NRC staff's conclusions in Section 4.5.1 about DOE's analysis of cumulative groundwater impacts from the NNSS and the Beatty disposal sites, the NRC staff concludes that the cumulative impacts on ecological resources at the Amargosa Farms area would be nonexistent or so small as to not be detectable or not noticeably affect nonhuman biota beyond the potential impacts from the repository alone.

Environmental Justice at Amargosa Farms

Section 3.4.2 provides the NRC staff's assessment of the potential for disproportionately high and adverse human health or environmental effects on minority and low-income populations in the Amargosa Valley area. Based on the information presented in Table 3-18, the NRC staff concludes that the low-income population in the Amargosa Valley Census County Division is a significant environmental justice population. Section 3.4.2 further states that based on the conclusions in Section 3.1.1 concerning impacts on groundwater, soils, and human health, that the NRC staff finds no environmental pathway that would physiologically affect minority or low-income populations differently from other segments of the general population. Therefore, the NRC staff concludes that no disproportionately high and adverse health or environmental impacts would occur to minority or low-income populations in the Amargosa Valley area.

Because the NRC staff has not identified any impacts related to environmental justice in the Amargosa Valley area, the NRC staff concludes that, likewise, no cumulative impacts related to environmental justice would occur in this area.

4.5.2.3 Cumulative Impacts on Affected Resources at Natural Surface Discharge Locations

This section evaluates cumulative impacts at current and potential future natural surface discharge locations (identified in Chapter 2). As in Chapter 3, the discussion of natural discharge locations considers both the present-day and future cooler/wetter climates. The potential future discharge locations are conservatively based on a future cooler/wetter climate.

Groundwater at Natural Surface Discharge Locations

In Chapter 3, the NRC staff assessed potential incremental groundwater impacts at the State Line Deposits/Franklin Well area (Section 3.1.2.1), the Furnace Creek Springs area (Section 3.1.2.2), the Middle Basin area (Section 3.1.2.2), and at Alkali Flat (Section 3.1.2.3). Summaries of these impact assessments and the NRC staff's conclusions for these areas are provided as follows.

The State Line Deposits (paleospring deposits) are in the area where the Amargosa River and Fortymile Wash join and the Franklin Well area refers to the stretch of the Amargosa River channel at the southern extent of the State Line Deposits area. There is no current surface discharge at this location, except for limited evapotranspiration in a narrow band of vegetation at Franklin Well (Section 2.3.3). Paleospring deposits at this location indicate that surface springs and playas are likely in a future cooler/wetter climate (Section 2.3.4). Section 3.1.2.1 describes several features of the aquifer environment in this area (e.g., its location downstream of Amargosa Farms and dilution from mixing with uncontaminated groundwater) that lead the NRC staff to conclude that groundwater concentrations and accumulations of material sorbed onto sediments would be less than in the aquifer environment at Amargosa Farms. The NRC staff concludes that the incremental impact on groundwater at the State Line Deposits/Franklin Well area would be SMALL.

To estimate groundwater impacts at Furnace Creek, the NRC staff conservatively assumed that the entire groundwater contaminant plume would discharge to Furnace Creek (instead of discharging partially at this location and partially at Middle Basin). Table 3-9 presents the estimated average concentrations of important radionuclides and nonradiological elements in groundwater discharging at Furnace Creek. The NRC staff finds that the only radiological and nonradiological material reaching Furnace Creek would be small amounts of Tc-99, I-129, and Mo, and thus the NRC staff finds that the incremental groundwater impacts at Furnace Creek would be SMALL.

To estimate groundwater impacts at Middle Basin, the NRC staff conservatively assumed that the entire groundwater contaminant plume would discharge to Middle Basin (instead of discharging partially at the Basin and partially at Furnace Creek). The NRC staff concludes that groundwater concentrations of the elements listed in Table 3-9 (for Furnace Creek) would be similar for discharges at the Middle Basin, but it is unlikely that free-flowing water would appear in the wet playa environment. As discussed in Section 3.1.2.2, the only radiological and nonradiological material reaching Middle Basin would be small amounts of Tc-99, I-129, and Mo, and thus the NRC staff finds that the incremental groundwater impact at Middle Basin would be SMALL.

Conservatively assuming that there is limited or no pumping at the Amargosa Farms area, groundwater modeling indicates that the majority of contaminants transported from Yucca Mountain will be discharged at Furnace Creek (or the State Line Deposits area in a future wetter climate) prior to reaching Middle Basin in Death Valley. The NRC staff concludes that only a small fraction of contaminants may be directed southward toward the Alkali Flat area. For this reason, as stated in Section 3.1.2.3, the NRC staff did not calculate estimates of contaminants in the groundwater at Alkali Flat. Rather, the NRC staff observes that the portion of the contaminant plume reaching Alkali Flat is less than 1 percent, and concludes that the incremental groundwater impacts at Alkali Flat would be a small fraction of those calculated for the other surface discharge areas. Therefore, incremental groundwater impacts for Alkali Flat would be SMALL.

Based on the information provided in Sections 4.4.1 and 4.4.2 concerning other actions, the NRC staff has identified only regional mining activity and NNSS tritium releases as additional actions or impacts that could contribute to groundwater impacts at surface discharge locations. Because tritium released from the NNSS would need to travel a long distance to these locations (further than for Amargosa Farms), tritium from the NNSS would likely decay to negligible levels before arriving at any surface discharge locations in conjunction with contaminants from the repository. Based on the NRC staff's conclusions in Section 4.5.1 about DOE's analysis of cumulative groundwater impacts from the NNSS and the Beatty disposal sites, and the NRC staff's assessment in Section 4.5.2.1 of cumulative groundwater impacts at the Amargosa Farms area, the NRC staff concludes that the cumulative impacts on groundwater at these surface discharge areas would be minimal and would not noticeably alter groundwater characteristics beyond the effects that could be attributed to the repository alone.

Soils at Natural Surface Discharge Locations

In Chapter 3, the NRC staff assesses potential incremental soil impacts at the State Line Deposits/Franklin Well area (Section 3.1.2.1), the Furnace Creek and Middle Basin areas (Section 3.1.2.2), and Alkali Flat (3.1.2.3). Summaries of the assessments and the NRC staff's conclusions for these areas are provided as follows.

Section 3.1.2.1 provides estimates of soil contaminant concentrations for the wet climate at the State Line Deposits/Franklin Well area because the NRC staff finds that contaminants would accumulate in soils only for the cooler/wetter climate state, when the water table could rise approximately 20 to 30 m [66 to 98 ft] above its present level. Table 3-6 provides estimates of the concentrations of radiological and nonradiological constituents in soil for this area under the cooler/wetter climate. At one million years, all contaminants remain below screening and impact levels, as shown in Table 3-6 and as described further in Section 3.1.2.1. Based on the NRC staff's analysis of the accumulation in soils of radiological and nonradiological material released from the repository, the NRC staff finds that the incremental impact on soils in the State Line Deposits/Franklin Well area would be SMALL.

Section 3.1.2.2 describes the accumulation of repository materials in soils at Furnace Creek and Middle Basin in Death Valley. Radionuclide contaminants would not reach either location in Death Valley within 10,000 years under the present-day climate, even with limited or no pumping. Over the longer time period, and in the cooler/wetter climate, only nonsorbing contaminants would reach Death Valley. Table 3-10 provides estimates of maximum soil/evaporite contaminant concentrations for radiological (I-129 and Tc-99) and nonradiological (Mo) constituents for these areas. Because the soil accumulations of radiological and nonradiological contaminants are very low, the NRC staff finds that incremental soil impacts associated with natural groundwater discharges at Furnace Creek Springs and Middle Basin would be SMALL.

As stated in Section 3.1.2.3, the NRC staff did not specifically calculate estimates of contaminants in the groundwater at Alkali Flat and thus did not calculate concentrations in soils. Rather, the NRC staff observes that the portion of the contaminant plume reaching Alkali Flat is expected to be very small (less than 1 percent of the potential release reaching the regulatory compliance location) and concludes that the incremental groundwater impacts at Alkali Flat would be a small fraction of those calculated for the other surface discharge areas. Thus, the resulting impacts on soils at Alkali Flat would also be a small fraction of the impacts on soils at the other discharge locations. Therefore, incremental soil impacts for Alkali Flat would be SMALL.

Based on the information provided in Sections 4.4.1 and 4.4.2 concerning other actions, the NRC staff has identified only regional mining activity and NNSS tritium releases as additional actions or impacts that could contribute to cumulative soils impacts at the State Line Deposits/Franklin Well area, the Furnace Creek and Middle Basin areas of Death Valley, and at Alkali Flat. Given the NRC staff's assessment of cumulative groundwater impacts provided in the previous section and for the Amargosa Farms area (Section 4.5.2.1), and the NRC staff's conclusions in Section 4.5.1 about DOE's analysis of cumulative groundwater impacts from the NNSS and the Beatty disposal sites, the NRC staff concludes that the cumulative impacts on soils at these areas would be minimal and would not noticeably alter the soil composition beyond the potential impacts from the repository alone.

Public Health at Natural Surface Discharge Locations

In Chapter 3, the NRC staff assessed potential incremental public health impacts at the State Line Deposits/Franklin Well area (Section 3.1.2.1), the Furnace Creek Springs and Middle Basin areas (Section 3.1.2.2), and at Alkali Flat (Section 3.1.2.3). Summaries of these assessments and the NRC staff's conclusions for these areas are provided as follows.

The largest contributors to dose for both the present-day and future cooler/wetter climates at the State Line Deposits area are I-129, Tc-99, Np-237, and Pu-242 (Figure 3-3). Combined-radionuclide peak dose (including all radionuclides) and body intake for nonradiological chemicals are provided in Table 3-7 for 10,000 and one million years for the future wetter climates. Section 3.1.2.1 states that estimates of dose and nonradiological body intake for the present-day climate are extremely small because of the small area affected (Franklin Well area) and the limited amount of evapotranspiration. For the future cooler/wetter climates, the peak dose of 0.34 mrem/yr [0.0034 mSv/yr] in Table 3-7 is a small fraction of the dose from natural background levels of approximately 300 mrem/yr [3.0 mSv/yr] (including radon) for Amargosa Valley and much lower than the NRC annual dose standards for a Yucca Mountain repository in 10 CFR Part 63 {15 mrem [0.15 mSv] for the first 10,000 years, and 100 mrem [1 mSv] for one million years, after permanent closure}. For all of the nonradiological contaminants at this location in the cooler/wetter climate, the estimates of body intake are significantly lower than the EPA Oral Reference Dose. Based on the NRC staff's analyses of radiological and nonradiological material released from the repository to the State Line Deposits/Franklin Well area, the NRC staff finds that the impact to public health would be SMALL.

Section 3.1.2.2 evaluates the public health impacts of estimated discharges at Furnace Creek and Middle Basin. Because of the longer flow path and sorption in the aquifer, only nonsorbing radionuclides reach the natural discharge locations in Death Valley. The primary contributors to dose at this location are the nonsorbing radionuclides Tc-99 and I-129. Table 3-11 in Section 3.1.2.2 provides the peak annual dose estimates for the Furnace Creek area. All estimated doses for either climate state are below 1 mrem [0.01 mSv], which is a small fraction of the dose from natural background levels of approximately 300 mrem/yr [3.0 mSv/yr] (including radon) for Amargosa Valley and much lower than the NRC annual dose standards for a Yucca Mountain repository in 10 CFR Part 63 {15 mrem [0.15 mSv] for the first 10,000 years, and 100 mrem [1 mSv] for one million years, after permanent closure}. The only nonradiological contaminant from the repository determined to be present in groundwater discharging at Furnace Creek is Mo, because of the longer flow path and sorption in the aquifer (Mo is conservatively assumed to be nonsorbing in the NRC staff's analysis). Table 3-12 provides estimates of peak daily intake for Mo for the one-million-year period in both present-day and cooler/wetter climates. The estimated daily intake of approximately 3 × 10^{-3} parts per million is lower than the EPA Oral Reference Dose.

For Middle Basin, radiological contaminants that contribute to estimated dose are limited to those elements whose transport in groundwater is not impacted by sorption processes. Tc-99 and I-129 are the primary contributors to dose at Middle Basin, as at Furnace Creek Springs. As groundwater flows to Middle Basin and evaporates, these elements are incorporated into the resulting evaporite mineral deposits. Table 3-13 summarizes the estimated peak annual doses for the Middle Basin area. All estimated doses are below 1 mrem [0.01 mSv], which is a small fraction of the dose from natural background levels of approximately 300 mrem/yr [3.0 mSv/yr] (including radon) for Amargosa Valley and much lower than the NRC annual dose standards for a Yucca Mountain repository in 10 CFR Part 63 {15 mrem [0.15 mSv] for the first 10,000 years, and 100 mrem [1 mSv] for one million years, after permanent closure}.

