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MDL-MGR-HS-000001 REV 00

October 2007

Irrigation Recycling Model

Prepared for:
U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Office of Repository Development
1551 Hillshire Drive
Las Vegas, Nevada 89134-6321

Prepared by:
Sandia National Laboratories
OCRWM Lead Laboratory for Repository Systems
1180 Town Center Drive
Las Vegas, Nevada 89144

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DISCLAIMER

QA: QA

Irrigation Recycling Model

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Model Signature Page/Change History

Complete only applicable items.

1. Total Pages: 140

2. Type of Mathematical Model

☒ Process Model ☐ Abstraction Model ☐ System Model

Describe Intended Use of Model

The purpose of this model is to provide radionuclide concentrations in the groundwater accounting for recycling of accumulated radionuclides from soil (irrigation with contaminated water) and unsaturated zone (residential septic systems) for a system level sensitivity analysis to determine impact to mean dose results.

3. Title

Irrigation Recycling Model

4. DI (Including Revision No. and Addendum No.):

MDL-MGR-HS-000001 REV00

	Printed Name	Signature	Date
5. Originator	Elena Kalinina	[signature]	10-25-07
6. Independent Technical Reviewer	Ming Zhu	[signature]	10/25/07
7. Checker	Al Eddebbarh	[signature]	10/29/07
8. QCS/Lead Lab QA Reviewer	Peter Persoff	[signature]	10/30/07
9. Responsible Manager/Lead	Bill Arnold	[signature]	10/30/07
10. Responsible Manager	Stephanie Kuzio for	[signature]	10/30/07

11. Remarks

Change History

12. Revision No. and Addendum No.	13. Description of Change
REV 00	Initial Issue

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FIGURES

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TABLES

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ACRONYMS

DOE	U.S. Department of Energy
DTN	data tracking number
EPA	Environmental Protection Agency
FEP	feature, event, and process
NAIP	National Agriculture Imagery Program
RMEI	reasonably maximally exposed individual
TSPA	total system performance assessment
TWP	technical work plan
UTM	universal transverse mercator
USGS	United States Geological Survey
YMRP	Yucca Mountain Review Plan

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1. PURPOSE

The overall objective of this work is to provide technical support to the evaluation of the feature, event, and process (FEP) 1.4.07.03.0A, "Recycling of Accumulated Radionuclides from Soils to Groundwater." This support will include development of a consequence irrigation recycling model that will be used to estimate radionuclide concentrations in the groundwater including recycling of accumulated radionuclides from soil (irrigation with contaminated water) and the unsaturated zone (residential septic systems). This model will be used in a total system performance assessment (TSPA) sensitivity analysis to evaluate the impact of the irrigation recycling model to mean dose results. This task also includes developing irrigation recycling modeling parameters and assessing uncertainties.

The irrigation recycling model report documents the development of the following:

- A conceptual model of irrigation recycling
- Mathematical representation of the conceptual model using GoldSim 9.60 (STN: 10344-9.60-00 [DIRS 180224])
- An interface between the irrigation recycling model and the saturated zone flow and transport abstraction model
- An interface between the irrigation recycling model and the biosphere process model
- The irrigation recycling modeling parameters and parameter uncertainty analysis
- An estimate of the effects of irrigation recycling on the radionuclide concentrations in the groundwater
- An estimate of the impacts of irrigation recycling to mean dose results based on the TSPA sensitivity analysis
- Validation of the irrigation recycling model.

The irrigation recycling model is based on a number of assumptions described in Section 5 of this report. Use of the model is limited by the conditions imposed by these assumptions. The limitations also apply to the irrigation recycling modeling parameters. The limitations in the knowledge of these parameters are addressed in the parameter uncertainty analysis (Section 6.5).

This model report is governed by the Office of Civilian Radioactive Waste Management Lead Laboratory *Technical Work Plan for: Evaluation of the FEP 1.4.07.03.0A - Recycling of Accumulated Radionuclides from Soils to Groundwater* (SNL 2007 [DIRS 181342]), which was developed in accordance with SCI-PRO-002, *Planning for Science Activities.* The work is performed in accordance with SCI-PRO-006, *Models.*

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2. QUALITY ASSURANCE

Development of this model report and the supporting modeling activities is subject to *Quality Assurance Requirements and Description* (DOE 2007 [DIRS 182051]) requirements. Approved Quality Assurance procedures identified in the technical work plan (TWP) (SNL 2007 [DIRS 181342], Section 4) have been used to conduct and document the activities described in this model report. The TWP (SNL 2007 [DIRS 181342], Section 8) also identifies the methods used to control the electronic management of data.

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3. USE OF SOFTWARE

3.1 QUALIFIED SOFTWARE

The qualified computer codes used directly in this model report are summarized in Table 3.1-1. All software was obtained from Software Configuration Management and is appropriate for the application. Only qualified codes were used within the range of validation as required by IM-PRO-003, *Software Management*.

Table 3.1-1. Computer Software Used in this Modeling Report

Software Name and Version (V)	Software Tracking Number	Description	Computer, Platform, and Operating System
GoldSim V. 8.02.500	10344-8.02-06 [DIRS 179360]	This code is the modeling software used in the total system performance assessment. The code allows for performing probabilistic simulations and includes the contaminant transport module.	PC, Windows 2003
GoldSim V. 9.60	10344-9.60-00 [DIRS 180224]	This is an updated version of GoldSim V. 8.02.500 (STN: 10344-8.02-05)	PC, Windows XP
GoldSim V. 9.60.100	10344-9.60-01 [DIRS 181903]	This is an updated version of GoldSim V. 9.60 (STN: 10344-9.60-00)	PC, Windows XP
ArcGIS 9.1	11205-9.1-00 [DIRS 176015]	ArcGIS was used to delineate irrigated areas on georeferenced aerial photography.	PC, Windows XP
EARTHVISION 5.1	10174-5.1-00 [DIRS 167994]	This software allows for creating three-dimensional models of geologic features.	SGI, IRIX 6.5

3.2 EXEMPT SOFTWARE

Several additional commercial, off-the-shelf software packages were used in this modeling report. Each is controlled by Yucca Mountain Project Software Configuration Management, and use of this software is appropriate for this application. The following software is exempt from IM-PRO-003, Section 2, last dash, requirements:

- **Autodesk Land Desktop Version 3 (608491-3-00):** Standard functions of the controlled commercial, off-the-shelf software Autodesk Land Desktop Version 3 (608491-3-00) were used to determine the centroid of each agricultural region. This software was used on the Windows 2000 platform.

- **Excel 2003:** Standard functions of the commercial, off-the-shelf software Excel 2003 were used for spreadsheet calculations and for plotting and visualization purposes. The calculations performed, inputs, and outputs are described in Section 6. All of the Excel files are included in output DTN: SN0703PASZIRMA.001. This software was used on the Windows XP platform.

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4. INPUTS

4.1 DIRECT INPUTS

All data, parameters, and other model inputs documented in Section 4.1 are used as direct inputs into the irrigation recycling modeling parameter uncertainty analyses and/or the irrigation recycling model. The listed data and the technical information are appropriate sources for the analyses documented in this model report. The data, the data tracking number (DTN) used as input, or the source of the data, are briefly described in Table 4.1-1. The qualification status of data input is indicated in the Technical Data Management System (TDMS) and in the Document Input Reference System (DIRS) database.

Table 4.1-1. Direct Inputs

Data Description	Data Tracking Number or Source	Where Discussed in this Report
Saturated Zone 1-D transport model	SN0702PASZFTMA.002 [DIRS 183471]	Section 6.5.1
GoldSim Biosphere Model Files for Calculating Groundwater and Volcanic Biosphere Dose Conversion Factors	MO0705GOLDSIMB.000 [DIRS 181281], file *ERMYN_GW_Rev01_PDC_Ac227.gsm*	Section 6.5.2.2
Alfalfa overwatering rate (infiltration rate beneath the irrigated fields)	BSC 2004 [DIRS 169673], Table 6.9-1	Section 6.5.2.1
Alfalfa irrigation rate	BSC 2004 [DIRS 169673], Table 6.5-2	Section 6.5.2.1
Annual water demand; agricultural use; commercial/industrial use; and individual/municipal water use	10 CFR 63 [DIRS 180319] for annual water demand and 66 FR 32074 [DIRS 155216], p.32,112 for water uses	Section 6.5.3.1
Gravimetric moisture content, dry bulk density, total water potential, and lithologic description of samples from six Amargosa Valley wells located within the irrigated fields	Stonestrom 2003 [DIRS 165862], p. 14 (dry bulk density), Appendix A (lithologic description) and Appendix B (gravimetric moisture and water potential data). These data are considered established fact (see Section 4.1.2.1 for details).	Section 6.5.3.8
Present-day climate water table elevations	DTN: MO0611SCALEFLW.000 [DIRS 178483], file *wt_HFM2006_X.dat*	Section 6.5.3.7
Particle tracks from the repository to the accessible environment	DTN: SN0704T0510106.008 [DIRS 181283], file *sz06-100.sptr2*	Section 6.5.3.7
Topographical data	DTN: MO0010COV00124.001 [DIRS 153783]	Section 6.5.3.7
Water table rise beneath the repository under glacial transition climate and location of the discharge point in vicinity of the boundary of the accessible environment	D'Agnese et al.1999 [DIRS 120425], Figure 13 (water table rise) and Figure 16 (discharge point location). These data are qualified for use in this report in Section 4.1.1.2.	Section 6.5.3.7
Coordinates, elevation, and lithostratigraphy in wells NC-EWDP-19IM1A, NC-EWDP-19IM2A, NC-EWDP-22SA, NC-EWDP-23P, and NC-EWDP-10SA	DTN: GS030108314211.001 [DIRS 163483], files *NC_EWDP_10SA_Lithlog.doc*, *NC_EWDP_1(IM1A_Lithlog.doc*, *NC_EWDP_19IM2A_Lithlog.doc*, *NC_EWDP_22SA_Lithlog.doc*, *NC_EWDP_23P_Lithlog.doc*	Section 6.5.3.3.3.1

Table 4.1-1. Direct Inputs (Continued)

Data Description	Data Tracking Number or Source	Where Discussed in this Report
Lithostratigraphy in well NC-EWDP-2DB	DTN: GS011008314211.001 [DIRS 158690]	Section 6.5.3.3.3.1
Digital orthophoto quadrangles	MO0706FD30MQMA.000 [DIRS 181355]. These data are qualified for use in this report in Section 4.1.1.1.	Sections 6.5.3.2.1 and 6.5.3.2.3
National Agriculture Imagery Program digital orthophoto quadrangles of part of Amargosa Valley	MO0706NAIPDQI9.000 [DIRS 181356]; qualified for use in this report in Section 4.1.1	Section 6.5.3.2.1
Residential locations	MO0309COV03136.000 [DIRS 181357]	Section 6.5.3.2.2
Specific discharge at Site 19D	DTN: LA0303PR831231.002 [DIRS 163561] (Table 3 in the file *IHLRWM_Reimus et al. doc*)	Section 6.5.3.3.3.2
Septic leach field application rate	EPA 2002 [DIRS 177934], Table 5-1 These data are considered established fact (see Section 4.1.2.2 for details).	Section 6.5.3.8
Indoor water uses	Wilkes et al. 2005 [DIRS 181326] These data are considered established fact (see Section 4.1.2.3 for details).	Section 6.5.3.4.2
Particle Density	Fetter 2001 [DIRS 156668], p.70 These data are considered established fact.	Section 6.5.3.8

Three data sets listed in Table 4.1-1 are qualified within Section 4.1.1 in accordance with Section 6.2.1 L of SCI-PRO-006 for use in this report. These data sets are from external sources and are not established fact. The data qualification plans are provided in Appendix A (geospatial data) and Appendix B (water table rise data). Three data sets listed in Table 4.1-1 are considered established facts as described in Section 4.1.2 and do not need qualification. The value for the particle density taken from the textbook (Fetter 2001 [DIRS 156668], p.70) is an established fact and does not need qualification.

4.1.1 Qualification of Unqualified Data Sets

Two unqualified geospatial data sets in DTN: MO0706FD30MQMA.000 [DIRS 181355] and DTN: MO0706NAIPDQI9.000 [DIRS 181356] are qualified for use in this model report in Section 4.1.1.1. The unqualified water table rise data from *Simulated Effects of Climate Change on the Death Valley Regional Ground-Water Flow System, Nevada and California* (D'Agnese et al. 1999 [DIRS 120425]) are qualified for use in this model report in Section 4.1.1.2.

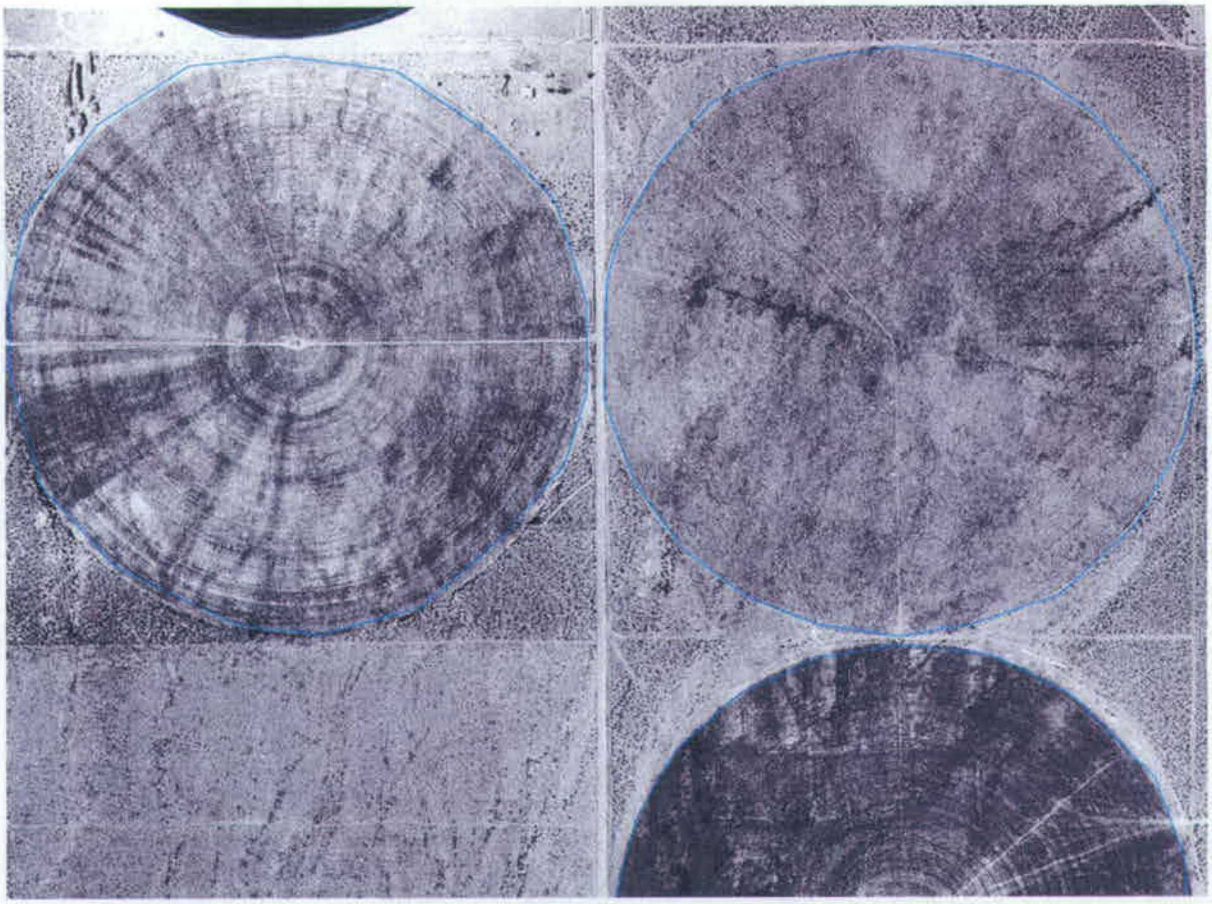
4.1.1.1 Qualification of Unqualified Geospatial Data Sets

Two geospatial data sets used as direct inputs in this model reports are unqualified. The data qualification of these data sets is provided below. The data qualification method used for these two data sets is Method 2 of Attachment 3 of SCI-PRO-001, *Corroborating Data*. The rationale for using this method is that corroborating data are available for comparison and the inferences drawn to corroborate the data can be clearly illustrated and documented. These geospatial data sets are independent of each other and contain images that were taken at different times.

- The unqualified DTN: MO0706FD30MQMA.000 [DIRS 181355], Four Digital 30 Minute Quad Mosaics of Part of the Amargosa Valley Area consists of black and white aerial photography in a mosaic pattern as 30-minute quads. These images are part of a large set covering most of Nevada and are available from the website of the Keck Library map collection at the University of Nevada Reno. The original source imagery was the United States Geological Survey (USGS) Digital Orthophoto Quarter Quads. These data are in universal transverse mercator (UTM) zone 11 coordinates, NAD83, GRS80. The resolution or pixel size is 1 meter. The quadrangles are East of Echo Canyon, Franklin Well, Leeland, and South of Amargosa Valley. These mosaics were produced by personnel from the Nevada Department of Transportation.

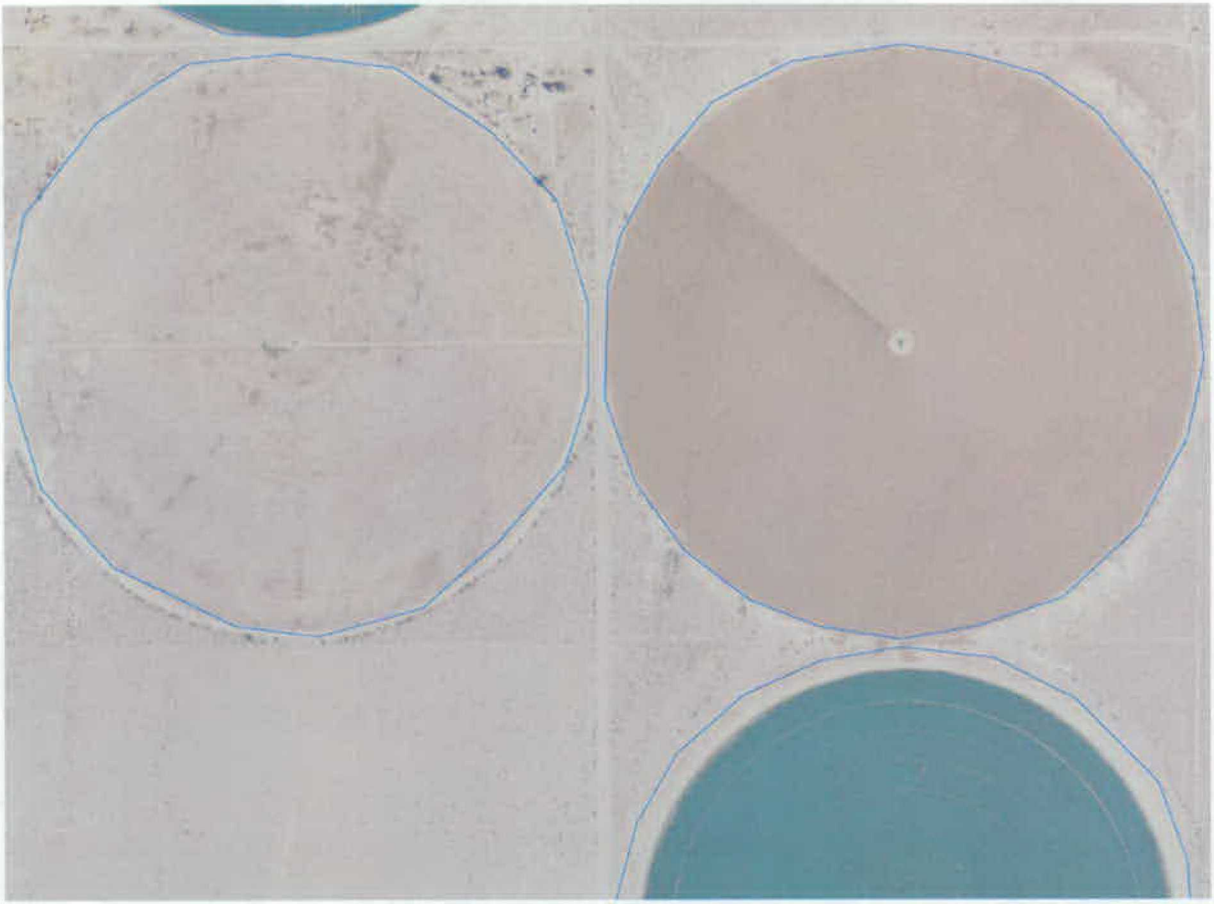
- The unqualified DTN: MO0706NAIPDQI9.000 [DIRS 181356] Nine National Agriculture Imagery Program (NAIP) digital quarter quad (3.75-minute) images of part of the Amargosa Valley area, consists of natural color aerial photography in 3.75-minute quarter quads. These images are part of a large set covering much of Nevada available from the website of the Keck Library map collection at the University of Nevada Reno. The imagery is from the NAIP. The data are in the UTM zone 11 coordinate, NAD83. The resolution or pixel size is 1 meter. Portions of the East of Echo Canyon, Franklin Well, Leeland, and South of Amargosa Valley quadrangles are included.

These data are used to delineate agricultural areas within the area of interest and specifically to assign a single centroid location to each agricultural area in the Amargosa Valley. Agricultural areas of interest approximate a quarter mile (or larger) center pivot. Acceptance criteria for the qualification of these data using corroboration will consist of visual inspection of the agricultural areas defined from one DTN set compared to the second data set. Both data sets are in the same coordinate/projection system, and no transformations are required. Georeferencing files are included with each data set, minimizing or essentially eliminating the need for interaction in viewing the data sets. Figures 4.1-1 and 4.1-2 show several of the defined areas on the 30 minute mosaics and on the NAIP photographs.



Source: DTN: MO0706FD30MQMA.000 [DIRS 181355].

Figure 4.1-1. 30-Minute Quad Mosaic of an Amargosa Valley Agricultural Area



Source: DTN: MO0706NAIPDQI9.000 [DIRS 181356].

Figure 4.1-2. Digital Quarter Quad (3.75-minute) Image of the Amargosa Valley Agricultural Area Shown in Figure 4.1-1

The visual inspection shows the appearance of the defined areas to be essentially identical with respect to the underlying photography. The extent and quality of the visual match can be easily verified throughout the area of interest. The fact that the same polygon appears in the same place on both images is evidence that they do corroborate each other. The polygonal outline that is visible in both figures is not part of the original image but was used for the purpose of delineating irrigated areas.

In addition to the essentially identical corroboration of the two data sets by visual inspection, other factors may be considered in this qualification process. Both data sets originated with separate federal organizations with long histories of aerial photography and mensuration using photography. Based on the factors considered above, both of the data sets, DTNs: MO0706FD30MQMA.000 [DIRS 181355] and MO0706NAIPDQI9.000 [DIRS 181356] are adequately and appropriately justified for use as direct input to this report.

4.1.1.2 Qualification of Unqualified Water Table Rise Data

The data qualification of the unqualified water rise data from the report by D'Agnese et al. (1999 [DIRS 120425]) used as direct inputs in this model report is considered below. The data to be qualified are: (1) the predicted water table rise of 120 m beneath the repository under the glacial transition climate conditions (D'Agnese et al. 1999 [DIRS 120425], Figure 13), and (2) the predicted location of the closest discharge point downgradient from well NC-EWDP-19D (D'Agnese et al. 1999 [DIRS 120425], Figure 16). The water rise data are used to estimate the depth to the water table and an increase in the aquifer saturated thickness under the glacial transition climate conditions as described in detail in Section 6.5.3.7. This information is included in output DTN: SN0703PASZIRMA.001 (directory *Parameters*, file *Depth_to_WT.xls*).

The data qualification method selected for qualification of the water table rise data for use in this model report is Method 5 of Attachment 3 of SCI-PRO-001, *Technical Assessment.* The rationale for using this method is that all the information required for technical data assessment, such as methodology and developmental results, is available from the report by D'Agnese et al. (1999 [DIRS 120425]). The data qualification plan is provided in Appendix B. The technical assessment is discussed below.

Determination that the employed methodology is acceptable – A water-resources investigations report by the USGS entitled *Simulated Effects of Climate Change on the Death Valley Regional Ground-Water Flow System, Nevada and California* (D'Agnese et al. 1999 [DIRS 120425]) provides estimate of the water table rise in the Death Valley region and near Yucca Mountain for the future climate conditions. These estimates are based on the simulations that investigate the effects of climate changes on the Death Valley regional ground-water flow system. Simulated water level changes and changes in discharge areas and flow near Yucca Mountain are provided. The simulations were performed with the code MODFLOWP. At the time of its use MODFLOWP was the industry standard for groundwater flow calculations. MODFLOWP (STN: 10144-2.3-00 [DIRS 150454]) was qualified for use in the YMP and was applied in *Recharge and Lateral Groundwater Flow Boundary Conditions for the Saturated Zone Site-Scale Flow and Transport Model* (BSC 2004 [DIRS 170015]) to estimate flow at the lateral boundaries of the saturated zone site-scale flow model. Model construction and review were performed in accordance with Yucca Mountain Project quality-assurance procedures and U.S. Geological Survey policy existing at that time.

Determination that confidence in data and developmental results is warranted – The regional ground-water studies conducted in support of this modeling were conducted by the U.S. Geological Survey as a part of the Yucca Mountain site-characterization project. The scope of this study was determined by Department of Energy Yucca Mountain Project guidelines. The regional model data were developed from published sources. The description of the data sources and methods of data development provided in the report by D'Agnese et al. (1999 [DIRS 120425]) are adequate and appropriate for the purpose. The model was validated using the climate indicators available for the past glacial climate conditions. In this validation, the modeling results obtained for the glacial transition climate were compared to the observed paleodischarge sites. Groundwater discharge occurred at most of the predicted paleodischarge sites.

Confirmation that the data have been used in similar applications – The data from the report by D'Agnese et al. 1999 ([DIRS 120425]) were used in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2007 [DIRS 181650]) for the applications that are similar to those for which the data are used in this model report. Corroborative information from simulations using the Death Valley regional groundwater flow model (D'Agnese et al. 1999 [DIRS 120425]) were used in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2007 [DIRS 181650]) to estimate the scaling factors for groundwater flow rates in the saturated zone under future climatic conditions. The estimates obtained from the weighting of the infiltration models and the Death Valley regional flow model for the glacial transition climate were considered to be very similar. The value corresponding to the one obtained from the Death Valley regional groundwater flow model was used as the groundwater flow scaling factor for the glacial transition climate in the saturated zone flow and transport abstraction model (SNL 2007 [DIRS 181650], Section 6.5[a]). The data from the report by D'Agnese et al. 1999 ([DIRS 120425]) are also used in the TSPA.

Other considerations – An updated Death Valley regional ground-water flow system model was developed later and documented in *Death Valley Regional Ground-Water Flow System, Nevada and California - Hydrogeologic Framework and Transient Ground-Water Flow Model* (Belcher 2004 [DIRS 173179]). The updated model provides more detailed representation of the hydrogeologic units. No estimates of the water table rise in the Death Valley region and near Yucca Mountain for the future climate conditions were done with this updated model. The water table rise is mostly affected by the changes in precipitation. The differences in hydrogeologic units should have small (if any) impacts on the water table rise. This is corroborated by the similarity in the infiltration ratios (glacial transition climate to present-day climate) estimated from the simulations of net infiltration in the area near Yucca Mountain (SNL 2007 [DIRS 174294]), weighting factors for alternative infiltration maps derived from calibration of the UZ site-scale flow model (SNL 2007 [DIRS 175177]), and the information from simulations using the Death Valley regional groundwater flow model (D'Agnese et al. 1999 [DIRS 120425]). Consequently, the use of the report by D'Agnese et al. (1999 [DIRS 120425]) is appropriate for this purpose.

Conclusion – Based on the technical assessment considered, the water table rise data from D'Agnese et al. (1999 [DIRS 120425]) are adequately and appropriately justified for use as direct input to this model report.

4.1.2 Data Sets Used as Established Facts

Three data sets used as direct inputs in this report are considered established facts. These data were not sponsored by the DOE Office of Civilian Radioactive Waste Management (OCRWM) and were not subject to the quality requirements of either the U.S. Nuclear Regulatory Commission (NRC) at 10 CFR 63, Subpart G [DIRS 180319] or the OCRWM *Quality Assurance Requirements and Description* (DOE 2007 [DIRS 182051]). Nevertheless, these data are suitable for YMP use because they are considered established fact from authoritative sources. As such, the data do not require qualification in accordance with the NRC Generic Technical Position *Qualification of Existing Data for High-Level Nuclear Waste Repositories* (Altman et al. 1988 [DIRS 103750]) and with SCI-PRO-001, *Qualification of Unqualified Data*. Information in support of this statement is provided below for each data set.

4.1.2.1 Amargosa Farms Wells Data

A publication by the USGS (Stonestrom et al. 2003 [DIRS 165862]) entitled *Estimates of Deep Percolation Beneath Native Vegetation, Irrigated Fields, and the Amargosa-River Channel, Amargosa Desert, Nye County, Nevada* provides data collected from 9 boreholes that are 10 to 16 meters deep. Appendix A of this USGS report describes the sediments observed from cores sampled at 0.5- to 1.0-m intervals, and Appendix B provides data on water content and potential. The irrigation recycling model uses this information as described in Section 6.5.3.8. This information is included in output DTN: SN0703PASZIRMA.001 (directory Parameters, *Saturation.xls*). Although this document mentions Yucca Mountain, it was written for the broader purpose to assist regulators in developing new water-quality standards.

This USGS publication is considered a factual and relevant source for the irrigation recycling model. Its approval by the Secretary of the Interior and the USGS Director signifies that the publications were thoroughly reviewed for quality, as well as their technical content. State and federal governments also consider the publication to be factual. Otherwise, they would not rely on the data to monitor radioactive contaminants, to develop water-quality standards, and to select sites for the disposal of low-level waste.

4.1.2.2 Septic Leach Field Data

Estimates from *Onsite Wastewater Treatment Systems Manual* (EPA 2002 [DIRS 177934]) of hydraulic loads (application rates) on septic leach fields were used to develop the maximum application rate as described in Section 6.5.3.9. This information is appropriate for this use because these data were collected by the U.S. Environmental Protection Agency (EPA) and represent the most complete compilation on the onsite wastewater treatment systems. The purpose of this manual is to serve as a technical guidance for the design, construction, operation, maintenance, and regulation of onsite systems. It is also intended to provide information to policy makers and regulators at the state, tribal, and local levels who are charged with responsibility for developing, administering, and enforcing wastewater treatment and management program codes. The data presented in the manual were collected by convening a team of subject matter experts from public agencies, private organizations, professional associations, and the academic community. Two representatives from the U.S. EPA Office of Water and a representative from the Office of Research and Development coordinated the project team for this document. Close coordination with the U.S. EPA Office of Wastewater Management and other partners at the federal, state, and local levels helped to ensure that the information in this manual supports and complements other efforts to improve onsite wastewater management across the nation. The data have been reviewed in accordance with the U.S. EPA policy and was approved for publication. As such, this information is recognized as an authoritative source on the wastewater systems and is considered established fact.

4.1.2.3 Indoor Water Use Data

Estimates from *Quantification of Exposure-Related Water Uses for Various U.S. Subpopulations* (Wilkes et al. 2005 [DIRS 181326]) of indoor water uses were used to develop the probability distribution for the fraction of water used indoors as described in Section 6.5.3.5. This information is appropriate for this use because these data were collected by the EPA and represent the most complete compilation on the indoor water uses. The purpose of this work was to understand population water-use behavior for indoor water-use activities as a function of demographic characteristics. In this report (Wilkes et al. 2005 [DIRS 181326]), frequencies and durations of use of showers, baths, clothes washers, dishwashers, toilets and faucets are presented and compared for various demographic groups derived from analyses of the National Human Activities Pattern Survey (NHAPS) database, the Residential End Uses of Water Study (REUWS) database, the Residential Energy Consumption Survey (RECS), as well as from current literature and manufacturer information. Volumes and flow rates are also analyzed from REUWS for the various water uses. Furthermore, tap water ingestion data are analyzed for various population groups derived from the Continuing Survey of Food Intake by Individuals (CSFII) as well as from NHAPS and current literature. Typical parameters of indoor water-uses are presented and recommended for use in human exposure modeling. As such, this information is recognized as an authoritative source on the wastewater systems and is considered established fact.

4.2 CRITERIA

The work described in this modeling report has been determined to be subject to the regulatory requirements listed in Table 4-2-1.

Table 4.2-1. Requirements Applicable to this Model

Requirement Title	Related Regulation
Requirements for Performance Assessment	10 CFR 63.114 [DIRS 180319]
Definitions for Subpart L (Postclosure Public Health and Environmental Standards)	10 CFR 63.302 [DIRS 180319]
Limits on Performance Assessments	10 CFR 63.342 [DIRS 180319]
Required Characteristics of the Reasonably Maximally Exposed Individual	10 CFR 63.312 [DIRS 180319]
Required Characteristics of the Reference Biosphere	10 CFR 63.312 [DIRS 180319]

The applicable federal regulations and technical requirements related to the activities associated with this work are generally implemented through the appropriate procedures identified in the TWP (SNL 2007 [DIRS 181342], Section 4). In particular, the requirements identified in 10 CFR 63.114 (a), (b), (c), and (g) [DIRS 180319] are implemented through SCI-PRO-006. No DOE order is applicable to the scope of work identified in this modeling report.

The activities described in this report will be subject to regulatory review per *Yucca Mountain Review Plan, Final Report* (YMRP) (NRC 2003 [DIRS 163274]) provisions and criteria. Appropriate YMRP acceptance criteria (provided below) relevant to process models for the unsaturated zone, saturated zone, and biosphere will be addressed because they are either implemented in the irrigation recycling model or are a part of the interface with the irrigation recycling model as explained below.

The irrigation recycling model implicitly includes the stand-alone version of the saturated zone flow and transport abstraction model (DTN: SN0702PASZFTMA.002 [DIRS 183471]). The mass fluxes calculated by this model represent the input into the irrigation recycling model (Section 6.4). The parameters defined in the saturated zone flow and transport abstraction model are directly used in the irrigation recycling model (Section 6.5.1). The irrigation recycling model implements simplified flow and transport in the unsaturated zone (Section 6.4), provides the interface with the biosphere model (Section 6.4), and uses a number of the biosphere modeling parameters (Section 6.5.2).

4.2.1 Acceptance Criteria from Section 2.2.1.3.6.3, Flow Paths in the Unsaturated Zone

Acceptance Criterion 1: ***System Description and Mode/Integration Are Adequate***

- Subcriterion (2) – The aspects of geology, hydrology, geochemistry, physical phenomena, and couplings that may affect flow paths in the unsaturated zone are adequately considered. Conditions and assumptions in the abstraction of flow paths in the unsaturated zone are readily identified and consistent with the body of data presented in the description.

- Subcriterion (3) – The abstraction of flow paths in the unsaturated zone uses assumptions, technical bases, data, and models that are appropriate and consistent with other related DOE abstractions. For example, the assumptions used for flow paths in the unsaturated zone are consistent with the abstractions of quality and chemistry of water contacting waste packages and waste forms; climate and infiltration; and flow paths in the saturated zone (NRC 2003 [DIRS 163274], Sections 2.2.1.3.3, 2.2.1.3.5, and 2.2.1.3.8). The descriptions and technical bases are transparent and traceable to site and design data.

- Subcriterion (5) – Sufficient data and technical bases to assess the degree to which FEPs have been included in this abstraction are provided.

- Subcriterion (7) – Average parameter estimates used in process-level models are representative of the temporal and spatial discretizations considered in the model.

- Subcriterion (8) – Reduction in unsaturated zone transport distances after a climate-induced water table rise is considered.

- Subcriterion (9) – Guidance in NUREG-1297 (Altman et al. 1988 [DIRS 103597]) and NUREG-1298 (Altman et al. 1988 [DIRS 103750]), or other acceptable approaches for peer review and data qualification is followed.

Acceptance Criterion 2: ***Data Are Sufficient for Model Justification***

- Subcriterion (1) – Hydrological and thermal-hydrological-mechanical-chemical values used in the license application are adequately justified. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided.

- Subcriterion (2) – Data on the geology, hydrology, and geochemistry of the unsaturated zone are collected using acceptable techniques.

- Subcriterion (6) – Accepted and well-documented procedures are used to construct and calibrate numerical models.

- Subcriterion (7) – Reasonably complete process-level conceptual and mathematical models are used in the analyses. In particular, (i) mathematical models are provided that are consistent with conceptual models and site characteristics; and (ii) the robustness of results from different mathematical models is compared.

Acceptance Criterion 3: ***Data Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably account for uncertainties and variabilities, and do not result in an underrepresentation of the risk estimate.

- Subcriterion (2) – The technical bases for the parameter values used in this abstraction are provided.

- Subcriterion (6) – Uncertainties in the characteristics of the natural system and engineered materials are considered.

Acceptance Criterion 4: ***Model Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – Alternative modeling approaches of FEPs consistent with available data and current scientific understanding are investigated. The results and limitations are appropriately considered in the abstraction.

