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:

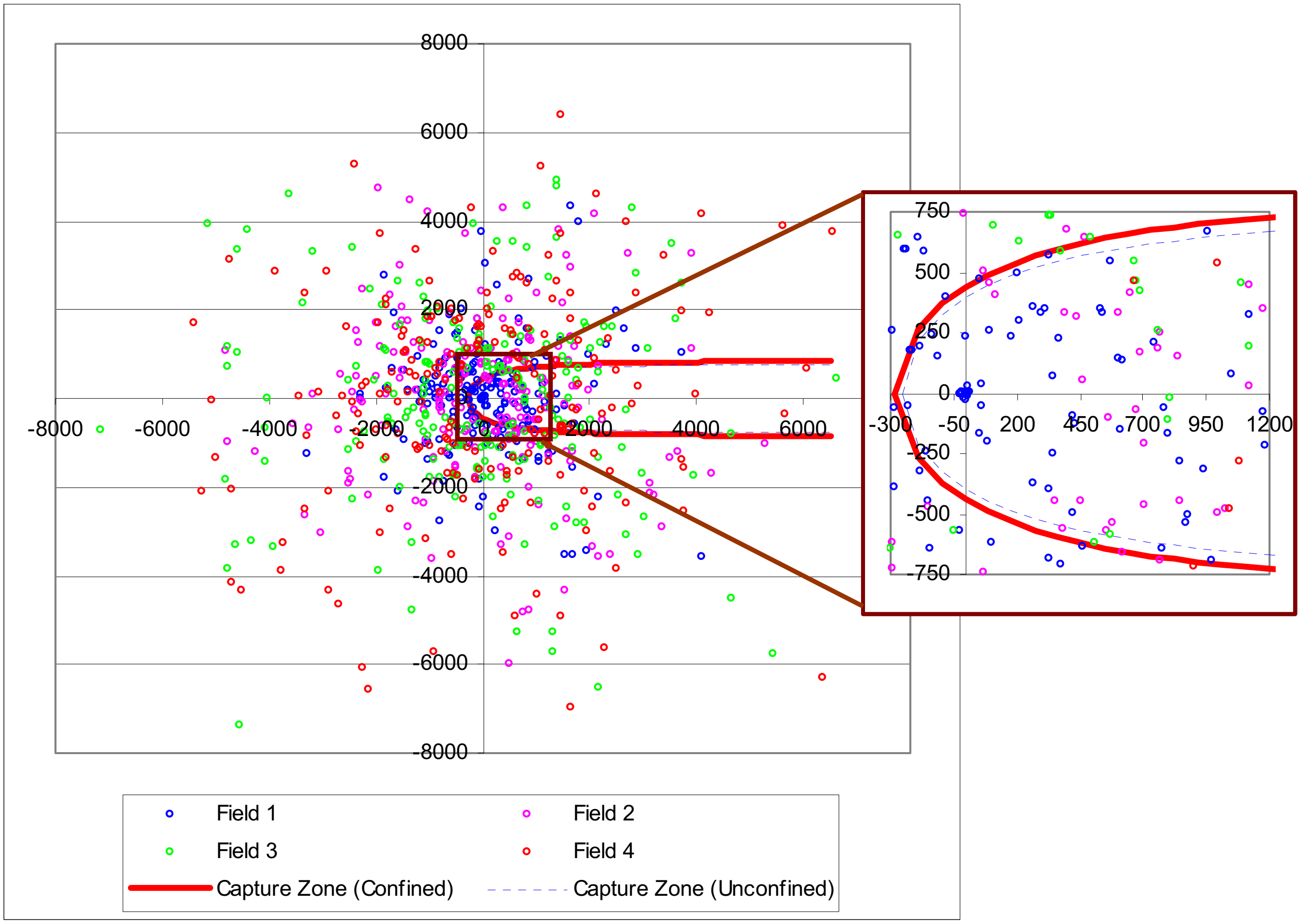
$$X_k = R_k Cos(\alpha_k) \text{ and } Y_k = R_k Sin(\alpha_k) \qquad \text{(Eq. 6.5-33)}$$

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:.