Compared to the dose estimates for the Furnace Creek area, peak annual dose estimates for Middle Basin are lower for both climate states, primarily due to the absence of a drinking water pathway at this location. Table 3-14 provides estimates of peak daily intake for Mo for the one-million-year period in both present-day and future wetter climates at Middle Basin. The estimated value of daily intake (from inhalation and ingestion of wind-blown contaminated soil, as there is no drinking water pathway) is lower than the EPA Oral Reference Dose. The NRC staff concludes that the incremental impacts from radiological and nonradiological contaminants associated with natural groundwater discharges at Furnace Creek and Middle Basin would be SMALL.

For Alkali Flat, the NRC staff did not calculate estimates of contaminants in the groundwater, and thus did not calculate concentrations in soils or potential doses to the public. There are no residents at Alkali Flat, and the potential exposure pathways are limited to inhalation and exposure to resuspended dust that may contain radiological and nonradiological contaminants precipitated from evaporating groundwater. The NRC staff observes that while the exposure pathways at Alkali Flat would be the same as those for Middle Basin, Alkali Flat is further from present population centers and has even fewer visitors or temporary occupants. Thus, the NRC staff concludes that the impacts at Alkali Flat would be a small fraction of those calculated for the other surface discharge locations and, thus, the incremental radiological and nonradiological public health impacts for Alkali Flat would be SMALL.

Based on the information provided in Sections 4.4.1 and 4.4.2 concerning other actions, the NRC staff has identified only regional mining activity and NNSS tritium releases as additional actions or impacts that could contribute to cumulative public health impacts at these areas. Given its assessment of cumulative groundwater and cumulative soils impacts provided in the previous sections, and based on the NRC staff's conclusions in Section 4.5.1 about DOE's analysis of cumulative groundwater impacts from the NNSS and the Beatty disposal sites, the NRC staff concludes that the cumulative impacts on public health at these areas would be nonexistent or would be so small as to not be detectable or not noticeably affect public health beyond the potential public health impacts from the repository alone.

Ecological Resources at Natural Surface Discharge Locations

As discussed in Section 3.2, the NRC staff evaluates the potential for nonhuman biota to be exposed to radionuclides at the State Line Deposits/Franklin Wells, Furnace Creek Springs, Middle Basin, and Alkali Flat based on the estimated magnitude of radioactivity in the environment as quantified by the human dose estimates provided in Sections 3.1.1 and 3.1.2 for present-day and future wetter climates and for both 10,000-year and one-million-year timeframes. Because the human dose estimates are a small fraction of background radiation exposure, the NRC staff concludes in Section 3.2 that the estimated levels of radioactivity in the environment would be well below levels for potential impacts to nonhuman biota.

The NRC staff also evaluates the potential for nonhuman biota to be exposed to potentially harmful levels of nonradiological chemicals based on the aquifer and soil concentrations in Sections 3.1.1 and 3.1.2 for present-day and future wetter climates and for both 10,000-year and one-million-year timeframes. The NRC staff compared the estimated aquifer and soil concentrations with ecological impact concentrations from available scientific data on the toxicity of the contaminant chemicals. Tables 3-16 and 3-17 compare estimated aquifer and soil concentrations at the State Line Deposits/Franklin Wells area and at Middle Basin and Furnace Creek, respectively, with ecological impact concentrations. The estimated water and soil concentrations of radiological and nonradiological contaminants at the State Line Deposits/Franklin Well area and Furnace Creek /Middle Basin are well below ecological impact concentrations, with the exception of Mo in the evaporite soil at Middle Basin. As discussed in Section 3.2, the evaporite soil at Middle Basin with the highest calculated Mo content corresponds to areas of sparse to no vegetation. This is because the high salinity in this soil is generally not conducive to plant growth. Therefore, the NRC staff concludes that it would be unlikely that a significant proportion of the diet for wildlife could be obtained from these areas, and that the actual exposure of local wildlife to Mo accumulated in soil would be negligible. Based on this analysis, the NRC staff concludes that the environmental impacts to nonhuman biota from radiological and nonradiological contaminants in these areas would be SMALL.

Because only a very small fraction of the contaminants are expected to reach Alkali Flat (see Section 3.1.2.3), impacts on nonhuman biota at Alkali Flat would be much lower than impacts at the other discharge areas identified previously. In addition, the NRC staff expects that Alkali Flat would remain a predominantly playa environment with sparse amounts of salt-tolerant vegetation growing in highly saline surficial material. Thus, the NRC staff concludes that impacts to nonhuman biota at Alkali Flat would also be SMALL.

Based on the information provided in Sections 4.4.1 and 4.4.2 concerning other actions, the NRC staff has identified only regional mining activity and NNSS tritium releases as additional actions or impacts that could contribute to cumulative ecological resources impacts at these areas. Given the NRC staff's assessment of cumulative groundwater and cumulative soils impacts provided previously in this section, and based on the NRC staff's conclusions in Section 4.5.1 about DOE's analysis of cumulative groundwater impacts from the NNSS and the Beatty disposal sites, the NRC staff concludes that the cumulative impacts on ecological resources at the State Line Deposits/Franklin Wells, Furnace Creek Springs and Middle Basin, and Alkali Flat would be minimal and not noticeably affect non-human biota beyond the potential impacts from the repository alone.

Historic and Cultural Resources at Natural Surface Discharge Locations

Section 3.3 provides a discussion of the NRC staff's review of DOE's historic and cultural resources impact assessments in its EISs. The NRC staff concludes in Section 3.3.5 that DOE adequately addressed the potential impacts on historic and cultural resources in its EISs, given DOE's defined region of influence and given that some consultation processes were still ongoing at the time the final 2008 SEIS was published. Based on the region of influence DOE described in its EISs as being limited to the Operator-Controlled Area, the NRC staff concludes that the surface discharge locations considered in this supplement are outside the region of influence DOE considered in its EISs. Thus, the NRC staff concludes that DOE would need to assess whether further consultation and investigation are necessary to account for potential impacts and potential cumulative impacts on historic and cultural resources that may be located in surface discharge areas.

Environmental Justice at Natural Surface Discharge Locations

Section 3.4.2 provides the NRC staff's assessment of the potential for disproportionately high and adverse human health or environmental effects on minority and low-income populations in Death Valley National Park. Section 3.4.2 refers to the NRC staff's assessment in Section 3.1.2.2 of the impacts at the Furnace Creek area and Middle Basin of Death Valley because only those areas are within an identified population center (Death Valley National Park). Therefore, this cumulative impacts analysis also assesses potential cumulative impacts only for the Furnace Creek and Middle Basin areas. Based on the information presented in Table 3-19, the NRC staff concludes that the minority population in the Death Valley Census County Division is a significant environmental justice population. The population in Death Valley is characterized in part by the Timbisha Shoshone Tribe on a parcel of land in the Furnace Creek area. The NRC staff acknowledges the sensitivities and cultural practices of the Timbisha Shoshone Tribe concerning the use and purity of springs in the Furnace Creek area. Based on the conclusions in Section 3.1.1 concerning impacts on groundwater, soils, and human health, the NRC staff found no environmental pathway that would affect minority or low-income populations differently from other segments of the general population; therefore, the NRC staff concludes that no disproportionately high and adverse health or environmental impacts would occur to minority or low-income segments of the population in the Death Valley area.

Because the NRC staff has not identified environmental justice impacts in the Death Valley area, the NRC staff concludes that, likewise, no cumulative impacts related to environmental justice would occur in this area.

4.6 Conclusion

Cumulative impacts on groundwater and from surface discharges of groundwater include the potential impacts of the proposed repository when added to the aggregate effects of other past, present, and reasonably foreseeable future actions. As described in Chapter 3 of this supplement, the incremental impacts from the proposed repository on groundwater resources and from surface discharges of groundwater would be SMALL. The cumulative impacts from the proposed repository when added to other past, present, and reasonably foreseeable Federal and non-Federal activities, such as those activities at the NNSS, would also be SMALL.

5 SUMMARY OF ENVIRONMENTAL CONSEQUENCES

This report supplements the U.S. Department of Energy's (DOE's) 2002 Environmental Impact Statement (EIS) and 2008 Supplemental EIS (SEIS) for a proposed geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain, Nevada, by providing additional analyses of impacts on groundwater and from surface discharges of groundwater, as identified in the U.S. Nuclear Regulatory Commission (NRC) staff's "Adoption Determination Report (ADR) for the U.S. Department of Energy's Environmental Impact Statements for the Proposed Geologic Repository at Yucca Mountain" (NRC, 2008a). This chapter summarizes the impact conclusions from the NRC staff's supplemental analyses and evaluates whether any of these supplemental analyses have identified any additional: (i) unavoidable adverse impacts, (ii) considerations regarding the relationship between local short-term uses of the environment and the maintenance and enhancement of long-term productivity, or (iii) irreversible and irretrievable commitments of resources. DOE previously summarized these impacts in Chapter 10 of its 2008 SEIS.

The direct and indirect impacts of this supplement are described in Chapter 3 and the cumulative impacts are described in Chapter 4. As discussed in Chapter 1, and as applied throughout this supplement, significance categories for potential environmental impacts are based on NRC guidance (NRC, 2003) and are characterized as follows:

> **SMALL**—The environmental impacts are not detectable or are so minor that they will neither destabilize nor noticeably alter any important attribute of the resource.
>
> **MODERATE**—The environmental impacts are sufficient to alter noticeably, but not to destabilize, important attributes of the resource.
>
> **LARGE**—The environmental impacts are clearly noticeable and are sufficient to destabilize important attributes of the resource.

Summary of Environmental Impacts

This NRC staff supplement evaluates the direct, indirect, and cumulative impacts on water and soil, public health, ecology, historic and cultural resources, and environmental justice for locations beyond the regulatory compliance location. The locations of the affected environment are described in Chapter 2, which include potential locations for groundwater pumping and natural surface discharge beyond the regulatory compliance location downstream along the groundwater flow path to Death Valley.

The NRC staff finds that all of the impacts on the resources evaluated in this supplement are SMALL. The NRC staff's analysis includes the impact of potential radiological and nonradiological releases from the repository on the aquifer and at surface discharge locations of groundwater beyond the regulatory compliance location. The peak annual individual radiological dose at any of the evaluated locations is 1.3 mrem [0.013 mSv] from pumping and irrigation at the Amargosa Farms area. The NRC staff concludes that all estimated radiological doses are SMALL because they are a small fraction of background radiation dose of 300 mrem/yr [3 mSv/yr] (including radon), and much lower than the NRC annual dose standards for a Yucca Mountain repository in 10 CFR Part 63 {15 mrem [0.15 mSv] for the first 10,000 years, and 100 mrem [1 mSv] for one million years, after permanent closure}. The NRC staff's peak dose estimates accounted for uncertainty in climate and in groundwater pumping at the Amargosa Farms area. Based on conservative assumptions about the potential for health effects from exposure to low doses of radiation, the NRC staff expects that the estimated radiation dose would contribute only a negligible increase in the risk of cancer or severe hereditary effects in the potentially exposed population. Impacts to other resources at all of the affected environments beyond the regulatory compliance location from radiological and nonradiological (i.e., chemical) material from the repository would also be SMALL, based on low estimated levels of the evaluated constituents in those potentially affected areas.

The cumulative impact analysis in Chapter 4 of this supplement contains the NRC staff's evaluation of the cumulative impacts for direct and indirect impacts identified in Chapter 3 when aggregated with the impacts of other actions that could affect the same resources. The NRC staff also evaluates how its findings in Chapter 3 and cumulative impact findings in Chapter 4 affect the conclusions provided by DOE in its assessment of cumulative impacts on groundwater in Chapter 8 of its EIS (DOE, 2002) and Chapter 8 of its SEIS (DOE, 2008a).

Unavoidable Adverse Impacts

Unavoidable adverse impacts are the direct, indirect, or cumulative impacts that remain after any proposed or required mitigation that could lessen impacts have been applied. The NRC staff considers the direct, indirect, and cumulative impacts summarized in the previous section to be the unavoidable adverse impacts of the proposed repository because the impact analyses have already taken into account applicable mitigating factors.