- Subcriterion (2) – The bounds of uncertainty created by the process-level models are considered in this abstraction.

- Subcriterion (3) – Consideration of conceptual model uncertainty is consistent with available site characterization data, laboratory experiments, field measurements, natural analog information, and process-level modeling studies; and the treatment of conceptual model uncertainty does not result in an underrepresentation of the risk estimate.

Acceptance Criterion 5: ***Model Abstraction Output Is Supported by Objective Comparisons***

- Subcriterion (1) – The models implemented in this total system performance assessment abstraction provide results consistent with output from detailed process-level models and/or empirical observations (laboratory and field testing and/or natural analogs).

- Subcriterion (2) – Abstractions of process-level models conservatively bound process-level predictions.

4.2.2 Acceptance Criteria from Section 2.2.1.3.7.3, Radionuclide Transport in the Unsaturated Zone

Acceptance Criterion 1: ***System Description and Model Integration Are Adequate***

- Subcriterion (2) – The description of the aspects of hydrology, geology, geochemistry, design features, physical phenomena, and couplings that may affect radionuclide transport in the unsaturated zone is adequate. For example, the description includes changes in transport properties in the unsaturated zone from water-rock interaction. Conditions and assumptions in the total system performance assessment (TSPA) abstraction of radionuclide transport in the unsaturated zone are readily identified and consistent with the body of data presented in the description.

- Subcriterion (3) – The abstraction of radionuclide transport in the unsaturated zone uses assumptions, technical bases, data, and models that are appropriate and consistent with other related DOE abstractions. For example, the assumptions used for radionuclide transport in the unsaturated zone are consistent with the abstractions of radionuclide release rates and solubility limits and flow paths in the unsaturated zone ((NRC 2003 [DIRS 163274], Sections 2.2.1.3.4 and 2.2.1.3.6). The descriptions and technical bases provide transparent and traceable support for the abstraction of radionuclide transport in the unsaturated zone.

- Subcriterion (5) – Sufficient data and technical bases for the inclusion of FEPs related to radionuclide transport in the unsaturated zone in the TSPA abstraction are provided.

- Subcriterion (6) – Guidance in NUREG-1297 (Altman et al. 1988 [DIRS 103597]) and NUREG-1298 (Altman et al. 1988 [DIRS 103750]), or other acceptable approaches for peer review and data qualification is followed.

Acceptance Criterion 2: ***Data Are Sufficient for Model Justification***

- Subcriterion (1) – Geological, hydrological, and geochemical values used in the license application are adequately justified (e.g., flow-path length, sorption coefficients, retardation factors, and colloid concentrations). Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided.

Acceptance Criterion 3: ***Data Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably accountable for uncertainties and variabilities, and do not result in an underrepresentation of the risk estimate.

- Subcriterion (4) – Uncertainty is adequately represented in parameter development for conceptual models, process-level models, and alternative conceptual models, considered in developing the abstraction of radionuclide transport in the unsaturated zone. This may be done either through sensitivity analyses or use of conservative limits.

Acceptance Criterion 4: ***Model Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – Alternative modeling approaches of FEPs are considered and are consistent with available data and current scientific understanding, and the results and limitations are appropriately considered in the abstraction.
- Subcriterion (2) – Conceptual model uncertainties are adequately defined and documented, and effects on conclusions regarding performance are properly assessed.
- Subcriterion (4) – Appropriate alternative modeling approaches are consistent with available data and current scientific knowledge, and appropriately consider their results and limitations, using tests and analyses that are sensitive to the processes modeled. Thus, for radionuclide transport through fractures, the DOE adequately considers alternative modeling approaches to develop its understanding of fracture distributions and ranges of fracture flow and transport properties in the unsaturated zone.

Acceptance Criterion 5: ***Model Abstraction Output Is Supported by Objective Comparisons***

- Subcriterion (2) – Outputs of radionuclide transport in the unsaturated zone abstractions reasonably produce or bound the results of corresponding process-level models, empirical observations, or both. The DOE abstracted models for Review Plan for Safety Analysis Report 2.2-79 (NRC 2003 [DIRS 163274]) radionuclide transport in the unsaturated zone are based on the same hydrological, geological, and geochemical assumptions and approximations, shown to be appropriate for closely analogous natural systems or experimental systems.
- Subcriterion (3) – Well-documented procedures accepted by the scientific community to construct and test the mathematical and numerical models are used to simulate radionuclide transport through the unsaturated zone.
- Subcriterion (4) – Sensitivity or bounding analyses are provided to support the TSPA abstraction of radionuclide transport in the unsaturated zone that cover ranges consistent with site data, field or laboratory experiments and tests, and natural analog research.

4.2.3 Acceptance Criteria from Section 2.2.1.3.8.3, Flow Paths in the Saturated Zone

Acceptance Criterion 1: ***System Description and Model Integration Are Adequate***

- Subcriterion (2) – The description of the aspects of hydrology, geology, geochemistry, design features, physical phenomena, and couplings that may affect flow paths in the saturated zone is adequate. Conditions and assumptions in the abstraction of flow paths in the saturated zone are readily identified and consistent with the body of data presented in the description.

- Subcriterion (3) – The abstraction of flow paths in the saturated zone uses assumptions, technical bases, data, and models that are appropriate and consistent with other related DOE abstractions. For example, the assumptions used for flow paths in the saturated zone are consistent with the TSPA abstraction of representative volume (NRC 2003 [DIRS 163274], Section 2.2.1.3.12). The descriptions and technical bases provide transparent and traceable support for the abstraction of flow paths in the saturated zone.

- Subcriterion (5) – Sufficient data and technical bases to assess the degree to which FEPs have been included in this abstraction are provided.

- Subcriterion (7) – Long-term climate change based on known patterns of climatic cycles during the quaternary period, particularly the last 500,000 years, and other paleoclimate data are adequately evaluated.

- Subcriterion (9) – The impact of the expected water table rise on potentiometric heads and flow directions, and consequently on repository performance, is adequately considered.

- Subcriterion (10) – Guidance in NUREG-1297 (Altman et al. 1988 [DIRS 103597]) and NUREG-1298 (Altman et al. 1988 [DIRS 103750]), or other acceptable approaches for peer review and data qualification is followed.

Acceptance Criterion 2: ***Data Are Sufficient for Model Justification***

- Subcriterion (1) – Geological, hydrological, and geochemical values used in the license application to evaluate flow paths in the saturated zone are adequately justified. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided.

- Subcriterion (2) – Sufficient data have been collected on the natural system to establish initial and boundary conditions for the abstraction of flow paths in the saturated zone.

- Subcriterion (3) – Data on the geology, hydrology, and geochemistry of the saturated zone used in the TSPA abstraction are based on appropriate techniques. These techniques may include laboratory experiments, site-specific field measurements, natural analog research, and process-level modeling studies. As appropriate, sensitivity or uncertainty analyses used to support the TSPA abstraction are adequate to determine the possible need for additional data.

- Subcriterion (4) – Sufficient information is provided to substantiate that the proposed mathematical groundwater modeling approach and proposed model(s) are calibrated and applicable to site conditions.

Acceptance Criterion 3: ***Data Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably accountable for uncertainties and variabilities, and do not result in an underrepresentation of the risk estimate.

- Subcriterion (2) – Uncertainty is appropriately incorporated in model abstractions of hydrologic effects of climate change, based on a reasonably complete search of paleoclimate data.

- Subcriterion (3) – Uncertainty is adequately represented in parameter development for conceptual models, process-level models, and alternative conceptual models, considered in developing the abstraction of flow paths in the saturated zone. This may be done through either sensitivity analyses or use of conservative limits. For example, sensitivity analyses and/or similar analyses are sufficient to identify saturated zone flow parameters that are expected to significantly affect the abstraction model outcome.

Acceptance Criterion 4: ***Model Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – Alternative modeling approaches of FEPs are considered and are consistent with available data and current scientific understanding, and the results and limitations are appropriately considered in the abstraction.

- Subcriterion (2) – Conceptual model uncertainties are adequately defined and documented, and effects on conclusions regarding performance are properly assessed. For example, uncertainty in data interpretations is considered by either analyzing reasonable conceptual flow models that are supported by site data or demonstrating through sensitivity studies that the uncertainties have little impact on repository performance.

- Subcriterion (4) – Appropriate alternative modeling approaches are consistent with available data and current scientific knowledge, and appropriately consider their results and limitations using tests and analyses that are sensitive to the processes modeled.

4.2.4 Acceptance Criteria from Section 2.2.1.3.9.3, Radionuclide Transport in the Saturated Zone

Acceptance Criterion 1: ***System Description and Model Integration Are Adequate***

- Subcriterion (2) – The description of the aspects of hydrology, geology, geochemistry, design features, physical phenomena, and couplings that may affect radionuclide transport in the saturated zone is adequate. For example, the description includes changes in transport properties in the saturated zone from water-rock interaction. Conditions and assumptions in the abstraction of radionuclide transport in the saturated zone are readily identified and consistent with the body of data presented in the description.

- Subcriterion (3) – The abstraction of radionuclide transport in the saturated zone uses assumptions, technical bases, data, and models that are appropriate and consistent with other related DOE abstractions. For example, assumptions used for radionuclide transport in the saturated zone are consistent with the TSPA abstractions of radionuclide release rates and solubility limits, and flow paths in the saturated zone (NRC 2003 [DIRS 163274], Sections 2.2.1.3.4 and 2.2.1.3.8, respectively). The descriptions and technical bases provide transparent and traceable support for the abstraction of radionuclide transport in the saturated zone.

- Subcriterion (5) – Sufficient data and technical bases for the inclusion of features, events, and processes related to radionuclide transport in the saturated zone in the TSPA abstraction are provided.

- Subcriterion (6) – Guidance in NUREG-1297 (Altman et al. 1988 [DIRS 103597]) and NUREG-1298 (Altman et al. 1988 [DIRS 103750]), or other acceptable approaches for peer review and data qualification is followed.

Acceptance Criterion 2: ***Data Are Sufficient for Model Justification***

- Subcriterion (1) – Geological, hydrological, and geochemical values used in the license application are adequately justified (e.g., flow path lengths, sorption coefficients, retardation factors, and colloid concentrations). Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided.

Acceptance Criterion 3: ***Data Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably accountable for uncertainties and variabilities, and do not result in an underrepresentation of the risk estimate.

- Subcriterion (4) – Parameter values for processes, such as matrix diffusion, dispersion, and ground-water mixing, are based on reasonable assumptions about climate, aquifer properties, and ground-water volumetric fluxes (NRC 2003 [DIRS 163274], Section 2.2.1.3.8).

- Subcriterion (5) – Uncertainty is adequately represented in parameter development for conceptual models, process-level models, and alternative conceptual models considered in developing the abstraction of radionuclide transport in the saturated zone. This may be done either through sensitivity analyses or use of conservative limits.

Acceptance Criterion 4: ***Model Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – Alternative modeling approaches of FEPs are considered and are consistent with available data and current scientific understanding, and the results and limitations are appropriately considered in the abstraction.
- Subcriterion (2) – Conceptual model uncertainties are adequately defined and documented, and effects on conclusions regarding performance are properly assessed.

4.2.5 Acceptance Criteria from Section 2.2.1.3.14, Biosphere Characteristics

Acceptance Criterion 1: ***System Description and Model Integration Are Adequate***

- Subcriterion (3) – Assumptions are consistent between the biosphere characteristics modeling and other abstractions. For example, the DOE should ensure that the modeling of FEPs, such as climate change, soil types, sorption coefficients, volcanic ash properties, and the physical and chemical properties of radionuclides are consistent with assumptions in other TSPA abstractions.
- Subcriterion (4) – Guidance in NUREG-1297 (Altman et al. 1988 [DIRS 103597]) and NUREG-1298 (Altman et al. 1988 [DIRS 103750]), or in other acceptable approaches for peer reviews, is followed.

Acceptance Criterion 2: ***Data Are Sufficient for Model Justification***

- Subcriterion (1) – The parameter values used in the license application are adequately justified (e.g., behaviors and characteristics of the residents of the town of Amargosa Valley, Nevada, and characteristics of the reference biosphere) and consistent with the definition of the reasonably maximally exposed individual (RMEI) in 10 CFR Part 63 [DIRS 180319]. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided.
- Subcriterion (2) – Data are sufficient to assess the degree to which FEPs related to biosphere characteristics modeling have been characterized and incorporated in the abstraction. As specified in 10 CFR Part 63 [DIRS 180319], the U.S. Department of Energy should demonstrate that features, events, and processes that describe the biosphere are consistent with present knowledge of conditions in the region surrounding Yucca Mountain. As appropriate, the U.S. Department of Energy sensitivity and uncertainty analyses (including consideration of alternative conceptual models) are adequate for determining additional data needs and evaluating whether additional data would provide new information that could invalidate prior modeling results and affect the sensitivity of the performance of the system to the parameter value or model.

Acceptance Criterion 3: ***Data Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably accountable for uncertainties and variabilities, do not result in an underrepresentation of the risk estimate. The models are consistent with the definition of the RMEI in 10 CFR Part 63 [DIRS 180319].

- Subcriterion (4) – Uncertainty is adequately represented in parameter development for conceptual models and process-level models considered in developing the biosphere characteristics modeling, either through sensitivity analyses, conservative limits, or bounding values supported by data, as necessary. Correlations between input values are appropriately established in the TSPA, and the implementation of the abstraction does not inappropriately bias results to a significant degree.

Acceptance Criterion 4: ***Model Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – Alternative modeling approaches of FEPs are considered and are consistent with available data and current scientific understanding, and the results and limitations of alternative modeling approaches are appropriately considered in the abstraction. Staff should evaluate alternate conceptual models of the biosphere or biosphere processes, recognizing that 10 CFR 63.305 and 63.312 [DIRS 180319] place a number of constraints on both the biosphere and the characteristics of the RMEI. Alternate conceptual models focus on exploring the variability and uncertainty in the physical FEPs, mindful of the regulatory constraints. Evaluation of behavior and characteristics of the RMEI emphasizes understanding the characteristics of the current residents of the town of Amargosa Valley, and uncertainty and variability in the data used to derive mean values.

4.3 CODES, STANDARDS, AND REGULATIONS

No codes, standards, or regulations other than those identified above in Section 4.2 were used in this model report.

5. ASSUMPTIONS

The assumptions used in this modeling report that were made in the absence of direct confirming data or evidence are described below as required in SCI-PRO-006. Other assumptions related to the modeling framework and modeling parameters are described in Section 6.

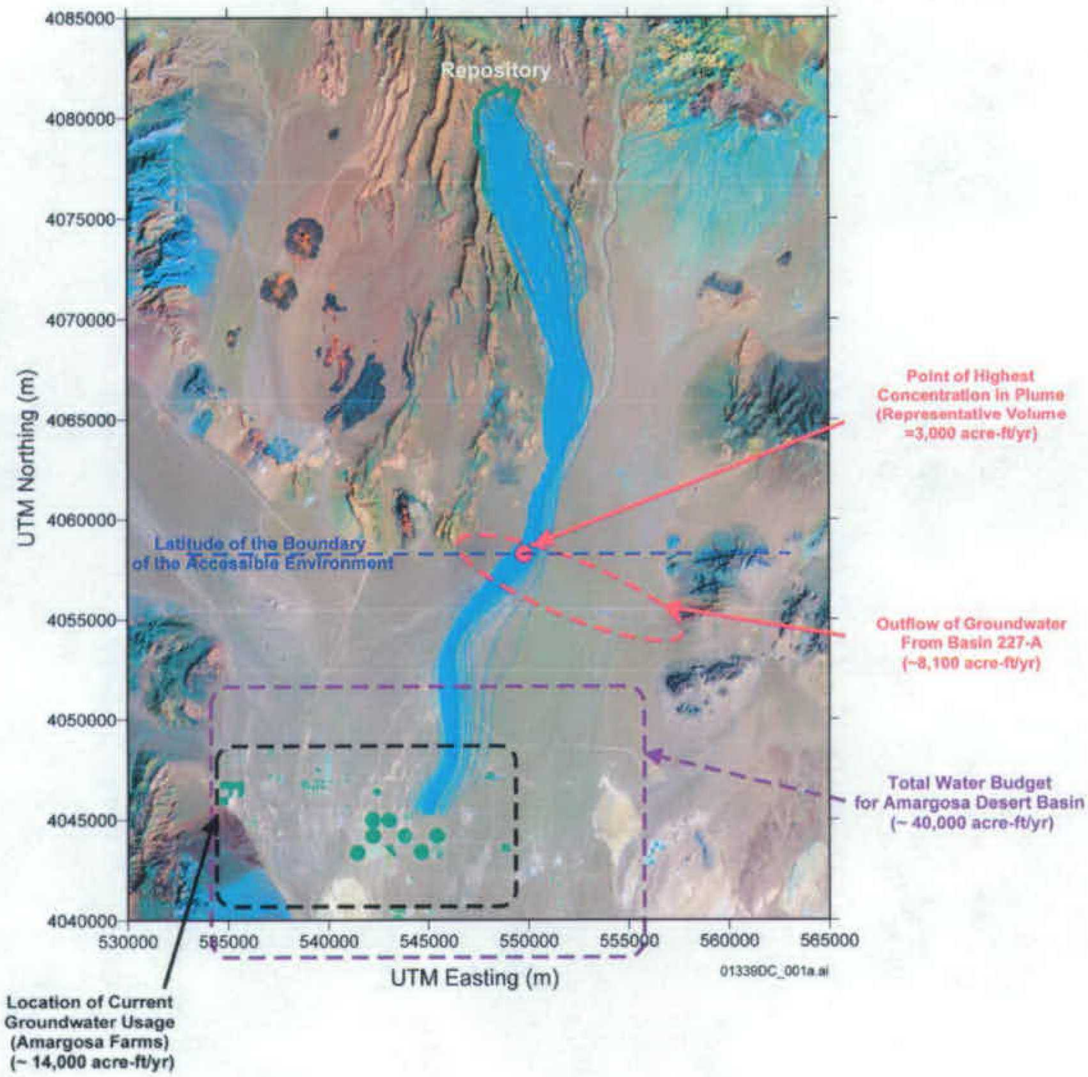
Two types of assumptions are applicable to the irrigation recycling model. The first type includes the assumptions that are related to the irrigation recycling model interfaces with the stand-alone saturated zone flow and transport abstraction model. These assumptions are defined in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2007 [DIRS 181650], Section 5). The second type includes the assumptions related to the regulatory framework and the physical processes applicable to the irrigation recycling. These assumptions are summarized below.

5.1 ASSUMPTIONS INFERRED FROM THE REGULATORY FRAMEWORK

Irrigation recycling affects the average concentrations in the groundwater supply of the hypothetical community in which the RMEI resides. The location of this hypothetical community and the community water supply well and the RMEI characteristics must be defined to model the irrigation recycling. The RMEI is defined in 10 CFR 63.102(i) [DIRS 180319] as a hypothetical person that lives in a community with characteristics of the town of Amargosa Valley. The required characteristics of the RMEI are provided in 10 CFR 63.312 [DIRS 180319]. The characteristics of the reference biosphere and the RMEI are based on current human behavior and biosphere conditions, even though the depth to the water table will change with changes in climate states. This is a conservative approach as it is likely that there will be less water use if the climate is wetter.

The regulatory framework in 10 CFR 63 [DIRS 180319] may be subject to different interpretations about the RMEI location and characteristics with respect to agricultural land use. Consequently, the corresponding assumptions are made based on the YMP understanding of the regulation.

1. **Hypothetical Community Location** – The hypothetical community is located at or in the vicinity of the boundary of the accessible environment of which the southernmost extent is defined in 10 CFR 63.302 [DIRS 180319] along a line at 36°40'13.6661" north latitude (Figure 5.1-1). The following definition in 10 CFR 63.312(a) [DIRS 180319] is used to support this assumption: The RMEI "lives in the accessible environment above the highest concentration of radionuclides in the plume of contamination." The location of the highest concentration in the plume of contamination in the accessible environment is where the flow paths originating at the repository intersect the boundary of the accessible environment. This approximately corresponds to the location of the well NC-EWDP-19D (Figure 5.1-1).



Sources: BSC 2005 [DIRS 174190], Section 6.2.46 (water budget information); SNL 2007 [DIRS 177391], Figure 6-17 (flow paths (light blue)).

NOTE: For illustration purposes only. The compliance point approximately corresponds to the location of the well NC-EWDP-19-D.

Figure 5.1-1. Locations of the Hypothetical and Current Groundwater Usage

2. **Hypothetical Well Location** – All water used by the hypothetical community is withdrawn from a hypothetical well. The hypothetical well is placed at the location of well NC-EWDP-19D (the point of the highest concentration in the plume) shown in Figure 5.1-1. The well location stays the same for all of the simulations. Multiple wells and/or a different location of the hypothetical well cannot be used because it would violate the maximum concentration requirement.

3. **Irrigated Fields Location** – Irrigation recycling will take place at the compliance point, where the hypothetical community is located, because such a process is known to take place elsewhere in the area (in Amargosa Valley), as the result of irrigated agriculture (Stonestrom et al. 2003 [DIRS 165862]). The current locations of the irrigated fields are shown in Figure 5.1-1.

4. **Total Water Use** – The hypothetical community uses the groundwater at the rate equal to the annual water demand of 3,000 ac-ft/yr. This assumption is based on the definition of RMEI in 10 CFR 63.312(c) [DIRS 180319] according to which RMEI "uses well water with average concentrations of radionuclides based on an annual water demand of 3,000 acre-feet." The assumption that 3,000 ac-ft/yr are extracted from the alluvial aquifer and are used by the community at the compliance point is a bounding assumption. The rule does not directly imply that the RMEI uses all of the annual water demand; that groundwater is pumped out of the aquifer; and that all of the water is used at the point of compliance. Alternative interpretations would be that the community uses only a portion of the annual water demand and some of the water is used outside of the compliance point. These interpretations would minimize the irrigation recycling impacts and are not considered in this report. The current water use in Amargosa Farms, the water budget for the Amargosa Desert Basin (groundwater source for the current water use), and water budget for the Basin 227-A (groundwater source for the hypothetical water use) are shown in Figure 5.1-1 for comparison.

5. **Water Uses by Categories -** The water use categories are similar to those used by the EPA in defining the basis for the 3,000 ac-ft annual water demand for the representative volume. The EPA assumption was that 85% of the water (2,550 ac-ft/yr) is used for alfalfa irrigation, about 3% (100 ac-ft/yr) for commercial/industrial water demand, and 4% (120 ac-ft/yr) for individual/municipal water demand (66 FR 32074 [DIRS 155216], p. 32,112). The remainder (230 ac-ft/yr) represents the residual uncertainty.

5.2 PHYSICAL PROCESS ASSUMPTIONS

The following assumptions were made about the physical processes related to irrigation recycling.

1. The pumping well captures the entire contaminant plume. This is a conservative assumption because well capture zone may be smaller than the contaminant plume based on capture zone analysis presented in Section 6.5.3.3.

2. The pumping is continuous, and the constant pumping rate is 3,000 ac-ft/yr. The irrigation with contaminated water is continuous as well. This is a bounding assumption because irrigation is not likely to be continuous.

3. The properties of the alluvium within the unsaturated zone (such as saturated hydraulic conductivity, effective porosity, and bulk density) are the same as those of the alluvium derived for the saturated zone. This is reasonable assumption because the same alluvial deposits are present in the saturated and unsaturated zone.

4. Continuous irrigation within the community boundaries results in the same percolation rates in the unsaturated zone everywhere beneath the community. This is bounding assumption because the infiltration rates will be lower beneath the non-irrigated areas.

5. The saturated zone parameters are climate-dependent (aquifer thickness and specific discharge depend on the governing climate states). The biosphere parameters used in irrigation recycling model are based on the present-day climate as required by the regulatory framework as described in *Biosphere Model Report* (SNL 2007 [DIRS 177399], Section 6.11.1.2).

6. The septic leach fields are located at the water table. This is a bounding assumption because it does not take credit for radionuclide transport within the unsaturated zone.

7. A piston flow conceptual model can be used to simulate the movement of moisture in the unsaturated zone. This is a simplified representation that does not incorporate the relationships between the pressure, saturation, and hydraulic conductivity under unsaturated conditions. The piston flow rate is equal to the percolation rate in the unsaturated zone. These assumptions are reasonable because they lead to the realistic transport velocities through the unsaturated zone (Section 7.2). Note that the percolation rate in the unsaturated zone beneath the irrigated fields is estimated in the biosphere process model (BSC 2004 [DIRS 169673], Table 6.9-1). This percolation rate is the result of all the processes occurring at the soil-atmosphere interface, such as crop evapotranspiration, soil evaporation, irrigation, precipitation, and other processes. Because the percolation rate is available, the irrigation recycling model uses this rate directly and does not simulate the soil-atmosphere interface to estimate percolation rate.

8. Radionuclides that reach the water table and are within the well capture zone are returned to the well volume without taking credit for the transport within the saturated zone. This is a bounding assumption because the radionuclides from the distant irrigation locations will have to travel noticeable distances through the saturated zone to reach the pumping well. Thus, radionuclide transport in the saturated zone is not considered.

6. MODEL DISCUSSION

6.1 MODELING OBJECTIVES

The primary objective of the irrigation recycling model is to provide a method to calculate radionuclide concentrations in the groundwater including the recycling of the radionuclides due to agricultural and residential use of the contaminated water at the point of compliance. Radionuclide concentrations in the groundwater represent inputs to the TSPA. The RMEI dose is calculated by multiplying these concentrations by the biosphere dose conversion factors derived from an analysis of the environmental transport of radionuclides and the human exposures based on the diet and living style of the current population of the town of Amargosa Valley.

The goal was to develop a method that would allow for the realistic representation of the system being considered. This method should include the existing mechanisms that remove the radionuclides from the recycling, such as soil erosion and water use outside of the well capture zone. The irrigation recycling model should provide consistent interfaces with the stand-alone saturated zone flow and transport abstraction model and the biosphere process model. The model uncertainty should be assessed through developing probability distributions for the irrigation recycling modeling parameters.

6.2 FEATURES, EVENTS, AND PROCESSES FOR THIS MODELING REPORT

As stipulated in *Technical Work Plan for: Evaluation of the FEP 1.4.07.03.0A - Recycling of Accumulated Radionuclides from Soils to Groundwater* (SNL 2007 [DIRS 181342]), this model report provides information that addresses FEP 1.4.07.03.0A. This is consistent with the assignment of FEPs in the FEP list for license application, DTN: MO0706SPAFEPLA.001 [DIRS 181613].

FEPs included for TSPA that are not directly addressed in this report but are relevant to this model analysis in accordance with their assignment in DTN: MO0706SPAFEPLA.001, *FY 2007 LA FEP List and Screening* are provided in Table 6.2-1. The table provides specific reference to the various sections within this document where issues related to each FEP are addressed. The FEPs that were excluded for TSPA are given in DTN: MO0706SPAFEPLA.001 [DIRS 181613], file *FEPs_be.mdb*, Table 7.1-1.

Table 6.2-1. Features, Events, and Processes Included in TSPA and Relevant to This Model Report

FEP No.	FEP Name	Sections That Support Disposition
1.3.01.00.0A	Climate change	5.2; 6.3; 6.5.3.3.3; 6.5.3.4.3; 6.5.3.5.1; 6.5.3.7.
1.3.07.02.0A	Water table rise affects SZ	5.2; 6.3; 6.5.3.3.3; 6.5.3.4.3; 6.5.3.5.1; 6.5.3.7.

Table 6.2-1. Features, Events, and Processes Included in TSPA and Relevant to This Model Report (Continued)

FEP No.	FEP Name	Sections That Support Disposition
1.4.07.02.0A	Wells	5.1; 5.2; 6.3; 6.4; 6.4.1; 6.5.3.1; 6.5.3.2.3; 6.5.3.3.3; 6.5.3.4.2; 6.5.3.4.3; 6.6; 7.1.
2.2.03.02.0A	Rock properties of host rock and other units	5.2; 6.3; 6.4.1; 6.4.2; 6.5.1; 6.5.2.2; 6.5.3.3.3; 6.5.3.8.
2.2.07.12.0A	Saturated groundwater flow in the geosphere	5.2; 6.3; 6.5.1; 6.5.3.3.1; 6.5.3.3.2; 6.5.3.3.3.
2.2.07.12.0B	Unsaturated groundwater flow in the geosphere	5.2; 6.3; 6.4.1; 6.4.2; 6.5.2.1; 6.5.2.2; 7.2.
2.2.07.15.0A	Advection and dispersion in the saturated zone	5.2; 6.3; 6.5.1; 6.5.3.3.1; 6.5.3.3.2; 6.5.3.3.3.
2.2.07.15.0B	Advection and dispersion in the unsaturated zone	5.2; 6.3; 6.4.1; 6.4.2; 6.5.2.1; 6.5.2.2; 7.2.
2.2.07.16.0A	Dilution of radionuclides in groundwater	5.1; 5.2; 6.3; 6.4; 6.5.1; 6.5.3.1; 6.6; 7.1.
2.2.08.09.0A	Sorption in the saturated zone	6.3; 6.5.1; 6.6.
2.2.08.09.0B	Sorption in the unsaturated zone	6.3; 6.4.1; 6.4.2; 6.5.2.2; 6.6.
2.2.08.10.0A	Colloidal transport in the saturated zone	6.3; 6.5.1; 6.6.
2.2.08.10.0B	Colloidal transport in the unsaturated zone	6.3; 6.4.1; 6.4.2; 6.5.2.2; 6.6.
2.3.02.02.0A	Radionuclide accumulation in soils	5.1; 6.3; 6.4; 6.5.2.2; 6.6.
2.3.02.03.0A	Soil and sediment transport in the biosphere	6.3; 6.4; 6.5.2.2; 6.6.
2.3.13.02.0A	Biosphere characteristics	5.1; 5.2; 6.3; 6.4; 6.5.2; 6.5.3.1; 6.5.3.2; 6.5.3.4.1; 6.5.3.4.3; 6.5.3.5; 6.5.3.6; 6.5.3.8.
2.4.04.01.0A	Human lifestyle	5.1; 5.2; 6.3; 6.5.2.1; 6.5.3.1; 6.5.3.2; 6.5.3.4.2.; 6.5.3.4.3; 6.5.3.5; 6.5.3.6.
2.4.09.01.0B	Agricultural land use and irrigation	5.1; 5.2; 6.3; 6.4; 6.5.2.1; 6.5.3.1; 6.5.3.2; 6.5.3.4.1; 6.5.3.4.3; 6.5.3.6; 6.5.3.8; 6.6; 7.2.

6.3 CONCEPTUAL MODEL

The conceptual model of irrigation recycling is based on the assumptions presented in Section 5. Additional assumptions not discussed in Section 5 follow.

Hypothetical Community and RMEI – Consistent with the requirements of 10 CFR 63 [DIRS 180319], it was assumed that a hypothetical community exists at or in the vicinity of the accessible environment boundary (latitude 36°40'13.6661" north, 10 CFR 63.302 [DIRS 180319]). The RMEI is a hypothetical person living in this community. Characteristics of the reference biosphere can be obtained based on the current biosphere conditions of the Yucca Mountain region. Characteristics of the RMEI can be obtained based on the current human behavior at the town of Amargosa Valley.

Hypothetical Well – The community uses 3,000 ac-ft/yr. This water is pumped out of a hypothetical well located at the compliance point, the point with the maximum concentrations in the contaminant plume. This point approximately coincides with the current location of the well NC-EWDP-19D. The location of this hypothetical well is fixed for the entire simulation period. The groundwater is pumped out of the alluvium aquifer. The water is withdrawn from the total alluvium thickness. This assumption is bounding because when only a portion of the aquifer is pumped, the portion of the plume outside of the pumped interval may not to be captured by the well.

Deep Percolation beneath the Irrigated Fields – Some population of the hypothetical community is involved in irrigated farming. Alfalfa is the main crop grown in Amargosa Valley (some other field and garden crops were also grown in Amargosa Valley) based on the results of the socioeconomic surveys (CRWMS M&O 1997 [DIRS 101090], Tables 3-12 and 3-13; YMP 1999 [DIRS 158212], Tables 10 and 11). It is reasonable to assume that the same is true for the hypothetical community located at the compliance point. Alfalfa irrigation results in deep percolation beneath the irrigated fields (Stonestrom et al. 2003 [DIRS 165862]). The rate of deep percolation is equal to the alfalfa overwatering rate. Using the overwatering rate for alfalfa is conservative for the irrigation recycling model. Alfalfa has relatively high overwatering rate, which results in faster recycling through the system. Such an assumption would not be conservative in the biosphere model (it is not used there because excessive overwatering would remove the radionuclides from the biosphere and thus lower the dose).

Water Uses – As explained in Section 5.1 at least 85% of the water pumped is used for irrigation and at least 4% of the water pumped is used for residential purposes (66FR 32074 [DIRS 155216]). The remaining 11% is distributed between the irrigational and residential uses as discussed in Section 6.5.3.

Locations of the Irrigated Fields and Residences – The irrigated fields are continuously utilized for some time at any given location. This is consistent with the pattern of active and fallow fields present in the Amargosa Valley area today. The locations of the residences also change with time. The fields and the residences can be at any location within the community boundary. The distances from the irrigated fields and residences to the hypothetical well can be obtained based on the analysis of the distributions of the fields and residences within the Amargosa Valley area. This is discussed in detail in Section 6.5.3.2.

Well Capture Zone – The annual withdrawal of 3,000 ac-ft from the hypothetical well under the conditions of groundwater flow in the alluvium aquifer results in formation of a capture zone around the pumping well. It is assumed that steady-state conditions are reached instantaneously and the capture zone shape remains the same during the entire period of simulation. Outside the capture zone, groundwater will flow past the well. Inside the capture zone, the flow will be drawn into the well. Consequently, if the fields and the residences are outside the capture zone, they are not contributing contaminants to the well. If the fields and the residences are inside the contaminant zone, they contribute contaminants to the pumping well and recycling occurs. This is discussed in Sections 6.5.3.4 and 6.5.3.5. In capture zone analysis, it is assumed that the alluvial aquifer is two-dimensional (Dupuit assumption of negligible vertical flow is applicable) and has an infinite extent and that the alluvial deposits are homogeneous. The aquifer recharge from the irrigated fields is not taken into the account, which is a conservative assumption because the additional recharge would result in a smaller capture zone. The aquifer thickness and specific discharge are constant and change instantaneously when the climate changes. This is consistent with the representation of the different climate states in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2007 [DIRS 181650]). The timing of climate changes is the same as in the TSPA model. The capture zone analysis is discussed in Section 6.5.3.3.

Radionuclide Transport in the Unsaturated Zone beneath the Irrigated Fields – Using contaminated water for irrigation results in radionuclide accumulation in the soils. Radionuclides accumulated in surface soils are transported through the unsaturated zone beneath the irrigated fields with the percolating water. The percolation rate corresponds to the alfalfa overwatering rate as mentioned above. The radionuclides are transported through the surface soils and the unsaturated zone with the advective flow. The transport processes include advection, dispersion, radionuclide-specific sorption in the surface soils and in the unsaturated zone, and mineral precipitation. This is discussed in Sections 6.5.1 and 6.5.2.

Unsaturated Zone Thickness beneath the Irrigated Fields – The thickness of the unsaturated zone (the transport distance) corresponds to the depth to the water table under the glacial transition climate conditions as discussed in Section 6.5.3.7. This is a reasonable assumption. The water table is closer to the surface under the glacial transition climate conditions than under the monsoon and present-day climate. The post-10k-yr climate is only slightly wetter than the glacial transition climate (SNL 2007 [DIRS 175177], Tables 6.1-2 and 6.1-3), and the impact on the water table should be small.

Soil Erosion – The radionuclides sorbed in the surface soil are subject to removal from the system with soil erosion. This assumption is consistent with the assumptions in *Biosphere Model Report* (SNL 2007 [DIRS 177399]). The discussion can be found in Sections 6.4 and 6.5.2.

Radionuclide Transport in the Saturated Zone beneath the Irrigated Fields – No credit for transport in the saturated zone is taken. This is a conservative assumption because some irrigated fields are located at significant distances from the well (Section 6.5.3.2.5). When radionuclides from the irrigated fields reach the water table, a portion of the radionuclides within the well capture zone returns to the pumping well, while the remainder is removed from the recycling system. This is calculated from the well recapture fraction as discussed in Section 6.4.

Radionuclide Transport in the Unsaturated Zone beneath the Septic Leach Fields – The radionuclides in the residential water used outdoors are removed from the recycling. The water used outdoors evaporates and there is no pathway to return the radionuclides dissolved in this water back to the unsaturated zone. The radionuclides in the water used indoors accumulate in the septic leach fields located at the water table. This is a bounding assumption because it does not consider transport through the unsaturated zone. Similar to the contribution of irrigated fields to recycling of radionuclides, only the residences located within the capture zone are assumed to contribute to radionuclide recycling. The radionuclides in the water used indoors in the residences located outside of the well capture zone are removed from the recycling system. This is discussed in Section 6.5.3.5. The radionuclides in the septic leach fields are subject to sorption and solubility limits.

Radionuclide Transport in the Saturated Zone beneath the Septic Leach Fields – No credit for transport in the saturated zone is taken. This is a conservative assumption because some residences (and associated leach fields) are located at significant distances from the well (Section 6.5.3.2.6).