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

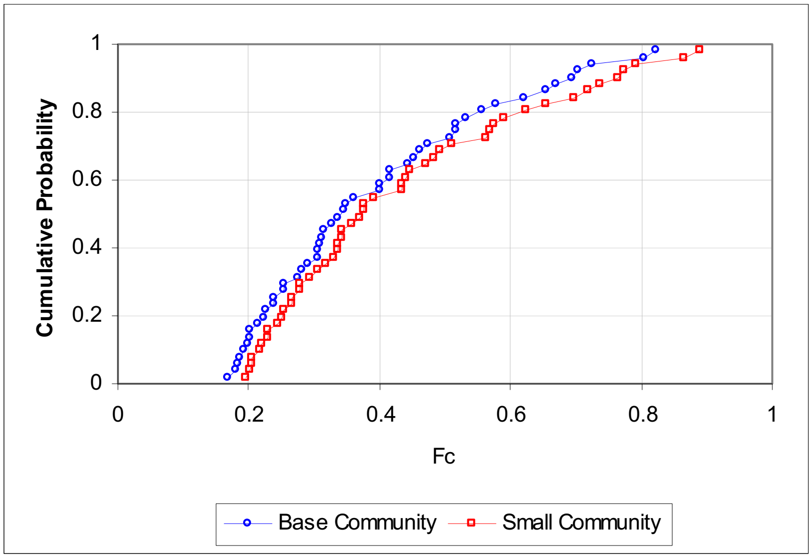
The well recapture fraction for the realization i ($F_{c,i}$) is then calculated as:

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

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.

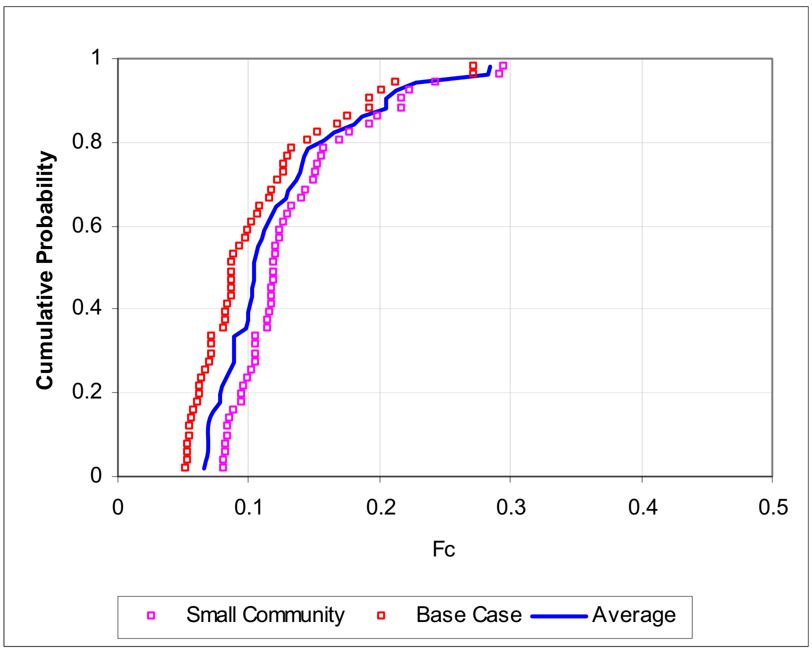
The distributions shown in Figure 6.5-9 were used only to compare the calculated F_c with the available estimate of this parameter. Only one estimate is available for the parameter F_c in the case when irrigation is assumed at the boundary of the accessible environment. This estimate is based on the 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.