Relationship between Short-term Uses of the Environment and the Maintenance and Enhancement of Long-Term Productivity

The NRC staff considered whether its supplemental impact analyses identify any additional potential impacts of short-term uses on long-term productivity from what DOE previously evaluated in its EISs. Because there are no changes to the proposed action under review, the NRC staff concludes there are no changes to the short-term uses of the environment, as assessed in DOE's EISs. Additionally, while this supplement considers potential repository impacts on the groundwater environment and from surface discharges along the groundwater flow path beyond the regulatory compliance location, the SMALL impact conclusions reached in this supplement entail no new and significant threats or contributions to the maintenance and enhancement of long-term productivity relative to the impacts previously described by DOE (2008a).

Irreversible and Irretrievable Commitments of Resources

The NRC staff considered whether this supplement identifies any additional irreversible and irretrievable commitments of resources. Because the analyses in this supplement do not change the proposed action or reveal any new and significant use or loss of finite resources, the NRC staff concludes that the supplement identifies no additional irreversible and irretrievable commitments of resources relative to the commitments that were previously described by DOE (2008a).

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7 GLOSSARY

Accessible environment: For this analysis, any point outside of the long-term controlled area of the repository at Yucca Mountain, including the atmosphere above the controlled area, land surface, and surface waters along the Yucca Mountain flow path. The specific definition used by the NRC for regulation of the repository at Yucca Mountain is given in 10 CFR 63.302.

Adsorption: The adhesion by chemical or physical forces of molecules or ions (of gases or liquids) to the surface of solid bodies. For example, the transfer of solute mass, such as radionuclides, in groundwater to the solid geologic surfaces with which it comes in contact. The term sorption is sometimes used interchangeably with this term.

Advection: The process in which solutes, particles, or molecules are transported by the motion of flowing fluid.

Alloy 22: A nickel-based, corrosion-resistant alloy containing approximately 22 weight percent chromium, 13 weight percent molybdenum, and 3 weight percent tungsten as major alloying elements. This alloy is used as the outer container material in U.S. Department of Energy’s waste package design for the repository at Yucca Mountain, Nevada.

Alluvial sediments, alluvial fan: Pertaining to the process of moving sediment by running water. An alluvial fan is a wedge-shaped sedimentary deposit of alluvium formed at the base of a slope in arid regions.

Aquifer: An underground layer of permeable, unconsolidated sediments or porous or fractured bedrock that yields usable quantities of water to a well or spring.

Biosphere: The regions of the surface, atmosphere, and waters of the earth occupied by living organisms.

Biosphere dose conversion factor: For purposes of this analysis, the factor that is used to convert the concentration of radiological contaminants in groundwater to calculate the annual dose to the reasonably maximally exposed individual, or other receptor with similar characteristics, due to a specific radionuclide.

Biota: The living organisms of a geographic region or time period considered as a group.

Carbonate rock: Rocks composed primarily of calcium or magnesium carbonate minerals, most commonly, limestone or dolomite. Carbonate rocks underlie extensive portions of the Great Basin in Nevada and the Death Valley regional groundwater flow system.

Colloid: As applied to radionuclide migration, colloids are large molecules or very small particles, having at least one dimension with the size range of 10^{-6} to 10^{-3} mm [10^{-8} to 10^{-5} in] that are suspended in a solvent. Colloids in groundwater arise from clay minerals, organic materials, or (in the context of a proposed geologic repository) from corrosion of engineered materials.

Confining unit: In geology, a confining unit is a rock or sediment unit of relatively low permeability that retards the movement of water in or out of adjacent aquifers.

Contaminants: In this analysis, materials that could be released from the repository into the groundwater and could impact water quality. These include both radiological and nonradiological materials.

Corrosion: The deterioration of a material, usually a metal, as a result of a chemical or electrochemical reaction with its environment. Corrosion includes, but is not limited to, general corrosion, microbially influenced corrosion, localized corrosion, galvanic corrosion, and stress corrosion cracking.

Cultural resource (historic resource): The remains of past human activity, including prehistoric era and historic era archaeological sites, historic districts, buildings, or objects with an associated historical, cultural, archaeological, architectural, community, or aesthetic value. Historic and cultural resources also include traditional cultural properties that are important to a living community of people for maintaining their culture.

Death Valley Regional groundwater Flow System model (DVRFS model): A model of groundwater conditions and flow for the Death Valley region developed by the U.S. Geological Survey. The model can simulate steady-state groundwater conditions with no withdrawal by pumping, as well as different pumping rates over time.

Decay (radioactive): The process by which a radionuclide spontaneously transforms into another element, called a decay product. That decay product may undergo further decay.

Discharge (surface): The areas where groundwater leaves the ground. Discharge points typically occur as springs or seepage into wetlands, lakes, and streams. Discharge also occurs as evapotranspiration.

Dose: A general term that may be used to refer to the amount of energy absorbed by an object or person per unit mass. Known as the “absorbed dose,” this reflects the amount of energy that ionizing radiation sources deposit in materials through which they pass, and is measured in units of radiation-absorbed dose (rad). The related international system unit is the gray (Gy), where 1 Gy is equivalent to 100 rad.

Evaporite: Geologic deposits composed of water-soluble mineral sediments that result from the evaporation of surface water.

Evapotranspiration: The loss of water by evaporation from the soil and other surfaces, including evaporation of moisture emitted or transpired from plants.

Flux: The amount of fluid (or mass) that flows through a unit area per unit time.

Geologic repository: An excavated, underground facility that is designed, constructed, and operated for safe and secure permanent disposal of high-level radioactive waste. A geologic repository uses an engineered barrier system and a portion of the site's natural geology, hydrology, and geochemical systems to isolate the radioactivity of the waste.

Groundwater: The water found beneath the Earth’s surface, usually in porous rock formations (aquifers) or in a zone of saturation, which may supply wells and springs, as well as base flow to major streams and rivers. Generally, it refers to all water contained in the ground.

Half-life: The time in which one-half of the atoms of a particular radioactive substance disintegrate into another nuclear form. Measured half-lives vary from millionths of a second to billions of years. Also called physical or radiological half-life.

Hydraulic gradient (groundwater): The rate of change of hydraulic head per unit of distance of flow at a given point and in a given direction; the measure of steepness between two or more hydraulic head measurements over the length of a flow path. For this analysis, the hydraulic gradient is used to determine the direction and rate of groundwater movement.

Hydraulic head (groundwater): The height to which water would rise in an open well expressed in units of length, as a measure of water pressure above a reference elevation. For an unconfined aquifer, the hydraulic head at a location coincides with the water table elevation. Hydraulic head measurements over a region determine the potentiometric surface.

Hydrology: The study of water that considers its occurrence, properties distribution, circulation, and transport, and includes groundwater, surface water, and rainfall.

Infiltration: For this analysis, infiltration is the precipitation or irrigation water that is not lost to evapotranspiration or runoff and enters the groundwater system.

Latent cancer fatality: A death that results from cancer caused by ionizing radiation following a latent, or dormant, period between the time of a radiation exposure and the time the cancer cells become active.

Longitudinal dispersion: The mixing of groundwater and contaminants in the direction of groundwater flow as water flows in an aquifer. Dispersion is the process whereby some of the contaminants travel at a different rate than the average velocity of the water.

Low-income populations: Persons whose average family income is below the poverty line. The poverty line takes into account family size and age of individuals in the family. In 2013, the poverty line for a family of four with two children below the age of 18 was $23,624. For any family below the poverty line, all family members are considered to be below the poverty line.

Low-level radioactive waste (LLRW): A general term for a wide range of items that have become contaminated with radioactive material or have become radioactive through exposure to neutron radiation. The radioactivity in these wastes can range from just above natural background levels to much higher levels, such as those observed in parts from inside the reactor vessel in a nuclear power reactor.

Matrix diffusion: The exchange between the fast-flowing groundwater in fractures and faults with slow-flowing water in the rock matrix.

Nonradiological contaminants: Contaminants that could be released from the proposed repository after permanent closure, including chemically toxic metals such as molybdenum, nickel, and vanadium. These materials generally originate from construction materials of the repository and the waste packages. Uranium, while a radioactive element, is also evaluated for its chemical toxicity as a nonradiological contaminant.

Playa: A dry lake bed at the bottom of a desert basin, sometimes temporarily covered with water. Playas have little or no vegetation, and are highly saline (salty) due to evaporation of groundwater near or at the ground surface. This leads to precipitation of salt minerals.

Potentiometric surface: A hypothetical surface representing the level to which groundwater would rise if not trapped in a confined aquifer. The potentiometric surface is equivalent to the water table in an unconfined aquifer.

Radioactivity: The property possessed by some elements (e.g., uranium) of spontaneously emitting energy in the form of radiation as a result of the decay (or disintegration) of an unstable atom. Radioactivity is also the term used to describe the rate at which radioactive material emits radiation. Radioactivity is measured in curies (Ci) and becquerels (Bq).

Radionuclide: An unstable isotope of an element that decays or disintegrates spontaneously, thereby emitting radiation. Approximately 5,000 natural and artificial radioisotopes have been identified.

Radiological contaminants: Radionuclide contaminants that could be released from the proposed repository after permanent closure.

Radioactive decay and ingrowth: The decay of radioactive material over time, which in turn may generate new radioactive contaminants (daughter products). The rate of decay and daughter products depend on the type of radioactive material.

Recharge (groundwater): Water entering an aquifer where permeable soil or rock allows water to enter the ground and reach groundwater.

Saturated zone: The subsurface ground area where water fills all of the openings (pores) in the soil or rock. Water that seeps deep into the ground continues downward under the force of gravity until it reaches this area.

Sorption: The binding, on a microscopic scale, of one substance to another. Sorption is a term that includes both adsorption and absorption and refers to the binding of dissolved radionuclides onto geologic solids or waste package materials by means of close-range chemical or physical forces. Sorption is a function of the chemistry of the radioisotopes, the fluid in which they are carried, and the material they encounter along the flow path.

Sorption coefficient: A numerical means to represent how strongly one substance sorbs to another.

Specific discharge: In hydrology, the rate of discharge of groundwater per unit area of a porous medium measured normal to the direction of flow. Synonymous with Darcy velocity.

Steady state (groundwater): That point when all input rates to a groundwater system are balanced by all the output rates.

Unsaturated zone: The zone between the land surface and the regional water table.

Water table: The upper limit of the saturated zone (the portion of the ground wholly saturated with water). The upper surface of a zone of saturation above which the majority of pore spaces and fractures are less than 100 percent saturated with water most of the time (unsaturated zone) and below which the opposite is true (saturated zone).

8 LIST OF PREPARERS

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10 INDEX

APPENDIX A

ANALYTICAL METHODS

APPENDIX A—ANALYTICAL METHODS

This appendix provides a description of the analysis methods used to determine impacts to affected environments beyond the regulatory compliance location. Section A.1 of this appendix describes the U.S. Nuclear Regulatory Commission (NRC) staff's analysis framework for evaluating impacts over the period of geologic stability (approximately one million years). Section A.2 describes processes at potential discharge sites that may affect concentrations and exposures and how those processes are analyzed for surface discharge.

The use of conservative assumptions simplifies calculations without underestimating impacts, and is warranted when the estimated impacts are small. Many of the conservative assumptions in the analyses for this supplement are discussed throughout the text. Section A.3 summarizes the important conservative assumptions used in the analyses.

A.1 Analysis Framework

The overall analytical framework used in this supplement extends the framework used in previous analyses performed by the U.S. Department of Energy (DOE) in its earlier Environmental Impact Statements (EISs) (DOE, 2008a; 2002) and Safety Analysis Report (SAR) (DOE, 2008b). In this supplement, the framework is extended to analyze both radiological and nonradiological contaminants for one million years after closure of the repository, and to analyze impacts at locations beyond the regulatory compliance location using transport and biosphere models.

In the 2002 EIS (DOE, 2002) and 2008 Supplemental EIS (SEIS) (DOE, 2008a), DOE principally used its Total System Performance Assessment (TSPA) model for assessing the effects of release and transport processes. This model was designed to evaluate those features, events, and processes of the engineered and natural barrier systems that affect repository performance (DOE 2008b, Chapter 2; NRC, 2015a). TSPA is a probabilistic model. Results are generated through multiple iterations with different values for input parameters as a way to account for uncertainties (the results of an iteration are termed a model realization). The 2002 EIS and 2008 SEIS used the dose calculated in TSPA as the principal measure of radiological impacts on groundwater. This dose was calculated following the criteria given in 10 CFR 63.312 for the reasonably maximally exposed individual (RMEI) residing "in the accessible environment above the highest concentration of radionuclides in the plume of contamination," a location approximately 18 km [11 mi] south of the repository along the groundwater flow path (the regulatory compliance location). The RMEI exposure pathway includes the well withdrawal of contaminated groundwater for drinking and irrigation, as well as inhalation of surface dust potentially contaminated by well water. DOE provided TSPA dose results for the one-million-year period following permanent closure of the repository. In addition, in the 2002 EIS and 2008 SEIS, DOE provided TSPA results for the concentration of radionuclides in groundwater for the 10,000-year period following permanent closure of the repository.