Radionuclide Concentrations in the Well – The radionuclides in the irrigation and residential water that are recaptured by the well are returned to the well. The radionuclide mass fluxes exiting the saturated zone flow and transport abstraction model are entirely captured by the well. The groundwater concentrations in the well are calculated based on these inputs as discussed in Sections 6.4 and 6.5.1. The resulting groundwater concentrations are passed to the TSPA. Without recycling of the irrigation and residential water, groundwater concentrations were calculated based on the radionuclide fluxes from the stand-alone saturated zone flow and transport abstraction model. There were no other fluxes into the well volume. This implementation is described in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2007 [DIRS 181650]). The irrigation recycling model should perform as a stand-alone saturated zone flow and transport abstraction model when both well recapture fraction and indoor residential fraction are zero.

6.4 MODEL FORMULATION

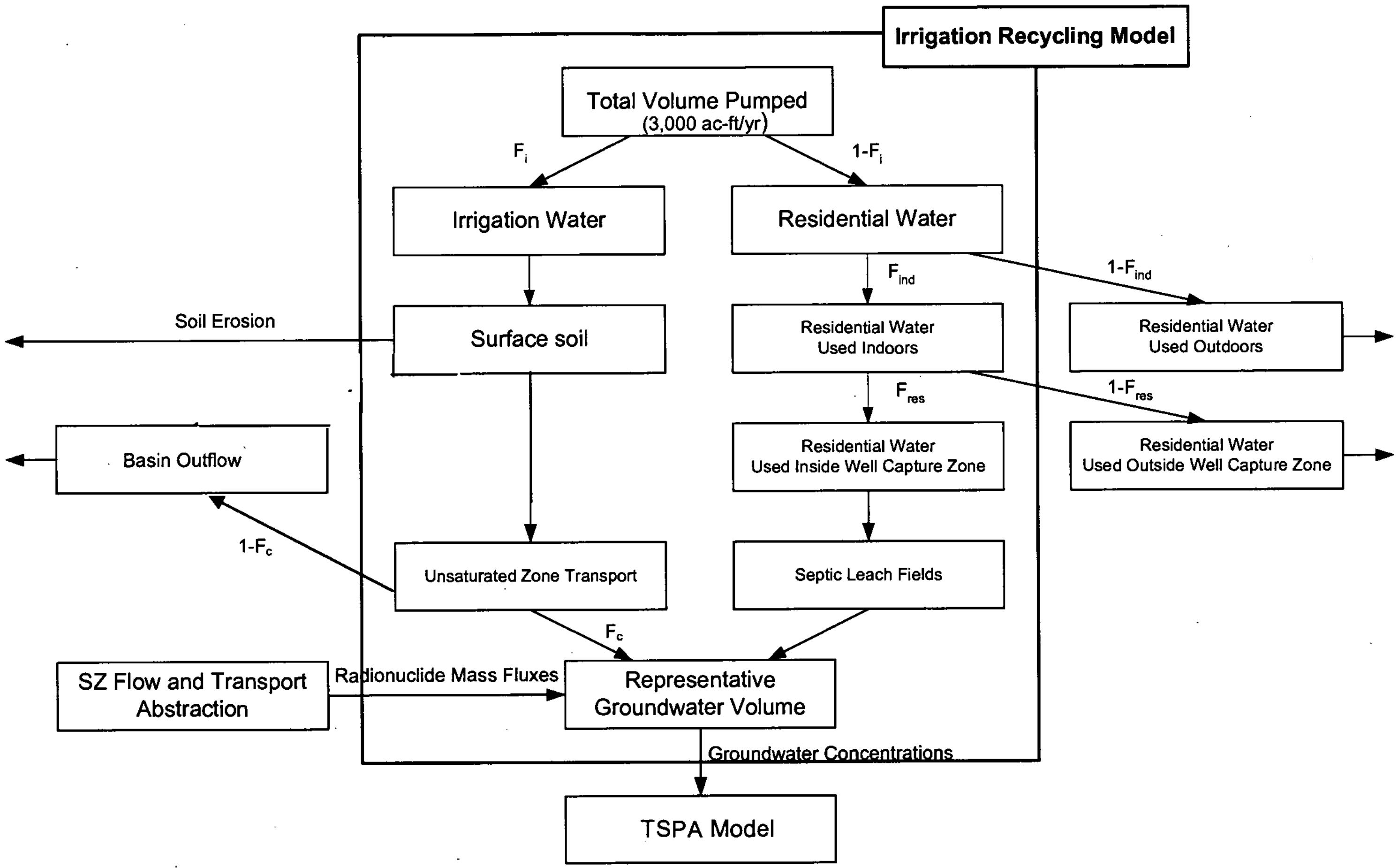
The conceptual model described in Section 6.3 is implemented as a stand-alone model using GoldSim 9.60 (STN: 10344-9.60-00 [DIRS 180224]). This model (file *Irrigation_Recycling_Model.gsm*) is in directory *Model* in output DTN: SN0703PASZIRMA.001. Using GoldSim software provides a consistent interface between the irrigation recycling model and TSPA model. The stand-alone irrigation recycling model was incorporated into the TSPA model to perform a sensitivity analysis in order to evaluate the impact of the irrigation recycling model to mean dose results (Section 6.7).

The logic diagram of the irrigation recycling model is shown in Figure 6.4-1. The irrigation recycling model is based on the stand-alone saturated zone flow and transport abstraction model (DTN: SN0702PASZFTMA.002 [DIRS 183471]). The irrigation recycling model was developed from this model by adding an additional module incorporating the irrigation recycling process. The formulation of the saturated zone flow and transport abstraction model is described in detail in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2007 [DIRS 181650]). The stand-alone saturated zone flow and transport abstraction model calculates the radionuclide fluxes at the boundary of the accessible environment. These fluxes represent the input into the well. The GoldSim cumulative integrator function is used to implement this input.

The GoldSim cell pathway is used to calculate the groundwater concentrations (*Representative Groundwater Volume* box in Figure 6.4-1). The only medium in this cell is water. The volume of the water is equal to the annual usage of 3,000 ac-ft. The radionuclide concentrations in this cell are calculated as the total radionuclide mass flux (radionuclide mass fluxes from the saturated zone flow and transport abstraction model and radionuclide mass fluxes due to irrigation recycling) divided by the 3,000 ac-ft/yr.

Another cell pathway represents the groundwater pumped from the hypothetical well (*Total Volume Pumped* box in Figure 6.4-1). The only medium in this cell is water. The inflow into this cell is equal to 3,000 ac-ft/yr. The outflows from this cell are to (1) the irrigation water use (*Irrigation Water* box) and (2) residential water use (*Residential Water* box). The first outflow is equal to 85% of the annual water use plus water use uncertainty (0% to 11%). The second outflow is equal to the annual water use minus the first outflow. The rationale for this water use assumption is provided in Section 6.5.3.1.

The pathway originating from the *Irrigation Water* box represents the irrigation water recycling. The pathway shown from the *Residential Water* box represents the residential water recycling.



NOTE: For illustration purposes only.

Figure 6.4-1. Irrigation Recycling Model Logic Diagram

6.4.1 Irrigation Water Recycling Pathway

The irrigation water recycling pathway consists of the surface soil cell (*Surface Soil* box) and 20 cells representing the unsaturated zone beneath the irrigated fields. The thickness of each cell is 2.5 m (Section 6.5.3.7). This discretization is comparable with the vertical discretization used in *UZ Flow Models and Submodels* (SNL 2007 [DIRS 175177]). The unsaturated zone modeling grid has on average 59 blocks in the vertical direction (SNL 2007 [DIRS 175177], Section 6.1.1) to represent the unsaturated zone thickness up to about 600 m. Twenty unsaturated zone cells are represented in Figure 6.4-1 by the box *Unsaturated Zone Transport*.

The surface soil cell consists of two media: water and soil. The parameters of the soil medium are taken from the biosphere process model (DTN: MO0705GOLDSIMB.000 [DIRS 181281]). These parameters are described in Section 6.5.2. The inflow into the soil cell is equal to the irrigation water use. The outflows from this cell are (1) outflow of water to the first cell representing the unsaturated zone and (2) outflow of soil to the erosional removal cell. The first outflow (this is a recharge flow) is equal to the product of the alfalfa overwatering rate (see Section 6.5.2) and the total area of the irrigated fields. The total area of the irrigated fields is calculated as the ratio of irrigational use and the alfalfa irrigation rate (Section 6.5.2). The second outflow is equal to the product of the erosion rate (Section 6.5.2) and the total field area. The soil cell area is equal to the total irrigated field area. The soil cell depth is equal to the surface soil thickness used in the biosphere process model (Section 6.5.2). The radionuclide-specific transport properties simulated in the soil cell are radionuclide partition coefficients (Section 6.5.2) and radionuclide solubilities (developed in the TSPA model).

Each unsaturated zone cell has two media: water and alluvium. Both the inflow into the cell and the outflow from the cell are equal to the recharge flow defined above. The alluvium in the unsaturated zone cells has the same properties as the alluvium in the saturated zone flow and transport abstraction model (as described in Section 6.5.1). The unsaturated zone cell area is equal to the total irrigated field area. The unsaturated zone cell height is equal to the depth to water table (defined in Section 6.5.3.6) divided by 20 (number of unsaturated zone cells). The radionuclide specific transport properties simulated in the unsaturated zone cells are radionuclide partition coefficients (Section 6.5.1) and radionuclide solubilities (developed in the TSPA model). The rationale for using multiple cells is to model longitudinal dispersion. The dispersion is incorporated through simulating mixing in each unsaturated zone cell.

The last (20th unsaturated zone cell) representing the unsaturated zone just above the water table has two outflows ($Q1_{20}$ and $Q2_{20}$). These outflows are calculated as:

$$Q1_{20} = (1 - F_c)\, Q_{rech} \qquad \text{(Eq. 6.4-1a)}$$

$$Q2_{20} = F_c Q_{rech} \qquad \text{(Eq. 6.4-1b)}$$

where F_c is the well recapture fraction (defined in Section 6.5.3.4) and Q_{rech} is the recharge flow defined above. $Q1_{20}$ represents the recharge flow from the irrigated fields located outside of the well capture zone, and $Q2_{20}$ represents the recharge flow from the irrigated fields located within the well capture zone. Note that the two outflows and the recharge flow in Equation 6.4-1 are volumetric flows and the corresponding units are L^3/T.

The radionuclides dissolved in the water exiting the last unsaturated zone cell with the outflow $Q2_{20}$ constitute the input into the *Representative Groundwater Volume* cell.

6.4.2 Residential Water-Recycling Pathway

The residential water-recycling pathway is implemented with one cell representing the septic leach fields (*Septic Leach Fields* box). The boxes shown in Figure 6.4-1 above this box are provided to demonstrate how the inflow into the septic leach fields is calculated. These boxes are not implemented as separate cells in the GoldSim model.

A septic leach field cell has two media: water and solid. The properties of the solid medium are assumed to be the same as the properties of the alluvium described in Section 6.5.1. The inflow into the cell ($Q1_{lf}$) is defined as:

$$Q1_{lf} = Q_{res} F_{res} F_{ind} \qquad \text{(Eq. 6.4-2)}$$

where Q_{res} is the residential water use, F_{res} is the fraction of the residential water used inside the capture zone, and F_{ind} is the fraction of the residential water used indoors (these two fractions are described in Section 6.5.3.5). Note that the inflow and the residential water use in Equation 6.4-2 are volumetric flows and the corresponding units are L^3/T.

Because the septic leach field cell is assumed to be located just above the water table, the outflow from this cell is directly into the *Representative Groundwater Volume* cell. The outflow ($Q2_{lf}$) is defined as:

$$Q2_{lf} = A_{lf} w \qquad \text{(Eq. 6.4-3)}$$

where A_{lf} is the total septic leach field area, and w is the alfalfa overwatering rate corresponding to the infiltration rate in the unsaturated zone (Section 6.5.2). Note that the outflow in Equation 6.4-3 is a volumetric flow and the corresponding units are L^3/T.

The infiltration rate in the unsaturated zone beneath the septic leach fields is assumed to be the same as the infiltration rate beneath the irrigated alfalfa fields (Equation 6.4-3). The continuous irrigation within the hypothetical community and the rotation of the irrigation fields are likely to produce similar conditions within the unsaturated zone beneath any place in the community, including alluvium saturation and infiltration rate. This assumption is bounding and it is discussed in Section 5.2.

The total septic leach field area is calculated as:

$$A_{lf} = \frac{Q1_{lf}}{q_{lf}} \qquad \text{(Eq. 6.4-4)}$$

where q_{lf} is the leach field application rate described in Section 6.5.3.9.

The septic leach field cell area is equal to the total septic leach field area. The cell depth is assumed to be 0.5 m. As explained in Section 6.5.3.9, this parameter is a part of a modeling setup and does not affect the modeling results. The radionuclide-specific transport properties simulated in the septic leach field cell are radionuclide partition coefficients (Section 6.5.1) and radionuclide solubilities (developed in the TSPA model).

The radionuclides dissolved in the water exiting the septic leach field cell with the outflow $Q2_{lf}$ constitute the input into the *Representative Groundwater Volume* cell.

6.5 MODEL INPUTS

The inputs to the irrigation recycling model include the modeling parameters defined in the stand-alone saturated zone flow and transport abstraction model, modeling parameters defined in the biosphere process model, and additional parameters developed specifically for the irrigation recycling model. As noted above, the irrigation recycling model implicitly includes the stand-alone saturated zone flow and transport abstraction model (DTN: SN0702PASZFTMA.002 [DIRS 183471]). A number of parameters defined in this model are used in the irrigation recycling model. These parameters and their use are described in Section 6.5.1. The irrigation recycling model does not implicitly include the biosphere process model. However, a number of parameters defined in the biosphere model (DTN: MO0705GOLDSIMB.000 [DIRS 181281], file *ERMYN_GW_Rev01_PDC_Ac227.gsm*) and *Agricultural and Environmental Input Parameters for the Biosphere Model* (BSC 2004 [DIRS 169673]) are used in the irrigation recycling model. These parameters and their use are described in Section 6.5.2. Finally, the additional parameters developed specifically for the irrigation recycling model are described in Section 6.5.3.

6.5.1 Inputs Related to Interface with the Stand-alone Saturated Zone Flow and Transport Abstraction Model

The interface between the irrigation recycling model and the stand-alone saturated zone flow and transport abstraction model (DTN: SN0702PASZFTMA.002 [DIRS 183471]) consists of the following:

(1) Radionuclide mass fluxes at the boundary of the accessible environment calculated by the saturated zone flow and transport abstraction model

(2) Saturated zone flow and transport abstraction model parameters.

The radionuclide mass fluxes at the boundary of the accessible environment constitute the input into the *Representative Groundwater Volume* cell as described in Section 6.4.

The parameters defined in the saturated zone flow and transport abstraction model and directly used in the irrigation recycling model are described below.

Note that the probabilistic parameters are defined in the saturated zone flow and transport abstraction model using look-up tables. Each table consists of 200 realizations of a parameter. This is done to synchronize the use of the probabilistic parameters in the saturated zone flow and transport abstraction model and the saturated zone one-dimensional transport model (SNL 2007 [DIRS 181650]). The same tables are used in the irrigation recycling model, and the calculations are synchronized between the saturated zone flow and transport abstraction model and irrigation recycling model as well.

The saturated zone flow and transport parameters are used to define the properties of 20 unsaturated zone cells. The following cell properties need to be defined:

- Cell water volume
- Cell alluvium mass
- Inflows into and outflows from each medium
- Alluvium density
- Effective alluvium porosity
- Radionuclide-specific partition coefficients.

Inflows and Outflows

The inflows into and outflows from each medium are defined in Section 6.4.

Cell Alluvium Mass

The cell alluvium mass (M_{cell}) is calculated as:

$$M_{cell} = \rho_{bulk} V_{cell} \tag{Eq. 6.5-1}$$

where ρ_{bulk} is alluvium dry bulk density (parameter *Alluvium_Density* defined as a look-up table in the saturated zone flow and transport abstraction model, DTN: SN0702PASZFTMA.002 [DIRS 183471]), and V_{cell} is the volume of the unsaturated zone cell calculated as the product of the unsaturated zone cell area and height (defined in Section 6.4).

Cell Water Volume

The cell water volume (V_w) is calculated as:

$$V_w = V_{cell} s \varphi \tag{Eq. 6.5-2}$$

where φ is alluvium porosity (constant parameter *Alluvium_Porosity* defined in the saturated zone flow and transport abstraction model, DTN: SN0702PASZFTMA.002 [DIRS 183471]), and s is the alluvium saturation in the unsaturated zone beneath the irrigated fields (developed in Section 6.5.3.8).

Alluvium Density

The alluvium dry bulk density is defined as described by Equation 6.5-1.

Effective Alluvium Porosity

The alluvium effective porosity (φ_{eff}) is parameter *NVF26* defined as a look-up table in the saturated zone flow and transport abstraction model (DTN: SN0702PASZFTMA.002 [DIRS 183471]).

Radionuclide-Specific Partition Coefficients in Alluvium

The radionuclide-specific partition coefficients are defined as follows (DTN: SN0702PASZFTMA.002 [DIRS 183471]):

- Partition coefficient for americium on reversible colloids in alluvium – parameter *Kd_Am_Allu_Rev_Colloid* in the saturated zone flow and transport abstraction model (a distribution)
- Partition coefficient for americium on irreversible colloids in alluvium – parameter *Kd_Allu_Irr* in the saturated zone flow and transport abstraction model (a distribution)
- Partition coefficient for cesium on reversible colloids in alluvium – parameter *Kd_Cs_Allu_Rev_Colloid* in the saturated zone flow and transport abstraction model (a distribution)
- Partition coefficient for strontium in alluvium – parameter *Kd_Sr_Al_Effective* in the saturated zone flow and transport abstraction model (a distribution)
- Partition coefficient for plutonium on reversible colloids in alluvium – parameter *Kd_Am_Allu_Rev_Colloid* in the saturated zone flow and transport abstraction model (a distribution)
- Partition coefficient for colloids based on the colloid retardation coefficient – parameter *Kd_Allu_Irr* in the saturated zone flow and transport abstraction model (a distribution)
- Partition coefficient for uranium in alluvium – parameter *Kd_U_Al_Effective* in the saturated zone flow and transport abstraction model (a distribution)
- Partition coefficient for protactinium on reversible colloids in alluvium – parameter *Kd_Am_Allu_Rev_Colloid* in the saturated zone flow and transport abstraction model (a distribution)
- Partition coefficient for neptunium in alluvium – parameter *Kd_Np_Al_Effective* in the saturated zone flow and transport abstraction model (a distribution)
- Partition coefficient for thorium on reversible colloids in alluvium – parameter *Kd_Am_Allu_Rev_Colloid* in the saturated zone flow and transport abstraction model (a distribution)
- Partition coefficient for radium in alluvium – parameter *Kd_Ra_Al_Effective* in the saturated zone flow and transport abstraction model (a distribution)
- Partition coefficient for selenium in alluvium – parameter *Kd_Se_Al_Effective* in the saturated zone flow and transport abstraction model (a distribution)

- Partition coefficient for tin on reversible colloids in alluvium – parameter *Kd_Sn_Allu_Rev_Colloid* in the saturated zone flow and transport abstraction model (a distribution).

The partition coefficients of ^{14}C, ^{129}I, ^{99}Tc, ^{36}Cl, and colloids are 0 as defined in the saturated zone flow and transport abstraction model.

6.5.2 Inputs Related to the Interface with the Biosphere Model

The interface with the biosphere model consists of the following:

(1) Biosphere parameters defined in the biosphere process model

(2) Supporting biosphere parameters.

The biosphere parameters defined in the biosphere model are the parameters included in DTN: MO0705GOLDSIMB.000 [DIRS 181281] (file *ERMYN_GW_Rev01_PDC_Ac227.gsm*). These parameters are directly used in the biosphere model component.

The other parameters are those that were developed in support of the biosphere process modeling parameters, but are not directly used in the biosphere process model.

6.5.2.1 Supporting Biosphere Parameters

Two supporting biosphere process modeling parameters are used in the irrigation recycling model.

The first parameter is the alfalfa irrigation rate, which is set equal to 1.94 m/yr (BSC 2004 [DIRS 169673], Table 6.5-2). The alfalfa irrigation rate, as well as the irrigation rates of several field crops, was used to develop the weighted average field crop irrigation rate used in the biosphere model. The only crop considered in the irrigation recycling model is alfalfa; therefore, the alfalfa (not the average) irrigation rate is used.

In the irrigation recycling model, the alfalfa irrigation rate w_{alf} is used to calculate the total area of the irrigated fields (A_f):

$$A_f = \frac{Q_{irr}}{w_{alf}} \qquad \text{(Eq. 6.5-3)}$$

where Q_{irr} is the annual volume of the groundwater used for irrigation. The total field area is at least 400.6 ac ($Q_{irr} \geq 2{,}550$ ac-ft/yr). As discussed in Section 6.4, the total area of the irrigated fields is used to define the area of the unsaturated zone cells.

The second parameter is the alfalfa overwatering rate, which is set equal to 0.149 m/yr (BSC 2004 [DIRS 169673], Table 6.9-1). The alfalfa overwatering rate, as well as overwatering rates of other 25 representative crops, was used to develop the average overwatering rate used in the biosphere model. The only crop considered in the irrigation recycling model is alfalfa; therefore, the alfalfa (not the average) overwatering rate is used.

In the irrigation recycling model, the alfalfa overwatering rate i_{alf} is used to calculate the total recharge flow beneath the irrigated fields (Q_{rech}):

$$Q_{rech} = A_f i_{alf} \quad \text{(Eq. 6.5-4)}$$

The alfalfa overwatering rate i_{alf} is used to calculate the flow beneath the septic leach fields (as described in Section 5.2), which is defined as the product of the total septic leach field area (Section 6.5.3.9) and i_{alf}. Note that the recharge flow in Equation 6.5-4 is a volumetric flow and the corresponding units are L^3/T.

6.5.2.2 Biosphere Modeling Parameters

As discussed above, the biosphere model component is not implicitly included in the irrigation recycling model. Thus, the biosphere parameters cannot be called in by using their names as in the case of the saturated zone flow and transport abstraction model. All of the biosphere model parameters had to be renamed within the irrigation recycling model, but their values stayed the same. Even though the parameters have been renamed for computational purposes, they remain the same parameters.

The biosphere parameters used in the irrigation recycling model were extracted from the GoldSim v. 8.02.500 (STN: 10344-8.02-07 [DIRS 179360]), file *ERMYN_GW_Rev01_PDC_Ac227.gsm* included in DTN: MO0705GOLDSIMB.000 [DIRS 181281]. The radionuclide sorption coefficients in soil were taken from the container named *Biosphere_Model\Nuclide_Database\Nuclide_Data_Kd_Coefficients*. The soil related parameters were taken from the container named *Biosphere_Model\Soil\SoilModel_Input.* GoldSim allows for presenting the final distribution values in a form of a lookup table which can be exported as a text file. This option was used to extract 1,000 realizations of each parameter described below.

A selector element was used to synchronize the biosphere process model and irrigation recycling model realizations to ensure that the same biosphere model input parameters are used in both models for any realization. This synchronization takes place when the irrigation recycling model is incorporated in the TSPA model for sensitivity analysis (Section 6.7). The selector element will allow the TSPA model to sample the same realization for biosphere model component and irrigation recycling calculations. The parameter names in the irrigation recycling model and biosphere model component do not have to be the same.

Erosion Rate

The erosion rate, r_{er}, is the biosphere modeling parameter *Erosion_Rate* in DTN: MO0705GOLDSIMB.000 [DIRS 181281] (file *ERMYN_GW_Rev01_PDC_Ac227.gsm*) and was used in the irrigation recycling model to calculate the solid mass flux q_{er} out of the surface soil layer (Section 6.5.4). The solid mass flux was calculated as:

$$q_{er} = r_{er} \; A_f \quad \text{(Eq. 6.5-5)}$$

where A_f is defined in Equation 6.5-3.

Soil Properties

The biosphere parameters used to define the properties of the soil cell pathway are (DTN: MO0705GOLDSIMB.000, file *ERMYN_GW_Rev01_PDC_Ac227.gsm*):

- Surface soil volumetric water content (θ_{soil}), parameter *Volume_Water*
- Surface soil dry bulk density (ρ_{soil}), parameter *Soil_Density*
- Surface soil depth (b_{soil}), parameter *Soil_Depth.*

The soil depth was used to calculate the volume of the soil cell as:

$$V_{soil} = A_f b_{soil} \quad \text{(Eq. 6.5-6)}$$

The soil volumetric water content was used to calculate the volume of water in the soil cell (V_{sw}):

$$V_{sw} = V_{soil}\theta_{soil} \quad \text{(Eq. 6.5-7)}$$

The soil dry bulk density was used to calculate the mass of soil in the soil cell (M_{soil}):

$$M_{soil} = V_{soil}\rho_{soil} \quad \text{(Eq. 6.5-8)}$$

Radionuclide-Specific Partition Coefficients in Soil

Radionuclide-specific partition coefficients in the surface soil are defined based on the following parameters in DTN: MO0705GOLDSIMB.000 [DIRS 181281] (file *ERMYN_GW_Rev01_PDC_Ac227.gsm*):

- *C_Kd* for carbon partition coefficient in soil
- *Cl_Kd* for chlorine partition coefficient in soil
- *Se_Kd* for selenium partition coefficient in soil
- *Sr_Kd* for strontium partition coefficient in soil
- *Tc_Kd* for technetium partition coefficient in soil
- *Sn_Kd* for tin partition coefficient in soil
- *I_Kd* for iodine partition coefficient in soil
- *Cl_Kd* for chlorine partition coefficient in soil
- *Cs_Kd* for cesium partition coefficient in soil
- *Pb_Kd* for lead partition coefficient in soil
- *Ra_Kd* for radium partition coefficient in soil
- *Ra_Kd* for actinium partition coefficient in soil
- *Th_Kd* for thorium partition coefficient in soil
- *Pa_Kd* for protactinium partition coefficient in soil
- *U_Kd* for uranium partition coefficient in soil
- *Np_Kd* for neptunium partition coefficient in soil
- *Am_Kd* for americium partition coefficient in soil.

Colloids are not considered in the biosphere model but are considered in the saturated zone flow and transport abstraction model. Consequently, the groundwater used for irrigation will contain colloids. As the partition coefficient for the colloids in soil is not defined, the zero-partition coefficient was used for the colloids with radionuclides reversibly and irreversibly attached to them. This allows for fast transfer of the colloids and associated radionuclides from soil to the unsaturated zone where colloid transport is considered the same way as in the saturated zone.

Not considering colloids in the biosphere process model is conservative from the perspective of biosphere modeling because it reduces radionuclide removal from the surface soil. In addition, the partition coefficients for agricultural soil used in the biosphere model were selected to represent the local conditions in a reasonable but cautious manner. The cautious approach involves the choices of parameter values (e.g., the partition coefficients) so that the radionuclide removal from soil is reduced. In the irrigation recycling model, the cautious approach would lead to making the opposite choices. However, these two approaches do not result in underestimating the dose to the RMEI because in the open system considered in the irrigation recycling model, the quantity of a radionuclide will produce a greater dose to the RMEI when contained in the biosphere (here in the surface soil) rather than leaving the soil by leaching and having much less than 100% chance of returning to the soil within the reference biosphere.

All the biosphere parameters described in this section are probabilistic parameters defined using look-up tables. Both the probability distributions of these parameters and the parameter values for each of the 1,000 realizations are defined in DTN: MO0705GOLDSIMB.000 [DIRS 181281] (file *ERMYN_GW_Rev01_PDC_Ac227.gsm*). The 1,000 realizations for each parameter were extracted from this DTN as described earlier and included in the irrigation recycling model.

6.5.3 Developed Irrigation Recycling Model Inputs

A number of model parameters needed to implement the irrigation recycling model as described in Section 6.4 were not available and were developed in this modeling report. These parameters include the following:

- Fraction of water used for irrigation and residential uses (Section 6.5.3.1)
- Well recapture fraction (Section 6.5.3.4)
- Fraction of water used indoors (Section 6.5.3.5)
- Fraction of residential water used within the well capture zone (Section6.5.3.5)
- Depth to water table beneath the irrigated fields (Section 6.5.3.7)
- Saturation within the unsaturated zone beneath the irrigated fields (Section 6.5.3.8)
- Leach field thickness and application rate (Section 6.5.3.9).

The discussion of how these parameters were developed and how they are used in the irrigation recycling model is provided in the corresponding sections.

6.5.3.1 Water Use

As described in Section 5.1, the hypothetical community well is assumed to pump 3,000 ac-ft/yr (10 CFR Part 63 [DIRS 180319]). The use of this water was assumed to be divided among the agricultural uses (irrigation) and domestic uses, similar to that used by the EPA in defining the basis for the 3,000 ac-ft annual water demand for the representative volume. The EPA assumption was that 85% is used for alfalfa irrigation, 3% for commercial/industrial water demand, 4% for individual/municipal water demand, and the remaining 8% represent residual uncertainty (66 FR 32074 [DIRS 155216]).

The current characteristics of the biosphere (based on the characteristics of the Yucca Mountain region) and RMEI (a hypothetical person that lives in this community with characteristics of the town of Amargosa Valley) and the assumption concerning the water uses described above were used to develop the irrigation and residential fractions. A few small industries that are currently located in the Amargosa Valley grow alfalfa as a part of their business and their water use is very similar to the agricultural use. Consequently, the commercial/industrial use can be either excluded or added to the residual uncertainty. It was further assumed that 85% of the water is always used for irrigation and 4% is always used for residential purposes. The remaining 11% representing the residual uncertainty is distributed between these two uses as:

$$F_i = 0.85 + f_{unc} \quad \text{(Eq. 6.5-8a)}$$

$$F_{other} = 1 - F_i \quad \text{(Eq. 6.5-8b)}$$

where F_i is the irrigation fraction, F_{other} is the fraction used for residential use, and f_{unc} is the residual uncertainty fraction. The residual uncertainty fraction is defined by a uniform distribution ranging from 0 to 0.11.

The irrigation fraction F_i is used to calculate the annual volume of water (ac-ft/yr) used for irrigation (Q_{irr}):

$$Q_{irr} = F_i * 3{,}000 \quad \text{(Eq. 6.5-9)}$$

Q_{irr} is a parameter used in Equation 6.5-3.

The irrigation fraction F_{other} is used to calculate the annual volume of water (ac-ft/yr) for residential use (Q_{res}):

$$Q_{res} = F_{other} * 3{,}000 \quad \text{(Eq. 6.5-10)}$$

Q_{res} is a parameter used in Equation 6.4-2.

All 3,000 ac-ft/yr are used by the hypothetical community. The only difference is in how much is used for the irrigation and residential purposes, and that amount is controlled by the parameter F_i (Equation 6.5-8a).

The conceptual model of the radionuclide recycling is an extension of the stylized exposure scenario for the hypothetical community and the RMEI. It is not to imply that such a community exists or will ever exist at the compliance location. The hypothetical community and the RMEI were defined by the regulator "to limit speculation about possible futures so that the performance assessments can provide meaningful input into the decision process and the decision process itself is not confounded with speculative alternatives" (66 FR 32074 [DIRS 155216]). In other words, although the population and the human activities in the Yucca Mountain region may change in the future (that includes Amargosa Valley and whatever activities currently take place there), from a regulatory prospective, there is always a hypothetical community located at the compliance point. The RMEI, who is a member of this community, would be among the most highly exposed individuals downgradient from Yucca Mountain, regardless of the futures of the real population of the region.

6.5.3.2 Hypothetical Community Characteristics

Certain characteristics of the Amargosa Valley community can be measured, summarized, and used to represent the spatial relationships of a hypothetical community. Hypothetical community characteristics are needed to define the potential locations of the irrigated fields and residences with regard to the hypothetical well. As discussed in Section 5.1, the hypothetical well location (current location of well NC-EWDP-19D) is fixed for the entire period of simulation. The locations of the irrigated fields and residences are assumed to move around within the community boundaries. As a result, any location within the community boundaries might be a residence or an irrigated field at some time during the simulation period. The distances to the irrigated fields and residences and the community boundaries are estimated based on the characteristics of the Amargosa Valley as discussed below. These distances are used in Sections 6.5.3.4 and 6.5.3.5 to calculate the well recapture fraction and residential water use fraction.

6.5.3.2.1 Irrigated Fields

Irrigated areas in the greater Amargosa Valley area were examined using a variety of sources of aerial and satellite images as described below. The locations of irrigated fields represent a composite of all locations that could be inferred from the images, not just those that were in use (i.e., irrigated) at the time an image was obtained.

One primary data set of four aerial photomosaics was used. These data were qualified for use in this report in Section 4.1.1. DTN: MO0706FD30MQMA.000 [DIRS 181355] consists of four, 30-minute quad mosaics of the Amargosa Valley area. These 30-minute mosaics are made up of 64 USGS digital Orthophoto Quarter Quads (3.75 minutes) mosaicked to a single rectified image. The rectified mosaic is spatially corrected and can be used as an accurate base map for measuring and defining the spatial relationships of the Amargosa Valley area. The four, 30-minute quadrangle areas include the Leeland, South of Amargosa Valley, Franklin Well, and East of Echo Canyon quadrangle areas. The mosaics include images collected from 1993 to 1999. All images are in digital form.

The black and white aerial photographs provided good pattern recognition material for identifying fields, both historic and present. Even very old fields are notably different than adjacent undisturbed areas. Row features, access roads, ditches, and plowing evidence can be readily seen. The areas that may have been used as agricultural fields were outlined and digitized. Areas that appear to be pasture, but that do not have marks of cultivation or clear water delivery were not included.

The second data source was DTN: MO0706NAIPDQI9.000 [DIRS 181356]. This DTN is made up of NAIP digital Quarter Quad images in natural color. Note that these data are qualified for use in this modeling report in Section 4.1.1. The NAIP imagery, which was collected in 2006, does not cover the entire area of interest and was used to corroborate the irrigated areas as defined from the 30-minute quadrangles. A few new irrigated areas were defined on the basis of the NAIP imagery where it provided a better examination of areas on the 30-minute quadrangles.

The resulting irrigated areas as defined by the imagery are in output DTN: SN0703PASZIRMA.001 (directory *Parameters*) in several formats. The images were processed using a PC with a Windows XP operating system. The software used was the qualified ArcGIS 9.1 (STN: 11205-9.1-00 [DIRS 176015]). The delineated irrigated areas are shown as green circles in Figure 6.5-1.

6.5.3.2.2 Residential Locations

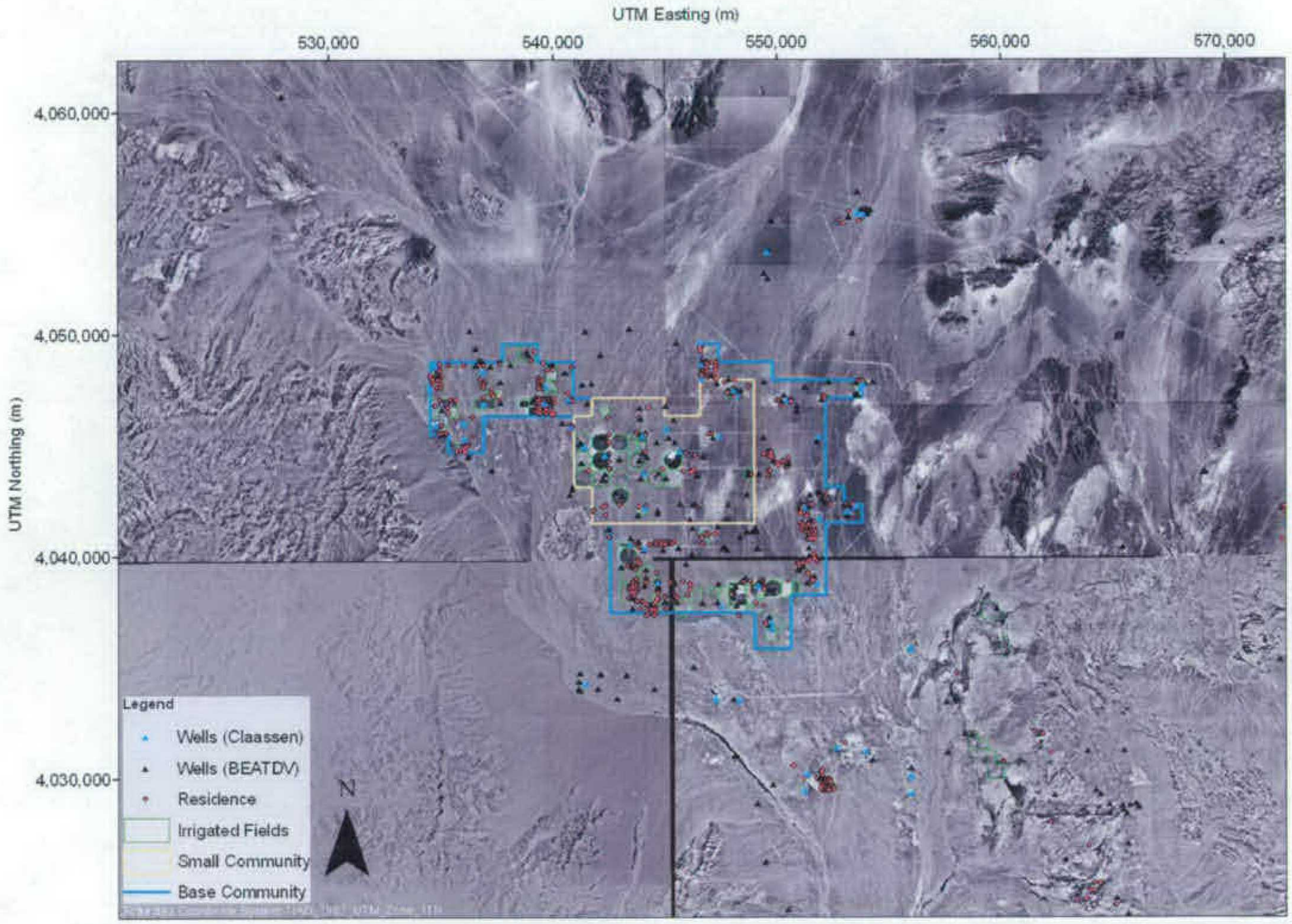
A scientific investigation of residential population density and distribution within 84 km of Yucca Mountain was conducted in support of the Radiological Monitoring Program during fiscal year 2003. The results of this investigation include 2003 estimates of the resident population within an area that includes the Amargosa Valley area (DTN: MO0309COV03136.000 [DIRS 181357]). Area-specific population data are required to estimate potential radiation exposure to the resident population within approximately 50 miles of the Yucca Mountain site.