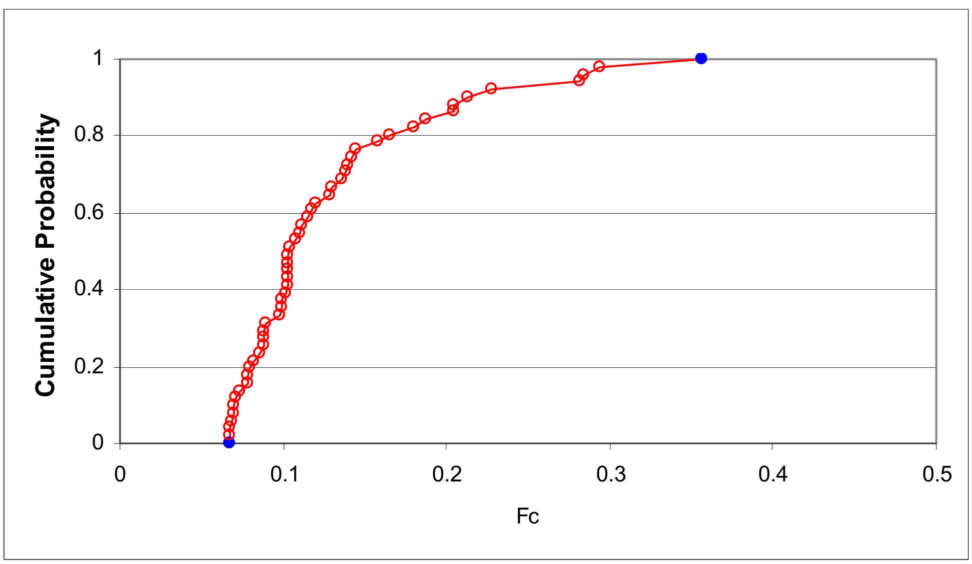


Source: Output DTN: SN0703PASZIRMA.001 (directory *Parameters,* file: *Recapture Fraction_Base_Case.xls*).

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

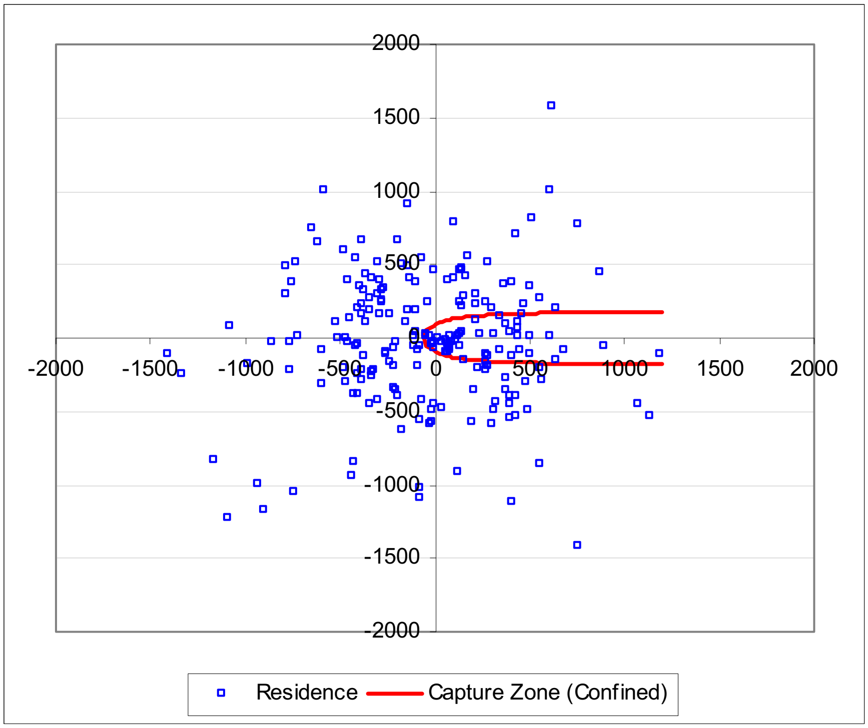
This section provides a discussion of the two parameters of the irrigation recycling model that are needed to calculate the fraction of residential water used indoors that is recaptured by the pumping well. These parameters are residential fraction (F_{res}) and indoor fraction (F_{ind}). The fraction 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.



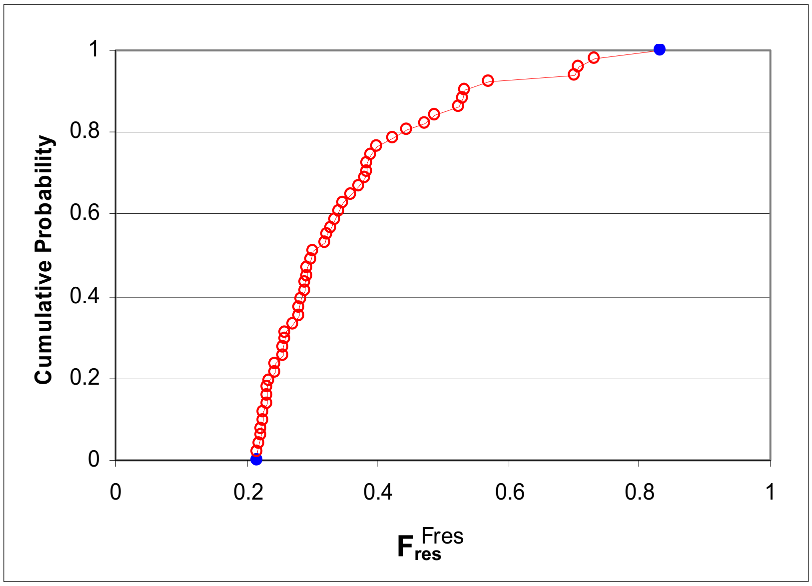
Source: Output DTN: SN0703PASZIRMA.001 (directory *Parameters*; file: *Irrigation_ Fraction_Base_Case.xls*).