In the 2002 EIS and 2008 SEIS, DOE considered impacts on groundwater at other locations beyond the regulatory compliance location to be no greater than those calculated by TSPA for the RMEI location. In the 2002 EIS, DOE applied fractional scaling factors to its TSPA results at the regulatory compliance location to provide estimates of impacts at more distant locations. These scaling factors accounted for increased dispersion of a contaminant plume downstream along the flow path to distances of 30 and 60 km [19 and 37 mi] from the repository location (DOE, 2002, Section 5.4.1; Appendix I.4.5), which approximately match the distances from the proposed repository to Amargosa Farms and Alkali Flat, respectively. DOE's estimation of the scaling factors did not consider sorption along the flow path or other processes that could affect impacts. In the 2008 SEIS, DOE did not use the scaling factors, but instead stated that contaminant concentrations, and thus impacts, for any areas beyond the regulatory compliance location can be no greater than those estimated for the regulatory compliance location. In the Adoption Determination Report (ADR) (NRC, 2008a), the NRC staff concluded that this generic description of affected environments and impacts was not sufficient for adoption.

A description of the source terms for radiological and nonradiological (toxic chemicals) contaminants is given in Section A.1.1, followed by, in Section A.1.2, a description of the transport models the NRC staff used for modeling the two transport segments (i) from the repository to the regulatory compliance location, and (ii) beyond the regulatory compliance location along the flow path to discharge locations, including descriptions of processes that occur along the different transport segments.

A.1.1 Source Term and Mass Flux at the Regulatory Compliance Location

In the 2002 EIS and 2008 SEIS, DOE estimated the source term (the total inventory of potential contaminants) for radionuclides for one million years, and for toxic chemicals for 10,000 years. Here, the source term is the released contaminants from the repository. Mass flux for this analysis is the rate at which contaminants flow from the proposed repository to the regulatory compliance location, and then beyond the regulatory compliance location; for example, to Amargosa Farms or Furnace Creek in Death Valley along the groundwater flow path.

This supplement uses TSPA results for the mass flux of radionuclides reaching the regulatory compliance location as an input in the transport model, which analyzes the movement of contaminants to different locations along the flow path. Using this mass flux for this supplement is conservative because the safety case evaluated for Yucca Mountain conservatively used the highest concentration of a plume passing the regulatory compliance location. All other points in the plume would have lower potential contaminant concentrations. As stated in Section 3.1, the NRC staff found DOE's TSPA methodology to be acceptable as part of its safety evaluation (NRC, 2014a, Section 2.2.1.4.1).

Because the source terms for radionuclides and toxic chemicals are estimated using different approaches, they are discussed separately in the next two subsections. This section provides a brief summary of the method for calculating mass flux that was used in the 2008 SEIS for the regulatory compliance location for radionuclides, and a description of the NRC staff's revised approach used in this supplement that extends the analysis period for the mass flux of nonradiological contaminants at the regulatory compliance location to one million years, which was not part of DOE's 2008 SEIS. The mass flux at the regulatory compliance location is a function of the releases from the repository and the effects of transport to the regulatory compliance location. The mass flux at the regulatory compliance location over the one million year period is used as an input to the transport model for the migration of radiological and nonradiological contaminants along the flow path towards Death Valley. This is described in Section A.1.2 (Transport to Affected Environments Beyond the Regulatory Compliance Location).

Source Term and Mass Flux at the Regulatory Compliance Location for Radionuclides

In the 2008 SEIS, DOE used mean results from the TSPA model to estimate the source term for radionuclides and transport to the regulatory compliance location. This supplement uses the same approach and results, but uses those results as inputs to the transport model that calculates movement of the contaminants beyond the regulatory compliance location (see Section A.1.2). The NRC staff found that the TSPA model and results were acceptable as part of its safety evaluation (NRC, 2014a; Section 2.2.1.4.1). The NRC staff also found, in its Adoption Determination Report (ADR) (NRC, 2008a), that use of the TSPA results as a source term for the regulatory compliance location is appropriate. The amounts of radionuclides released from the repository over time are an intermediate result of the TSPA simulation. The simulations also include transport through the unsaturated and saturated zones below the repository to the regulatory compliance location approximately 18 km [11 mi] from the repository. The 2002 EIS also used this approach, but with an earlier version of the TSPA model. The TSPA model is a probabilistic tool that models uncertainty and variability in many parameters, including the effects of future climate change. The TSPA model also includes probability-weighted scenario classes, which represent different events or processes that can cause failure of the engineered barriers (such as drip shields or waste packages) and cause the release of contaminants from the repository. In the 2008 SEIS, mean results for 300 TSPA realizations were used to construct a combined scenario case that included the nominal, early failure, igneous intrusion, and seismic ground motion-fault displacement scenario classes. This supplement tracks 31 radionuclides from the TSPA results as the source term for calculating radiological impacts in affected environments. The NRC staff reviewed the list in DOE (2014a, Table B-3 and B-4) and found that the list included the most important contributors to dose as part of the NRC staff’s safety evaluation (NRC, 2014a; Section 2.2.1.4.1).

In the 2002 EIS and the 2008 SEIS, DOE used the transport submodels in the TSPA code to estimate radionuclide movement to the regulatory compliance location. The TSPA transport model incorporates the following five transport processes:

- ***Advection*** is the migration of contaminants by the rate of groundwater flow;
- ***Matrix diffusion*** is the exchange between the fast-flowing groundwater in fractures and faults with slow-flowing water in the rock matrix;
- ***Sorption*** is the exchange of contaminants between groundwater and rock surfaces; the sorption coefficient describes the partitioning of the contaminant between groundwater and the rock (solid phase); the magnitude of sorption is dependent on the element, the rock, and the groundwater chemistry;
- ***Colloidal transport*** is the sorbing of contaminants onto colloidal particles, which can then be transported as undissolved species; and
- ***Radioactive decay and ingrowth*** is the decay of radioactive material over time, which in turn may generate new radioactive contaminants (daughter products), depending on the type of radioactive material.

The transport model and outputs for radionuclides used for analyses in this supplement have not changed from those in the 2008 SEIS. These TSPA simulation outputs produced the mass fluxes of radionuclides arriving at the regulatory compliance location as a function of time for the one-million-year period. The NRC staff found these TSPA results acceptable as part of its safety evaluation (NRC, 2014a; Section 2.2.1.4.1). These results are used as the source term in this supplement for calculations of transport beyond the regulatory compliance location.

The TSPA model used for the license application was derived using the draft rule (70 FR 53313) for the licensing of a geologic repository at Yucca Mountain. The final rule (74 FR 10811), in addition to other changes not relevant to this supplement, incorporated a slightly different distribution for deep percolation (the amount of water moving from the surface to a great enough depth that it is not removed by evaporation or transpiration) than the draft rule. This distribution represents the effect of future climates for the period from 10,000 to one million years after repository closure, which is applicable to the cooler/wetter climate state used in this supplement. The revised distribution in the final rule led to a slightly larger mean value of percolation for the 10,000 to one million year period, which could potentially have affected TSPA results. The NRC staff concluded in the SER that the slight change in the mean and distribution of deep percolation in the final rule had no significant effect on repository performance (NRC, 2014a; Section 2.2.1.3.6.3.2), and therefore no significant effect on the release of radionuclides from the repository and transport to the regulatory compliance location, and hence, no significant effect on the source term used in this supplement for the regulatory compliance location.

Source Term and Mass Flux at the Regulatory Compliance Location for Nonradiological Contaminants

In its 2002 EIS and 2008 SEIS, DOE performed a screening analysis where it compared chemical contaminants of materials used in the construction of the repository (including waste package materials) with the U.S. Environmental Protection Agency (EPA) substance list from the Integrated Risk Information System (2002 EIS Section I-6; 2008 SEIS Section F.5). Besides toxicity information from the EPA substance list, a second component of DOE’s screening process was the consideration of the potential for each chemical to migrate to the accessible environment (in DOE’s analysis, the regulatory compliance location). For nonradiological material, DOE only considered the first 10,000 years after closure in its screening analysis. The source term that DOE developed for nonradiological chemicals was based on the thickness of corroded material and the total surface area of repository construction and waste package material exposed to corrosion. Because only a few packages were predicted to fail in the first 10,000 years after permanent closure, chemically toxic materials from within the waste packages were not considered.

In the 2002 EIS and 2008 SEIS, DOE assumed the release rate due to corrosion was uniform over the entire 10,000-year period. In the 2002 EIS, the chemicals of concern resulting from the DOE screening analysis were chromium (Cr), molybdenum (Mo), nickel (Ni), and vanadium (V). In the 2008 SEIS, DOE screened out Cr on the basis that the expected predominant form would be Cr (III) (chromium in a valance state of +3) in the repository environment, which is nontoxic to humans and relatively insoluble; that is, significant levels would not be dissolved in water, and thus would not migrate into the groundwater. DOE stated that the more toxic form, Cr (VI), would not form by corrosion of the waste package material (Alloy 22) or stainless steel under repository conditions (2008 SEIS, Section F-5.1). If Cr (VI) forms from such corrosion in the repository, the DOE screening analysis in the 2008 SEIS found that Cr (VI) is efficiently and quickly reduced to Cr (III) (Eary and Rai, 1989; Palmer and Puls, 1994) in the expected repository environment. The NRC staff, in its safety evaluation, found the DOE description of the repository chemical environment to be acceptable (NRC, 2014a; Section 2.2.1.3.3). For nonradiological contaminants in the 2002 EIS and 2008 SEIS, DOE applied the quantity of nonradiological chemicals released from corrosion of construction and waste package materials directly to the pumping well at the regulatory compliance location, thus conservatively excluding any transport-related delays or reductions.

This appendix describes the estimation of mass flux of nonradiological contaminants applied to the regulatory compliance location over the entire one-million-year period, beyond the 10,000 year period evaluated by DOE. This description begins with the source term at the repository and adjusts for transport processes along the saturated flow path to estimate the one-million-year mass flux at the regulatory compliance location. The release of contaminants from the repository is conservatively applied directly to the unsaturated-saturated zone boundary below the repository. Because more waste packages are expected to fail during the one-million-year period, compared to the number of expected failures during the first 10,000 years, toxic chemical contaminants from fuel assemblies and other materials inside waste packages are considered in addition to the materials (e.g., stainless steel or Alloy 22) considered in the 2008 SEIS. From the inventory of material inside failed waste packages, uranium (U) is the only additional contaminant added to the list of toxic chemicals because of its large quantity and its high toxicity (DOE, 2014a). For U, the source term is derived from TSPA results for radionuclides as the sum of all U isotopes arriving at the regulatory compliance location (as all forms of U are radioactive) (DOE, 2014a). Based on this screening process, which considers mobility and toxicity (DOE, 2014a), no other contaminants from inside waste packages are added to the list. Therefore, total U is added to Mo, Ni, and V as the toxic chemicals considered in this supplement. The NRC staff reviewed the mobility and toxicity screening process used by DOE and finds no other elements in the construction and waste package materials that should be included in this supplement.

To estimate the mass flux reaching the regulatory compliance location, the source term from the repository is adjusted using a two-step procedure to account for delays and reductions during transport between the repository and the regulatory compliance location. First, a simplified model is used for the release rate of nonradiological contaminants (Mo, V, Ni) from the repository to estimate the mass flux at the unsaturated-saturated boundary approximately 300 m [1,000 ft] below the repository. The release rate model approach is based on the analysis in DOE (2014a), which used the following assumptions and values:

- The materials that corrode to produce nonradiological contaminants include construction material, all waste package material, and internal fuel assemblies and spent fuel. The number of failed waste packages is taken from the TSPA output for the combined scenario case. As described earlier in this section, the combined case includes the nominal, early failure, igneous intrusion, and seismic ground motion-fault displacement scenario classes;

- The mobilization rate for each element is calculated based on the corrosion rate used in the DOE’s SAR (DOE, 2008b) and the exposed area of all external material (from construction and waste packages) and internal material (exposed in failed waste packages). Note that DOE (2014a) allowed corrosion to proceed indefinitely; for this supplement the release ends when the thickest component has been completely corroded. More details on this release model are provided in the following paragraphs; and

- The mobilization rate is applied at the unsaturated-saturated zone boundary, and a transport model based on breakthrough curves from the TSPA (DOE, 2008b) is used to determine the mass flux reaching the regulatory compliance location 18 km [11 mi] from the repository.