DTN: MO0309COV03136.000 [DIRS 181357] contains point features of the 2003 population distribution within the 84 km radiological monitoring grid for the 2000 census geography. The resulting residential locations are shown in Figure 6.5-1 as brown dots.

6.5.3.2.3 Wells

The well locations are only used to help delineate the community boundaries. The grid blocks that include a well are not considered empty even if they do not have a field or a residence.

Two DTNs were used to define well locations in the area and several points were identical in them (DTNs: LA0309EK831223.001 [DIRS 165471]; MO9903COV97533.000 [DIRS 181358]). The resulting well locations are shown in Figure 6.5-1 as blue and black triangles.



Sources: DTNs: MO0706FD30MQMA.000 [DIRS 181355]; MO0309COV03136.000 [DIRS 181357]; LA0309EK831223.001 [DIRS 165471]; MO9903COV97533.000 [DIRS 181358].

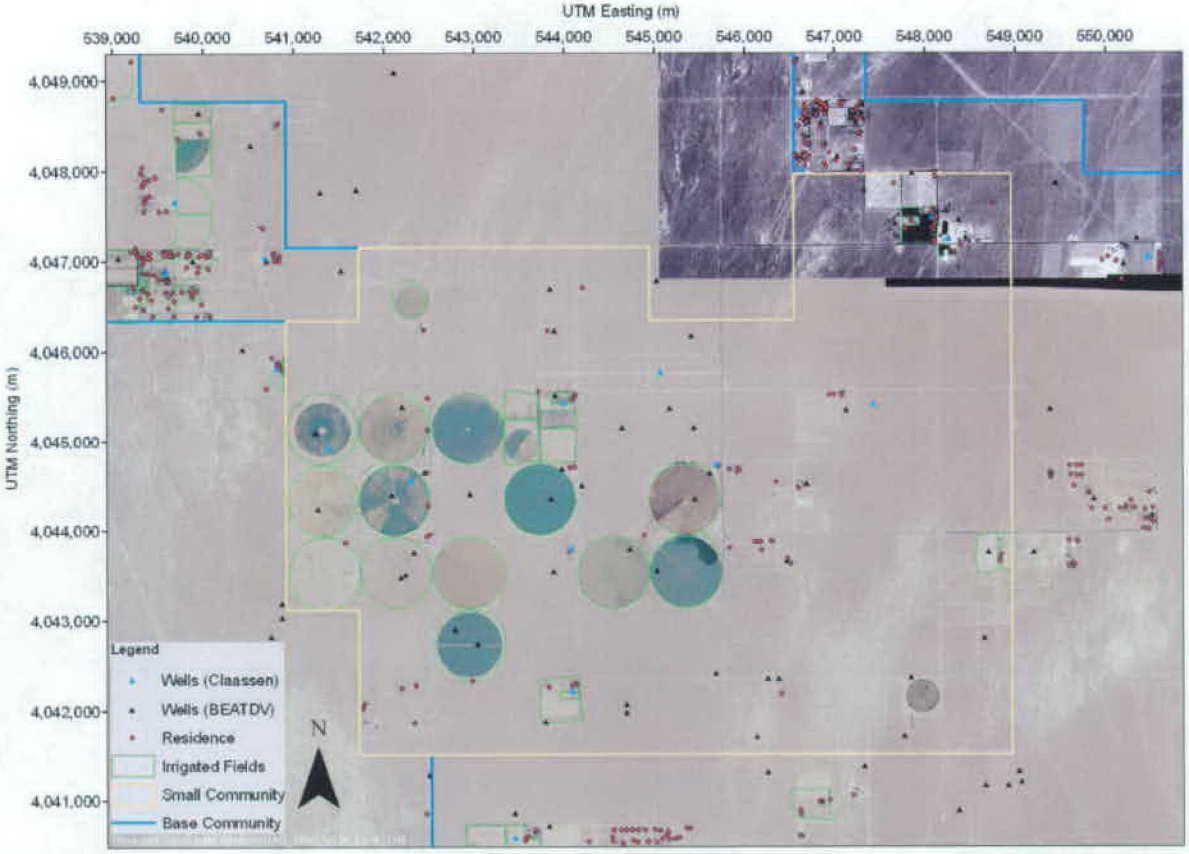
Figure 6.5-1. Amargosa Valley and Assumed Boundaries of the Base Community and Small Community

6.5.3.2.4 Community Definition

The current locations of the irrigated fields and residences are spread over a large area around the town of Amargosa Valley. These locations are not random but rather are determined, at least in part, by the federal land ownership and soil quality. The fields and residences are typically distributed in clusters within this area. Using the location of irrigated areas, residences, and wells, one could outline a community boundary that includes essentially all residences and irrigated areas. Such a community area naturally excludes the Ash Meadows and Highway 95 areas. It was assumed that a community could be defined as a group of closely located clusters. This is a conservative assumption. A larger community would have more empty spaces and greater distances to the fields and residences from any arbitrarily selected point within that community. This would in turn result in fewer fields and residences located within the well capture zone.

Specifically to define such a community, the following approach was used. First, a map of the Amargosa Valley area was prepared that included the locations of agricultural fields, residential addresses, and wells as shown in Figure 6.5-1. Next, a grid with a half-mile spacing or resolution was constructed. The half-mile grid was used because the irrigated fields represent circles with approximate half-mile diameters. The community was defined as a contiguous range of grid cells (one-half mile square) that included a field, a residence, or a well. The boundaries of the resulting base community are shown as a blue line in Figure 6.5-1.

A smaller community represented by one cluster of features was also defined within the base community as shown in Figure 6.5-1 (location of the small community within the base community) and Figure 6.5-2. This was done to evaluate the effect of the community size when estimating well recapture fraction (as discussed in Section 6.5.3.4).



Sources: DTNs: MO0706NAIPDQI9.000 [DIRS 181356]; MO0706FD30MQMA.000 [DIRS 181355]; MO0309COV03136.000 [DIRS 181357]; LA0309EK831223.001 [DIRS 165471]); and MO9903COV97533.000 [DIRS 181358].

Figure 6.5-2. Small Community Area

6.5.3.2.5 Distances to the Irrigated Fields

The annual volume of water available for irrigation dictates the number of the fields in the community. As discussed in Section 6.5.3.1, the community could use from 2,550 (85%) to 2,880 (96%) ac-ft/yr for alfalfa irrigation. The alfalfa irrigation rate is 1.94 m/yr (Section 6.5.2). As a result, the irrigated area could be from 401 to 453 ac. The irrigated fields are circles with one-half mile diameters, having an area of 125 ac or a little bit smaller. The number of fields that could be irrigated is then from 3.2 to 3.6 fields. It was assumed that there are four irrigated fields for this study.

The locations of the currently and previously irrigated fields, as well as the residences, are shown in Figures 6.5-1 and 6.5-2. To quantify the distances from the hypothetical well to the fields, it was assumed that the well could be located anywhere within the community. Then, the distances from the center of each 1/2-mile grid cell within the community boundary to the centroids of irrigated fields were calculated for the base and small communities. Separate distributions of such distances were constructed for the first, second, third, and fourth irrigated field closest to the well.

The base community calculations are in *Base_Case_Field_Distances.xls,* and the small community calculations are in *Small_Communuty_Distances.xls* in output DTN: SN0703PASZIRMA.001 (directory *Parameters*). The coordinates of the grid block nodes and the irrigated field centroids (calculated using standard functions within Autodesk Land Desktop Version 3 (608491-3-00)) can be examined in output DTN: SN0703PASZIRMA.001, *Base_Case_Field_Distances.xls* and *Small_Communuty_Distances.xls* (in directory *Parameters*). The distance distributions for the base community and small community are shown in Figures 6.5-3 and 6.5-4, respectively. As expected, the distances are smaller in the case of the small community.

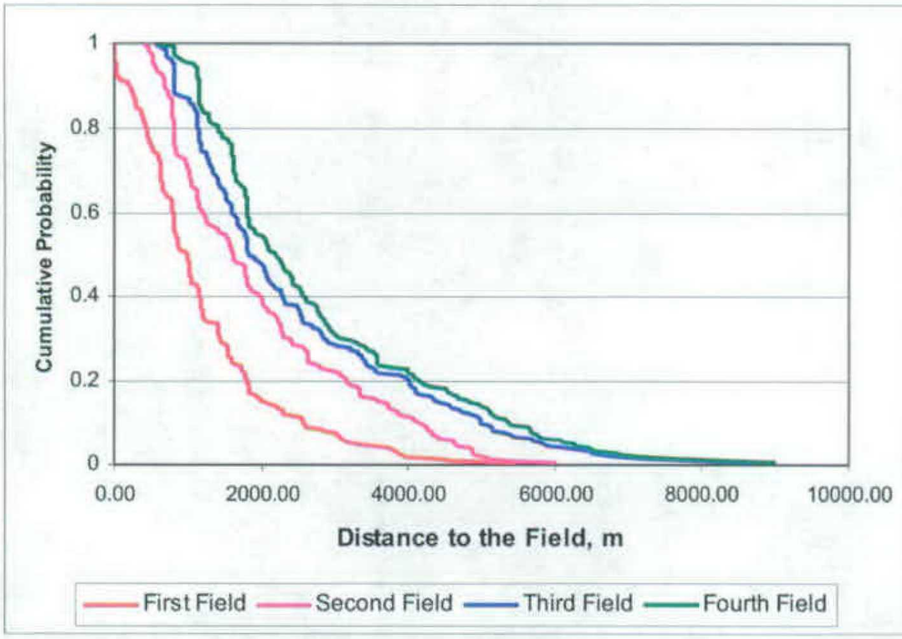
The distance to the irrigated fields distributions are used to define the potential locations of the irrigated fields with regard to the hypothetical well as described in Section 6.5.3.4.1.

6.5.3.2.6 Distances to the Residences

The distances from the residences are computed for arbitrary locations in the center of the grid cells. The distribution of these distances is used to represent the distribution of distances of residences from a hypothetical well placed within the community over the highest concentration in the plume of contamination. This distribution was calculated for the base community case only (Figure 6.5-5). The maximum distance from the hypothetical well to the closest residence is about 1,700 m (or 1 mi), meaning that the closest residence is two blocks away from the hypothetical well. 82% of the residences (Figure 6.5-5) are located closer than 800 m (1/2 mi) to the hypothetical well, which means that they are either next to the well grid block or in the well grid block. As a result, the community size should not affect the distances to the residences as in the case of irregularly spaced fields.

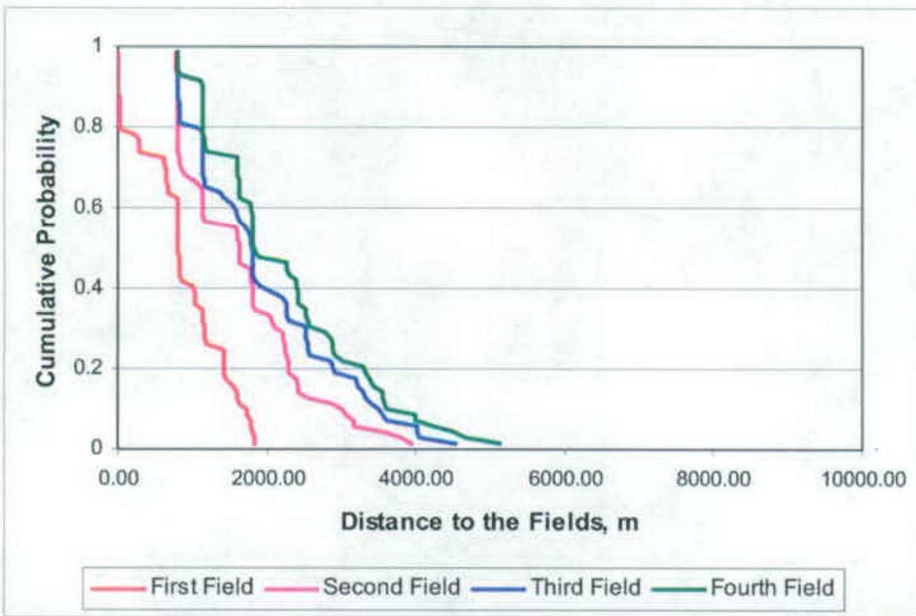
The distance probability distribution was obtained by calculating the distances from the center of each grid element within the base community boundary to the closest residence. These calculations are in *Residence_Distances.xls* in output DTN: SN0703PASZIRMA.001 (directory *Parameters*). The coordinates of the grid block nodes and the residences can be examined in the spreadsheet *Residence_Distances.xls* (output DTN: SN0703PASZIRMA.001, directory *Parameters*). The distance distribution is shown in Figure 6.5-5.

The distance to the residences distribution is used to define the potential locations of the residences with regard to the hypothetical well as described in Section 6.5.3.5.1.



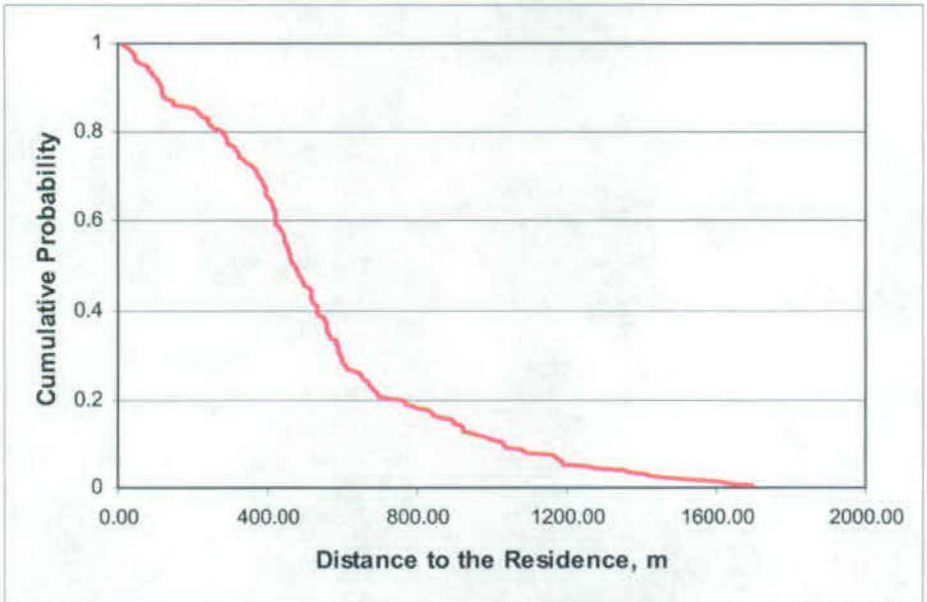
Source: Output DTN: SN0703PASZIRMA.001, *\Parameters\Base_Case_Fields_Distances.xls.*

Figure 6.5-3. Distance from the Well to the Irrigated Fields Distribution for the Base Community Case



Source: Output DTN: SN0703PASZIRMA.001, *\Parameters\Small_Community_Distances.xls.*

Figure 6.5-4. Distance from the Well to the Irrigated Fields Distribution for the Small Community Case



Source: Output DTN: SN0703PASZIRMA.001, *\Parameters\Residence_Distances.xls.*

Figure 6.5-5. Distance from the Well to the Closest Residence Distribution

6.5.3.3 Capture Zone Analysis

The capture zone dimensions calculated in this section are used in Sections 6.5.3.4 and 6.5.3.5 to calculate the well recapture fraction and residential water use fraction (the fraction of the residential water used within the well capture zone). As discussed in Section 5.2, a hypothetical well is continuously pumping water out of the whole thickness of the alluvium aquifer at a rate equal to 3,000 ac-ft/yr. The pumping results in a capture zone that includes the upgradient and downgradient areas that will drain into the pumping well. When the well is pumped long enough, the capture zone will extend upgradient to the closest groundwater divide. From this moment on, the shape of the capture zone will remain constant with time (Section 6.3). Outside of the capture zone, groundwater will flow around the well and continue downgradient. Inside the capture zone, the flow will drain into the cone of depression created by the pumping well. As discussed in Section 5.2, it is assumed that the capture zone will reach steady-state conditions instantaneously. The other assumptions related to the capture zone analysis are discussed in Section 6.3.

The alluvium aquifer around well NC-EWDP-19D (hypothetical well location) is under unconfined conditions (SNL 2007 [DIRS 177394], Appendix F1.2). Around the NC-EWDP-22S, the alluvium aquifer is partially under unconfined and partially under confined conditions (SNL 2007 [DIRS 177394], Appendix F1.2). Consequently, both unconfined and confined aquifer conceptual models are valid representations of the alluvium aquifer. Both conceptual models were considered, and these models are described below.

6.5.3.3.1 Confined Aquifer

An analytical solution describing the edge of the capture zone when steady-state conditions are reached assuming a two-dimensional homogeneous aquifer of an infinite extent under confined conditions can be described by the following equation (Fetter 2001 [DIRS 156668]):

$$x = \frac{-y}{\tan(2\pi uBy / Q)} \quad \text{(Eq. 6.5-11)}$$

where x and y are the capture zone edge coordinates, Q is the well pumping rate, u is the groundwater-specific discharge in the absence of pumping, and B is the aquifer thickness (Figure 6.5-6 a). In this formulation, the pumping well is fully penetrating and is located in the center of the coordinate system ($x = 0$ and $y = 0$). This solution does not consider the aquifer recharge (as discussed in Section 6.3).

The distance x_0 from the pumping well downstream to a stagnant point location (at this location $y = 0$) is given as (Fetter 2001 [DIRS 156668]):

$$x_0 = \frac{-Q}{2\pi uB} \quad \text{(Eq. 6.5-12)}$$

This equation is derived from Equation (6.5-11) using $\lim y \to 0$.

The maximum width of the capture zone as x approaches infinity is given by (Fetter 2001 [DIRS 156668]):

$$y_{\max} = \frac{\pm Q}{2uB} \quad \text{(Eq. 6.5-13)}$$

This equation is derived by rearranging Equation 6.5-11 and using $x \to \infty$.

As it can be seen from Equations 6.5-11 through 6.5-13, two parameters define the capture zone dimensions when the pumping rate is constant. These parameters are the specific discharge and the aquifer thickness.

6.5.3.3.2 Unconfined Aquifer

An analytical solution describing the edge of the capture zone when steady-state conditions are reached assuming a two-dimensional homogeneous aquifer of an infinite extent under unconfined conditions can be described by the following equation (Fetter 2001 [DIRS 156668]):

$$x = \frac{-y}{\tan(\pi k (h_1^2 - h_2^2) y / (QL))} \quad \text{(Eq. 6.5-14)}$$

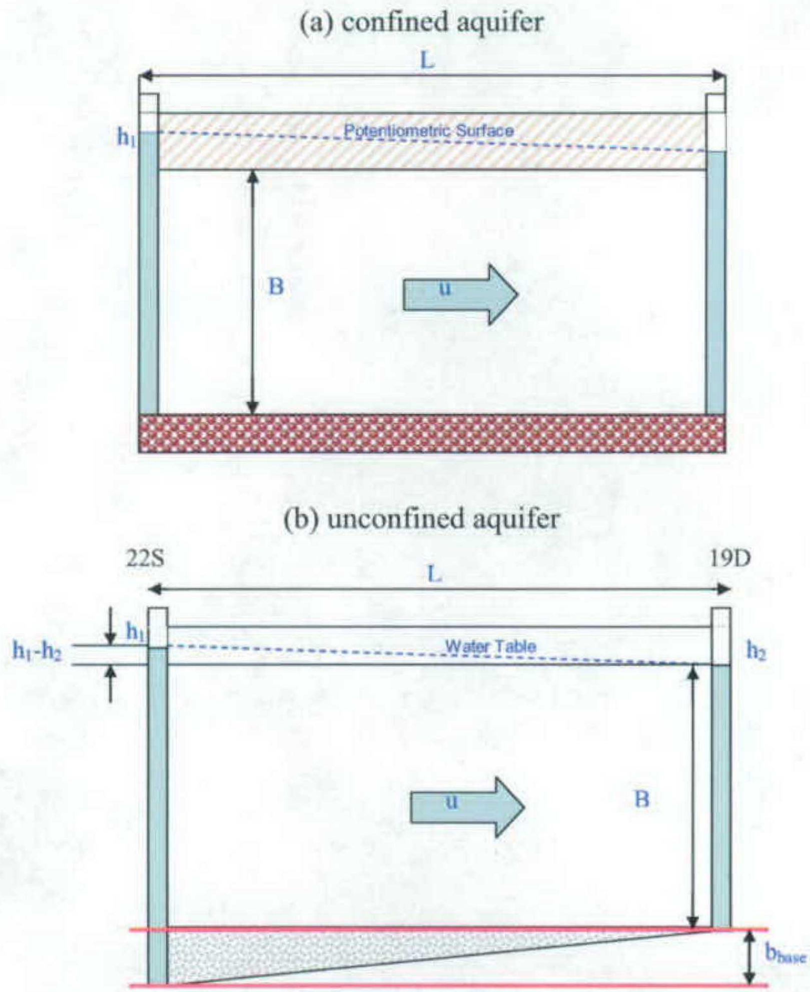
where k is the aquifer hydraulic conductivity, h_1 and h_2 are the distances from the water table to the bottom of the aquifer at two wells located along the gradient, and L is the distance between these two wells. This is demonstrated in Figure 6.5-6b. This solution does not take into the account the aquifer recharge (as discussed in Section 6.3).

The distance x_0 from the pumping well downstream to a stagnant point location (at this location y = 0) is given as (Fetter 2001 [DIRS 156668]):

$$x_0 = \frac{-QL}{\pi k(h_1^2 - h_2^2)} \quad \text{(Eq. 6.5-15)}$$

The maximum width of the capture zone as x approaches infinity is given by (Fetter 2001 [DIRS 156668]):

$$y_{\max} = \frac{\pm QL}{k(h_1^2 - h_2^2)} \quad \text{(Eq. 6.5-16)}$$



Source: For illustration purposes only.

Figure 6.5-6. Conceptual Representation of the Alluvium Aquifer for Capture Zone Analysis

As can be seen from Figure 6.5-6b, the following equation can be written for h_1:

$$h_1 = B + (h_1 - h_2) = B + \Delta h_0 \qquad \text{(Eq. 6.5-17)}$$

Using Equation 6.5-17, one can obtain the following expression:

$$(h_1^2 - h_2^2) = \Delta h_0 (2B + \Delta h_0) \qquad \text{(Eq. 6.5-18)}$$

Using Equation 6.5-18, Equations 6.5-14 through 6.5-16 can be written as:

$$x = \frac{-y}{\tan(\pi u(2B + \Delta h_0)\, y / Q)} \qquad \text{(Eq. 6.5-19)}$$

$$x_0 = \frac{-Q}{\pi u(2B + \Delta h_0)} \qquad \text{(Eq. 6.5-20)}$$

$$y_{max} = \frac{\pm Q}{u(2B + \Delta h_0)} \qquad \text{(Eq. 6.5-21)}$$

These equations were obtained using the following formula (Fetter 2001 [DIRS 156668]):

$$u = k \frac{\Delta h_0}{L} \qquad \text{(Eq. 6.5-22)}$$

Equations 6.5-19 through 6.5-21 allow us to use the same parameters for both confined and unconfined aquifers. These parameters are specific discharge u and aquifer thickness B. In the case of the unconfined aquifer, one more parameter is needed: Δh.

The greater the aquifer thickness, the specific discharge, and the Δh, the smaller the capture zone dimensions.

Equation 6.5-11 for the confined aquifer can be rearranged and written in the following form (Javandel and Tsang 1986 [DIRS 181303]):

$$y = \pm \frac{Q}{2Bu} - \frac{Q}{2\pi Bu} \tan^{-1} \frac{y}{x}, \; x>0 \qquad \text{(Eq. 6.5-23)}$$

Using the same logic as above, Equation 6.5-19 for the unconfined aquifer can be rewritten as:

$$y = \pm \frac{Q}{u(2B + \Delta h_0)} - \frac{Q}{u(2B + \Delta h_0)} \tan^{-1} \frac{y}{x}, \; x>0 \qquad \text{(Eq. 6.5-24)}$$

Equations 6.5-23 and 6.5-24 were used in the spreadsheet calculations (Excel files *Recapture Fraction_Base_Case.xls, Irrigation Fraction_Base_Case.xls,* and *Small_Community_Fc.xls* in output DTN: SN0703PASZIRMA.001, directory *Parameters*) because they are written for coordinate y as opposed to Equations 6.5-11 and 6.5-19, which were written for coordinate x. The algorithm implemented in the well recapture fraction analysis (Section 6.5.3.4) requires calculation of coordinate y for any given coordinate x. Equations 6.5-23 and 6.5-24 require iterative solution.

Equations 6.5-23 and 6.5-24 are valid for $x>0$ when π has to be added to arctangent. In cases where $x<0$, the following equations apply:

$$y = \pm \frac{Q}{2\pi B u} \tan^{-1}\frac{y}{x} \text{ , x<0} \qquad \text{(Eq. 6.5-25)}$$

$$y = \pm \frac{Q}{u(2B + \Delta h_0)} \tan^{-1}\frac{y}{x} \text{ , x<0} \qquad \text{(Eq. 6.5-26)}$$

Equations 6.5-23 and 6.5-25 can be derived from Equation 6.5-11, and Equations 6.5-24 and 6.5-26 can be derived from Equation 6.5-19. In these equations, y is present in the right and left hand sides.

Equations 6.5-23 and 6.5-24 can be solved using Excel solver for a circular reference. To solve Equations 6.5-25 and 6.5-26 using circular reference solver, these equations need to be rewritten as:

$$y = \varsigma \pm \frac{Q}{2\pi B u} \tan^{-1}\frac{y}{x} \qquad \text{(Eq. 6.5-27)}$$

$$y = \varsigma \pm \frac{Q}{u(2B + \Delta h_0)} \tan^{-1}\frac{y}{x} \qquad \text{(Eq. 6.5-28)}$$

Where ζ represents the accuracy of the solution (ζ was set equal to 0.001 m). Thus, the location of the capture zone edge was estimated with the accuracy equal to 1 mm.

Equations 6.5-23, 6.5-24, 6.5-27, and 6.5-28 define the edge of the capture zone as a function of the parameters u, B, and Δh_0. These parameters are described below.

6.5.3.3.3 Capture Zone Parameters

The probability distributions were developed for each of three capture zone parameters. Two scenarios were considered. In the first, the present-day climate values were used. In the second, the mean weighted values over the period of simulation were used. The mean weighted parameter value (P_{mean}) was calculated as:

$$P_{mean} = P_{pd}\frac{t_{pd}}{T} + P_m\frac{t_m}{T} + P_{gt}\frac{t_{gt}}{T} \qquad \text{(Eq. 6.5-29)}$$

where P_{pd} is the present-day climate parameter value, P_m is the parameter value for monsoon climate, P_{gt} is the parameter value for glacial transition climate, T is the period of simulation

(20,000 years), t_{pd} is the present-day climate duration (600 years), t_m is the monsoon climate duration (1,400 years), and t_g is the glacial transition climate duration (18,000 years). The climate durations are the same as in the saturated zone flow and transport abstraction model (DTN: SN0702PASZFTMA.002 [DIRS 183471]). The period of simulation and the durations of the different climate is redefined when the irrigation recycling model is incorporated in the TSPA model to conduct the sensitivity analysis (Section 6.7).

The present-day climate values (Scenario 1) are used to calculate the present-day climate well recapture fraction as described in Section 6.5.3.4. The present-day climate well recapture fraction based on these estimates is compared to the other available estimates. The mean values calculated using Equation 6.5-29 (Scenario 2) are used to calculate the well recapture fraction (Section 6.5.3.4) and the indoor residential fraction (Section 6.5.3.5) that represent an input in the irrigation recycling model.

6.5.3.3.3.1 Aquifer Thickness

The aquifer thickness probability distribution is based on the lithostratigraphic data available for the well NC-EWDP-19D (hypothetical pumping well location) and surrounding Nye County wells (DTNs: GS030108314211.001 [DIRS 163483] (files *NC_EWDP_10SA_Lithlog.doc*, *NC_EWDP_1(IM1A_Lithlog.doc*, *NC_EWDP_19IM2A_Lithlog.doc*, *NC_EWDP_22SA_Lithlog.doc*, *NC_EWDP_23P_Lithlog.doc*) and GS011008314211.001[DIRS 158690]) and the present-day climate water table elevation data from DTN: MO0611SCALEFLW.000 [DIRS 178483] (file *wt_HFM2006_X.dat*). These data are summarized in Table 6.5-1.

Table 6.5-1. Saturated Alluvium Thickness in the NC-EWDP Wells

Well Number	Ground Elevation (m)	Alluvium Thickness (m)	Water Table Elevation (m)	Saturated Alluvium Thickness (m)
NC-EWDP-10SA	903.4	366	727.0	189.6
NC-EWDP-23P	853.4	396.2	724.2	267.0
NC-EWDP-2DB	801.3	280.7	706.1	185.5
NC-EWDP-19D	819.0	249.9	712.01	142.91
NC-EWDP-22S	868.4	320.1	724.81	176.51

Sources: DTNs: GS030108314211.001 [DIRS 163483] (files *NC_EWDP_10SA_Lithlog.doc*, *NC_EWDP_1(IM1A_Lithlog.doc*, *NC_EWDP_19IM2A_Lithlog.doc*, *NC_EWDP_22SA_Lithlog.doc*, *NC_EWDP_23P_Lithlog.doc*); GS011008314211.001 [DIRS 158690], and MO0611SCALEFLW.000 [DIRS 178483] (file *wt_HFM2006_X.dat*).

There are no qualified data for well NC-EWDP-5SB. The unqualified data for this well show an alluvium thickness of 366 m. These data are supported by an article by Spengler (2006 [DIRS 181302], Plate 2). The saturated thickness in this well is 250.0 m based on the ground elevation of 839.06 m and depth to water table of 723.6 m. This thickness is within the range defined in Table 6.5-1.

Based on data in Table 6.5-1, the aquifer thickness is from 143 to 267 m. A uniform distribution with this range was assigned to the aquifer thickness. The distribution was sampled using Monte Carlo sampling technique in GoldSim, and the resulting 50 values for the thickness were obtained. These calculations are in *Capture_Zone_Parameters.gsm* in output

DTN: SN0703PASZIRMA.001 (directory *Parameters*). This distribution is based on the present-day climate estimates.

The aquifer thickness will be greater under the monsoon and glacial transition climate conditions due to the rise in water table. The predicted water table rise in well NC-EWDP-19D under the glacial transition conditions was 68 m as described in Section 6.5.3.7. This water table rise was used to calculate the aquifer thickness under the glacial climate conditions. No credit was taken for the predicted, noticeably greater water table rise in the upstream area where the most of the capture zone will be located. No credit was also taken for the increase in the aquifer thickness during the monsoon climate. It was assumed that the water table during the monsoon climate was the same as during the present-day climate. While the water table rise might not be conservative for estimating effects of irrigation recycling (the predicted water table rise was purposely biased to the larger values), the other two assumptions are conservative and the overall approach is reasonably conservative.

The mean weighted aquifer thickness was calculated using Equation 6.5-29. The aquifer thickness during the glacial transition period was calculated as the present-day climate aquifer thickness plus 68 m (predicted water table rise). These calculations are in *Recapture Fraction_Base_Case.xls, Small_Community_Fc.xls,* and *Irrigation Fraction_Base_Case.xls* in output DTN: SN0703PASZIRMA.001 (directory *Parameters*). The mean value is calculated for each of 50 realizations of the present-day climate aquifer thickness.

6.5.3.3.3.2 Specific Discharge

The estimates of the specific discharge at the well NC-EWDP-19D site are available from DTN: LA0303PR831231.002 [DIRS 163561] (Table 3 in the file *IHLRWM_Reimus et al.doc*). The specific discharge values range from 1.2 to 9.4 m/yr. This is a conservative estimate of the specific discharge. The maximum specific discharge obtained based on the gradient between well NC-EWDP-19D and well NC-EWDP-22S is 12.2 m/yr (DTN: LA0303PR831231.002 [DIRS 163561], Table 3 in the file *IHLRWM_Reimus et al.doc*). Larger values were also obtained based on the site-scale flow model results. These specific discharge estimates are not sufficient to construct any distribution except the uniform one. Thus, a uniform distribution with this range was assigned to the specific discharge. The distribution was sampled using the Monte Carlo sampling technique in GoldSim, and the resulting 50 values for the specific discharge were obtained. These calculations are in the GoldSim file *Capture_Zone_Parameters.gsm* in output DTN: SN0703PASZIRMA.001 (directory *Parameters*). This distribution is based on the present-day climate estimates.

The specific discharges during the monsoon and glacial transition climates were obtained following the same approach as in *Saturated Zone Flow and Transport Model Abstraction* (SNL 2007 [DIRS 181650]). Here, the specific discharges during the future climates are calculated as:

$$u_m = 1.9u \text{ and } u_{gt} = 3.9u \qquad \text{(Eq. 6.5-30)}$$

where u_m is the specific discharge during the monsoon climate, and u_{gt} is the specific discharge during the glacial transition climate. The multipliers (1.9 and 3.9) in Equation 6.5-30 are from the saturated zone flow and transport abstraction model (DTN: SN0702PASZFTMA.002 [DIRS 183471]). While the multipliers for the specific discharge might not be conservative for estimating effects of irrigation recycling (these multipliers were purposely biased to the larger values so as not to underestimate transport times), the specific discharge was defined conservatively (as previously described) and the overall approach is reasonably conservative.

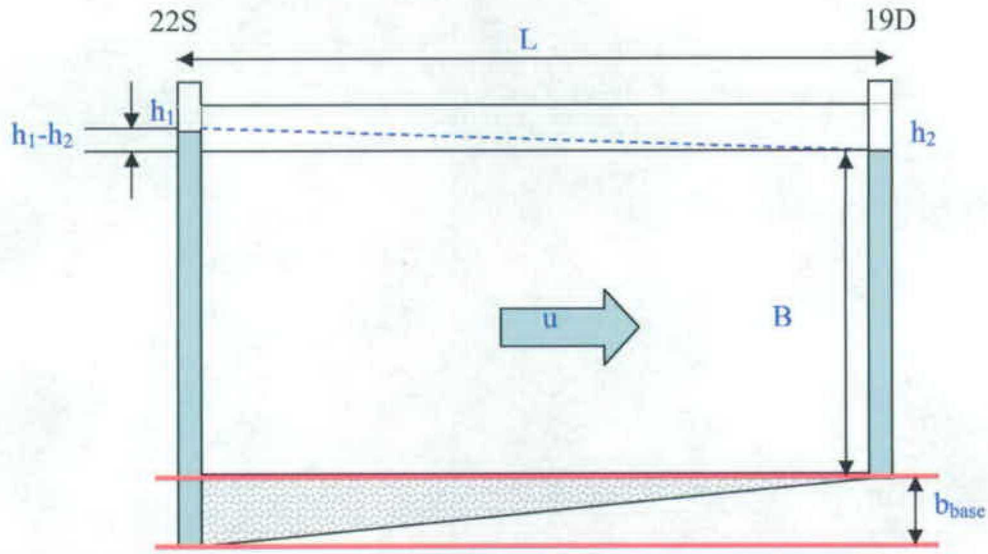
The mean weighted specific discharge was calculated using Equation 6.5-29. These calculations are in the Excel files *Recapture Fraction_Base_Case.xls, Small_Community_Fc.xls,* and *Irrigation Fraction_Base_Case.xls* in output DTN: SN0703PASZIRMA.001 (directory *Parameters*). The mean value is calculated for each of 50 realizations of the present-day climate specific discharge.