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

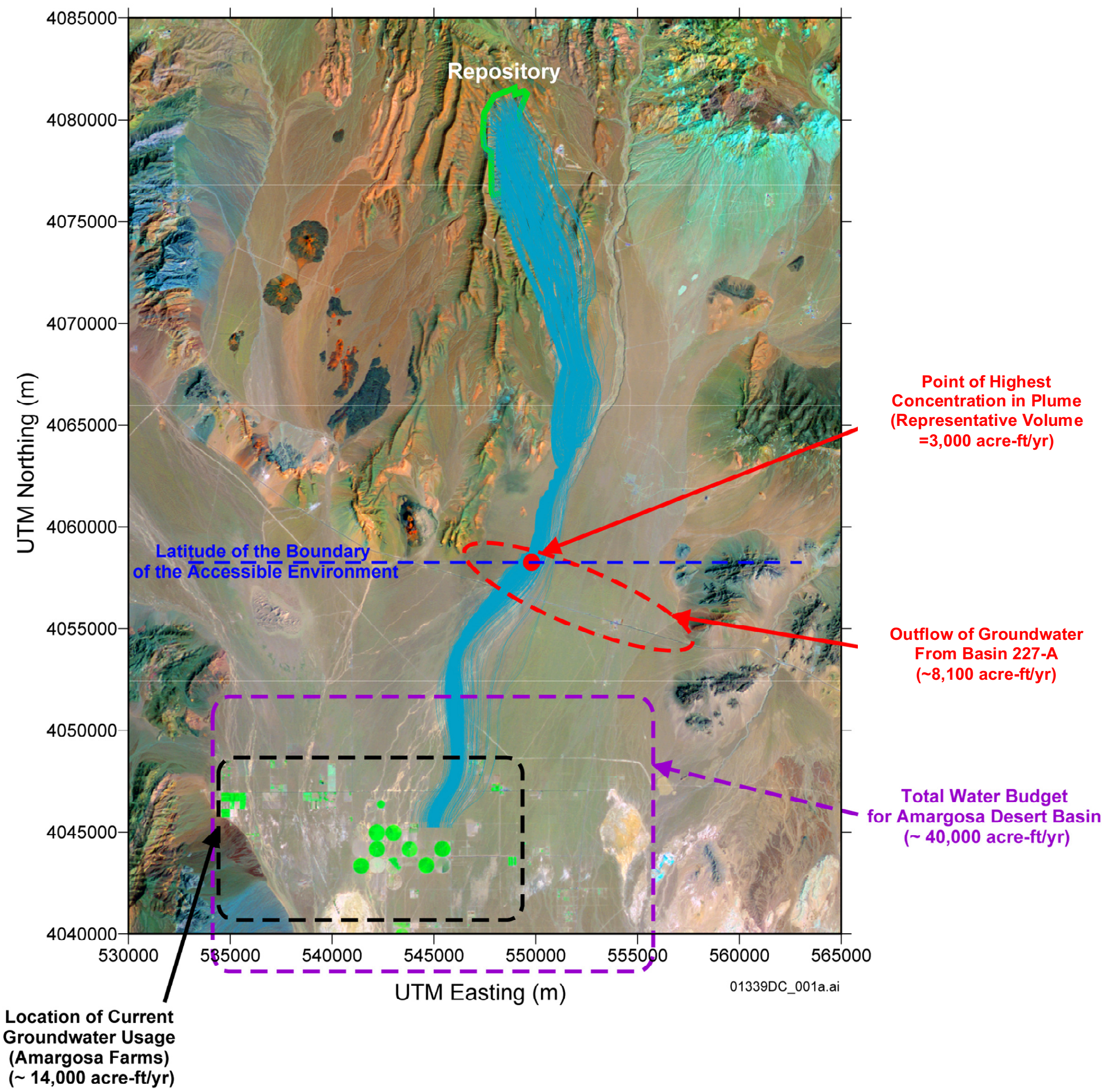
Sources: Wilkes et al. 2005 [DIRS 181326]; Southern Nevada Water Authority 2007 [DIRS 183400].