The analysis in DOE (2014a) included an unrealistic assumption of the total amount of nonradiological contaminants that could be released from the repository. For the calculations in this supplement, the NRC staff constrained the total amount of the source of the nonradiological contaminants available in the repository, specifically the Alloy 22 (the high-nickel alloy that makes up the outer barrier of the waste packages) and the 316NG stainless steel (both exposed in the repository structures, and used in the internal components of the waste packages) such that the total release cannot exceed the amount in the repository. Using the corrosion rates from DOE’s SAR, exposed stainless steel from rock bolts, tunnel and drift liners, and other installed rock supports would be completely corroded in 10,000 years. Internal waste package components would corrode over a period of 500,000 years (as exposed in failed waste packages), and Alloy 22 would corrode over 600,000 years. Figure A–1 (top) illustrates the mass flux mobilized by corrosion and applied directly to the unsaturated-saturated zone boundary below the repository.

The release rate calculated for each of the nonradiological contaminants is used to generate the mass flux at the unsaturated zone-saturated zone interface below the repository. This approach explicitly (and conservatively) neglects any delay or reduction potentially caused by transport out of the engineered barriers and through the unsaturated zone below the repository.

Next, the mass flux at the regulatory compliance location for nonradiological contaminants is calculated from the mass flux at the unsaturated zone-saturated zone boundary, modified to account for delays and reductions along the approximately 18-km [11-mi] flow path to the regulatory compliance location. Breakthrough curves from the TSPA are used to transfer the mass fluxes of Mo, Ni, and V from the unsaturated-saturated zone boundary below the repository to mass fluxes at the regulatory compliance location. Appropriate analog breakthrough curves were selected by matching sorption properties of the nonradiological contaminant with breakthrough curves derived for radiological contaminants with similar sorption properties. A breakthrough curve represents the arrival of a contaminant at a location as a function of time, and reflects the transport velocity and sorption characteristics of the contaminants for the various processes operating in the aquifer. The processes implemented in the TSPA model account for advection, matrix diffusion, dispersion, sorption, and colloidal processes. Together with the release rate from the repository (Section A.1.1), the breakthrough curve provides the mass of nonradiological contaminants at the regulatory compliance location as a function of time, which is used as input for the transport calculation beyond the regulatory compliance location described in the next subsection. The mass fluxes of nonradiological material at the regulatory compliance location are provided in Figure A–1 (bottom), which represents the nonradiological releases over the one-million-year period.

Sorption

Sorption is the process whereby contaminants are removed from the water through attachment to solid grains in the rock. For a continuous contaminant source, sorption causes a delay in the arrival of the peak contaminant levels at downstream locations, but does not reduce the peak contaminant level. The inclusion of longitudinal dispersion smooths sharp contaminant fronts (such as the pulse of the nonradiological contaminant release shown in the top of Figure A–1), and only affects the timing of the first arrival of the contaminant at downstream locations.

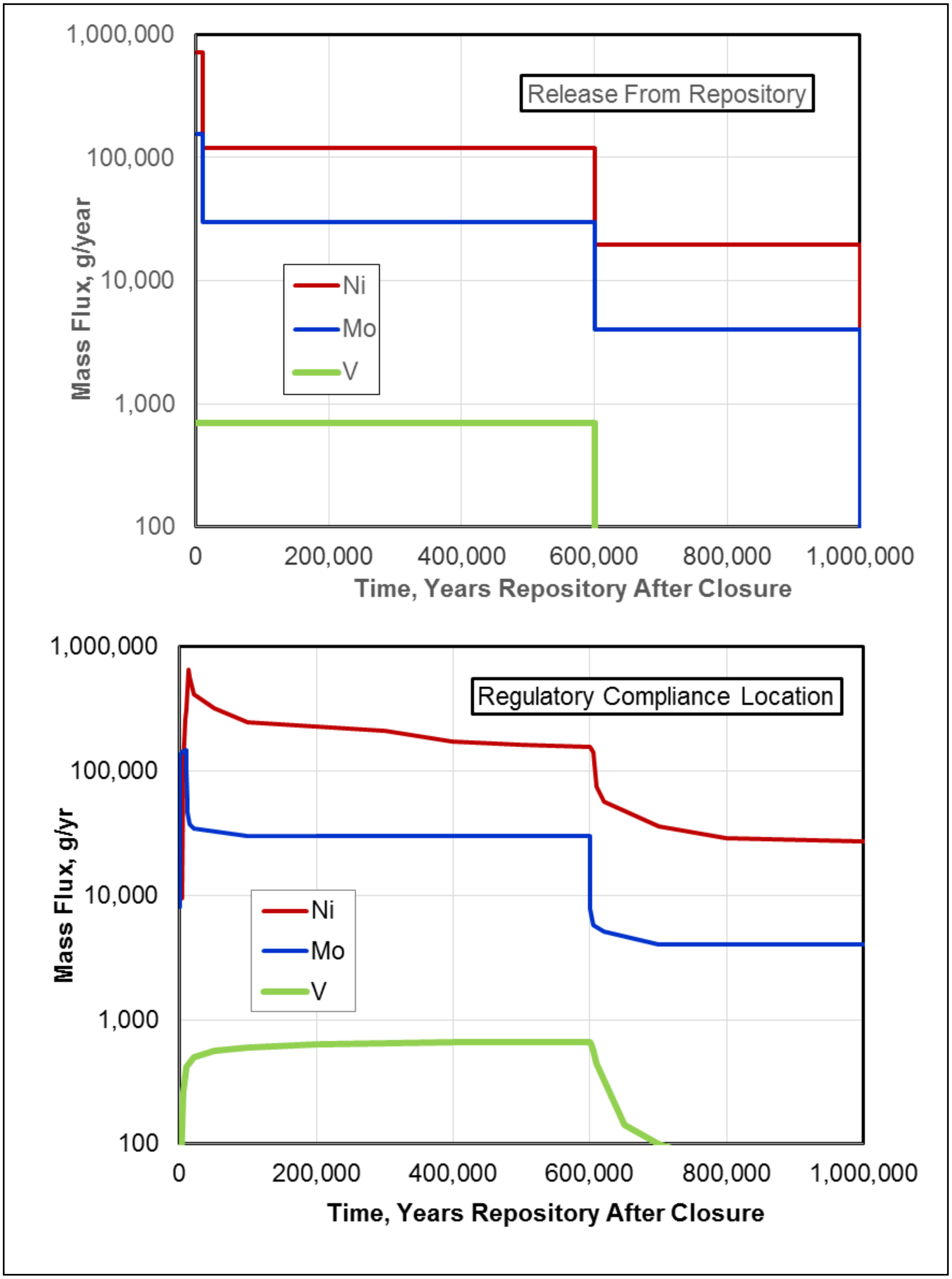

Figure A–1. Mass Flux for Mo, Ni, and V Released From Repository (Top) and Reaching the Regulatory Compliance Location (Bottom). To Plot All Three Metals on the Same Graph, a Logarithmic Mass Flux Scale Is Used.

A.1.2 Transport to Affected Environments Beyond the Regulatory Compliance Location

In its 2002 EIS, DOE considered transport beyond the regulatory compliance location only through the use of fractional scaling factors for both radiological and nonradiological contaminants. These factors were applied to the TSPA outputs at the regulatory compliance location to assess impacts at more distant locations. These scaling factors nominally accounted for the increased dispersion of a contaminant plume migrating downstream from the approximately 18-km [11-mi] regulatory compliance location (DOE, 2002, Section 5.4.1 and Appendix I.4.5). In its 2008 SEIS, DOE stated that dose and concentration, and thus impacts, for areas beyond the regulatory compliance location can be no greater than those estimated for the regulatory compliance location.

In this supplement, the NRC staff uses the transport analysis is the U.S. Geological Survey's (USGS) Death Valley Regional Flow System (DVRFS) model (Belcher and Sweetkind, 2010). The DVRFS model uses the publicly available MODFLOW software (Harbaugh, 2005; Harbaugh, et al., 2000), which is the most widely-used groundwater modeling software. The USGS has been developing the DVRFS model for more than 15 years (Belcher, 2004; Belcher and Sweetkind, 2010; D'Agnese, et al., 1999). The NRC staff reviewed and accepted the DVRFS model as used in the SAR (DOE, 2008b; Section 2.3.9) in its safety evaluation (NRC, 2014a; Section 2.2.1.3.8). As used in this supplement, the DVRFS model was updated (SNL, 2014) by including additional years (1999–2003; in addition to original 1913–1999 data) of pumping data from Amargosa Farms. The DVRFS model (SNL, 2014) is used in this supplement to determine flow pathways and inputs for the transport model. The NRC staff reviewed the changes to the inputs and the resulting output, and determines that the DVRFS model (SNL, 2014) is acceptable for use in the analyses in this supplement. Based on the NRC staff's reviews of the DVRFS models described above, the NRC staff finds the DVRFS model to be a reasonable representation of the flow system in the Death Valley region, including the flow path from Yucca Mountain to Death Valley.

The next sections describe the transport approach used in this supplement to analyze the transport of radiological and nonradiological contaminants from the regulatory compliance location to affected environments along the groundwater flow path to Death Valley. The description includes the identification of the likely transport pathways and the transport model, including processes and properties.

Identification of Pathways

The model the NRC staff uses for identifying the transport pathways and determining the flow characteristics along those pathways is based on the DVRFS model [Belcher and Sweetkind (2010)], modified to include data on groundwater pumping from 1913 to 2003 (SNL, 2014). Implemented with the MODFLOW software (Harbaugh, 2005; Harbaugh, et al., 2000), USGS's DVRFS model includes particle-tracking capabilities. Particle tracking is a technique commonly used to delineate flow pathways. Particles move through the model domain based on the flow direction and velocity at each cell in the model. Flow pathways are identified by releasing particles at the regulatory compliance location and tracking where the particles move within the DVRFS. Adsorption, colloidal filtering, decay, or other mechanisms that limit movement of the particles along with the water are neglected in this analysis for simplification and conservatism. In the DOE (2014a) analysis, 8,024 particles were released at the regulatory compliance location and tracked. The 8,024 particles used at the regulatory compliance location were derived from release of 10,000 particles from Yucca Mountain in the Yucca Mountain Site-Scale

Flow Model (SNL, 2007a). When pumping is included in the DVRFS model, all particles are captured by the wells in Amargosa Farms. When no pumping is included (the pre-pumping model, representing groundwater conditions prior to 1913), particle tracking identifies two potential pathways downstream of Amargosa Farms. The strongly predominant path is approximately southward through Amargosa Farms, turning southwestward to westward beneath the Funeral Mountains, to the springs at Furnace Creek, and on to Middle Basin in Death Valley (DOE, 2014a; Figure 3-1). A potential alternative path (only two particles out of 8,024 leaving the regulatory compliance location took this course) is southward past Amargosa Farms to surface discharge at Alkali Flat (DOE, 2014a; Figure 3-2). For this analysis, these two particles represent the limited possibility that a small amount of contamination could divert from the predominant pathway.

Particle tracking results in the DVRFS model indicate that the contaminants would travel through several different water-bearing segments (parts of the aquifer) along the flow path. Each of these segments has different transport properties. For the analysis in this supplement, the length of transport segments along each identified pathway are estimated from the DVRFS model, using separate steady state simulations with and without pumping in Amargosa Farms (as in DOE, 2014a). The segment lengths represent flow in different rock formations. Flow beyond the regulatory compliance location is primarily in volcanic-alluvial or carbonate-hosted aquifers. For the nonpumping scenario, two different aquifer types predominate in the flow path to Death Valley (DOE, 2014a): (i) the volcanic-alluvial basin fill unit comprises 46 percent of the path; and (ii) the lower carbonate aquifer comprises 40 percent. For the pumping scenario, the entire path (from the regulatory compliance location to Amargosa Farms) is comprised of various basin fill volcanic-alluvial units (DOE, 2014a). The NRC staff finds that the DVRFS segment lengths and hydrogeological units along the flow paths as described by DOE are acceptable and reasonable because (i) the NRC staff found the DVRFS model an acceptable representation of groundwater flow in the region (see above), (ii) the NRC staff reviewed the flow segment lengths and found them to be reasonably consistent with distances from maps of the hydrogeological units, and (iii) the hydrogeological units and their spatial representation are direct inputs from the model developed by the USGS (Belcher and Sweetkind, 2010).

Transport Model

The mass flux at the regulatory compliance location was estimated from the release and transport of contaminants from the repository, as described in Section A.1.1. This section describes how the contaminants at the regulatory compliance location are modeled to move different distances downstream using a different transport model than that used for the transport between the repository and the regulatory compliance location.