6.5.3.3.3.3 Parameter Δh_0

Parameter Δh_0 represents the difference in the aquifer-saturated thickness between the downgradient and upgradient wells. In the case of an aquifer with a horizontal base (Figure 6.5-6), Δh_0 can be calculated as the difference in the water table elevations between these two wells. In the case when the base of the aquifer is sloping, the difference will consist of the difference in the water table elevations (Δh) and the difference between the elevations of the aquifer base (b_{base}) at these two locations (Figure 6.5-7). Consequently, parameter Δh_0 can be expressed as:

$$\Delta h_0 = \Delta h + b_{base} \qquad \text{(Eq. 6.5-31)}$$

Parameter Δh was estimated based on the water table elevations in wells NC-EWDP-19D and NC-EWDP-1922S (Table 6.5-1). Well NC-EWDP-22S is located 4.6 km downgradient from the NC-EWDP-19D. The difference in the water table elevations is 12.8 m. Parameter b_{base} is 20.8 m based on the data in DTN: GS030108314211.001 [DIRS 163483], (files *NC_EWDP_10SA_Lithlog.doc, NC_EWDP_1(IM1A_Lithlog.doc, NC_EWDP_19IM2A_ Lithlog.doc, NC_EWDP_22SA_Lithlog.doc, NC_EWDP_23P_Lithlog.doc*) summarized in Table 6.5-1.



Source: For illustration purposes only.

NOTE: Red lines define an interval within which the aquifer base is located in the conceptual model considered. Any horizontal line within this interval may represent the aquifer base.

Figure 6.5-7. Conceptual Representation of the Aquifer Base

Note that the capture zone solutions are for the aquifers with horizontal bases. Thus, the bottom of the alluvial aquifer was approximated by a horizontal line as shown in Figure 6.5-7. Depending on the approximation, b_{base} ranges from 0 to 20.8 m. Based on Equation 6.5-31, parameter Δh_0 ranges from 12.8 to 33.58 m. A uniform distribution with this range was assigned to Δh_0. The distribution was sampled using the Monte Carlo sampling technique in GoldSim, and the resulting 50 values for Δh_0 were obtained. These calculations are in the GoldSim file *Capture_Zone_Parameters.gsm* in output DTN: SN0703PASZIRMA.001 (directory *Parameters*). This distribution is based on the present-day climate estimates.

The parameter Δh_0 corresponding to the monsoon and glacial transition climates was obtained following the same approach as in specific discharge calculations described in Section 6.5.3.3.3.2. As can be seen from Equation 6.5-22, the only climate-dependent parameter affecting specific discharge in this formula is Δh_0, which in this case is equal to Δh = 12.8 m. Consequently, Δh_m corresponding to the monsoon climate is 12.8 × 1.9 = 24.32 m, and Δh_{gt} corresponding to the glacial transition climate is 12.8 × 3.9 = 49.92 m. Parameter b_{base} does not depend on climate. The resulting parameter Δh_0 corresponding to the monsoon and glacial transition climates was calculated using Equation 6.5-31.

The mean weighted value of Δh_0 was calculated using Equation 6.5-29. These calculations are in *Recapture Fraction_Base_Case.xls, Small_Community_Fc.xls,* and *Irrigation Fraction_Base_Case.xls* in output DTN: SN0703PASZIRMA.001 (directory *Parameters*). The mean value is calculated for each of 50 realizations of the present-day climate value of the parameter Δh_0.

6.5.3.4 Well Recapture Fraction

Well recapture fraction (F_c) represents a direct input into the irrigation recycling model as described in Section 6.4. This is an important parameter that defines how much of the contaminated water used for irrigation will be recycled (drawn back to the pumping well). When F_c=0, irrigation water is not being recycled. When F_c =1, all irrigation water is recycled (recaptured by the well).

The approach that is used to estimate the well recapture fraction combines the analysis of the distances to the irrigated fields within the community boundary (Section 6.5.3.2) with the analysis of the capture zone dimensions (Section 6.5.3.3). When the spatial distributions of the fields around the well (produced by assuming the uniform angular distribution of the distances for the first to fourth field closest to the well) are combined with the spatial extent of the plume of contamination, it is possible to determine the number of irrigated fields that fall inside the well capture zone (including the capture zone edge). F_c can then be calculated as the ratio of the number of irrigated fields within the well capture zone to the total number of fields, which corresponds to the fraction of the irrigated area that falls inside the well capture zone.

A field is represented by its center, and the field area is not taken into account. When a large number of locations are considered, the field area should not affect the results because if a field center is located on the capture zone edge, approximately the half of this field (half of the circle) will be located outside the capture zone. However, the entire field will be considered being inside the capture zone because its center is. Similarly, if a field center is located just outside the capture zone edge, approximately the half of this field (half of the circle) will be located inside the capture zone. However, the entire field will be considered being outside the capture zone because its center is. As a result, the total field area located outside the capture zone and considered being inside will be approximately equal to the total field area located inside the capture zone and considered being outside.

This approach allows for incorporating probability distributions that describe the locations of the irrigated fields and probability distributions for the parameters that define the capture zone sizes. As the result, a probability distribution can be obtained for the parameter F_c. It is implemented as follows.

6.5.3.4.1 Potential Locations of the Irrigated Fields

Potential locations of the irrigated fields are defined with regard to the hypothetical well. As it as discussed in Section 5.1, the hypothetical well location is fixed for the entire period of simulation. The locations of the irrigated fields are assumed to move around within the community boundaries. As a result, any location within the community boundaries might be an irrigated field at some time during the simulation period, although not with equal probability. Based on the distribution of the fields relative to the well (Figure 6.5-4), field distances closer to the well are more probable that the distances farther away. When the locations of the four fields are sampled, it is possible that at some periods of time all the irrigated fields will be within the capture zone; at some other periods of time less than four fields (including zero) will be within the capture zone. The distributions of the distances to the irrigated fields can thus be used to calculate all the potential locations of irrigated fields within the community boundary. These potential locations can be used to estimate the probability that the irrigated fields are located within the well capture zone. As explained in Section 6.5.3.2, the distances to the irrigated fields within the community boundary were based on those that are present-day characteristics of Amargosa Valley. The distributions represent the distances from the well of the first to fourth field closest to that well. The distributions were constructed for the base community and the small community. It is assumed that an irrigated field can be located at that distance in any randomly selected direction. The coordinates of the fields were obtained by randomly sampling a counter clockwise angle between the positive axis x and the center of the field. There are 204 realizations of distances for each of the four closest irrigated fields (this corresponds to the number of grid blocks in the base community). Using random number generator function in Excel (r), 816 (204 × 4) realizations of angles (α) measured in radians were obtained as:

$$\alpha_k = 2\pi r_k \qquad k = 1, 816 \qquad \text{(Eq. 6.5-32)}$$

where k is the realization number. The radial coordinates of the field centers defined by the distance from the well R_k and the angle α_k were converted to Cartesian coordinates X_k and Y_k using the following formulae:

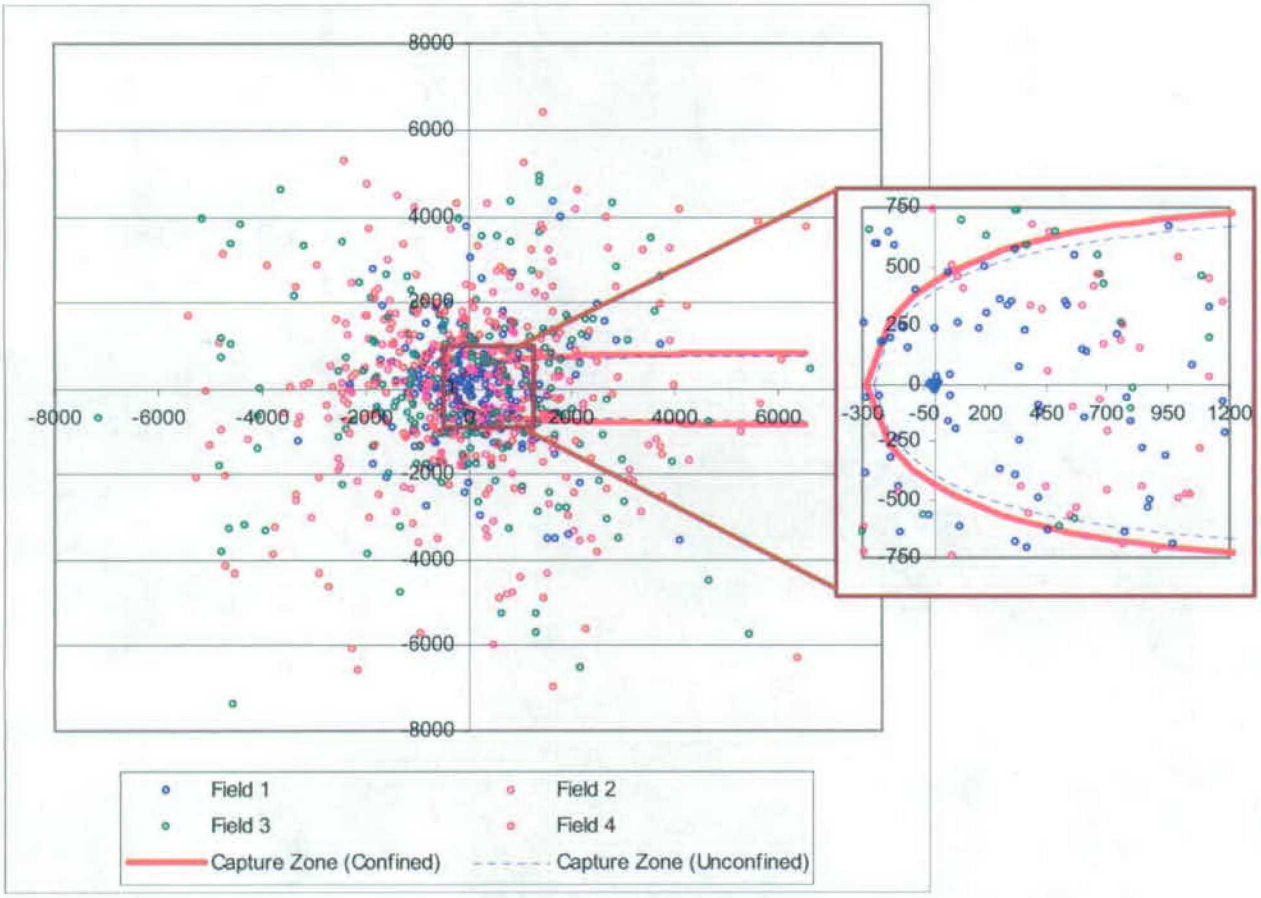
$$X_k = R_k Cos(\alpha_k) \text{ and } Y_k = R_k Sin(\alpha_k) \qquad \text{(Eq. 6.5-33)}$$

The resulting locations of the potential fields are shown in Figure 6.5-8 for the case of the base community. These calculations are in the Excel files *Recapture Fraction_Base_Case.xls* and *Small_Community_Fc.xls* in output DTN: SN0703PASZIRMA.001 (directory *Parameters*).

The same procedure was used to define locations in the case of the small community. The number of the distance realizations obtained for the small community is 68 for each of the four fields (this corresponds to the number of grid blocks in the small community). The small community distance distributions were sampled using the GoldSim Monte Carlo technique to generate the same number of realizations (204) as in the case of the base community. The cumulative distance distributions for each of the four fields were defined using data in the Excel file *Small_Community_Distances.xls* (output DTN: SN0703PASZIRMA.001 (directory *Parameters*). These cumulative distributions were used in the GoldSim file *Small_Community.gsm* (output DTN: SN0703PASZIRMA.001, directory *Parameters*) to generate 204 distance realizations for each field.

6.5.3.4.2 Capture Zone Location

Fifty locations of the capture zone were calculated by sampling the capture zone parameters B, u, and Δh_0, as described in Section 6.5.3.3. For x_i>0, the coordinate y_i of the capture zone edge was calculated using Equation 6.5-23 for the confined aquifer and Equation 6.5-24 for an unconfined aquifer. For x_i<0, the coordinate y_i was calculated using Equation 6.5-27 for the confined aquifer and Equation 6.5-28 for an unconfined aquifer.



Source: Output DTN: SN0703PASZIRMA.001 (directory *Parameters*, file: *Recapture Fraction_Base_Case.xls*).

NOTE: Distances are in meters.

Figure 6.5-8. Locations of the Potential Irrigated Fields Within the Base Community

The calculations were done for the present-day climate and the mean climate-weighted values of parameter distributions. The capture zone dimensions calculated for the present-day climate were used to calculate the present-day climate well recapture fraction (Section 6.5.3.4.3). The present-day climate well recapture fraction calculated in this analysis was compared to an existing estimate of the present-day climate well recapture fraction in Section 6.5.3.4.3. Also, the median present-day climate value of the well recapture fraction was used to define the maximum value of the well recapture fraction distribution used in the irrigation recycling model as described in Section 6.5.3.4.3. The capture zone dimensions calculated using the mean climate-weighted values of the parameter distributions were used to develop the distribution of the well recapture fraction used in the irrigation recycling model as described in Section 6.5.3.4.3. An example capture zone (for the realization #6), together with the sampled locations of the irrigated fields, is shown in Figure 6.5-8.

6.5.3.4.3 Well Recapture Fraction

In the calculation of the well recapture fraction, it was assumed that the flow is aligned with the negative direction of the *x*-axis. This is done for convenience only. The direction can be arbitrarily selected because the fields are assumed to be uniformly distributed in any direction from the pumping well. To determine the well capture fraction, each of the 50 realizations of the capture zone dimensions (as determined by sampling the capture zone parameters) was combined with the same 816 locations of the irrigated fields shown in Figure 6.5-8. Each field location has coordinates X_k and Y_k, as described in Section 6.5.3.4.1. For each X_k, the coordinate of the capture zone was calculated as described in Section 6.5.3.4.2. A field is considered to be inside the well capture zone if, for a given X_k, the following is true:.

$$y_k \leq Abs(Y_{k,i}) \qquad \text{(Eq. 6.5-34)}$$

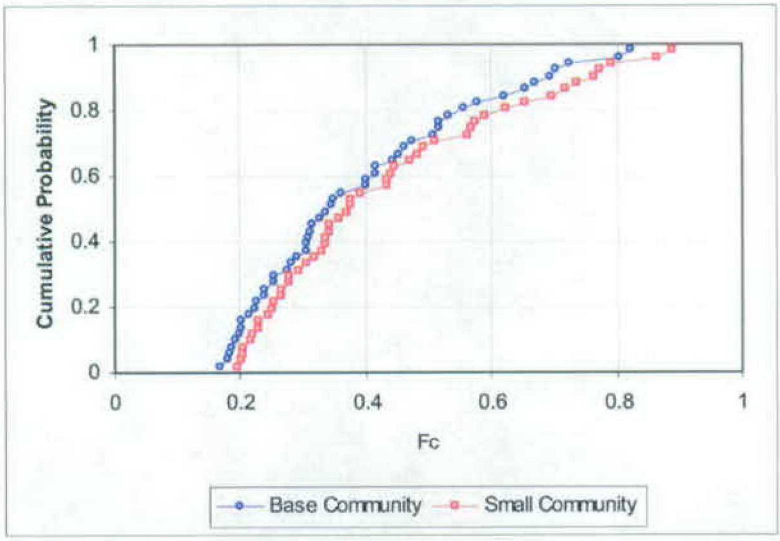
The well recapture fraction for the realization i ($F_{c,i}$) is then calculated as:

$$F_{c,i} = \frac{n_i}{N} \qquad \text{(Eq. 6.5-35)}$$

where n_i is the number of the irrigated fields calculated in the realization i (out of possible 816) that are located inside the well capture zone, averaged between the confined and unconfined aquifers, assuming each conceptual model has equal probability. N is the number of irrigated fields in each model realization (N = 816).

Fifty values of the well recapture fraction, F_c, were calculated using the parameter distribution for the present-day climate and the climate-weighted average parameter values for the base community and the small community. The community definitions for these two cases are provided in Section 6.5.3.2.4. The results of these calculations are presented in Figure 6.5-9 (the calculations can be found in Excel files *Recapture Fraction_Base_Case.xls* and *Small_Community_Fc.xls* included in the output DTN: SN0703PASZIRMA.001 (directory *Parameters*. This figure is presented for illustration only. The values of the well recapture fraction for the use in the irrigation recycling model are further developed, as described below.

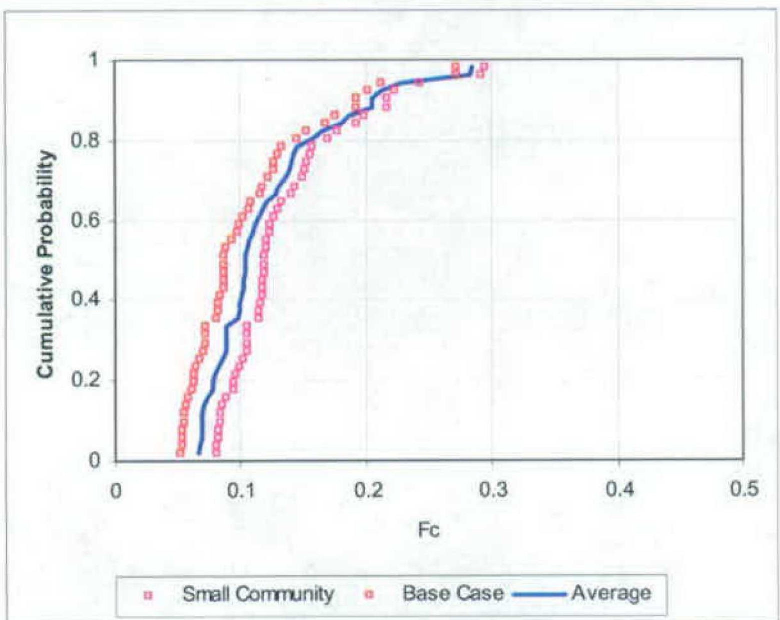
The distributions shown in Figure 6.5-9 were used only to compare the calculated F_c with the available estimate of this parameter. Only one estimate is available for the parameter F_c in the case when irrigation is assumed at the boundary of the accessible environment. This estimate is based on the present-day climate water balance approach described in details in *Features, Events, and Processes in SZ Flow and Transport* (BSC 2005 [DIRS 174190]). The estimated F_c using this approach is 0.37, which is in good agreement with the 50th percentile values of the F_c distribution obtained in this report (0.34 and 0.37 for the base and small community correspondingly). Note that the estimate in *Features, Events, and Processes in SZ Flow and Transport* (BSC 2005 [DIRS 174190]) represents an expected value, and there is no either probability distribution or range derived for this parameter. Also, the water balance method describes the present-day climate conditions and is not directly applicable to the future climates because there are no estimates of the water balance parameters for these climates.



Source: Output DTN: SN0703PASZIRMA.001 (directory *Parameters,* file: *Recapture Fraction_Base_Case.xls*).

Figure 6.5-9. Well Recapture Fraction Based on the Present-Day Climate Parameter Distribution

The results of the calculations based on the climate-weighted average parameter distributions are shown in Figures 6.5-10 for both the base community and small community. These communities are defined is Section 6.5.3.2.4.

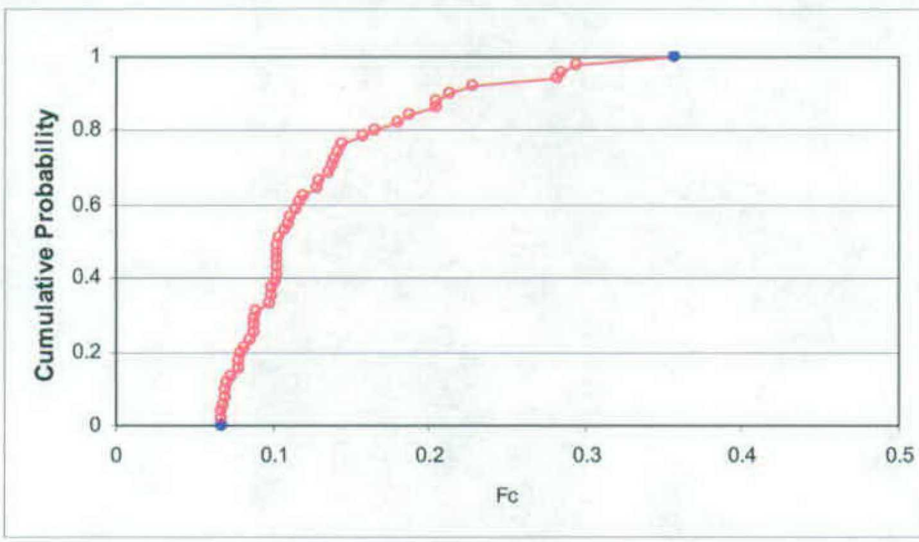


Source: Output DTN: SN0703PASZIRMA.001 (directory *Parameters,* file: *Recapture Fraction_Base_Case.xls*).

Figure 6.5-10. Well Recapture Fraction Based on the Climate-Weighted Average Parameter Distributions

The well recapture fraction distributions differ at the lower end of F_c but are very similar at the upper end (see Figure 6.5-10). Consequently, the community size does not affect the upper limit of the well recapture fraction. This is an important finding because it bounds the maximum recycling of irrigation water that might occur.

The F_c distribution incorporated into the irrigation recycling model represents an average between the base community and small community (Figure 6.5-10). This distribution has endpoints corresponding to the probabilities of 0.98 and 0.02 (resulting from using 50 realizations). A cumulative distribution can be defined in GoldSim by specifying the probabilities and corresponding parameter values. The values have to be provided for probabilities of 0 and 1. The F_c value corresponding to the cumulative probability of 0 was defined using linear extrapolation of the last five data points on the lower part of the tail. The resulting F_c is 0.067. The F_c value corresponding to the cumulative probability of 1 obtained by extrapolation is 0.326. Because the upper limit is important for bounding the recycling of the irrigation water, the F_c value corresponding to the cumulative probability of 1 was set equal to the 50th percentile value based on the present-day climate parameter distributions (this is the average of median values calculated for the base and small communities). The resulting F_c is 0.357. Consequently, the F_c distribution includes the median of the present-day climate distribution. The resulting distribution is shown in Figure 6.5-11. This distribution is specified for the parameter F_c in the GoldSim file, *Irrigation_Recycling_Model.gsm* (output DTN: SN0703PASZIRMA.001, directory *Model*).



Source: Output DTN: SN0703PASZIRMA.001 (directory *Parameters*; file: *Recapture Fraction_Base_Case.xls* and directory *Model*; file: *Irrigation_Recycling_Model.gsm*).

Figure 6.5-11. Well Recapture Fraction Cumulative Distribution Used in Irrigation Recycling Model

The mean F_c of this distribution is 0.128.

6.5.3.5 Indoor Residential Water Use Fraction

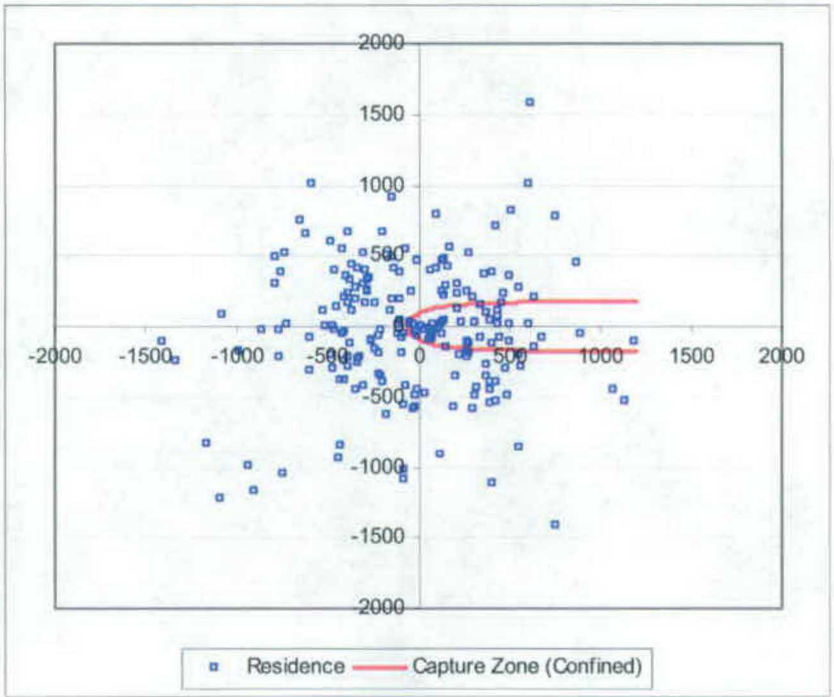
This section provides a discussion of the two parameters of the irrigation recycling model that are needed to calculate the fraction of residential water used indoors that is recaptured by the pumping well. These parameters are residential fraction (F_{res}) and indoor fraction (F_{ind}). The fraction of the residential water used indoors that falls within the capture zone is calculated as the product of F_{res} and F_{ind} (Equation 6.4-2).

6.5.3.5.1 Residential Fraction

Residential fraction (F_{res}) represents a direct input into the irrigation recycling model as described in Section 6.4. This is an important parameter that defines how much of the contaminated water used for residential purposes will be recycled (drawn back to the pumping well). In a case when F_{res} = 0, no residential water is recycled. In a case where F_{res} = 1, all irrigation water used indoors is recycled (recaptured by the well).

The same approach, as that described in Section 6.5.3.4 for calculating the recapture fraction of the irrigation water, was used to calculate the fraction of the recaptured residential water. The method consisted of defining the potential locations of the residences, delineating the well capture zone, and calculating the residential fraction by superimposing the locations of the residences and the well capture zone.

There are 204 realizations of the distances from the well to the closest residence. The potential locations of the residences obtained from this distribution and randomly sampled angle are shown in Figure 6.5.12.



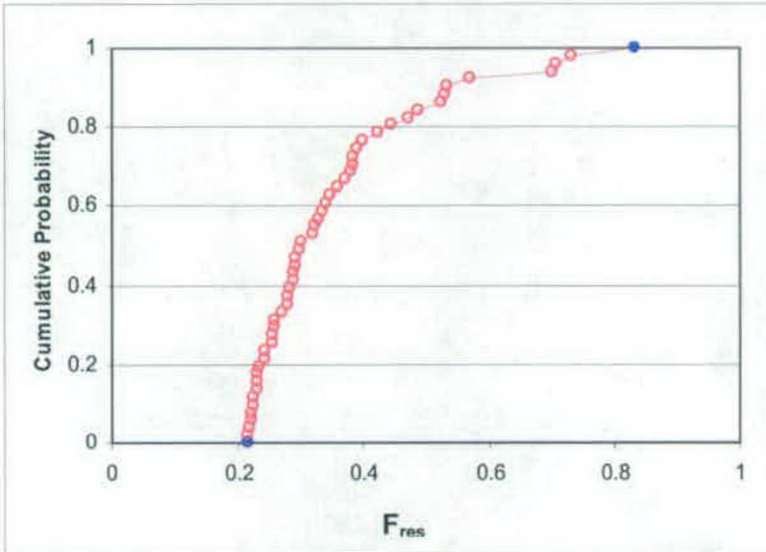
Source: Output DTN: SN0703PASZIRMA.001 (directory *Parameters*; file: *Irrigation_ Fraction_Base_Case.xls*).

NOTE: The distances are in meters. The unconfined aquifer capture zone is not shown because in the figure scale the differences between the confined and unconfined aquifer capture zones would not be visible.

Figure 6.5-12. Locations of the Potential Residences Within the Base Community

The capture zone location was calculated using the present-day climate and the climate-weighted average capture zone parameter distributions as described in Section 6.5.3.4. The residential fraction F_{res} was calculated using Equation 6.5-35 (F_{res} is $F_{c,i}$ in this equation) in which n_i represented the number of residences located within the capture zone calculated by realization i and $N = 204$. The resulting cumulative distribution based on climate-weighted average parameter distributions is shown in Figure 6.5-13. The distribution based on the present-day climate parameter distributions was used for setting the upper limit of F_{res} as discussed below.

The F_{res} value corresponding to the cumulative probability of 0 was defined using linear extrapolation of the last five data points on the lower part of the tail. The resulting F_{res} is 0.215. The F_{res} value corresponding to the cumulative probability of 1 obtained by extrapolation is 0.809. Because the upper limit is important for bounding the recycling of the residential water, the climate-weighted F_{res} value corresponding to the cumulative probability of 1 was set equal to the 50th percentile value based on the present-day climate parameter distributions (this is the average between the median values calculated for the base and small communities). The resulting F_{res} is 0.831, which is larger than the value obtained using extrapolation and is thus more conservative (more residences will be located inside the capture zone). Also, the F_{res} distribution includes the median of the present-day climate distribution, thus the current climate conditions are represented. This distribution is specified for the residential fraction (parameter *Res_Fr*) in the GoldSim file, *Irrigation_Recycling_Model.gsm* (output DTN: SN0703PASZIRMA.001, directory *Model*).



Source: Output DTN: SN0703PASZIRMA.001 (directory *Parameters*; file: *Irrigation Fraction_Base_Case.xls* and directory *Model*, file: *Irrigation_Recycling_Model.gsm*).

Figure 6.5-13. Residential Fraction Cumulative Distribution Used in Irrigation Recycling Model

6.5.3.5.2 Indoor Fraction

Indoor fraction (F_{ind}) represents a direct input into the irrigation recycling model as described in Section 6.4. Parameter F_{ind} defines how much of the residential water is used indoors. As discussed in Section 6.5.3, the water used outdoors is assumed to be permanently removed from the recycling system.

The EPA studied indoor water uses extensively and reported its findings in *Quantification of Exposure-Related Water Uses for Various U.S. Subpopulations* (Wilkes et al. 2005 [DIRS 181326]). The purpose of their study was to analyze the population behavior for indoor water use activities. Based on this study, the water use parameters are presented and recommended for use in human exposure modeling.

Collected in this study were data on use of baths and showers, faucets, dishwashers, washers, toilets, and water consumption. These data were used to estimate the average indoor water use and the lower and upper limits of that use.

The data provided by Wilkes et al. (2005 [DIRS 181326]) are reported in terms of number of events per person per day and gallons used per event. These data are summarized in Table 6.5-2.

The total gallons used per day shown in Table 6.5-2 are calculated for a household of four people. The lower limit is calculated using the event volume minus 2 standard deviations (if available). The upper limit is calculated using the event volume plus 2 standard deviations (if available). Based on the values obtained from the Wilkes et al. (2005 [DIRS 181326]) study, the total water use is 326,000 gal/yr (893.151 gal/day) per household.

Table 6.5-2. Summary of Indoor Water Usage

Event	Gallons Used per Event (mean)	Gallons Used per Event (standard deviation)	Number of Events per Day per Person	Total Gallons Used per Event per Day (mean)	Total Gallons Used per Event per Day (upper limit)	Total Gallons Used per Event per Day (lower limit)
Shower	15.8	1.75	1	63.2	77.2	49.2
Bath	40	—	0.32	51.2	51.2	51.2
Faucets	0.7	1	17.4	48.72	187.92	0
Water Consumption	0.15	—	4	0.6	0.6	0.6
Toilets	3.98	1.2	5.2	82.784	132.704	32.864
Dishwasher	8		0.164	5.257	5.257	5.257
Washer	37.74	8.932	0.329	49.601	73.08	26.123
Total	—	—	—	301.362	527.961	165.244
Percent of Total Water Use	—	—	—	33.7	59.1	18.5

Source: Wilkes et al. 2005 [DIRS 181326].

The average water use indoors is 34% (see Table 6.5-2). This number is in good agreement with the data published by the Southern Nevada Water Authority (SNWA 2007 [DIRS 183400]) according to which 30% of water is used indoors in southern Nevada. The comparison of these data and the data provided by Wilkes et al. (2005 [DIRS 181326]) is provided in Table 6.5-3. The percentage used for different activities is in good agreement as well.

Table 6.5-3. Comparison of the Indoor Water Usage

Indoor Water Use Activity	Total Indoor Use (%)	
	Southern Nevada Water Authority 2007 [DIRS 183400])	Wilkes et al. 2005 [DIRS 181326]
Shower	16.8	21.0
Faucets	15.7	16.2
Toilets	26.7	27.5
Washers	21.7	16.5
Dishwashers	1.4	1.7
Bathes, leaks, and other	17.6	17.0

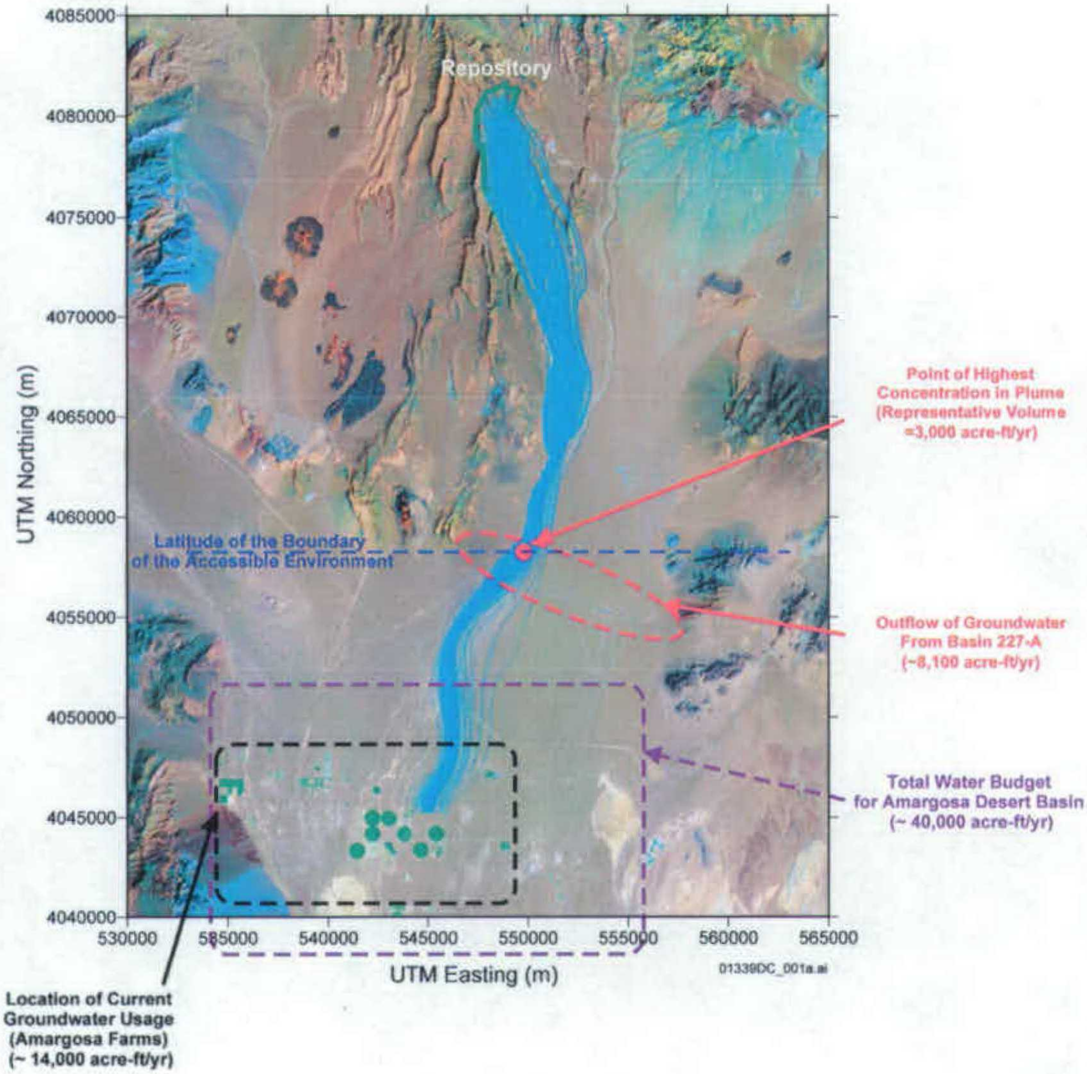
Sources: Wilkes et al. 2005 [DIRS 181326]; Southern Nevada Water Authority 2007 [DIRS 183400].

NOTE: Data from Wilkes et al. 2005 [DIRS 181326] are calculated using mean values per each indoor use category in Table 6.5-2.

Based on the data in Table 6.5-2, a uniform distribution ranging from 0.185 to 0.591 is defined for the indoor residential fraction (parameter *Indoor_Fr*) in the GoldSim file *Irrigation_Recycling_Model.gsm* (output DTN: SN0703PASZIRMA.001, directory *Model*).

6.5.3.6 Hypothetical Community Representation

The representation of the hypothetical community is shown in Figure 6.5-14. The locations of the irrigated fields and residences shown in this figure are from Sections 6.5.3.4 and 6.5.3.5. As can be seen from this figure, there are visible similarities between the existing community at the Amargosa Valley area and the hypothetical community constructed at the boundary of the accessible environment.



Source: For illustration purposes only.

NOTE: Red circles represent the locations of the first closest irrigated fields; purple circles represent the locations of the second closest irrigated fields; blue circles represent the locations of the third closest irrigated fields; green circles represent the locations of the fourth closest irrigated fields; and orange squares represent the locations of the closest residences.

Figure 6.5-14. Hypothetical Community Representation

The purpose of the analysis considered in Sections 6.5.3.4 and 6.5.3.5 was not to place all the field locations within the alluvial deposits. A few points representing fields fall on the bedrock. If these locations are moved closer to fall within the alluvium, this still would be outside of the capture zone and would not affect the results of the analysis.