For this supplement, transport in the saturated zone (i.e., the aquifer) downstream of the regulatory compliance location is modeled using the one-dimensional pipe model described in DOE (2014a). The entire contaminant plume is assumed to be contained in the pipe. As described below, a one-dimensional representation is conservative compared to a three-dimensional model because it neglects vertical and lateral dispersion, and thus likely overestimates maximum contaminant concentrations.

Transport in the pipe is based on an analytical solution of the advection-dispersion equation modified for sorption and decay. The exact solution to the equation (Lapidus and Amundsen, 1952; Equation 9) is simplified by dropping the term for short distances. The concentration-based solution is multiplied by the volumetric flux to convert it to a mass flux-based solution. In addition, a mathematical identity for the complementary error function in the solution is used to avoid potential computational difficulties which can occur with a numerical approach. Whereas the analytical solution for transport is valid for a constant source term, solutions for different magnitudes of the source term that occur at different times are additive. Because the mass flux at the regulatory compliance location changes with time, the solution approach is to break up the source term into step changes (of radionuclide and nonradiological contaminant mass fluxes) and solve the transport equation for each source term step. The solution for a location and time is then the sum of contributions from each source term step.

Analytical Solutions for Transport Equations

An analytical solution to the transport equation is a mathematical solution in the form of mathematical expression. It is also called a closed-form solution. A numerical solution is an alternative method for solving the transport equation. Numerical solutions are needed for complex problems, but the results only approximate the solution to the transport equation. The choice of solution method generally is determined by the complexity of the problem, and by the intended usage and needs of the results.

Transport processes of sorption, longitudinal (in the direction of the flow path) dispersion, and radioactive decay and ingrowth are incorporated in the model, but matrix diffusion and colloidal processes are not included. Neglecting matrix diffusion is conservative for estimating impacts because diffusion reduces concentrations of contaminants. DOE's TSPA includes these processes, so their effects are included in the mass of radionuclides calculated to arrive at the regulatory compliance location. Neglecting colloidal transport beyond this point may under-represent the mass flux to affected environments. However, the NRC staff reviewed the magnitude of colloidal transport included in the TSPA and determined that this process was not significant to dose, and hence the mass of radionuclides that is used to estimate that dose at the regulatory compliance location (NRC, 2014a; Section 2.2.1.4.1). Because the same radionuclides and transport processes in the TSPA are analyzed in this supplement, not including colloidal processes will not significantly affect the estimated impacts. The processes of radioactive decay and ingrowth are approximated by adjusting the input source term for the one-dimensional pipe model to account for decay or ingrowth that would take place between the regulatory compliance location and the downstream location (e.g., Amargosa Farms or Death Valley).

The primary inputs for the transport model are sorption properties for each contaminant and flow path characteristics from the DVRFS model. Sorption analyses in this supplement use values from DOE (2014a; Table B-1). For radionuclides in volcanic and alluvial rock units, DOE derived the sorption values from the low end of the range provided in the SAR (DOE, 2008b; Table 2.3.9-14), and updated them based on more recent literature (DOE, 2014a). Larger values of sorption coefficients lead to delayed arrivals of contaminants at downstream locations, such as delays in the time of peak concentrations. The NRC staff found that the values in DOE's SAR were acceptable as part of its safety evaluation (NRC, 2014a, Section 2.2.1.3.10). Further, sensitivity analyses using a set of significantly lower sorption values for all contaminants (except non-sorbing species where the sorption coefficient is zero) (DOE, 2014a, Table B-16; DOE, 2008b, Table 2.3.9-14) showed only a 15 percent increase in dose and body uptake impacts (DOE, 2014a). This small increase in impacts would not change the conclusions in Chapter 3 of this supplement. Therefore, the NRC staff finds the sorption properties in DOE (2014a, Tables B-1) reasonable for use in this supplement for the transport model.

Secular equilibrium for decay chain isotopes is a valid assumption when the sorption coefficients of parent and daughter products of radionuclides are similar in magnitude. In its 2002 EIS and 2008 SEIS, DOE assumed secular equilibrium for all radionuclides in decay chains. In DOE (2014a), DOE screened radionuclide decay chains for parent and daughter radionuclides with large differences in respective sorption coefficients. DOE identified the actinium, neptunium, thorium, and uranium series in the screening analysis (DOE, 2014a). The NRC staff reviewed the screening of radionuclide series for secular disequilibrium in the SAR, and found this same list acceptable for use in the SAR (NRC, 2014a; Section 2.2.1.3.9). In this supplement, the effect of secular disequilibrium is accounted for by applying a scaling factor to the dose conversion factors for radionuclides of parent-daughter pairs with different sorption characteristics. Any factor above one has the effect of increasing the estimated dose impact of the identified radionuclide species. Following the approach described in Olszewska-Wasiolek and Arnold (2011), the factors used in this supplement are 8.7 for Ra-228 and 1.8 for lead-210 (Pb-210) and Ra-226 (shown in DOE, 2014a, Tables B-3 and B-4).

For the flow path characteristics, DOE derived the following from the DVRFS model: (i) bulk density, porosity, and flow path length in each rock unit (referred to as flow segments), and (ii) specific discharge. The values for each flow path are provided in DOE (2014a, Table B-1), and their derivation is summarized below. The NRC staff finds the DVRFS hydrogeological properties of each flow segment along the flow paths acceptable and reasonable because (i) the NRC staff found the DVRFS model of Belcher and Sweetkind (2010) an acceptable representation of groundwater flow in the region in its safety evaluation (NRC 2014a; Section 2.2.1.3.8), (ii) the NRC staff reviewed the flow segment lengths in DOE (2014a) and found them to be reasonably consistent with distances from maps of the hydrogeological units (e.g., Belcher and Sweetkind, 2010), and (iii) the hydrogeological units and their spatial representation are direct inputs from the model developed by the USGS (Belcher and Sweetkind, 2010).

These parameters are derived as follows. Particle track modeling indicates the different hydrogeological units that water flows through along the paths from the regulatory compliance location to either Amargosa Farms or to Furnace Creek/Middle Basin. The distance the particle travels in each hydrogeological unit is the length of the flow segment, which, when summed, provides the total flow path length. For bulk density and porosity, a single value for the entire flow path length is derived using a distance-weighted average of the properties for the individual segments along the pathway. Specific discharge is calculated as the average travel time of particles divided by the total length of the flow path. For the cooler/wetter climate state, the specific discharge rate is increased by a factor of 3.9 over that of the present-day climate to account for potentially faster groundwater flow under the wetter conditions. Whereas a cooler/wetter climate would lead to both a higher water table and faster flow rates, the NRC staff review in the SER (NRC, 2014a; Section 2.2.1.3.8) concluded that only the faster flow rates need be considered for the transport model. The factor of 3.9 was derived from simulations of wetter conditions using the DVRFS model (D'Agnese, et al., 1999; SNL, 2008, Table 6-5), and was used for the glacial-transition climate in TSPA model simulations (DOE, 2008b, Section 2.4). The NRC staff reviewed the basis for the factor of 3.9 and found it to be an acceptable representation of the glacial-transition climate and for the long-term climate change during the 10,000 to one million-year period in its safety evaluation (NRC, 2014a, 2.2.1.3.8).

A separate calculation is required to estimate contaminant concentrations in the aquifer environment between the regulatory compliance location and Amargosa Farms (see Section 3.1.1) because the one-dimensional pipe-model approximation does not account for the potential plume dimensions. The contaminant concentration for the aquifer environment is estimated as the difference between the amount of radiological or nonradiological mass at the regulatory compliance location and that at the Amargosa Farms divided by the volume of the aquifer environment. The volume of the aquifer environment is conservatively estimated by the dimensions of the particle tracking traces in DOE (2014a, Figure 3-1; 2008b, Figure 2.3.9-14). This volume estimate is conservative because particle tracking neglects lateral and vertical dispersion, which would lead to larger aquifer volumes and lower concentrations. From these values, representative dimensions of the plume are 3 km [1.9 mi] wide and 100 m [330 ft] thick The third dimension of the volume is the distance between the regulatory compliance location and Amargosa Farms, which is 17 km [10.5 mi]. The next section provides a description of processes at surface discharge locations, for which the mass fluxes are used as input to estimate impacts at those locations.

A.2 Processes at Discharge Sites

For groundwater withdrawal for irrigation, a conceptual model for the recycling of irrigation water pumped to the surface was not included in DOE's 2002 EIS or 2008 SEIS. The irrigation recycling model used in this supplement is described in Section A.2.1. Processes that can affect accumulation, concentration, and potential remobilization of groundwater-borne contaminants, including the influence of different chemical conditions at natural discharge sites such as springs or evapotranspiration at wet playas, are discussed in Section A.2.2.

A.2.1 Groundwater Pumping, Recycling, and Irrigation

Groundwater may be discharged at the surface due to pumping or through natural discharge features, such as springs, seeps, and wet playas. In the Amargosa Farms region, a significant amount of shallow alluvial aquifer groundwater is pumped and used as a source of domestic and commercial water supply and for the irrigation of crops. As irrigation water is applied to soils, its chemical constituents can be taken up by crops, sorbed to soils, and concentrated by the effects of evaporation and transpiration. These processes can lead to the buildup of salts and other elements detrimental to continued farming and the broader ecosystem. In addition, in the Amargosa Farms region, excess irrigation water is applied to compensate for evaporation and to limit the buildup of salts in the root zone of the soil (DOE, 2014a). Excess irrigation is the practice of applying more irrigation water than is needed by the particular crop, thus enabling the excess water to recharge the water table while carrying the salts (and in this modeling case, some of the contaminants) away from the upper soil layers. The water that reinfiltrates the aquifer then becomes available again for groundwater pumping.

This practice adds a complicating factor in assessing impacts from irrigation where irrigation water percolates deep into the subsurface and is recaptured and recycled at pumping locations. Where this occurs, the recycling process increases concentrations of contaminants in the groundwater and thus increases the concentrations of contaminants as they are reapplied to the surface during irrigation. Groundwater pumping at Amargosa Farms is on the order of 17,000 acre-ft/yr [21 million m^3/yr]. This high volume of irrigation indicates that use of an irrigation recycling model is warranted for the assessment of impacts at Amargosa Farms.

For this supplement, a mathematical analytical solution describing an equilibrium concentration is used to incorporate the impacts of irrigation recycling at the Amargosa Farms area, following the approach in DOE (2014a; SNL, 2007b). This mathematical solution, referred to hereafter as the special-case model, neglects the effects of radioactive decay. Neglecting decay overestimates radionuclide concentrations and, therefore, impacts. DOE (2014a) notes that more detailed irrigation recycling models have been developed (SNL, 2007b; Kalinina and Arnold, 2013), but that the special-case model represents a limiting case of the more detailed irrigation recycling models. The NRC staff finds that the irrigation recycling model in DOE (2014a) represents a reasonable, limiting case that would lead to conservative results for this analysis.

The output of the recycling irrigation model that is used in this supplement is used to increase the amount of recycled groundwater. The irrigation recycling model includes two factors to calculate the change in concentration of dissolved contaminants in groundwater resulting from irrigation recycling: (i) the amount of pumped water used for irrigation and (ii) the amount of irrigation water recaptured by pumping wells (DOE, 2014a). For the first factor, 86 percent of pumped groundwater on average in the Amargosa Farms area is used for irrigation (Moreno and Justet, 2008). For the second factor, this supplement conservatively assumes that 100 percent of the irrigation water is subsequently recaptured by the Amargosa Farms area wells, and also assumes no decay of the contaminants. In addition, this model also assumes that none of the contaminants in the plume are sorbed to the aquifer during deep percolation. As a result of these factors and assumptions, the model used in this supplement produces an increase in groundwater contaminant concentrations by a factor of 7.1, which is much larger than values (1.1 to 1.5) used to assess the impacts of irrigation recycling at the regulatory compliance location in the SAR (DOE, 2014a; Kalinina and Arnold, 2013; SNL, 2007b). The calculated changes in groundwater concentrations are then applied to the contaminant concentrations in the transport model for the Amargosa Farms area to incorporate the impact of irrigation recycling in the groundwater pumping scenario. The NRC staff finds the DOE implementation of the irrigation recycling model in DOE (2014a) acceptable and reasonable for use in this supplement because (i) the NRC staff reviewed the irrigation model in the SER and found it acceptable as part of its safety evaluation (NRC, 2014a; Section 2.2.1.3.14); and (ii) the irrigation recycling model input for recapture was changed to a maximum possible value, and the percentage of pumped groundwater in Amargosa Farms was set to the actual value determined by Moreo and Justet (2008); and (iii) radioactive decay is conservatively neglected for the recaptured water.

Two forms of the irrigation recycling model used in this supplement are applied at two locations: Amargosa Farms and the State Line/Franklin Well area. Recycling is included for Amargosa Farms where wells that pump water for irrigation are generally located in the farm fields where the irrigation water is applied. Recycling is not included in the salt marsh model used for the State Line/Franklin Well area because the water from springs and marshes would not be applied at the location it is discharged. In any potential irrigation at the State Line/Franklin Well area, fresh water from springs and marshes would be diverted to locations downstream from the extraction location where soils are not highly saline. In this type of environment, areas close to springs and marsh areas would contain high levels of salts, and thus would be unsuitable for agriculture.

A.2.2 Processes at Surface Discharge Locations that Could Affect Accumulation, Concentration, and Potential Remobilization of Contaminants

In the 2002 EIS and 2008 SEIS, DOE did not include an assessment of impacts from groundwater-borne contaminants downstream of the regulatory compliance location.

Although potential groundwater flow paths downstream of the compliance location were discussed in the 2008 SEIS, there was limited description of groundwater-surface interaction processes and no quantitative assessment of impacts from groundwater discharging at the ground surface beyond the regulatory compliance location.

As discussed in Chapter 2, natural groundwater surface discharge features in the Yucca Mountain region include springs, seeps, evapotranspiration zones with near-surface water table levels, and wet and dry playas. For the analysis in this supplement, these are grouped into springs and wet playas, or are neglected because exposure pathways for evapotranspiration are much smaller than for springs or wet playas. Besides present-day features, there are also paleospring deposits (e.g., the State Line Deposits) along the groundwater pathway from Yucca Mountain that show surface discharge during past wetter climate periods (Section 2.3). The specific processes that occur at these different types of groundwater discharges are dependent on several factors, including the host rock lithology, the groundwater chemistry, the topographic setting, the rate of evaporation, and the ecology of the sites (e.g., Douglas, 2004; Hardie, 1968; Quade, et al., 1995; Reynolds, et al., 2007).

Springs and paleosprings in the Yucca Mountain region are often associated with brownish, fine-grained, silt-sand sediment deposits; variable carbonate cementing of sediments; and greenish clay deposits (Quade, et al., 1995). Quade, et al. (1995) classified the springs into two main types:

- Springs where the water table intersects with the ground surface (free-face discharge, exemplified by the State Line Deposits) and
- Springs controlled by faulting or other geologic features (structure-controlled discharge, exemplified by springs at Furnace Creek).

In areas adjacent to both spring types, an ecological hierarchy is commonly developed in which plants transition from sparse xerophytes (plants adapted to very arid environments) upgradient of the spring, to large phreatophytes (deep-rooted plants that obtain water from the water table) near the spring, to grassy wet meadows downstream from the spring (Quade, et al., 1995). These ecological zones trap different types of sediment and produce the brownish silts, green clays, and calcite-cemented crusts near the zone edges (Quade, et al., 1995). When the water table is lowered, as in the present-day climate, erosion and channeling of the sediments deposited in the paleospring can occur, and the phreatophytes are replaced by xerophytes (Quade, et al., 1995). This process can be observed in the Furnace Creek spring area. Because the regions near these springs would have limited agricultural activity, the analyses in this supplement do not include irrigation recycling for these areas. However, the analyses do include potential exposure from use of the springs as a drinking water source, as well as impacts from exposure to sediments contaminated by groundwater.

As groundwater moves closer to the surface or is discharged at the surface, it is impacted by gas exchange with the atmosphere, sorption on minerals in the soil, and concentration effects. Groundwater in the subsurface typically has an elevated concentration of carbon dioxide (CO_2), relative to surface water in equilibrium with the atmosphere, due to chemical exchange with carbonate rocks in the aquifer. As the groundwater is discharged, it re-equilibrates with the atmosphere. Depending on the overall chemical composition of the groundwater, the loss of CO_2 may result in the precipitation of carbonate minerals, such as calcite. In the Yucca Mountain region, precipitation of calcite is observed at springs that originate from the carbonate aquifer, like those in Ash Meadows or Furnace Creek (Johannesson, et al., 1997; Paces, et al., 1997). Other effects from the loss of CO_2 may include an increase in pH (alkalinity) of the groundwater. Both pH and CO_2 concentration changes can affect the potential for sorption onto soil and other surface sediments. The modeling described in this supplement uses the sorption values reported in DOE (2014a) to calculate the retention of contaminants on soils and sediments. The mean values reflect a range of sorption values that capture the range of pH and CO_2 effects on sorption.

At wet playas, the upward movement of groundwater is not driven by water table interactions, but by capillary action that draws the groundwater upward. Nearer the surface, the groundwater is subject to evaporation and evapotranspiration. These processes tend to concentrate the chemical constituents in the groundwater and increase the total dissolved solids (TDS) content of the water. As more water is lost, the water becomes more saline, and solubility limits for minerals may be exceeded. Various carbonates, salts, and other evaporite minerals may precipitate. This action produces a soft surface of evaporite phases that are typically rich in minerals such as calcium carbonate, hydrated calcium sulfate, sodium chloride, and sodium sulfate (DOE, 2014a). The specific types of evaporite minerals that form are dependent on the initial groundwater chemistry and the extent of evaporation, and the deposits are often zoned (Hardie, 1968). The evaporite deposits are found both in the capillary fringe area and on the surface of a playa (DOE, 2014a); extreme evaporation in a closed basin can lead to thick, zoned sequences of relatively pure evaporite minerals, as in Badwater Basin in Death Valley (e.g., Hunt and Mabey, 1966). As the evaporite mineral crystals form, they also displace and mix with the rock-derived sediments (often fine silts and clays), expanding the sediments upward (DOE, 2014a; Reynolds, et al., 2007). The playa deposits with evaporite minerals are often described as “fluffy” with large pore space and low density (Reynolds, et al., 2007). At the surface, microbial activity may produce mats that trap additional sediment and control the types of mineral phases that form (Douglas, 2004). Sometimes a more compact, but still friable (easily crumbled) material forms, which contains a lower fraction of evaporate minerals (DOE, 2014a). These types of deposits are associated with lower rates of evaporation or lower salinity in the groundwater (DOE, 2014a). The residual water is highly mineralized. For example, at Alkali Flat (Franklin Lake Playa), stagnant water has TDS content of 70,000 to 80,000 ppm, and drainage paths have water with TDS content of 6,000 to 20,000 ppm (DOE, 2014a; Reynolds et al. 2007). For comparison, water with less than 250 ppm TDS is generally considered to be potable.

The effect of evaporation and evaporite mineral formation on the contaminants is to concentrate them in the groundwater and eventually incorporate them into the evaporite mineral phases. The dose model in this supplement does not include assumptions about preferential retention or partitioning of contaminants into specific precipitated minerals. Although some preferential partitioning is likely, this is a reasonable assumption that ensures all contaminants are available for subsequent dose assessments due to exposure to evaporite particulates from soil disturbances. If preferential partitioning occurred, contaminants would only be available for exposure pathways for some fraction of time. At other times, burial and precipitation of uncontaminated evaporates would lead to lesser or no impacts.

In this supplement, contaminant concentrations are estimated in the surficial materials at wet playas by using the ratio of the contaminant concentration to the observed TDS in the groundwater. This approach for estimating contaminant concentrations in surficial materials is conservative for several reasons. First, this approach conservatively assumes that evaporites are the only component of the surficial material; including the rock-derived component (e.g., silt, clay) of the surficial material would dilute the contaminant concentration. Second, the TDS in the groundwater is conservatively assumed to be 257 ppm, which is the TDS from the J-13 well.

The J-13 well measured the volcanic aquifer below Fortymile Wash and upstream of the regulatory compliance location. Because TDS generally increases with the time or distance that water is below ground, the TDS from J-13 is lower than that in groundwater downstream of the regulatory compliance location. For comparison, the measured TDS of spring water at Furnace Creek is approximately 600 ppm TDS (Steinkampf and Werrell, 1998); using this value for TDS would decrease the contaminant concentration in evaporite to less than half that of the estimate provided in Chapter 3 of this supplement. Third, this approach for estimating evaporite concentrations is conservative because the evaporites, which include potential contaminants, can be redistributed by wind and rainfall. Since many of the evaporite minerals are highly soluble, they can be dissolved and redistributed during periods of water inundation and flow. Redistribution of the contaminated evaporite particulates would tend to disperse contaminants over a larger area and dilute their concentration.

A.2.3 Biosphere Exposure and Dose Conversion

This section provides a discussion of the biosphere model, which includes exposure pathways and the conversion of contaminant levels to a dose (for radionuclides) or a body uptake (for nonradiological contaminants) for each of those pathways.

For radiological and nonradiological contaminants that reach the biosphere (or accessible environment), either through groundwater pumping or natural surface discharge, the impacts to that environment are assessed by first determining the exposure pathways. The contaminant level (i.e., concentration) is then converted to an impact using a dose conversion factor for radionuclides or a body uptake factor for toxic chemicals. The dose conversion and body uptake factors depend on the exposure pathways in each environment. For radionuclides, the resulting annual dose to humans is compared against natural background levels and the criteria specified for safety in 40 CFR Part 197 and 10 CFR Part 63 for the RMEI. For nonradiological contaminants, body uptake is compared directly against an Oral Reference Dose (e.g., EPA, 1999a,b; 1997a,b; 1994).

In its 2002 EIS and 2008 SEIS, DOE assessed impacts using a conceptual biosphere model with a broad range of water uses and exposure pathways, as shown in Figure A–2. In this supplement, three environments with different exposure pathways are developed. These three environments are:

- Environment 1: Irrigation Pumping and an Agricultural Community
- Environment 2: Surface Discharge as Springs with a Local Non-Farming Community
- Environment 3: Surface Discharge at Wet Playas

The biosphere exposure framework in Figure A–2 lists a range of potential pathways, but not all water uses and exposure pathways apply to each environment in this supplement. For the pathways for each environment, dose conversion factors were derived from SNL (2007c) for the 31 radionuclides that make up the source term from the repository (DOE, 2014a). The NRC staff, as part of its safety evaluation, found the biosphere exposure framework and dose conversion factors to be acceptable (NRC, 2014a; Section 2.2.1.3.14). The impacts from total U and the nonradiological contaminants Mo, Ni, and V are assessed by estimating the daily uptake amount.

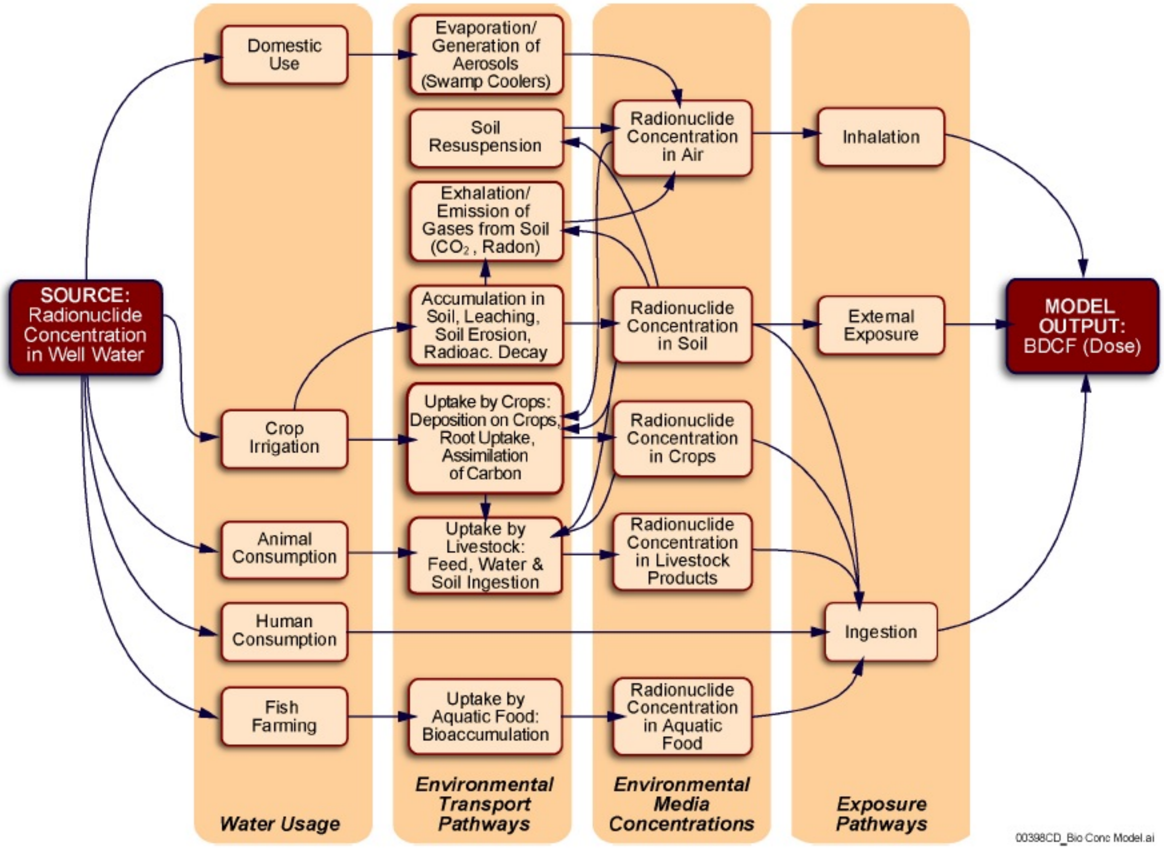

Figure A–2. Water Uses and Exposure Pathways in the Biosphere Conceptual Model. See Text for Discussion of Relevant Pathways for Each Environment. (Source: SNL, 2007c, Figure 6.3-3).