6.5.3.7 Depth to Water Table

The depth to the water table beneath the irrigated fields defines the distance over which the radionuclides are transported in the unsaturated zone. The current depth to the water table beneath well NC-EWDP-19D is 107.0 m (Table 6.5-1). The depth to the water table beneath the upgradient well NC-EWDP-22S is 143.6 m (Table 6.5-1). The depth to the water table will change due to the rise in water table during the monsoon and glacial transition climates. As discussed in Section 6.3, the depth to the water table is assumed to be equal to the depth corresponding to the glacial transition climate for the entire period of simulation. This is a reasonable assumption (Section 6.3) because the shorter is the distance traveled in the unsaturated zone, the faster the recycling time is through the system (the time when equilibrium concentrations establish).

The estimates of the rise in water table during the glacial transition climate are available from *Simulated Effects of Climate Change on the Death Valley Regional Ground-Water Flow System, Nevada and California* (D'Agnese et al. 1999 [DIRS 120425]). These data are qualified for use in this model report in Section 4.1.1.2. According to these estimates, the water table would rise 120 m beneath the repository (D'Agnese et al. 1999 [DIRS 120425], Figure 13). The water table rises to the surface at a number of discharge points. The closest discharge point located on the flow path from the repository downgradient from the well NC-EWDP-19D and north from the Amargosa Valley area shown by D'Agnese et al. (1999 [DIRS 120425], Figure 16) has UTM northing of 4052000 m and UTM easting of 546152 m. The predicted water table rise beneath wells NC-EWDP-19D and NC-EWDP-22S was estimated using these data as described below.

First, the average flow path from the repository was obtained using the data in DTN: SN0704T0510106.008 [DIRS 181283] (file *sz06-100.sptr2*) and EARTHVISION V. 5.1 (STN: 10174-5.1-00 [DIRS 167994]) These data represent the coordinates of 1,000 particle tracks that are generated by the site-scale flow model as described in *Saturated Zone Site-Scale Flow Model* (SNL 2007 [DIRS 177391]). For each 100-m interval in the north-south direction, the average easting and elevation were calculated to determine a single average flow path. The resulting flow path is shown in Figure 6.5-15. This average flow path originates from UTM northing of 4081400 m and UTM easting of 548877 m.

Using the *x* and *y* coordinates of the average flow path, the surface elevations of the points located on the flow path were determined using topographic data from DTN: MO0010COV00124.001 [DIRS 153783]. Similarly the present day water table elevations were determined using water level data from DTN: MO0611SCALEFLW.000 [DIRS 178483] (file *wt_HFM2006_X.dat*). Both the water table elevations and the surface elevations were queried along the average flow path and the data placed into *Depth_to_WT.xls* (DTN: SN0703PASZIRMA.001, directory *Parameters*).

The predicted water table elevation beneath the repository during the glacial transition climate was set equal to 914.5 m (the current elevation of 794.6 m + 120 m water table rise). Note that the average flow path (Figure 6.5-15) starts at the northern part of the repository where the water table elevation is higher than the water table elevation beneath most of the repository, which is about 730 m. The predicted water table elevation at the discharge point during the glacial transition climate was set equal to the surface elevation at this point (759.8 m). The predicted water table elevations during the glacial transition climate along the flow path (H_i) were calculated using linear interpolation as:

$$H_i = H_i^0 + \Delta H_{disch} - (\Delta H_{rep} - \Delta H_{disch})\frac{m_i}{M} \qquad \text{(Eq. 6.5-36)}$$

where

H_i^0 is the water table elevation at the discharge point

ΔH_{disch} is the predicted water table rise at the discharge point (57.6 m)

ΔH_{rep} is the predicted water table rise beneath the repository

m_i is the number of 100-m intervals in the north-south direction measured along the flow path to a point(s) of interest (wells NC-EWDP-19-D and NC-EWDP-22-S).

M is the total number of 100-m intervals in the north-south direction located on the flow path (294 100-m intervals make up the flow path distance from the repository to the discharge point).

Sources: DTN: SN0704T0510106.008 [DIRS 181283] (file *sz06-100.sptr2*) and output DTN: SN0703PASZIRMA.001 (directory *Parameters*, file: *Depth_to_WT.xls*).

NOTE: The blue squares show the locations of the wells NC-EWDP-19D (lower) and NC-EWDP-22S (upper).

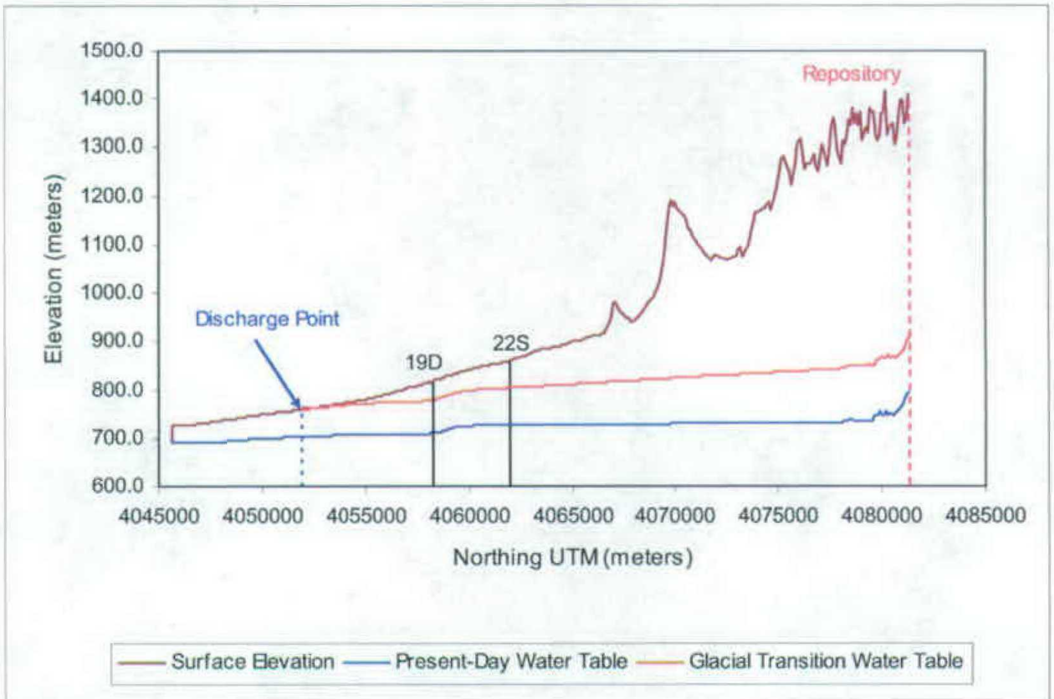
Figure 6.5-15. An Average Flow Path from the Repository

The results are shown in Figure 6.5-16. The predicted water table elevations corresponding to the glacial transition climate estimated beneath wells NC-EWDP-19D and NC-EWDP-22S are 780.3 and 804.5 m, respectively. The depths to the water table corresponding to the glacial transition climate in these two wells are 38.7 and 63.9 m.

The depth to the water table used in the irrigation recycling model was set equal to the geometric mean of these two values to provide a bias to a smaller (bounding) value. The geometric mean is 49.7 m. The depth to water table (parameter *Depth_to_WT*) was set equal to 50 m in *Irrigation_Recycling_Model.gsm* (output DTN: SN0703PASZIRMA.001, directory *Model*).

The depth to water table is used to calculate the cell height of the unsaturated zone. As discussed in Section 6.4, the height of each unsaturated zone cell is equal to the depth to water table divided by the number of unsaturated zone cells. Consequently, the height of each unsaturated zone cell is 2.5 m.

A predicted increase in the saturated thickness of the aquifer at the location of well NC-EWDP-19D is 68.3 m. It is 79.7 m at the location of well NC-EWDP-22S. The predicted increase in saturated thickness of the aquifer is the result of higher water levels during the glacial-transition climate. The increase in the saturated thickness of 68 m (bounding value) was used in Section 6.5.3.3 in the well capture zone analysis.



Source: Output DTN: SN0703PASZIRMA.001 (directory *Parameters*, file: *Depth_to_WT.xls*).

Figure 6.5-16. Present-Day Climate and Predicted Glacial Transition Climate Water Table Elevations along the Flow Path from the Repository

6.5.3.8 Alluvium Saturation in the Unsaturated Zone beneath the Irrigated Fields

The alluvium saturation in the unsaturated zone beneath the irrigated fields is used to calculate the volume of water in each cell pathway representing the unsaturated zone in the irrigation recycling model (Equation 6.5-2). The existing unsaturated zone data cannot be used to define alluvium saturation beneath the irrigated fields because these data represent conditions with very little recharge.

A significant recharge due to continuous irrigation was observed in the Amargosa Valley area (Stonestrom et al. 2003 [DIRS 165862]). It was assumed that the alluvium saturation observed beneath the irrigated fields in the hypothetical community will be similar to the saturation beneath the irrigated fields in the Amargosa Valley area.

Extensive studies were undertaken by the USGS in the Amargosa Valley area to estimate the rates of deep percolation beneath the cultivated fields. These studies are reported by Stonestrom et al. (2003 [DIRS 165862]).

As a part of these studies, three sites were established within the Amargosa Valley area. The boreholes were drilled at each site. Six boreholes are located on the existing irrigated fields. The borehole locations are shown in Figure 6.5-17. Wells AFCA2 and AFCA3 are located in Field 1, which is the newest field that was continuously irrigated during approximately 8 years prior to this study. Wells AFCA4 and AFCA5 are located in Field 2, the oldest field that has been in production since 1961, but was intermittently irrigated in 1980s. Wells AFPLA1 and AFPL2 are located in Field 3, which has been continuously irrigated at least for 14 years prior to sampling.

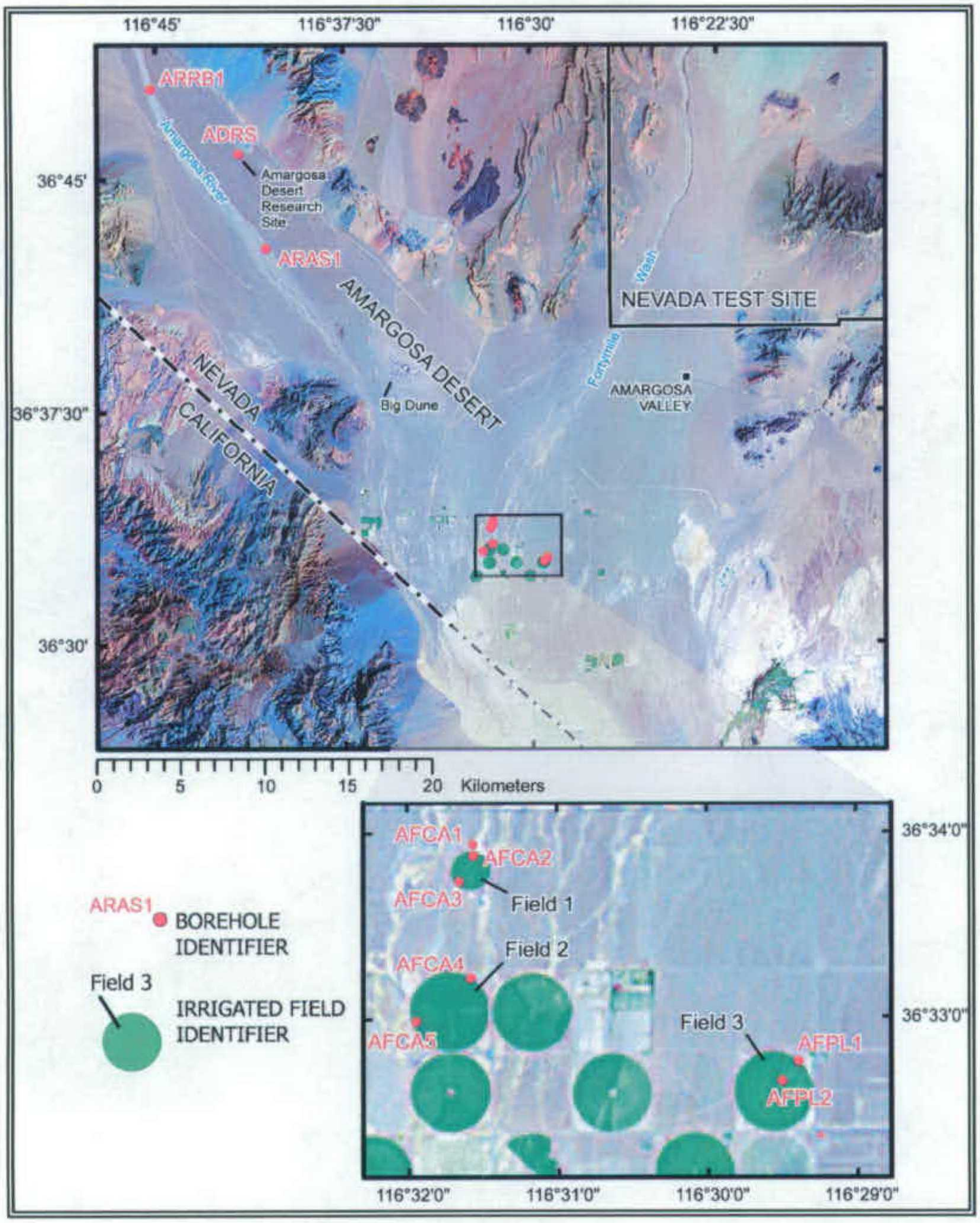
The borehole data collected include gravimetric water content, total water potential, and lithologic description of the samples collected. The data are reported in the tables provided by Stonestrom et al. (2003 [DIRS 165862], Appendices A (lithologic data) and B (other data)). These data are qualified for use in this report in Section 4.1.2.1.

The gravimetric water content and total water potential data reported by Stonestrom et al. (2003 [DIRS 165862], Appendix B) were copied into *Saturation.xls* (output DTN: SN0703PASZIRMA.001, directory *Parameters*). The lithologic data reported by Stonestrom et al. (2003 [DIRS 165862], Appendix A) were used to identify samples either as sand or silt or sand with silt. The lithologic data were used to fill in the data gaps. If gravimetric water content was not available for a sample, the corresponding value was calculated by linearly interpolating the available data using the closest sample below and above with the same lithology. If only one sample with the same lithology was available, the same value was assigned to the sample with the data gap because the samples from different lithologic units have significantly different moisture content.

The gravimetric water content was used to calculate the volumetric water content (Fetter 2001 [DIRS 156668]):

$$\theta_v = \theta_g \rho_b \qquad \text{(Eq. 6.5-37)}$$

where θ_v is the volumetric moisture content, and ρ_b is the dry bulk density.



Source: Stonestrom et al. 2003 [DIRS 165862], Figure 2.

NOTE: For illustration purposes only.

Figure 6.5-17. Location of the Boreholes in the Amargosa Farms Area

The dry bulk density was estimated to be from 1.5 to 1.7 g/cm^3 with the average of 1.6 g/cm^3 for all the wells (Stonestrom et al. 2003 [DIRS 165862], p. 29). Three bulk density values were used: 1.5 g/cm^3, 1.6 g/cm^3, and 1.7 g/cm^3 as described below. The volumetric water content was used to estimate sample water depth d_i as:

$$d_i = \theta_v^i b_i \tag{Eq. 6.5-38}$$

where b_i is the sample thickness. The water depth (d_i) estimated for each sample is an equivalent of the pore water volume in each sample expressed as the pore water height (depth) in this sample. The sample area is not relevant because all the samples have the same areas.

The total water depth D_w within the profile was calculated as:

$$D_w = \sum_{1}^{N_s} d_i \tag{Eq. 6.5-39}$$

where N_s is the number of core samples in the borehole. The total water depth within the profile (D_w) is an equivalent of the total volume of pore water within the sampled profile.

The cumulative water depth as a function of the sample depth for the six wells is shown in Figure 6.5-18 for the value of dry bulk density of 1.6 g/cm^3. The effects of the lithology and differences in irrigation practices are not very significant (see Figure 6.5-18). The field irrigated for a long time (Field 3, wells AFPL1 and AFPL2) shows similar conditions as the field irrigated for a shorter period of time (Field 1, wells AFCA2 and AFCA3) or irrigated intermittently (field 2 wells AFCA4 and AFCA5). This means that the steady-state conditions are reached in less than 8 years (irrigation duration at the new field).

The saturation s was calculated for each borehole as (Fetter 2001 [DIRS 156668]):

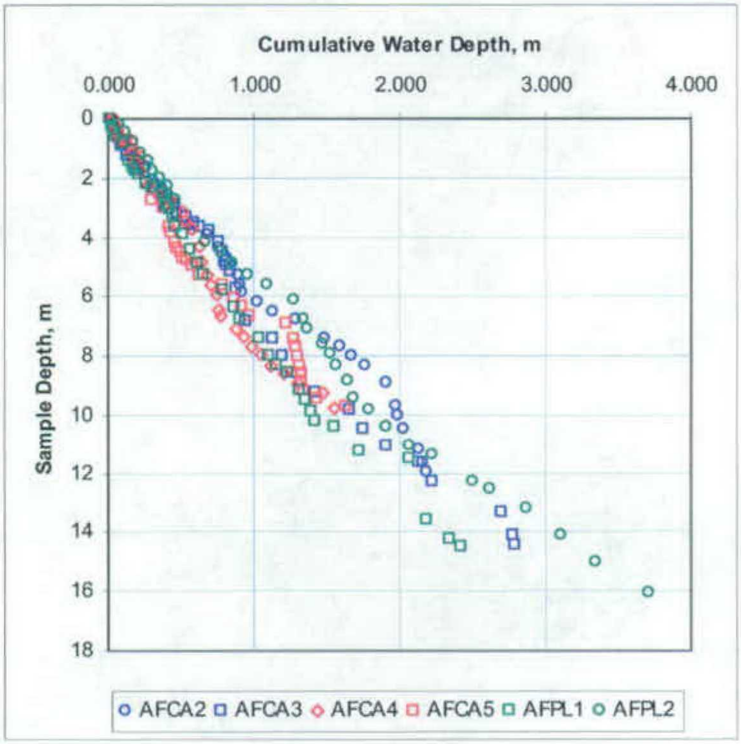
$$s = \frac{\overline{\theta}_v}{\varepsilon} \text{ and } \overline{\theta}_v = \frac{D_w}{D_b} \tag{Eq. 6.5-40}$$

where ε is the average alluvium porosity, and D_b is the borehole total depth.

The estimates of the porosity are not available from the report by Stonestrom et al. (2003 [DIRS 165862]). Two approaches were used to estimate porosity. In the first approach (method 1 in Table 6.5-4), the porosity was assumed to be equal to the maximum volumetric water content measured in a borehole. In the second approach (method 2 in Table 6.5-4), the following formula was used to calculate porosity (Fetter 2001 [DIRS 156668], Equation 3.9):

$$\varepsilon = 1 - \frac{\rho_b}{\rho_d} \tag{Eq. 6.5-41}$$

where ρ_d is the particle density. The particle density is known to have little variation, and for most rocks and soils the value of 2.65 g/cm^3 can be assumed (Fetter 2001 [DIRS 156668], p. 70). This value was used in the calculations.



Source: Output DTN: SN0703PASZIRMA.001 (directory *Parameters*, file: *Saturation.xls*).

Figure 6.5-18. Cumulative Water Depth Profiles in Six Amargosa Farms Boreholes

The results of these calculations are summarized in Table 6.5-4. The saturation ranges from 0.261 to 0.664 (see Table 6.5-4). These estimates are not sufficient to construct any distribution except the uniform one. Thus, a uniform distribution with this range was assigned to the saturation in the unsaturated zone beneath the irrigated fields. This distribution is assigned to the saturation (parameter *Saturation*) in the GoldSim file *Irrigation_Recycling_Model.gsm* (output DTN: SN0703PASZIRMA.001, directory *Model*).

Table 6.5-4. Mean Saturation in the Amargosa Farms Boreholes

Borehole Name	Mean Saturation			
	Method 1	Method 2		
	$\varepsilon = \theta_{max}$	ρ_b = 1.5 g/cm^3	ρ_b = 1.6 g/cm^3	ρ_b = 1.7 g/cm^3
AFCA2	0.409	0.392	0.458	0.538
AFCA3	0.372	0.417	0.487	0.571
AFCA4	0.415	0.335	0.391	0.459
AFCA5	0.261 (minimum)	0.351	0.410	0.482
AFPL1	0.437	0.358	0.418	0.491
AFPL2	0.497	0.484	0.565	0.664 (maximum)

Source: Output DTN: SN0703PASZIRMA.001 (directory *Parameters*, file: *Saturation.xls*).

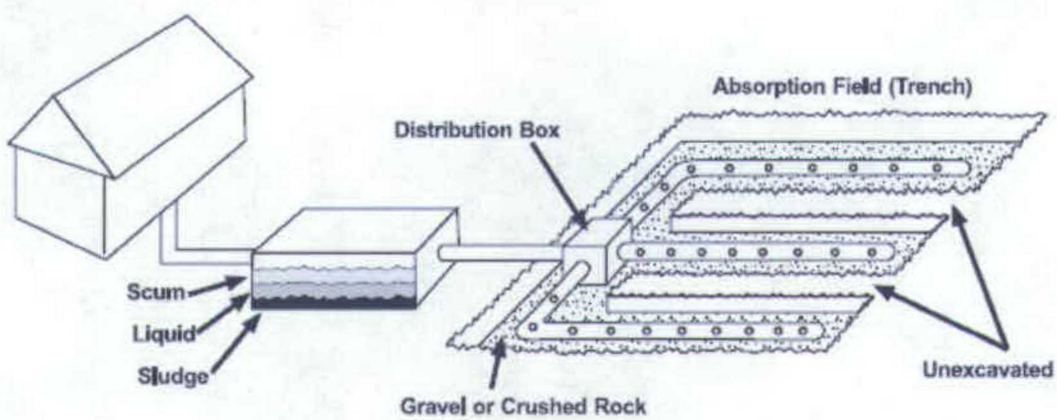
6.5.3.9 Septic Leach Field Parameters

As discussed in Section 6.3, all the residential water used indoors is assumed to go through the septic system. A diagram illustrating a common septic system is shown in Figure 6.5-19. The individual parts of the system are the septic tank, a distribution box, and a septic leach field. The first part in the system is the septic tank that accepts discharges from all types of indoor use. The segregated and relatively clear liquid from the septic tank flows into a small distribution box where it is then metered out to several perforated pipes. These pipes then deliver the liquid to a large soil surface area called a septic leach field or absorption field for absorption.

The septic fields of all residences located within the well capture zone are represented in the irrigation recycling model as one cell pathway (Section 6.5.4). The cell properties are calculated from two septic leach field parameters: septic leach field thickness and septic leach field application rate. The alluvium in the cell is assumed to have the same properties as the alluvium in the saturated and unsaturated zones. Fully saturated conditions (with a saturation of 1) are assumed in this cell.

The septic leach field thickness is used to define the cell height. This parameter is set equal to 0.5 m (parameter *Abs_Field_Thickn*) in the GoldSim file *Irrigation_Recycling_Model.gsm* (output DTN: SN0703PASZIRMA.001, directory *Model*).

The height of the cell is used to calculate the cell water volume and cell alluvium mass. The cell height should not affect the calculations because GoldSim uses advective flux only to transport mass and does not track the movement of the media (GoldSim Technology Group 2003 [DIRS 166228]).



Source: Reproduced from Figure 4-1 in EPA 2002 [DIR 18515].

NOTE: For illustration purposes only.

Figure 6.5-19. Diagram of a Common Septic System

The septic leach field application rate (hydraulic load) is used to calculate the septic leach field area in Equation 6.4-4. The septic leach field area is used in turn to calculate the outflow from the leach field cell (Equation 6.4-3): the greater the outflow, the faster the recycling in the system.

The suggested range for the application rates (septic tank effluents) in *On Site Wastewater Treatment Systems Manual* (EPA 2002 [DIRS 177934], Table 5-1) is from 0.6 to 4.0 cm/day. The maximum value defined by this range was used for the application rate. There are two reasons for using the maximum application rate value. First, the alluvium deposits at the hypothetical community location are moderately to highly permeable (SNL 2007 [DIRS 177394], Appendix F). Second, the higher application rate results in faster recycling and, thus, is a bounding value. The application rate equal to 4.0 cm/day (14.6 m/yr) was used as an application rate (parameter *Appl_Rate*) in the GoldSim file *Irrigation_Recycling_Model.gsm* (output DTN: SN0703PASZIRMA.001, directory *Model*).

6.6 MODELING RESULTS

The modeling results presented in this section were obtained from the stand-alone irrigation recycling model. As discussed in Section 6.4, this model calculates the radionuclide concentrations in the groundwater. Consequently, the potential impacts of irrigation recycling can be only estimated with regard to the radionuclide concentrations. The impact of the irrigation recycling to mean dose results was evaluated as a part of the TSPA sensitivity analysis (Section 6.7). The irrigation recycling model was incorporated into the TSPA model to perform this analysis.

To demonstrate the irrigation recycling impacts on the radionuclide concentrations, three model runs were performed. The only differences among these runs were in the values of the well recapture fraction (F_c), residential fraction (F_{res}), and indoor water use fraction (F_{ind}). All other modeling parameters were the same.

The saturated zone flow and transport modeling parameters used were from realization number 100 as defined in the saturated zone flow and transport abstraction model. The biosphere modeling parameters were from realization number 100 as defined in the biosphere process model. Note that there is no correlation between the choices of realization number 100 for the saturated zone flow and transport abstraction model and biosphere model. The corresponding parameters can be found in GoldSim file *Irrigation_Recycling_Model.gsm* (output DTN: SN0703PASZIRMA.001, directory *Model*). They are not listed in this report because they have very little impacts (if any) on the equilibrium radionuclide concentrations. The residual uncertainty fraction f_{unc} was set equal to 0.055 (even distribution of residual uncertainty between irrigation and residential uses). The saturation in the unsaturated zone beneath the irrigated fields was set equal to 0.627.

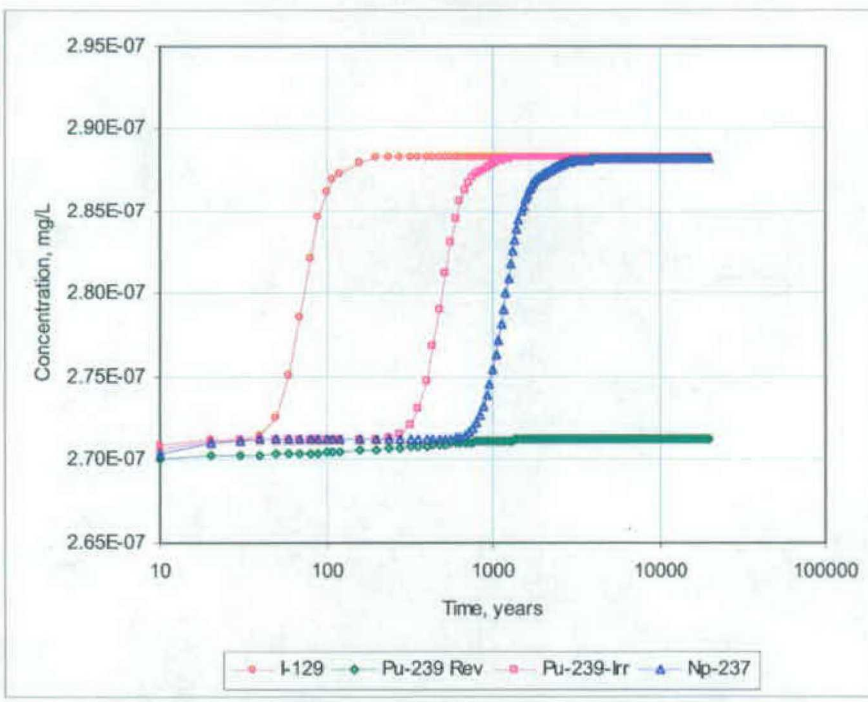
The radionuclide mass fluxes from the saturated zone flow and transport abstraction model at the boundary of the accessible environment were set equal to 1 g/yr for ^{129}I, ^{237}Np, ^{239}Pu reversibly attached to colloids, and ^{239}Pu irreversibly attached to colloids. Other radionuclide mass fluxes were set equal to 0. This allows for demonstrating the effects of recycling for radionuclides with different sorption capabilities.

The parameter values used in the first run corresponded to the minimum values of parameters F_c, F_{res}, and F_{res}. These values are 0.066, 0.215, and 0.185, respectively. This is based on the distributions obtained for these parameters in Sections 6.5.3.4 and 6.5.3.5. The purpose of this run was to estimate minimum impact on the radionuclide concentrations.

The parameter values used in the second run corresponded to the median values of parameters F_c, F_{res}, and F_{ind}. These values are 0.104, 0.300, and 0.388, respectively. This is based on the distributions obtained for these parameters in Sections 6.5.3.4 and 6.5.3.5. The purpose of this run was to estimate the most likely impact on radionuclide concentrations.

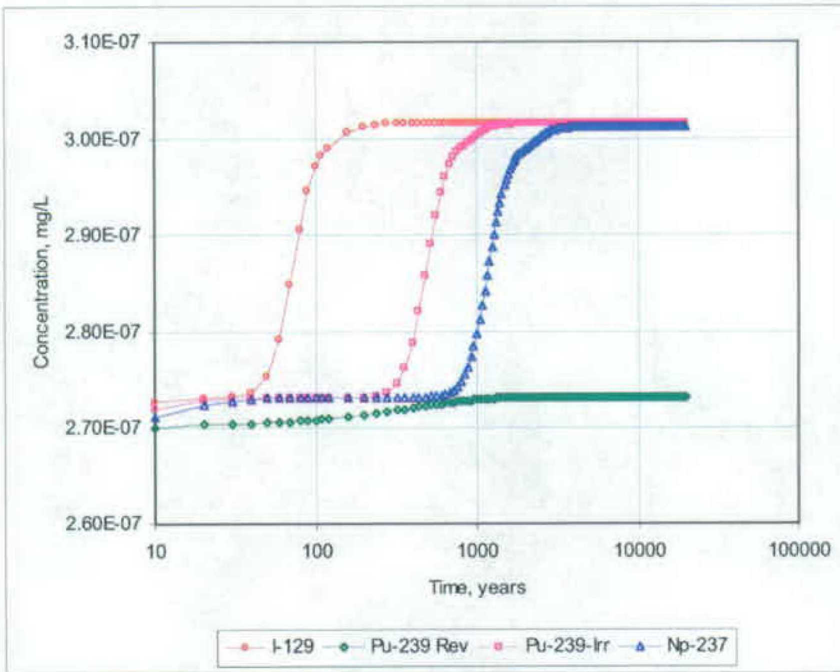
The parameter values used in the third run corresponded to the maximum values of parameters F_c, F_{res}, and F_{ind}. These values are 0.357, 0.831, and 0.591, respectively. This is based on the distributions obtained for these parameters in Sections 6.5.3.4 and 6.5.3.5. The purpose of this run was to estimate maximum impact on radionuclide concentrations.

The results of these three runs are presented in Figures 6.6-1 through 6.6-3. The concentration of ^{239}Pu reversibly attached to colloids at about 10 years from the beginning of simulation (2.71×10^{-7} mg/L) represents the radionuclide concentrations without irrigation recycling. The minimum impact corresponds to an increase in concentrations of 1.06, the most likely increase is 1.10 times, and the maximum increase is 1.56 times for ^{129}I, ^{237}Np, and ^{239}Pu irreversibly attached to colloids. The concentrations of ^{239}Pu reversibly attached to colloids are practically not affected by the irrigation recycling during the period of simulation.



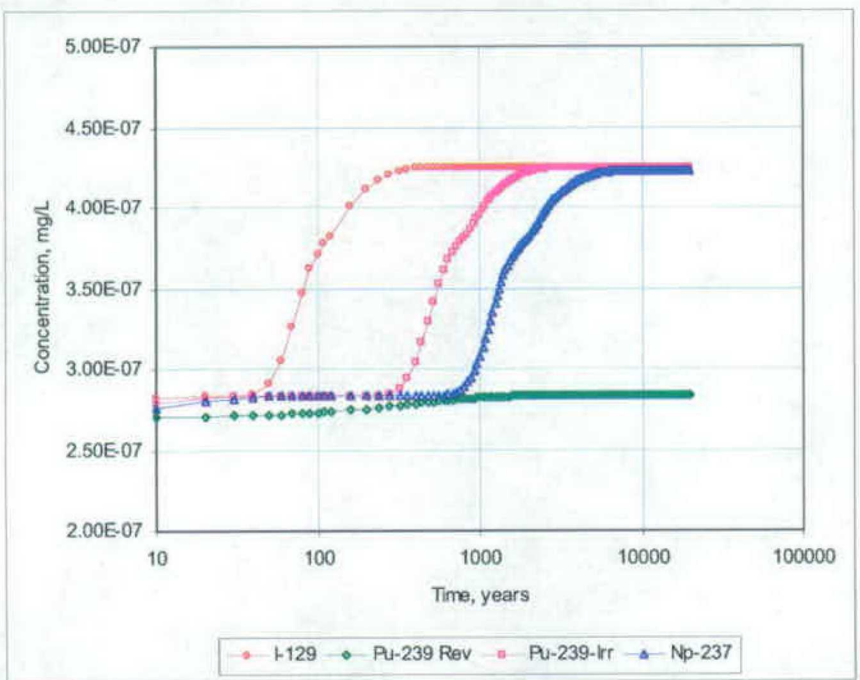
Source: Output DTN: SN0703PASZIRMA.001 (directory *Results*, file: *Modeling_Results.xls*).

Figure 6.6-1. Radionuclide Concentrations in the Groundwater Well Corresponding to the Minimum Values of F_c, F_{ind}, and F_{res}



Source: Output DTN: SN0703PASZIRMA.001 (directory *Results*, file: *Modeling_Results.xls*).

Figure 6.6-2. Radionuclide Concentrations in the Groundwater Well Corresponding to the Median Values of F_c, F_{ind}, and F_{res}

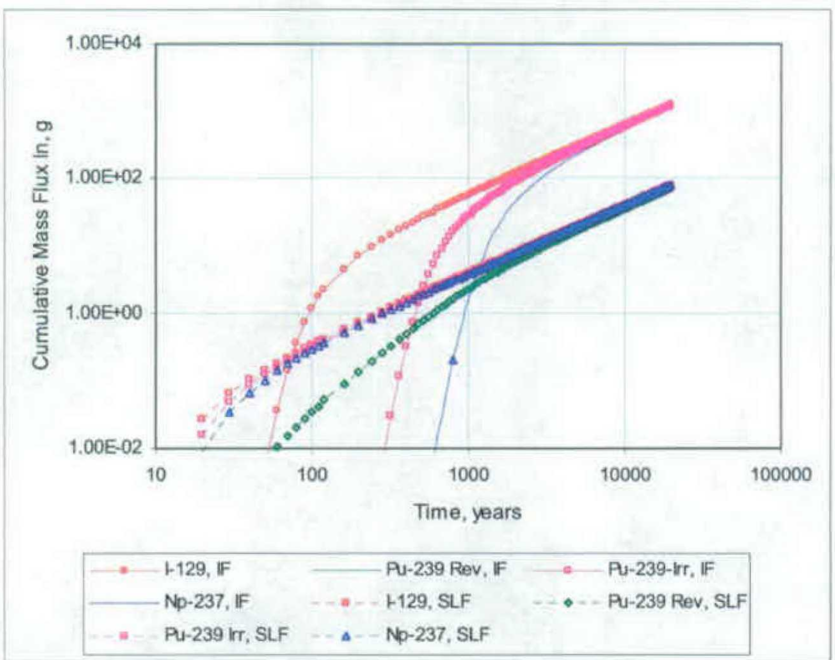


Source: Output DTN: SN0703PASZIRMA.001 (directory Results, file: *Modeling_Results.xls*).

Figure 6.6-3. Radionuclide Concentrations in the Groundwater Well Corresponding to the Maximum Values of F_c, F_{ind}, and F_{res}

All radionuclides reach equilibrium concentrations within the period of simulation (20,000 years), except ^{239}Pu reversibly attached to colloids (see Figure 6.6-1). The cumulative radionuclide mass fluxes into the *Representative Groundwater Volume* cell from the irrigated field and the septic leach field (residential water use) pathways are shown in Figures 6.6-4 through 6.6-6. The mass fluxes from the septic leach fields show at early times, are about an order of magnitude smaller than from the irrigated fields at later times and depend less on radionuclide sorption capabilities (see Figures 6.6-4 through 6.6-6). This is because there is no unsaturated zone transport from the septic leach fields, and the annual volume of water used for residential purposes is about 10 times smaller than the annual volume of water used for irrigation. As a result, the irrigated field pathway is the main contributor to the concentration build-up. The impacts of irrigation recycling on concentrations of the highly sorbed radionuclides will be very small because the equilibrium concentrations will not be reached.