Environment 1: Irrigation Pumping and an Agricultural Community

This environment includes groundwater pumping for irrigation and groundwater use for a domestic and commercial water supply in an agricultural community. Presently, Amargosa Farms is the only location along the flow path from Yucca Mountain where extensive groundwater pumping occurs. The population eats locally grown food, both plants grown in fields and animals raised in the area, and works and lives in areas where the soils could become contaminated by water pumped for irrigation. Some fraction of the contaminants can leach back into the aquifer and possibly be recaptured by pumping wells, and some fraction would escape by soil erosion. In addition, decay and ingrowth will affect radionuclide concentrations. These processes are captured in the recycling irrigation model described in Section A.2.1.

The dose pathways for this environment (e.g., Amargosa Farms) are (i) external (body) exposure to contaminated soil, dust or water; (ii) inhalation of contaminated soil particles (including Ra-226) and vapor from evaporative coolers; and (iii) ingestion of water, crops, meat, fish, and soil. These pathways have not changed from those used in the 2002 EIS and 2008 SEIS. The dose conversion factors used in this supplement are from DOE (2014a, Table B-3), which were derived from the maximum values in the distributions provided in the SAR (DOE, 2008a; Table 2.3.10-12). The NRC staff found the dose conversion factors in the SAR acceptable in its safety evaluation (NRC, 2014a; Section 2.2.1.3.14). The dose conversion factors have been adjusted for secular disequilibrium for identified radionuclides as described in Section A.2.2.

The intake of toxic chemicals from the repository (Mo, Ni, V, and total U) at an agricultural community is based on daily intakes by a 70-kilogram [150-lb] person drinking 2 liters [8.5 cups] of water per day. The daily intake is equal to the water concentration times the daily amount consumed, divided by the weight of a person.

Environment 2: Surface Discharge at Springs with a Local Non-Farming Community

For Environment 2, groundwater is discharged in springs and lost by evapotranspiration. The spring water may be used for a local water supply. The areas surrounding springs are sites for evaporation and transpiration that could lead to evaporite minerals forming in contaminated soils, and potentially plants with contaminated uptake. Examples of spring environments along the groundwater flow path are Furnace Creek Springs under the present-day and wetter climate states, or the State Line Deposits/Franklin Well area under a wetter climate state.

The biosphere model for a spring environment includes exposure pathways of (i) inhalation of contaminants in dust resuspended into the air and vapor from evaporative coolers, (ii) ingestion of water for drinking and inadvertent ingestion of soil, and (iii) external exposure from contaminant deposits at or near the ground surface. The model does not include groundwater pumping or ingestion of contaminated foods. The dose conversion factors used in this supplement are from DOE (2014a, Table B-4), which were derived from the maximum values in the distributions provided in the SAR (DOE, 2008a; Tables 2.3.10-11 and 2.3.10-12). The NRC staff found the dose conversion factors in the SAR acceptable in its safety evaluation (NRC, 2014a; Section 2.2.1.3.14). The dose conversion factors have been adjusted for secular disequilibrium for identified radionuclides, as described in Section A.2.2.

Intake of chemical contaminants at a springs-type environment is based on daily intakes by a 70-kilogram [150-lb] person drinking 2 liters [8.5 cups] of water per day. The daily intake is equal to the water concentration times the daily amount consumed, divided by the weight of a person.

Environment 3: Surface Discharge at Wet Playas

At playas, groundwater comes close to the ground surface and evaporates or transpires, leaving evaporite minerals in the surficial materials (soil and evaporite). The evaporite mineral content and percentage in the surficial materials can be highly variable. The nonevaporite material is comprised of soil present prior to playa formation, the windblown dust deposited concurrently with evaporite precipitation, and other sediment carried in from higher elevations by sporadic flooding. Water in the surficial materials and at the surface can be highly variable in composition, but is often saline. Intermittent or local springs may also occur, but the amount of potable water is generally insufficient to support a local human population. The environment is not conducive to farming, and natural vegetation is typically sparse and composed of salt-tolerant species. Examples of playas without prominent springs are the Middle Basin of Death Valley and Alkali Flat. For future wetter climates, the State Line Deposits area would likely also have wet playas, but may also have springs, pools, and marshes.

The exposure pathway for playas includes (i) inhalation of resuspended contaminated dust, (ii) ingestion of contaminated water and inadvertent ingestion of evaporites, and (iii) external (body) exposure to contaminated water or evaporites. A full-time resident living at the discharge areas with the exposure pathways is conservatively assumed. To account for periodic airborne resuspension of surface contaminants without significant soil disruption (i.e., no heavy machinery causing dust resuspension), a value of 0.1 mg/m^3 [6 × 10^{-9} lb/ft^3] is used for the annual average airborne particle concentration. This represents a maximum long-term value for airborne particle concentrations in the affected environment. The value for resuspension is taken from the distribution provided in DOE (2008b; Table 2.3.10-10). The NRC staff finds this an acceptable and reasonable value, because the NRC staff found the distribution to be acceptable as part of its safety evaluation (NRC, 2014a; Section 2.2.3.1.14). The airborne particle concentration is used with a long-term average breathing rate and an assumed inhalation intake duration for the entire year. These assumptions conservatively overestimate both annual intakes of inhaled contaminants and annual doses. Dose conversion factors used for Environment 3 were derived from SNL (2007c, Tables 6.4-4 to 6.4-6), which the NRC staff found acceptable as part of its safety evaluation (NRC, 2014a; Section 2.2.1.3.14).

Intake of chemical contaminants is for a receptor who is active on the playa but not operating heavy machinery that would create dust. It is based on daily intakes by a 70-kilogram [150-lb] person inadvertently ingesting or breathing dust from contaminated evaporites. The amount inhaled is estimated from the concentration of suspended particles. The daily intake is equal to the evaporite concentration times the daily amount ingested and inhaled, and divided by the weight of a person.

Climate States

Biosphere dose conversion factors would differ for different climate states because groundwater use and resulting exposures vary with climate. For example, a cooler/wetter climate requires less irrigation and thus results in a lower concentration of radionuclides in fields due to the use of less (potentially contaminated) groundwater for irrigation. The present-day climate, which is characterized as the driest of the anticipated climate states, would have the highest biosphere dose conversion factors. For the calculations of impact in this supplement, biosphere dose conversion factors for the present-day climate were used for all of the climate scenarios for conservatism.

A.3 Conservative Assumptions Used in the Model Calculations

Many conservative assumptions were used in the calculations of impacts in Chapter 3. Because of these conservatisms, the NRC staff expects that the actual impacts would be smaller than those calculated in this supplement. The most notable conservatisms in the analyses in this supplement include:

- At each natural surface discharge location, it was assumed that the entire contaminant plume was discharged therein. This likely overestimates the impacts at any one location because contaminants from the repository would likely discharge at several discharge locations. For example, for the present-day climate with no pumping (Analysis Case 2), it is much more likely that some fraction of the plume would discharge at Furnace Creek Springs, and that a larger fraction would continue to Middle Basin. Or, if pumping in Amargosa Farms is at some significantly lower rate than is used in Analysis Case 1, some portion of the contaminants could bypass Amargosa Farms irrigation wells and discharge instead at Furnace Creek and Middle Basin.

- The dose conversion factors for the Amargosa Farms area are derived for the characteristics of the RMEI (a hypothetical individual) in a manner that results in maximum annual and lifetime doses, which would not necessarily be representative of the population. The dose to the population in Amargosa Farms would be less than that to the maximally exposed hypothetical individual.

- The dose conversion factors are derived for the present-day climate and would be less for a future wetter climate. The dose conversion factors for the present-day climate were applied to both climates in the analyses for Section A.2.3, and thus likely overestimate dose for the future wetter climate.

- Natural surface discharge rates are likely underestimated for future climate conditions, which would affect estimates used for the no pumping scenario in Analysis Case 2. Model estimates of discharge flow rates are supported by indirect measurements, and were used at Middle Basin (evapotranspiration), Furnace Creek (spring flow), and Alkali Flat (evapotranspiration). However, current regional pumping likely lowers the natural surface discharge rates compared to what might be expected without pumping. Use of a lower surface discharge flow rate would overestimate the concentration of contaminants using the biosphere model described in Section A.2.3, and thus potentially overestimate impacts.

- Lateral and vertical dispersion are not considered along the flow path beyond the regulatory compliance location. Dispersion spreads out the plume and reduces the peak concentration wherever it would occur. Mixing of the contaminated plume with water from other aquifers along the path increases dispersion, such that the concentrations in the plume would decrease at each location where mixing occurs. Mixing of water from beneath Yucca Mountain with other components occurs at the (i) confluence of groundwater from east of Fortymile Wash into Amargosa Desert near Amargosa Farms (east of Fortymile Wash and west of Ash Meadows); (ii) confluence of Fortymile Wash with eastward-flowing groundwater in Amargosa Desert; and (iii) confluence with the carbonate aquifer south of Amargosa Farms, either under the Funeral Mountains or with groundwater from Ash Meadows in Carson Slough and Alkali Flat.

- The irrigation recycling model (see Section A.2.1) neglected radioactive decay and sorption of contaminants. This provides a conservative result because it does not include reductions in contaminant concentrations in the soil column during percolation back into the aquifer.

- The NRC staff’s evaluation assumes that doses and intakes would be proportional to evaporite concentrations at playas. This is a conservative assumption because (i) low-end estimates of dissolved solids in the water were used to estimate radiological and nonradiological concentrations in the precipitated evaporites, (ii) zonation of evaporation sequences and burial may reduce availability of contaminants for dust resuspension, and (iii) rock-based clastic soils and windblown dust would make up some of the surficial material, and therefore reduce the effective concentration of contaminants.

The magnitude of the effect of these conservative assumptions is not quantified in this model. Each of these assumptions serves to potentially overestimate the calculated potential impacts of contaminants on groundwater and the aquifer, and surface discharge sites to capture uncertainty and the range of potential impacts.

APPENDIX B

RESPONSES TO PUBLIC COMMENTS

APPENDIX B—RESPONSES TO PUBLIC COMMENTS

This appendix is intentionally left blank in the draft supplement. In the final supplement, this appendix will include comments and responses received on the draft supplement.

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11. ABSTRACT (200 words or less)
This supplement evaluates the potential environmental impacts on groundwater and impacts associated with the discharge of any contaminated groundwater to the ground surface due to potential releases from a geologic repository for spent nuclear fuel and high-level radioactive waste at Yucca Mountain, Nye County, Nevada. This supplements the U.S. Department of Energy's (DOE's) 2002 Environmental Impact Statement (EIS) and its 2008 Supplemental EIS for the proposed repository in accordance with the findings and scope outlined in the U.S. Nuclear Regulatory Commission (NRC) staff's 2008 Adoption Determination Report for DOE's EISs. This supplement assesses the potential environmental impacts with respect to potential contaminant releases from the repository that could be transported through the volcanic-alluvial aquifer in Fortymile Wash and Amargosa Desert, and to the Furnace Creek/Middle Basin area of Death Valley. This supplement evaluates the potential radiological and nonradiological impacts on the aquifer environment, soils, ecology, and public health, as well as the potential for disproportionate impacts on certain populations. In addition, this supplement assesses the potential for cumulative impacts associated with other past, present, or reasonably foreseeable future actions. The NRC staff finds that the potential impacts on the resources evaluated in this supplement would be SMALL.

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