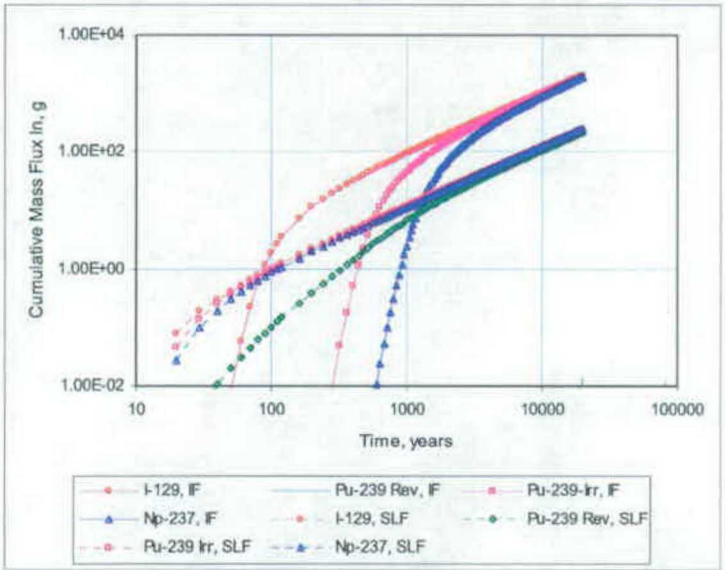
The effectiveness of the removal processes is shown in Figure 6.6-7 for ^{237}Np. The most effective removal mechanism is with the irrigation water that is not recaptured by the pumping well that accounts for 87% (minimum and median parameter values) to 88% (maximum parameter values) of the mass removed. The removal with the residential indoor water that is not recaptured by the pumping well is 8% (maximum parameter values) to 10% (minimum and median parameter values). The erosional removal is 3% (minimum and median parameter values) to 4% (maximum parameter values).



Source: Output DTN: SN0703PASZIRMA.001 (*\Results\Modeling_Results.xls*).

NOTE: IF denotes the radionuclide fluxes from the irrigated fields and SLF denotes the radionuclide fluxes from the septic leach fields.

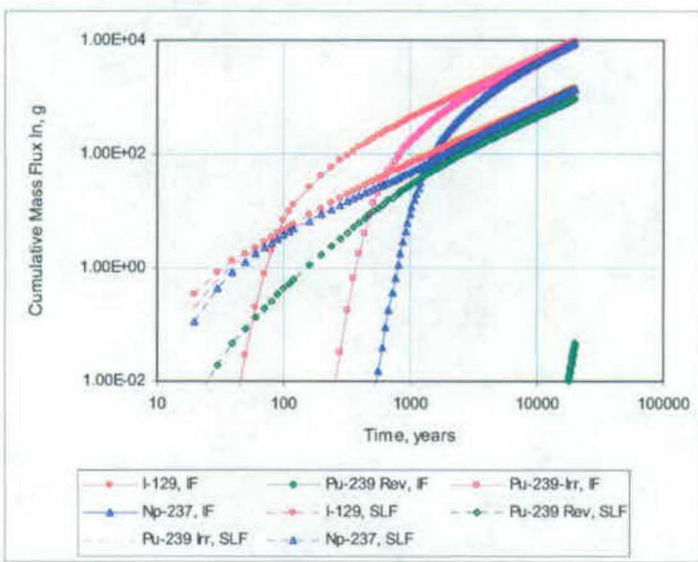
Figure 6.6-4. Cumulative Radionuclide Mass Fluxes into the Representative Groundwater Volume Cell from the Irrigated Fields Path and Septic Leach Fields Path Corresponding to the Minimum Values of F_c, F_{ind}, and F_{res}



Source: Output DTN: SN0703PASZIRMA.001 (*\Results\Modeling_Results.xls*).

NOTE: IF denotes the radionuclide fluxes from the irrigated fields and SLF denotes the radionuclide fluxes from the septic leach fields.

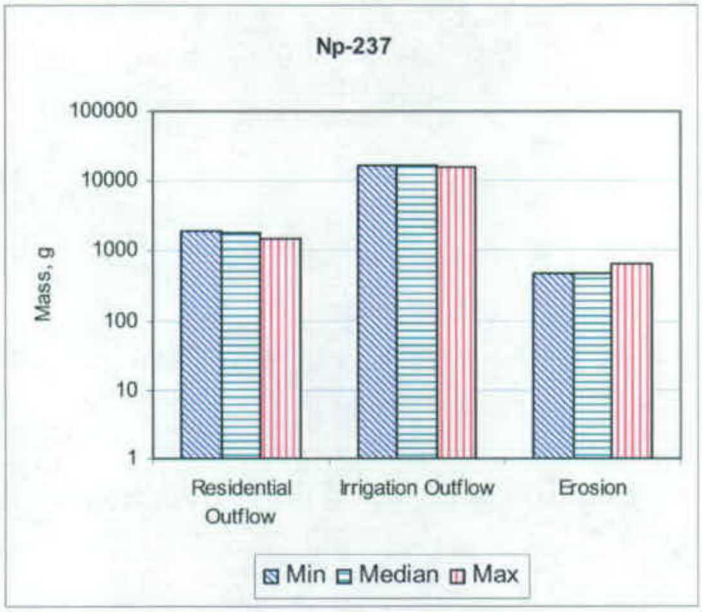
Figure 6.6-5. Cumulative Radionuclide Mass Fluxes into the Representative Groundwater Volume Cell from the Irrigated Fields Path and Septic Leach Fields Path Corresponding to the Median Values of F_c, F_{ind}, and F_{res}



Source: Output DTN: SN0703PASZIRMA.001 (*\Results\Modeling_Results.xls*).

NOTE: IF denotes the radionuclide fluxes from the irrigated fields and SLF denotes the radionuclide fluxes from the septic leach fields.

Figure 6.6-6. Cumulative Radionuclide Mass Fluxes into the Representative Groundwater Volume Cell from the Irrigated Fields Path and Septic Leach Fields Path Corresponding to the Maximum Values of F_c, F_{ind}, and F_{res}



Source: Output DTN: SN0703PASZIRMA.001 (*\Results\ Modeling_Results.xls*).

Figure 6.6-7. Total Mass Removed from Recycling

The other modeling parameters not considered in the sensitivity runs above are as follows:

- Depth to water table
- Saturation
- Residual uncertainty fraction
- Leach field thickness
- Leach field application rate.

These parameters do not affect the equilibrium concentrations of the long-lived radionuclides. They only affect the time when the equilibrium concentrations are established.

6.7 IMPACTS OF THE IRRIGATION RECYCLING MODEL TO MEAN DOSE RESULTS

The impacts of the irrigation recycling model to mean dose results were evaluated as a part of the TSPA sensitivity analysis. In this analysis the irrigation recycling model (GoldSim file *Irrigation_Recycling_Model.gsm*, output DTN: SN0703PASZIRMA.001, directory *Model*) was implemented in the TSPA-LA compliance model. The implementation was executed by incorporating the standalone irrigation recycling model into Version 5.0 of the TSPA-LA model implemented with GoldSim v. 9.60.100 (STN: 10344-9.60-01 [DIRS 181903]). Slight modifications were made to the irrigation recycling model to reflect the structure of the TSPA-LA model. All parameters sampled using stochastic GoldSim elements were put in the TSPA-LA model *Epistemic_Params* submodel container: *\Input_Params_ Epistemic\Epistemic_Params_SZ_Transport\Recycling_Model_Uncert_Inputs*. In addition, the remaining elements found in the container, *\TSPA_Model\SZ_Transport\Model_Inputs_ SZ_Transport\Input_Params_SZ_Transport\Irrigation_Recycling_Model\Recycling_Parameters*, of the standalone irrigation recycling model were divided into two containers, one for the input parameters and one for calculated parameters.

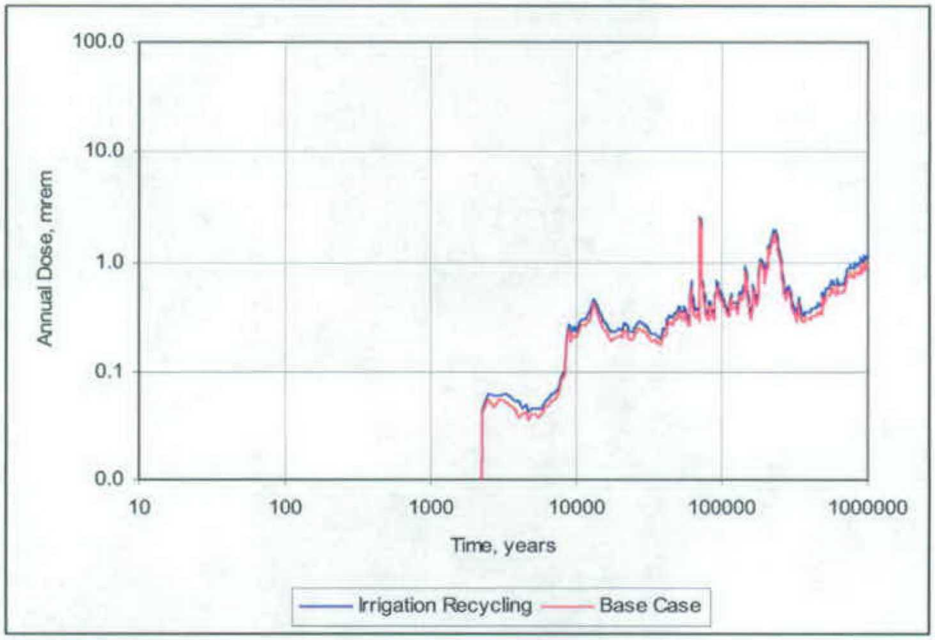
After implementation of the stand-alone irrigation recycling model into Version 5.0 of the TSPA-LA model, the compliance model 1,000,000-year Seismic-Ground Motion (GM) and igneous scenarios were run with the irrigation recycling model included. The results of these runs were saved as text files using GoldSim export function. These files are included in output DTN: SN0703PASZIRMA.001 (directory *Results\TSPA Runs*). The results of these runs were compared to the results of the compliance model. The results of the compliance model are also saved as text files and included in the output DTN: SN0703PASZIRMA.001 (directory *Results\TSPA Runs*). The data from these text files were imported into an Excel file *TSPA_Results.xls* (output DTN: SN0703PASZIRMA.001, directory *Results\TSPA Runs*) to do data comparison and plotting. The GoldSim 9.60.100 (STN: 10344-9.60-01 [DIRS 181903]) compliance model that includes irrigation recycling was submitted in output DTN: SN0709IRSENANL.001. The following two GoldSim files included in this DTN implement igneous and seismic scenarios with the irrigation recycling:

- v5.000_GS_9.60.100_SZ_Recycle_Prototype_Igneous_1Myr.gsm – Igneous scenario with irrigation recycling
- v5.000_GS_9.60.100_SZ_Recycle_Seismic_1Myr.gsm – Seismic scenario with irrigation recycling.

In these runs, the partition coefficient of ^{240}Pu on irreversible colloids in soil was greater than 0. This should not have any impacts on the following comparisons because ^{240}Pu is insignificant.

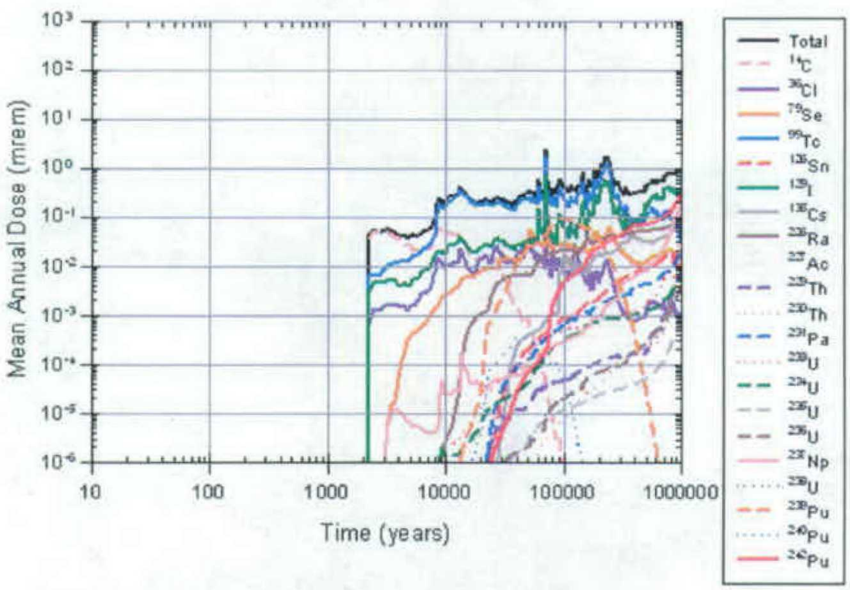
Seismic-Ground Motion (GM) Scenario

The Seismic-GM scenario results are shown in Figures 6.7-1 and 6.7-2. Figure 6.7-1 depicts the Seismic-GM scenario probability weighted mean annual total doses for the compliance model (denoted as Base Case) and the model that includes irrigation recycling (denoted as Irrigation Recycling). There is about 11% increase in simulated dose at the time of peak dose and about 15% as an average over the 1 million-year simulation period due to including irrigation recycling. Figure 6.7-2 depicts the individual radionuclide mean annual doses for the model that includes irrigation recycling. The nonsorbing radionuclides such as ^{14}C, ^{99}Tc, and ^{129}I are the dominant contributors to the total dose results (Figure 6.7-1). ^{14}C is a major contributor during the first 10,000 years and ^{99}Tc and ^{129}I are the major contributors during all the period of simulation.



Source: Output DTN: SN0703PASZIRMA.001 (*Results*\TSPA Runs*TSPA_Results.xls*).

Figure 6.7-1. Probability Weighted Mean Annual Total Dose, Seismic-GM Scenario

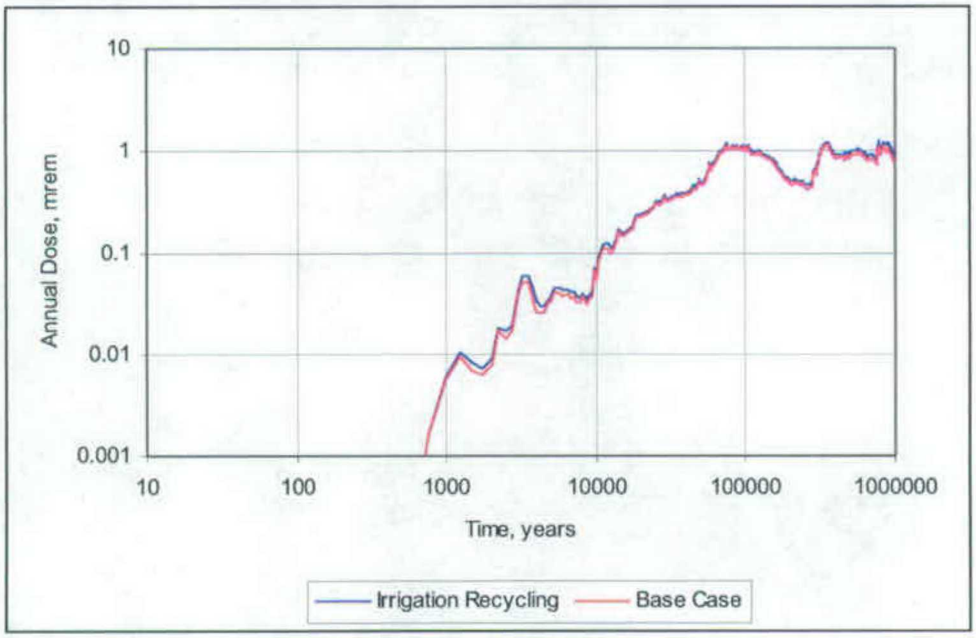


Source: Output DTN: SN0703PASZIRMA.001 (*Results**TSPA Runs*, file: *v5.000_SZ_Recycle_Seismic_1Myr_RN_Dose_WT.txt*).

Figure 6.7-2 Individual Radionuclide Mean Annual Doses, Seismic-GM Scenario with the Irrigation Recycling Model

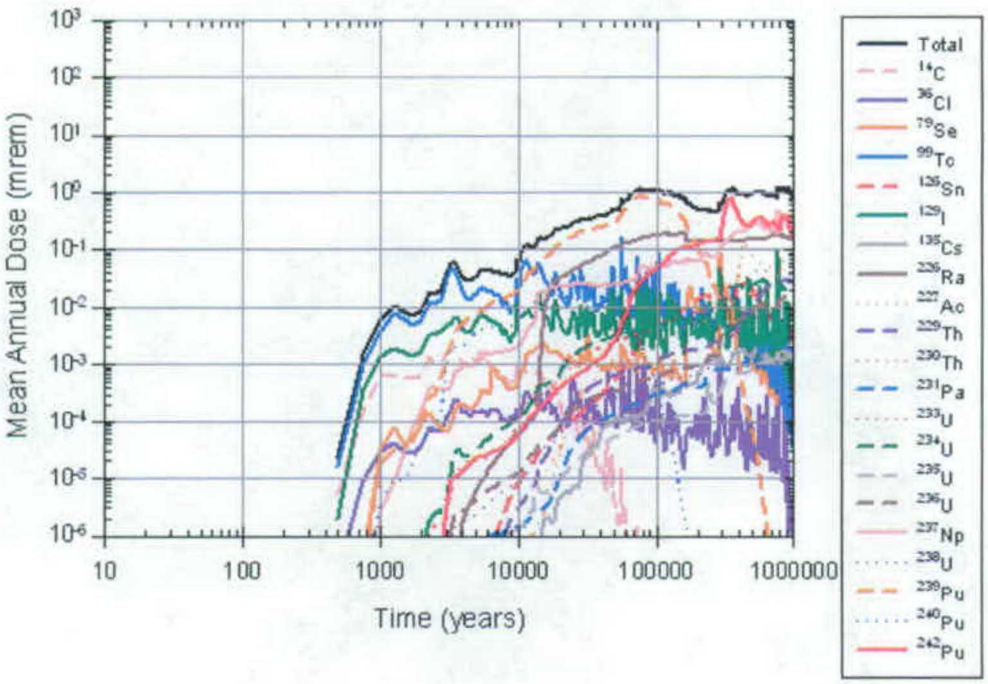
Igneous Scenario

The Igneous scenario results are shown in Figures 6.7-3 and 6.7-4. Figure 6.7-3 depicts the Igneous scenario probability weighted mean annual total doses for the Compliance Model (denoted as Base Case) and the model that includes irrigation recycling (denoted as Irrigation Recycling). There is about 7% increase in simulated dose at the time of peak dose and about 8% as an average over the 1 million year simulation period due to including irrigation recycling. Figure 6.7-4 depicts the individual radionuclide mean annual doses for the model that includes irrigation recycling. The times where the greatest degree of increase took place are times where nonsorbing radionuclides such as ^{99}Tc and slightly-sorbing radionuclides such as ^{237}Np dominate the total dose results. Note that ^{99}Tc, ^{129}I, and ^{239}Pu are the most dominant contributors to dose early in the simulation and ^{237}Np and ^{242}Pu are the two most dominant contributors to dose at the end of the simulation. During the time span where little difference in results is exhibited, ^{239}Pu which is mainly a reversible colloid highly influenced by sorption in the rock matrix, is the dominant contributor to dose. ^{226}Ra which is moderately-sorbing species is the next most important contributor to dose during this time span.



Source: Output DTN: SN0703PASZIRMA.001 (*Results*\TSPA Runs*TSPA_Results.xls*).

Figure 6.7-3. Probability Weighted Mean Annual Total Dose, Igneous Scenario



Source: Output DTN: SN0703PASZIRMA.001 (*\Results\TSPA Runs*, file: *v5.000_SZ_Recycle_Igneous_1Myr_RN_Dose_WT.txt*)

Figure 6.7-4. Individual Radionuclide Mean Annual Doses, Igneous Scenario with the Irrigation Recycling Model

The differences between the model with irrigation recycling and the base case are greater for the Seismic-GM scenario than for Igneous scenario. This can be explained based on the major contributors to the total dose. As it was discussed above, the major contributors to the mean annual total dose in the Seismic-GM scenario are nonsorbing radionuclides during all the period of simulation. Removal of these radionuclides from the irrigation recycling system due to soil erosion is very limited because of the short residence time in the soil compartment. As the result, the impacts of the irrigation recycling are more noticeable. The major contributors to the total mean annual dose in the Igneous scenario during later times are moderately sorbing and strongly sorbing radionuclides. Removal of these radionuclides from the irrigation recycling system due to soil erosion is significant and the irrigation recycling impacts are less noticeable than in Seismic-GM scenario.

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7. VALIDATION

The irrigation recycling model was validated in accordance with the TWP (SNL 2007 [DIRS 181342]). As stated in the TWP (SNL 2007 [DIRS 181342], Section 2.3), the irrigation recycling model has a potential for being used to support the license application submittal and needs to be validated to Level II as classified in SCI-PRO-002, Attachment 3. The first and the third methods as defined in SCI-PRO-006, Section 6.3.2 were used in validation. Using these methods is consistent with the intended use of the model and required level of confidence. Comparison of the modeling results with the actual measurements and analytical solution provides explicit evidence of the ability of the model to simulate irrigation recycling.

The irrigation recycling modeling results are compared with the mathematical analytical solution of equilibrium concentration for open-system behavior with recycling (method 3) in Section 7.1. The corroboration of the modeling results with the available field data (method 1) is considered in Section 7.2.

7.1 COMPARISON OF THE IRRIGATION RECYCLING MODELING RESULTS AND AN OPEN SYSTEM ANALYTICAL SOLUTION

A mathematical analytical solution describing equilibrium concentration of a nondecaying species in an open-system behavior with recycling was developed (BSC 2005 [DIRS 174190], Appendix B) specifically to address the FEP "Recycling of Accumulated Radionuclides from Soils to Groundwater." This solution accounts for two mechanisms of contaminant removal. The first mechanism is contaminant removal with the water used for other than irrigation purposes. The second mechanism is removal with the groundwater that is not recaptured by the well. The steady-state concentration of a nondecaying species C_w in the groundwater in this system can be expressed as (BSC 2005 [DIRS 174190], Appendix B):

$$C_w = \frac{m_{sz}}{Q_T(1-F_i F_c)} \qquad \text{(Eq. 7.1-1)}$$

where m_{sz} is the mass flux from the saturated zone, Q_T is the total annual groundwater usage, and F_i is the fraction of groundwater used for irrigation. Fraction of water used for other than irrigation purposes is equal to $1-F_i$.

The steady-state concentration of a nondecaying species C_{w0} in the groundwater in this system without irrigation recycling can be expressed as (BSC 2005 [DIRS 174190], Appendix B):

$$C_{w0} = \frac{m_{sz}}{Q_T} \qquad \text{(Eq. 7.1-2)}$$

Using Equations 7.1-1 and 7.1-2, an increase in concentration due to recycling can be expressed as:

$$\frac{C_w}{C_{w0}} = \frac{1}{1-F_i F_c} \qquad \text{(Eq. 7.1-3)}$$

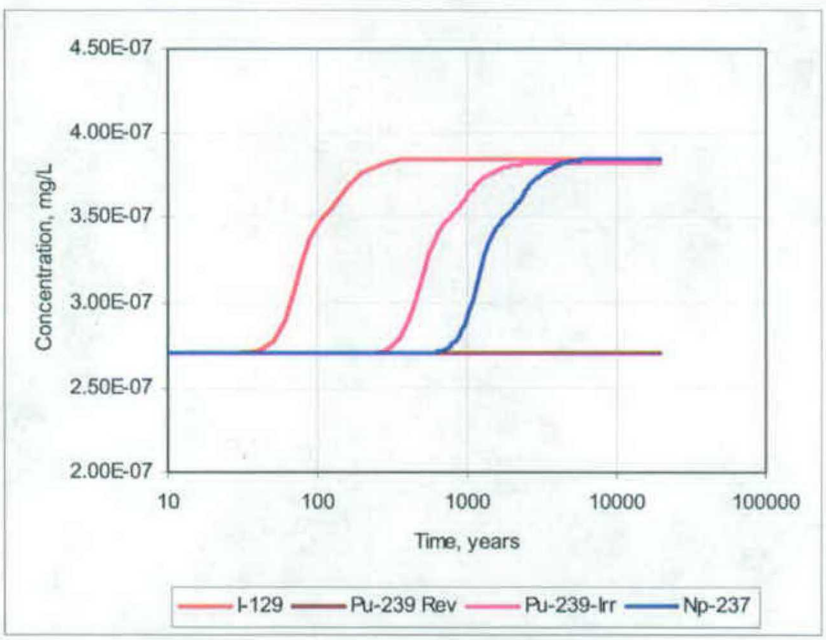
Equations 7.1-1 through 7.1-3 were used to calculate the equilibrium concentrations in both cases with and without irrigation recycling and the increase in concentration due to recycling. The following parameter values were used:

- Q_T = 3,000 ac-ft/yr (3.7×10^6 m^3/yr)
- F_i = 0.85
- F_c = 0.35.

The resulting concentrations are $C_{w0} = 2.7012 \times 10^{-7}$ mg/L and $C_w = 3.8452 \times 10^{-7}$ mg/L. The concentration increases 1.424 times.

The irrigation recycling model run was performed using the same parameter values as defined above. The fraction of the residential water used within the well capture zone (parameter F_{res}) was set equal to zero to exclude recycling via the residential pathway. The residual water use uncertainty (parameter f_{unc}) was set equal to zero to yield F_i = 0.85. The erosional flux was set to zero to exclude erosional removal.

The results are shown in Figure 7.1-1. The equilibrium concentrations are 2.702×10^{-7} mg/L (based on the concentration of ^{239}Pu reversibly attached to colloids that is not affected by irrigation recycling) and $C_w = 3.845 \times 10^{-7}$ mg/L (based on the ^{129}I concentration that reached equilibrium during the first 1,000 years). The concentration increase is 1.424 times. The difference between the modeling results and the analytical solution is less than 0.1%. Consequently, this validation criteria described in the TWP (SNL 2007 [DIRS 181342]) is satisfied.



Source: Output DTN: SN0703PASZIRMA.001 (directory *Results*, file: *Validation_Results.xls*).

Figure 7.1-1. Radionuclide Concentrations in the Groundwater (F_c = 0.35 and F_{res} = 0)

7.2 CORROBORATION OF THE IRRIGATION RECYCLING MODELING RESULTS WITH THE AVAILABLE FIELD DATA

The estimates of the deep percolation rates beneath the cultivated fields in the Amargosa Valley area are available from the report by Stonestrom et al. (2003 [DIRS 165862]). As discussed in Section 6.5.3.8, six boreholes were drilled within three irrigated fields (Figure 6.5-17) as part of these studies. The percolation rates were estimated from the chloride mass balance and chloride and nitrate displacement methods.

The following formula was used in the chloride mass balance method (Stonestrom et al. 2003 [DIRS 165862]):

$$D_p = (C_e P + C_i I + C_f F) / C \qquad \text{(Eq. 7.2-1)}$$

where D_p is the rate of deep percolation; C_e is the effective chloride concentration in precipitation, including dry fallout; P is the precipitation rate; C_i is the concentration of chloride in irrigation water, I is the annual irrigation rate; C_f is the concentration of chloride in the applied fertilizer; F is the fertilizer application rate; and C is the average chloride concentration in pore water below the zone influenced by evapotranspiration.

The average chloride concentrations below the root zone were measured in the borehole core samples. The uncertainties in these estimates arise primarily from fairly large uncertainties in total chloride deposition from atmospheric and irrigation processes. Using the high-end chloride deposition rate results in a higher deep percolation rate (chloride balance maximum in Table 7.2-1). Using the low-end chloride deposition rates results in a lower deep percolation rate (chloride balance minimum in Table 7.2-1).

In the chloride and nitrate displacement method, the deep percolation was estimated as (Stonestrom et al. 2003 [DIRS 165862]):

$$D_p = \theta \frac{z_2 - z_1}{t_2 - t_1} \qquad \text{(Eq. 7.2-2)}$$

where θ is the average volumetric water content between z_1 and z_2, and z_1 and z_2 are the depths of a solute marker at times t_1 and t_2, respectively.

The transport velocities (v) and time of transport through the unsaturated zone (t) were calculated as:

$$v = \frac{D_p}{\theta} \quad \text{and} \quad t = \frac{B}{v} \qquad \text{(Eq. 7.2-3)}$$

where B is the depth to the water table beneath the irrigated fields equal to 35 m (Stonestrom et al. 2003 [DIRS 165862]). These data are summarized in Table 7.2-1.

Based on the data in Table 7.2-1, the transport velocity in the unsaturated zone beneath the irrigated fields ranges from 0.48 to 3.30 m/yr, and the transport time ranges from 10.6 to 73.5 years. The mean transport velocity is 1.4 m/yr, and the mean transport time is 25 years.

A few irrigation recycling modeling runs were done to simulate transport of a conservative species through the unsaturated zone beneath the irrigated fields under conditions similar to the Amargosa Farms. The residential pathway and the erosional removal were excluded from these runs in the same way as was done in Section 7.1. The depth to water table was set equal to 35 m.

Two parameters affect the transport velocities in the unsaturated zone – saturation and the overwatering rate. As discussed in Section 6.5.3.8, the saturation in the unsaturated zone beneath the irrigated fields is defined as a uniform distribution from 0.261 to 0.664. The overwatering rate is 0.149 m/yr. The standard deviation in the average overwatering rate used in the biosphere model and equal to 0.0695 m/yr (DTN: MO0705GOLDSIMB.000 [DIRS 181281], file *ERMYN_GW_Rev01_PDC_Ac227.gsm*) was used to introduce the uncertainty in the overwatering rate defined as a constant in the irrigation recycling model. The maximum overwatering rate was defined as 0.2185 (0.149 m/yr plus one standard deviation). The minimum overwatering rate was defined as 0.0795 (0.149 m/yr minus one standard deviation).

Table 7.2-1. Estimated Transport Velocities and Transport Times in the Unsaturated Zone Beneath the Irrigated Fields in the Amargosa Valley Area

Borehole Name	Transport Velocity (m/yr)	Method Used	Transport Time in Unsaturated Zone (years)
AFCA2	0.476	Cl Mass Balance Min	73.5
AFCA3	0.850	Cl Mass Balance Min	41.2
AFCA4	2.500	Cl Mass Balance Min	14.0
AFCA5	1.063	Cl Mass Balance Min	32.9
AFPL1	1.563	Cl Mass Balance Min	22.4
AFPL2	1.273	Cl Mass Balance Min	27.5
AFCA2	0.667	Cl Mass Balance Max	52.5
AFCA3	1.150	Cl Mass Balance Max	30.4
AFCA4	3.313	Cl Mass Balance Max	10.6
AFCA5	1.438	Cl Mass Balance Max	24.3
AFPL1	2.063	Cl Mass Balance Max	17.0
AFPL2	1.727	Cl Mass Balance Max	20.3
AFCA2	0.905	Cl Displacement	38.7
AFCA3	1.500	Cl Displacement	23.3
AFCA4	1.063	N Displacement	32.9
AFCA5	0.813	N Displacement	43.1
mean	1.40	—	25.0

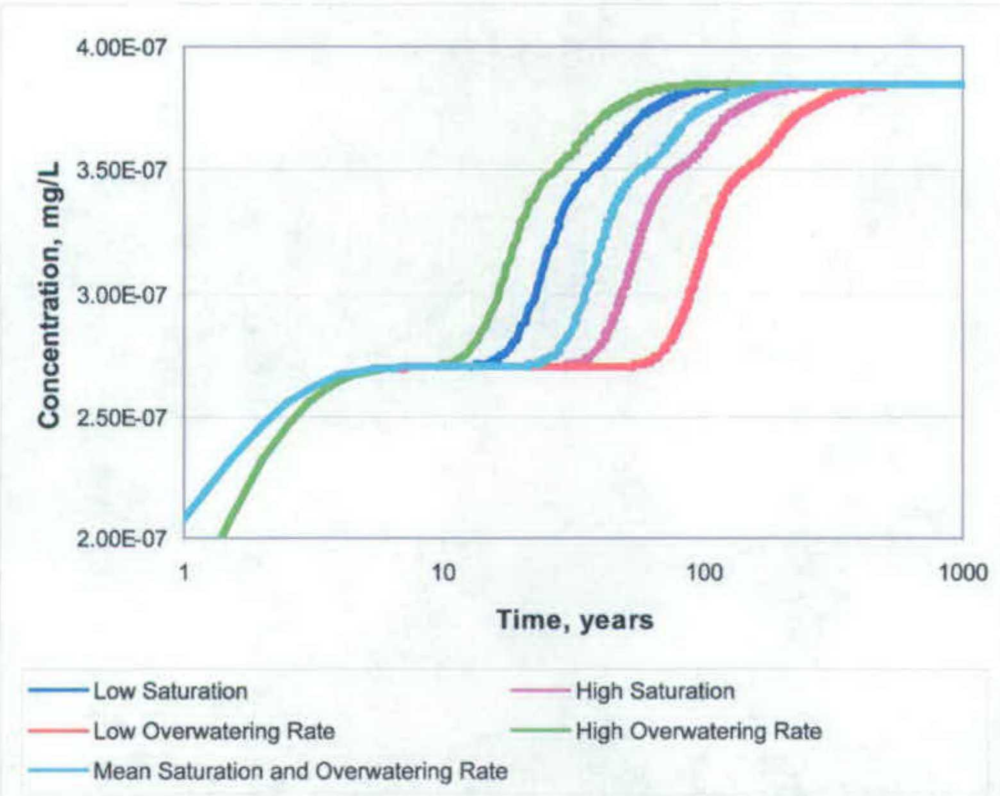
Source: Stonestrom et al. 2003 [DIRS 165862], Table 4.

NOTE: Min = minimum; Max = maximum.

The following five runs were carried out:

- Minimum saturation and overwatering rate of 0.149 m/yr (low saturation in Figure 7.2-1)
- Maximum saturation and overwatering rate of 0.149 m/yr (high saturation in Figure 7.2-1)
- Minimum saturation and maximum overwatering rate (high overwatering rate in Figure 7.2-1)
- Maximum saturation and minimum overwatering rate (low overwatering rate in Figure 7.2-1)
- Mean saturation (0.463) and mean overwatering rate of 0.149 m/yr minimum saturation and maximum overwatering rate (mean saturation and overwatering rate in Figure 7.2-1).

The results of these five runs are shown in Figure 7.2-1 for ^{129}I that simulates a conservative tracer such as chloride or nitrate used in the report by Stonestrom et al. (2003 [DIRS 165862]). The transport time ranges from 10.5 to 60 years (see Figure 7.2-1). The transport time under the mean saturation and mean overwatering rate is 23 years. These results are in a good agreement with the field data according to which the transport time ranges from 11 to 74 years, and the mean transport time is 25 years.



Source: Output DTN: SN0703PASZIRMA.001 (directory *Results*, file: *Validation_Results.xls*).

Figure 7.2-1. Irrigation Recycling Model Simulations of the Transport of a Conservative Tracer in the Unsaturated Zone Beneath the Irrigated Fields

The data on transport velocities in the unsaturated zone similar to Amargosa Farms conditions are available (Roark and Healy 1998 [DIRS 165864]). The site of their work is near Roswell, New Mexico. The climate of this region is semi-arid with an average annual precipitation of 35.6 cm based on 1972 to 1992 data. The unsaturated zone is made of alluvial deposits of the Pecos River composed of sand, silt, and clay. The studies were conducted at two irrigated fields—west field and east field. The depth to the water table beneath the irrigated fields was 37 m. The irrigation rates at the two study areas were 0.96 m/yr at the west field and 1.70 m/yr at the east field. Alfalfa was grown in the fields.

Three neutron-moisture-meter holes were drilled at each field to the depth of 6 m. The data collected in the boreholes were used to estimate deep percolation beneath the irrigated fields by applying three different methods: the volumetric moisture method, water budget method; and chloride mass balance method.

The mean deep percolation rates calculated using the volumetric moisture method were 22.3 and 31.7 cm/yr in the west (results from three boreholes) and east (results from two boreholes) fields, respectively. The transport velocities shown in Table 7.2-2 were calculated by dividing the percolation rates by the average volumetric moisture content within the profile equal to 0.186.

The deep percolation rates, calculated using the chloride mass balance method, were 16.4 in the west field and 81.6 cm/yr in the east field. The corresponding transport velocities shown in Table 7.2-2 are 0.89 and 4.4 m/yr, respectively.

The deep percolation rates calculated using the chloride mass balance method were 15.0 cm/yr at the west field and 38.0 cm/yr at the east field. The corresponding transport velocities shown in Table 7.2-2 are 0.81 and 2.1 m/yr, respectively.

Table 7.2-2. Estimated Transport Velocities in the Unsaturated Zone Beneath the Irrigated Fields in the Roswell Area

Study Area	Transport Velocity (m/yr)	Method Used
West field	0.89	Water budget
	1.2	Volumetric moisture
	0.81	Chloride mass balance
East field	4.4	Water budget
	1.7	Volumetric moisture
	2.1	Chloride mass balance

Source: Roark and Healy 1998 [DIRS 165864].

The overall range of transport velocities is from 0.81 to 4.4 m/yr. The transport velocity ranges are similar to that observed beneath the irrigated fields in the Amargosa Farms area and that obtained from the irrigation recycling model.

Based on the comparison between the modeling results and available field data, it can be concluded that the range of uncertainty in transport velocity obtained for a nonsorbing, nondecaying species in the irrigation recycling model falls within the range in measured values of transport velocity. Consequently, the validation criterion described in the TWP (SNL 2007 [DIRS 181342]) is satisfied.

7.3 VALIDATION SUMMARY

The irrigation recycling model was validated to Level II as classified in Attachment 3 of SCI-PRO-002 in accordance with the TWP (SNL 2007 [DIRS 181342], Section 2.3). The first and the third methods as defined in SCI-PRO-006, Section 6.3.2 were used in validation.

The third method included the comparison of the irrigation recycling modeling results with the mathematical analytical solution of equilibrium concentration for open-system behavior with recycling derived in *Features, Events, and Processes in SZ Flow and Transport* (BSC 2005 [DIRS 174190], Appendix B). The difference between the equilibrium concentration of a nondecaying species obtained from the irrigation recycling model and calculated by an analytical solution using the same parameters F_c (well recapture fraction) and F_i (fraction of water used for irrigation) is less than 0.1%. The same conclusion applies to the concentration increase due to the recycling (ratio of equilibrium concentration with recycling and without recycling). Consequently, the validation criteria set in the TWP (SNL 2007 [DIRS 181342]) with regard to this comparison (10% difference was specified) are satisfied.

The first method included corroboration of the modeling results with the available field data. The available field data considered included the estimates of the transport velocity in the unsaturated zone beneath the irrigated fields in the Amargosa Farms area (Stonestrom et al. 2003 [DIRS 165862]) and at a similar site located in Roswell, New Mexico (Roark and Healy 1998 [DIRS 165864]). The irrigation recycling model was used to simulate the transport of a nonsorbing species through the unsaturated zone. The uncertainty in the saturation within the unsaturated zone and overwatering rate was used in these simulations to produce the range in the calculated transport times. Based on the comparison between the modeling results and available field data, it was concluded that the range of uncertainty in transport velocity obtained for a nonsorbing, nondecaying species in the irrigation recycling model falls within the range in measured values of transport velocity. Consequently, the validation criteria set in the TWP (SNL 2007 [DIRS 181342]) are satisfied.

8. CONCLUSIONS

8.1 SUMMARY OF MODELING ACTIVITIES

The stand-alone irrigation recycling model was developed to provide technical support to the evaluation of the FEP "Recycling of Accumulated Radionuclides from Soils to Groundwater 1.4.07.03.0A." This model was used in a sensitivity analysis to evaluate the impact of the irrigation recycling model to mean dose results. The model was developed using GoldSim 9.60 (STN: 10344-9.60-00 [DIRS 180224]).

The stand-alone irrigation recycling model calculates radionuclide concentrations in the groundwater based on (1) radionuclide mass fluxes exiting the saturated zone flow and the transport abstraction model and (2) radionuclide mass fluxes due to recycling of accumulated radionuclides from soil (irrigation with contaminated water) and the unsaturated zone (residential septic systems). These concentrations are passed to the TSPA. The stand-alone irrigation recycling model is incorporated into the TSPA model in order to calculate doses for sensitivity analysis.

The irrigation recycling model implicitly includes a stand-alone one-dimensional saturated zone flow and transport abstraction model (DTN: SN0702PASZFTMA.002 [DIRS 183471]). This model calculates the radionuclide fluxes at the boundary of the accessible environment given a radionuclide mass, which represents the input for calculating concentrations in the groundwater. The same parameters and parameter distributions as defined in the saturated zone flow and transport abstraction model are used in the irrigation recycling model. The same realization of a parameter is used in the saturated zone flow and transport abstraction model and the irrigation recycling model to synchronize the calculations.

The irrigation recycling model does not implicitly include the biosphere process model. The biosphere modeling parameters are copied into the irrigation recycling model. The same realization of a parameter is used in the biosphere model and irrigation recycling model to synchronize the calculations. This synchronization takes place when the irrigation recycling model is incorporated into the TSPA model.

The constant values or probability distributions were developed for the irrigation recycling model specific input parameters that had not been defined elsewhere. These parameters are:

- Fraction of water used for irrigation (constant), Section 6.5.3.1
- Fraction of water representing residual uncertainty in water use (distribution), Section 6.5.3.1
- Fraction of residential water used indoors (distribution), Section 6.5.3.5.2
- Fraction of residential water used within the well capture zone (distribution), Section 6.5.3.5.1
- Fraction of irrigation water recaptured by the well (distribution), Section 6.5.3.4.3

- Depth to water table (constant), Section 6.5.3.7
- Alluvium saturation in the unsaturated zone beneath the irrigated fields (distribution), Section 6.5.3.8
- Septic leach field application rate and thickness (constant), Section 6.5.3.9.

Well-recapture fraction and fraction of residential water used within the well capture zone (residential fraction) are the irrigation recycling modeling parameters that have the greatest impact on the radionuclide concentrations in groundwater. The probability distributions were developed for these fractions based on the analysis of the distances to the irrigated fields and residences within the hypothetical community and an analysis of the capture zone from a hypothetical well. The well recapture fraction is estimated from the number of irrigated fields that fall inside the well capture zone. The residential fraction is estimated from the number of residences that fall inside the well capture zone. Uncertainties in the potential locations of the irrigated fields and residences, uncertainties in the parameters affecting the capture zone dimensions (such as the aquifer thickness and specific discharge), and uncertainties in indoor water uses were considered when developing these probability distributions.

The irrigation recycling modeling runs were performed to demonstrate the potential impacts of the well recapture fraction and indoor residential fraction on the radionuclide concentrations in the groundwater (Section 6.6). The maximum, minimum, and most likely impacts were estimated in terms of increase in concentrations due to recycling for nonsorbing, moderately sorbing, and highly sorbing radionuclides. It was shown that the most significant impacts on groundwater concentration are from recycling of contaminated irrigation water. The impacts due to recycling of the contaminated residential water are about order of magnitude smaller.

The other irrigation recycling modeling parameters do not affect the equilibrium radionuclide concentrations. These parameters affect the time when equilibrium is established. The probability distribution was developed for the saturation in the unsaturated zone beneath the irrigated fields. The bounding constant values were developed for the depth to water table and septic leach field parameters (thickness and application rate). Using bounding values results in faster recycling which, in turn, results in an earlier equilibrium.

The impacts of the irrigation recycling model to mean dose results were evaluated as a part of the TSPA sensitivity analysis (Section 6.7). In this analysis the stand-alone irrigation recycling model was implemented in the TSPA-LA compliance model. The compliance model 1,000,000-year seismic-Ground Motion (GM) and igneous scenarios were run with the irrigation recycling model included and the results were compared to the base case results. The increases in the total mean annual doses due to irrigation recycling at the time of peak dose were about 11% for seismic-GM and about 7% for igneous scenarios correspondingly. The average over the 1 million year simulation period increases in the total doses due to irrigation recycling were comparable to the ones calculated for the time of peak dose. When TSPA simulated dose is dominated by non-sorbing radionuclides (as in seismic-GM scenario) the impact of irrigation recycling is greater and when the simulated dose is dominated by moderately to strongly sorbing radionuclides (as in Igneous scenario) the impact of irrigation recycling is less due to removal of the radionuclides by soil erosion.

The irrigation recycling model is validated, and the results of the validation are documented in this report (Section 7). The irrigation recycling model calculates the same equilibrium concentrations as the analytical solution derived for a simplified recycling (BSC 2005 [DIRS 174190], Appendix B). The transport velocities in the unsaturated zone calculated by the irrigation recycling model fall within the range observed in similar conditions beneath the irrigated fields.

8.2 MODEL OUTPUTS

8.2.1 Developed Output

The technical output from this modeling report is provided in output DTN: SN0703PASZIRMA.001 and output DTN: SN0709SENANL.001.

Output DTN: SN0703PASZIRMA.001

The directory *Model* in this DTN contains the irrigation recycling model and all files required to run this model as a stand-alone GoldSim 9.60 (STN: 10344-9.60-00 [DIRS 180224]) application.

The directory *Parameters* in this DTN contains the files with the calculations performed to develop the irrigation recycling modeling parameters.

The directory *Results* in this DTN contains the results of the modeling runs (Section 6.6), including the validation runs (Section 7). Subdirectory *TSPA_Runs* includes the outputs from the TSPA Compliance model with irrigation recycling used in the TSPA sensitivity analysis (Section 6.7).

Output DTN: SN0709SENANL.001

This DTN contains two GoldSim files representing Version 5.0 of the TSPA-LA model implemented in GoldSim v. 9.60.100 (STN: 10344-9.60-01 [DIRS 181903]) and modified to include irrigation recycling model. One file implements Igneous scenario and another file implements Seismic-ground motion scenario. The results of the TSPA runs for these scenarios are saved in the form of the text files and are included in the DTN.

8.2.2 Output Uncertainties and Limitations

Both uncertainties in the modeling parameters and model output were considered in this modeling report. The probability distributions were developed to address the uncertainties in the irrigation recycling model parameters. The probability distributions for these parameters are provided in output DTN: SN0703PASZIRMA.001 (directory *Parameters*) and incorporated in the irrigation recycling model provided in output DTN: SN0703PASZIRMA.001 (directory *Model,* file: *Irrigation_Recycling_Model.gsm*). Bounding parameter values were used in a few cases in which there were no data to develop probability distributions. The distributions for the other model parameters were taken from the stand-alone saturated zone flow and transport abstraction model (DTN: SN0702PASZFTMA.002 [DIRS 183471]) and from the biosphere process model (DTN: MO0705GOLDSIMB.000 [DIRS 181281]), file

ERMYN_GW_Rev01_PDC_Ac227.gsm). The uncertainties in these parameters and corresponding probability distributions were developed outside of this modeling report and used in the irrigation recycling model as they are to maintain consistency between all the models.

The uncertainties in model output were considered in the analysis of the modeling results (Sections 6.6 and 6.7). The modeling results are provided in output DTN: SN0703PASZIRMA.001 (directory *Results*). The uncertainty in the model output is evaluated with regard to the uncertainty in the radionuclide concentrations in the groundwater and with regard to the uncertainty in the total mean annual dose.

Use of the irrigation recycling model is subject to the limitations and restrictions imposed by the assumptions presented in Sections 5, 6.3, 6.4, and 6.5. Limitations related to the parameter values are addressed in Section 6.5, which describes how the parameters were developed and the uncertainties were incorporated.

8.3 YUCCA MOUNTAIN REVIEW PLAN ACCEPTANCE CRITERIA

This section considers the acceptance criteria in *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274]) associated with this model report. Only those acceptance criteria applicable to this model report (Section 4.2) are discussed. In most cases, the applicable acceptance criteria are not addressed solely by this report. The acceptance criteria are fully addressed when this report is considered in conjunction with other analysis and model reports on the unsaturated zone, saturated zone, and biosphere.

As discussed in Section 4.2, the process models for the unsaturated zone, saturated zone, and biosphere have to be addressed because they are either implemented in the irrigation recycling model or are a part of the interface with the irrigation recycling model.

8.3.1 Acceptance Criteria from Section 2.2.1.3.6.3, Flow Paths in the Unsaturated Zone

Acceptance Criterion 1: ***System Description and Model Integration Are Adequate***

- Subcriterion (2) – Sections 6.3 and 6.4 adequately describe and identify the aspects of hydrology, geology, physical phenomena, and couplings that may affect radionuclide transport in the unsaturated zone. Section 6.5 describes how the hydrogeologic properties of the unsaturated zone were defined. The alluvium hydrogeologic properties affect flow in the unsaturated zone.

- Subcriterion (3) – The abstraction of radionuclide transport in the unsaturated zone incorporated in this report uses assumptions, technical bases, data, and models that are appropriate and consistent with the abstractions of radionuclide release rates and solubility limits and flow paths in the unsaturated zone. The descriptions and technical bases provided in support of the abstraction of radionuclide transport in the unsaturated zone in Sections 6.3, 6.4, and 6.5 are transparent and traceable.

- Subcriterion (5) – This modeling report provides sufficient data and technical bases for the inclusion of FEPs related to radionuclide transport in the unsaturated zone in the TSPA abstraction.

- Subcriterion (7) – Average parameter estimates used in process-level models are representative of the temporal and spatial discretizations considered in the model as discussed in Section 6.3 and 6.5.

- Subcriterion (8) – Reduction in unsaturated zone transport distances after a climate-induced water table rise is considered in the model as discussed in Section 6.5.3.

- Subcriterion (9) – This model was developed in accordance with *Quality Assurance Requirements and Description* (DOE 2007 [DIRS 182051]), which commits to the NUREGs and associated procedures as discussed in Section 2.

Acceptance Criterion 2: ***Data Are Sufficient for Model Justification***

- Subcriterion (1) – Hydrological values used in this modeling report are adequately justified. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided in Section 6.5.

- Subcriterion (2) – Data on the geology and hydrology of the unsaturated zone are collected using acceptable techniques. These techniques included site-specific field measurements and studies described in Sections 6.5.3.

- Subcriterion (6) – Accepted and well-documented procedures are used to construct and calibrate numerical models. The detailed description of this is provided in Section 6.4.

- Subcriterion (7) – Reasonably complete process-level conceptual and mathematical models are used in the analyses as described in Section 6.4. The mathematical model discussed in Section 6.4 is consistent with conceptual model and site characteristics defined in Sections 5 and 6.3. The robustness of results from different mathematical models is compared in Section 7.1, where the developed mathematical model is compared to an analytical solution.

Acceptance Criterion 3: ***Data Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – The irrigation recycling model developed in this model report uses parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably accountable for uncertainties and variabilities, and do not result in an under-representation of the risk estimate. The development of the modeling parameters is discussed in Section 6.5. For the majority of the parameters, the probability distributions are developed. In a few cases when the data were not sufficient to develop probability distributions, the bounding values were used.

- Subcriterion (2) – The technical bases for the parameter values used in this abstraction are provided in Section 6.5.

- Subcriterion (6) – Uncertainties in the characteristics of the natural system are considered and presented in Section 6.5. The uncertainties are addressed by developing probability distributions for the major parameters.

Acceptance Criterion 4: ***Model Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – Alternative modeling approaches consistent with available data and current scientific understanding, were used in developing modeling parameters as described in Section 6.5. The results and limitations were appropriately considered in the abstraction and presented in Section 6.5.

- Subcriterion (2) – The bounds of uncertainty created by the process-level models are considered in this abstraction. A corresponding discussion is provided in each case when these bounds are used in developing model parameters (Section 6.5).

- Subcriterion (3) – Consideration of conceptual model uncertainty is consistent with available site characterization data, field measurements, natural analog information, and process-level modeling studies. The comparison of the modeling results and the available field data are presented in Section 7.2. The treatment of conceptual model uncertainty does not result in an underrepresentation of the risk estimate as discussed in Section 5 and Section 6.3 with regard to the conceptual model assumptions and in Section 6.5 with regard to the modeling parameters.

Acceptance Criterion 5: ***Model Abstraction Output Is Supported by Objective Comparisons***

- Subcriterion (1) – The models implemented in this abstraction provide results consistent with the available site-specific field data and data from the natural analog site as described in Section 7.2.

- Subcriterion (2) – Abstractions of process-level models conservatively bound process-level predictions as described in Section 5 and Section 6.3 with regard to the conceptual model assumptions and in Section 6.5 with regard to the modeling parameters.

8.3.2 Acceptance Criteria from Section 2.2.1.3.7.3, Radionuclide Transport in the Unsaturated Zone

Acceptance Criterion 1: ***System Description and Model Integration Are Adequate***

- Subcriterion (2) – Sections 6.3 and 6.4 adequately describe the aspects of hydrology, geology, physical phenomena, and couplings that may affect radionuclide transport in the unsaturated zone. Section 6.5 describes how the transport properties of the unsaturated zone alluvium were defined. The alluvium transport properties affect transport in the unsaturated zone. The abstraction assumptions provided in Sections 5 and 6.3 are readily identified and consistent with the body of data presented in the modeling report.

- Subcriterion (3) – The abstraction of radionuclide transport in the unsaturated zone incorporated in this model report uses assumptions, technical bases, data, and models that are appropriate and consistent with the abstractions of radionuclide release rates and solubility limits and flow paths in the unsaturated zone. The descriptions and technical bases provided in support of the abstraction of radionuclide transport in the unsaturated zone in Sections 6.3, 6.4, and 6.5 are transparent and traceable.

- Subcriterion (5) – This modeling report provides sufficient data and technical bases for the inclusion of FEPs related to radionuclide transport in the unsaturated zone in the TSPA abstraction.

- Subcriterion (6) – This model was developed in accordance with *Quality Assurance Requirements and Description* (DOE 2007 [DIRS 182051]), which commits to the NUREGs and associated procedures as discussed in Section 2.

Acceptance Criterion 2: ***Data Are Sufficient for Model Justification***

- Subcriterion (1) – Section 6.5 adequately justifies geological, hydrological and geochemical values used. This includes the flow-path length in the unsaturated zone, sorption coefficients, and colloid concentrations. Section 6.5 provides adequate descriptions of how these data were used, interpreted, and appropriately synthesized into the parameters.

Acceptance Criterion 3: ***Data Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – The model developed in this model report uses parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably accountable for uncertainties and variabilities, and do not result in an underrepresentation of the risk estimate. The development of the modeling parameters is discussed in Section 6.5. For the majority of the parameters, the probability distributions are developed. In a few cases when the data were not sufficient to develop probability distributions, the bounding values were used.

- Subcriterion (4) – Sections 5 and 6.3 adequately address the conceptual model uncertainties. Section 6.5 addresses the uncertainties in the model parameters. The conservative limits are used when the data are not sufficient to develop probability distributions.

Acceptance Criterion 4: ***Model Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – Alternative modeling approaches consistent with available data and current scientific understanding were considered in developing modeling parameters as described in Section 6.5. The results and limitations were appropriately incorporated in the abstraction and presented in Section 6.5.

- Subcriterion (2) – The bounds of uncertainty created by the process-level models are considered in this abstraction. A corresponding discussion is provided in each case when these bounds are used in developing model parameters (Section 6.5).

- Subcriterion (4) – Consideration of conceptual model uncertainty is consistent with available site characterization data, field measurements, natural analog information, and process-level modeling studies. The comparison of the modeling results and the available field data are presented in Section 7.2. The treatment of conceptual model uncertainty does not result in an underrepresentation of the risk estimate as discussed in Sections 5 and 6.3 with regard to the conceptual model assumptions and in Section 6.5 with regard to the modeling parameters.

Acceptance Criterion 5: ***Model Abstraction Output Is Supported by Objective Comparisons***

- Subcriterion (2) – Outputs of radionuclide transport in the unsaturated zone abstractions produce the results consistent with the available site-specific field data and data from the natural analog site as described in Section 7.2.

- Subcriterion (3) – Section 6.4 documents the procedures accepted by the scientific community used to construct and test the mathematical and numerical models used to simulate radionuclide transport through the unsaturated zone.

- Subcriterion (4) – Sections 6.6 and 7.2 discuss the results of the sensitivity analyses. The results presented in Section 7.2 demonstrate the consistency with the site-specific field observation and are corroborated by the field data from the natural analog site.

8.3.3 Acceptance Criteria from Section 2.2.1.3.8.3, Flow Paths in the Saturated Zone

Acceptance Criterion 1: ***System Description and Model Integration Are Adequate***

- Subcriterion (2) – Sections 6.3 and 6.4 adequately describe the aspects of hydrology, geology, physical phenomena, and couplings that may affect flow paths in the saturated zone. Section 6.5 describes how the hydrogeologic properties of the saturated zone alluvium were developed. The alluvium properties affect the saturated zone flow path and the well capture zone dimensions.

- Subcriterion (3) – The abstraction of flow paths in the saturated zone uses assumptions, technical bases, data, and models that are appropriate and consistent with the TSPA abstraction of representative volume. The descriptions and technical bases provided in support of the abstraction of radionuclide transport in the unsaturated zone in Section 6.3, 6.4, and 6.5 are transparent and traceable.

- Subcriterion (5) – This model report provides sufficient data and technical bases to assess the degree to which FEPs have been included in this abstraction.

- Subcriterion (7) – The irrigation recycling model incorporates long-term climate change, based on known patterns of climatic cycles during the quaternary period, particularly the last 500,000 years, and other paleoclimate data as discussed in Section 6.5.
- Subcriterion (9) – The irrigation recycling model incorporates the impact of the expected water table rise on potentiometric heads and flow directions as discussed in Section 6.5
- Subcriterion (10) – This model was developed in accordance with *Quality Assurance Requirements and Description* (DOE 2007 [DIRS 182051]), which commits to the NUREGs and associated procedures as discussed in Section 2.

Acceptance Criterion 2: ***Data Are Sufficient for Model Justification***

- Subcriterion (1) – Section 6.5 adequately justifies geological and hydrological values used to evaluate flow paths in the saturated zone and provides sufficient description of how the data were used, interpreted, and appropriately synthesized into the parameters are provided.
- Subcriterion (2) – As it is described in Section 6.5, sufficient data have been collected to establish initial and boundary conditions for the abstraction of flow paths in the saturated zone.
- Subcriterion (3) – Data on the geology and hydrology of the saturated zone are based on appropriate techniques. These techniques include site-specific field measurements and process-level modeling studies discussed in Section 6.5 and used to support parameter development.
- Subcriterion (4) – Sufficient information is provided in Sections 5, 6.3, and 6.4 to substantiate that the proposed mathematical groundwater modeling approach and proposed models are calibrated and applicable to site conditions.

Acceptance Criterion 3: ***Data Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – The model developed in this model report uses parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably account for uncertainties and variabilities, and do not result in an under-representation of the risk estimate. The development of the modeling parameters is discussed in Section 6.5. For the majority of the parameters, the probability distributions are developed. In a few cases when the data were not sufficient to develop probability distributions, the bounding values were used.
- Subcriterion (2) – Section 6.5 discusses how the hydrologic effects of climate change are incorporated in model abstractions.

- Subcriterion (3) – Section 6.5 discusses how the uncertainty in the model parameters is incorporated. The uncertainty is addresses through developing probability distributions for the saturated zone flow parameters.

Acceptance Criterion 4: ***Model Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – Alternative modeling approaches consistent with available data and current scientific understanding, were considered in developing modeling parameters as described in Section 6.5. The results and limitations were appropriately incorporated in the abstraction and presented in Section 6.5.

- Subcriterion (2) – Sections 5 and 6.3 adequately document the conceptual model uncertainties. The uncertainty in the saturated zone flow parameters are addressed by considering probability distributions for these parameters as described in Section 6.5. Both, unconfined and confined conditions are considered in the analysis of the well capture zone.

- Subcriterion (4) – As discussed in Section 6.5, appropriate alternative modeling approaches are consistent with available data and current scientific knowledge.

8.3.4 Acceptance Criteria from Section 2.2.1.3.9.3, Radionuclide Transport in the Saturated Zone

Acceptance Criterion 1: ***System Description and Model Integration Are Adequate***

- Subcriterion (2) – Sections 6.3 and 6.4 adequately describe the aspects of hydrology, geology, physical phenomena, and couplings that may affect radionuclide transport in the saturated zone. Section 6.5 describes how the transport properties of the saturated zone alluvium were developed. Conditions and assumptions in the abstraction of radionuclide transport in the saturated zone are identified in Sections 5, 6.3, and 6.5 and consistent with the body of data presented in the report.

- Subcriterion (3) – The abstraction of radionuclide transport in the saturated zone uses assumptions, technical bases, data, and models that are appropriate and consistent with the abstractions of radionuclide release rates and solubility limits, and flow paths in the saturated zone. Section 6.5 provides transparent and traceable descriptions and technical bases in support of the radionuclide transport abstraction in the saturated zone.

- Subcriterion (5) – This model report includes sufficient data and technical bases for the inclusion of features, events, and processes related to radionuclide transport in the saturated zone.

- Subcriterion (6) – This model was developed in accordance with *Quality Assurance Requirements and Description* (DOE 2007 [DIRS 182051]), which commits to the NUREGs and associated procedures as discussed in Section 2.

Acceptance Criterion 2: ***Data Are Sufficient for Model Justification***

- Subcriterion (1) – Section 6.5 adequately justifies geological, hydrological and geochemical values used. This includes the sorption coefficients, and colloid concentrations in the saturated zone. Section 6.5 provides adequate descriptions of how these data were used, interpreted, and appropriately synthesized into the parameters.

Acceptance Criterion 3: ***Data Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – The model developed in this model report uses parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably account for uncertainties and variabilities, and do not result in an under-representation of the risk estimate. The development of the modeling parameters is discussed in Section 6.5. For the majority of the model parameters, the probability distributions are developed. In a few cases where the data were not sufficient to develop probability distributions, the bounding values were used.

- Subcriterion (4) – Parameter values for dispersion and ground-water mixing are based on reasonable assumptions about climate, aquifer properties, and ground-water volumetric fluxes as described in Section 6.5.

- Subcriterion (5) – Section 6.3 adequately address the conceptual model uncertainties with regard to the transport in the saturated zone. Section 6.5 addresses the uncertainties in the model parameters. The conservative limits are used where the data are not sufficient to develop probability distributions.

Acceptance Criterion 4: ***Model Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – Alternative modeling approaches consistent with available data and current scientific understanding, were considered in developing modeling parameters as described in Section 6.5. The results and limitations were appropriately incorporated in the abstraction and presented in Section 6.5.

- Subcriterion (2) – Section 6.3 adequately document the conceptual model uncertainties. The uncertainty in the saturated zone transport parameters are addressed by considering probability distributions for these parameters as described in Section 6.5.

8.3.5 Data Acceptance Criteria from Section 2.2.1.3.14, Biosphere Characteristics

Acceptance Criterion 1: ***System Description and Model Integration Are Adequate***

- Subcriterion (3) – The assumptions described in Sections 5, 6.3, and 6.5 are consistent between the biosphere characteristics modeling and other abstractions. This concerns the assumptions about the climate change, soil types, sorption coefficients, and the physical and chemical properties of radionuclides that are used in the irrigation recycling model.

- Subcriterion (4) – This model was developed in accordance with Quality Assurance Requirements and Description (DOE 2007 [DIRS 182051]), which commits to the NUREGs and associated procedures as discussed in Section 2.

Acceptance Criterion 2: ***Data Are Sufficient for Model Justification***

- Subcriterion (1) – The behaviors and characteristics of the residents of the town of Amargosa Valley, Nevada, and characteristics of the reference biosphere are adequately justified in Sections 5, 6.3, and 6.5 of this model and are consistent with the definition of the reasonably maximally exposed individual (RMEI) in 10 CFR Part 63 [DIRS 180319]. Section 6.5 provides adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters.

- Subcriterion (2) – This modeling report provides sufficient data to assess the degree to which FEPs related to biosphere characteristics modeling have been characterized and incorporated in the abstraction. As it is described in Sections 5, 6.3, and 6.5, the assumptions and parameters considered are consistent with the present knowledge of conditions in the region surrounding Yucca Mountain. An alternative conceptual model (small community) was considered in developing the distributions of the distances to the irrigated fields and to the residences in a hypothetical community (Section 6.5.3.2).

Acceptance Criterion 3: ***Data Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – The irrigation recycling model developed in this model report uses parameter values; assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably account for uncertainties and variabilities, do not result in an under-representation of the risk estimate, and are consistent with the definition of the RMEI in 10 CFR Part 63 [DIRS 180319] as discussed in Sections 5, 6.3, and 6.5.

- Subcriterion (4) – Sections 5 and 6.3 adequately address the conceptual model uncertainties with regard to the reference biosphere. Section 6.5 addresses the uncertainties in the model parameters. The conservative limits are used when the data are not sufficient to develop probability distributions.

Acceptance Criterion 4: ***Model Uncertainty Is Characterized and Propagated Through the Model Abstraction***

- Subcriterion (1) – Irrigation recycling model is consistent with constraints on both the biosphere and the characteristics of the RMEI defined in 10 CFR 63.305 and 63.312 [DIRS 180319]. Evaluation of behavior and characteristics of the RMEI is based on the characteristics of the current residents of the town of Amargosa Valley, and uncertainty and variability in the data used to derive mean values as described in Section 6.5.

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181326 Wilkes, C.R.; Mason, A.D.; Niang, L.L.; Jensen, K.L.; Hern, S.C. 2005. *Quantification of Exposure-Related Water Uses for Various U.S. Subpopulations.* EPS/600/R-06/003. Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development. ACC: LLR.20070612.0022.

9.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

180319 10 CFR 63. 2007. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. Internet Accessible.

155216 66 FR 32074. 40 CFR Part 197, Public Health and Environmental Radiation Protection Standards for Yucca Mountain, NV; Final Rule. ACC: MOL.20050418.0113.

IM-PRO-002, *Control of the Electronic Management of Information.*

IM-PRO-003, *Software Management.*

PM-PRO-001, *Procurement Documents.*

SCI-PRO-002, *Planning for Science Activities.*

SCI-PRO-003, *Document Review.*

SCI-PRO-004, *Managing Technical Product Inputs.*

SCI-PRO-006, *Models*.

TST-PRO-001, *Submittal and Incorporation of Data to the Technical Data Management System*.

9.3 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

158690 GS011008314211.001. Interpretation of the Lithostratigraphy in Deep Boreholes NC-EWDP-19D1 and NC-EWDP-2DB Nye County Early Warning Drilling Program. Submittal date: 01/16/2001.

163483 GS030108314211.001. Interpretation of the Lithostratigraphy in Deep Boreholes NC-EWDP-18P, NC-EWDP-22SA, NC-EWDP-10SA, NC-EWDP-23P, NC-EWDP-19IM1A, and NC-EWDP-19IM2A, Nye County Early Warning Drilling Program, Phase III. Submittal date: 02/11/2003.

163561 LA0303PR831231.002. Estimation of Groundwater Drift Velocity from Tracer Responses in Single-Well Tracer Tests at Alluvium Testing Complex. Submittal date: 03/18/2003.

165471 LA0309EK831223.001. UTM Coordinates for Selected Amargosa Desert Wells. Submittal date: 09/05/2003.

153783 MO0010COV00124.001. Coverage: YM24KFS2. Submittal date: 10/26/2000.

181357 MO0309COV03136.000. Coverage: RADPOP03S. Submittal date: 09/30/2003.

178483 MO0611SCALEFLW.000. Water Table for the Saturated Zone Site Scale Flow Model. Submittal date: 11/15/2006.

181281 MO0705GOLDSIMB.000. Goldsim Biosphere Model Files for Calculating Groundwater and Volcanic Biosphere Dose Conversion Factors. Submittal date: 06/06/07.

181355 MO0706FD30MQMA.000. Four Digital 30 Minute Quad Mosaics of Part of the Amargosa Valley Area. Submittal date: 06/12/2007.

181356 MO0706NAIPDQI9.000. Nine National Agriculture Imagery Program (NAIP) Digital Quarter Quad (3.75 Minute) Images OF Part OF THE Amargosa Valley Area. Submittal date: 06/12/2007.

181613 MO0706SPAFEPLA.001. FY 2007 LA FEP List and Screening. Submittal date: 06/20/2007.

181358 MO9903COV97533.000. Coverage: BETDVWELS. Submittal date: 03/18/1999.

183471 SN0702PASZFTMA.002. Saturated Zone 1-D Transport Model. Submittal date: 10/15/2007.

181283 SN0704T0510106.008. Flux, Head and Particle Track Output from the Qualified, Calibrated Saturated Zone (SZ) Site-Scale Flow Model. Submittal date: 06/06/07.

9.4 OUTPUT DATA, LISTED BY DATA TRACKING NUMBER

SN0703PASZIRMA.001. Irrigation Recycling Model. Submittal date: 09/26/07.

SN0709IRSENANL.001. TSPA Sensitivity Analysis with Irrigation Recycling. Submittal date: 09/26/07.

9.5 SOFTWARE CODES

176015 ArcGIS Desktop V. 9.1. 2005. WINDOWS XP. STN: 11205-9.1-00.

167994 EARTHVISION V. 5.1. 2003. IRIX 6.5. STN: 10174-5.1-00.

179360 GOLDSIM V. 8.02 500. 2006. WINDOWS 2003. STN: 10344-8.02-06

180224 GoldSim V. 9.60. 2007. WINDOWS 2000, WINDOWS XP, WINDOWS 2003. STN: 10344-9.60-00.

181903 Goldsim V. 9.60.100. 2007. WIN 2000, 2003, XP. STN: 10344-9.60-01.

150454 MODFLOWP V. 2.3. 1999. STN: 10144-2.3-00.

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APPENDIX A
GEOSPATIAL DATA QUALIFICATION PLAN

Data Qualification Plan

Complete only applicable items.

QA: QA

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Section I. Organizational Information		
Qualification Title Qualification of Aerial Imagery of the Amargosa Valley Area		
Requesting Organization PA / Natural Systems		
Section II. Process Planning Requirements		
1. List of Unqualified Data to be Evaluated ---MO0706FD30MQMA.000. FOUR DIGITAL 30 MINUTE QUAD MOSAICS OF PART OF THE AMARGOSA VALLEY AREA. Submittal date: 06/12/2007. ---MO0706NAIPDQI9.000. NINE NATIONAL AGRICULTURE IMAGERY PROGRAM (NAIP) DIGITAL QUARTER QUAD (3.75 MINUTE) IMAGES OF PART OF THE AMARGOSA VALLEY AREA. Submittal date: 06/12/2007.		
2. Type of Data Qualification Method(s) [Including rationale for selection of method(s) (Attachment 3) and qualification attributes (Attachment 4)] The data qualification method used for these two data sets is Method 2 of Attachment 3 of SCI-PRO-001, Corroborating Data. The rationale for using this method is that the extent and quality of corroborating data available for comparison is very good and the inferences drawn to corroborate the data can be clearly illustrated and documented. Data qualification attribute 9, 10, and 11 from the Attachment 4 of SCI-PRO-001 will be used in the data qualification.		
3. Data Qualification Team and Additional Support Staff Required Elena Kalinina (chair) Originator of MDL-MGR-HS-000001 Rev 0 Tim Vogt No additional support staff is required. Both team members are independent of the data acquisition.		
4. Data Evaluation Criteria Evaluation criteria for the qualification of these data using corroboration will consist of visual inspection of the agricultural areas defined from one DTN set compared to the second data set. Both data sets are in the same coordinate/projection system and no transformations are required. Geo-referencing files are included with each data set minimizing or essentially eliminating the need for interaction in preparing the data sets. ArcGIS 9.2 (STN: 11205-9.2-00) will be used to prepare the corroborating information.		
5. Identification of Procedures Used SCI-PRO-006 and SCI-PRO-001		
6. Plan coordinated with the following known organizations providing input to or using the results of the data qualification No organizations outside of Natural Systems were coordinated during development of the Data Qualification Plan.		
Section III. Approval		
Qualification Chairperson Printed Name Elena Kalinina	Qualification Chairperson Signature [signature]	Date 07-12-07
Responsible Manager Printed Name Stephanie Kuzio	Responsible Manager Signature Clifford K. Ho [signature] for Stephanie Kuzio	Date 7/12/07

SCI-PRO-001.1-R1

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APPENDIX B
WATER TABLE RISE DATA QUALIFICATION PLAN

Data Qualification Plan

Complete only applicable items.

QA: QA

Page 1 of 1

Section I. Organizational Information

Qualification Title

Qualification of the Water Table Rises in the Death Valley Region and Near Yucca Mountain for the Future Climate Conditions.

Requesting Organization

PA / Natural Systems

Section II. Process Planning Requirements

1. List of Unqualified Data to be Evaluated

Predicted water table rise data near Yucca Mountain for the glacial transition climate from D'Agnese, F.A.; O'Brien, G.M.; Faunt, C.C., and San Juan, C.A. 1999. *Simulated Effects of Climate Change on the Death Valley Regional Ground-Water Flow System, Nevada and California.* Water-Resources Investigations Report 98-4041. Denver, Colorado: U.S. Geological Survey. TIC: 243555 [DIRS 120425].

2. Type of Data Qualification Method(s) [including rationale for selection of method(s) (Attachment 3) and qualification attributes (Attachment 4)]

The data qualification method used for these data is Method 5 of Attachment 3 of SCI-PRO-001, Technical Assessment. The rationale for using this method is that all the information required for technical data assessment, such as methodology and developmental results, is available from D'Agnese et al.1999 [DIRS 120425]. Data qualification attribute 1, 2, 3, 6, and 9 from the Attachment 4 of SCI-PRO-001 will be used in the data qualification. The data will be qualified for use in the *Irrigation Recycling Model*, MDL-MGR-HS-000001 Rev 00.

3. Data Qualification Team and Additional Support Staff Required

Elena Kalinina (chair) Originator of MDL-MGR-HS-000001 Rev 00
Tim Vogt
No additional support staff is required.
Both team members are independent of the data acquisition.

4. Data Evaluation Criteria

Technical assessment of the data will consist of reviewing data collection and development methodology and evaluating developmental results. Data qualification attribute 1, 2, 3, 6, and 9 from the Attachment 4 of SCI-PRO-001 will be used in the data qualification.

5. Identification of Procedures Used

SCI-PRO-006 and SCI-PRO-001

6. Plan coordinated with the following known organizations providing input to or using the results of the data qualification

No organizations outside of Natural Systems were coordinated during development of the Data Qualification Plan.

Section III. Approval

Qualification Chairperson Printed Name	Qualification Chairperson Signature	Date
Elena Kalinina	[signature]	10-04-07
Responsible Manager Printed Name	**Responsible Manager Signature**	**Date**
Stephanie Kuzio	[signature]	10/4/07

SCI-PRO-001 1-R1

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