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

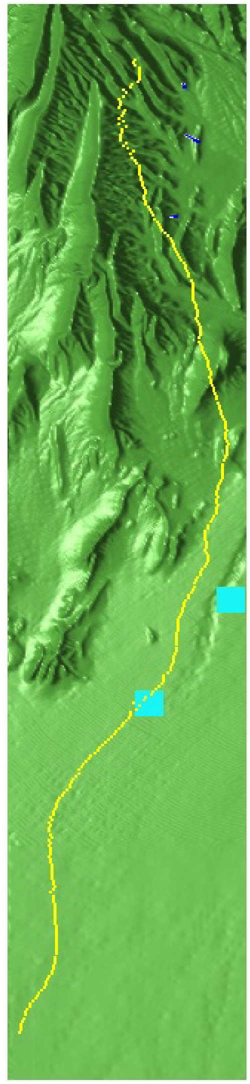
H_i^0 is the water table elevation at the discharge point

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).

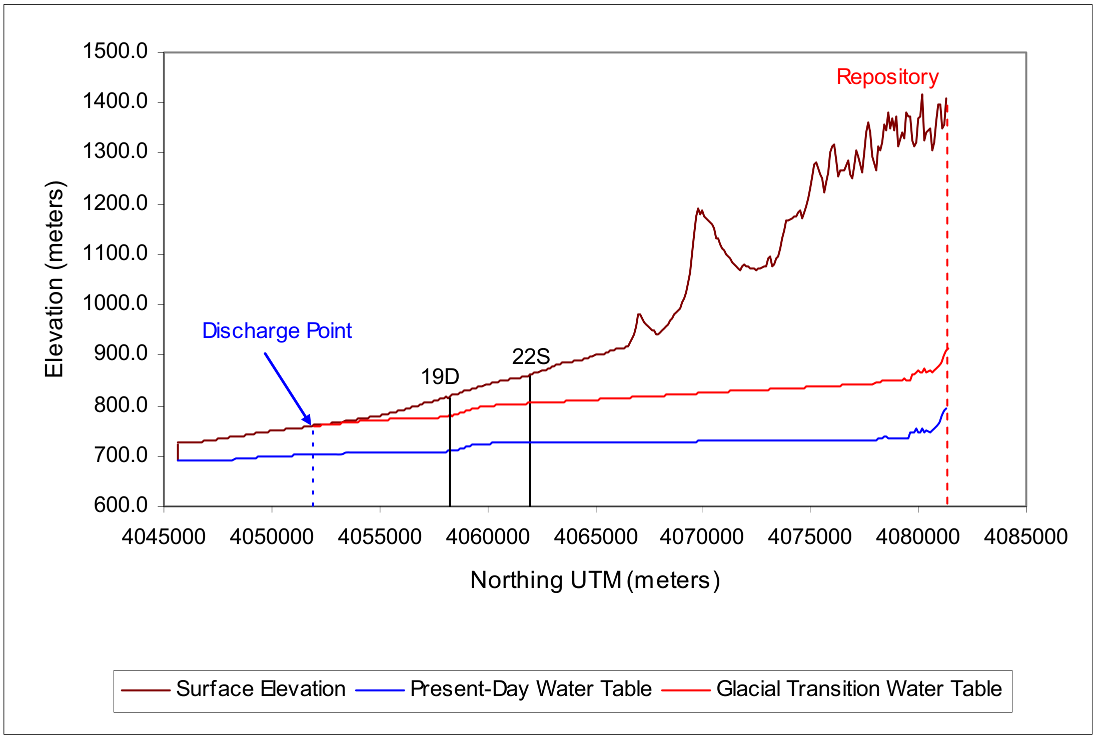
Figure 6.5-15. An Average Flow Path from the Repository

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.

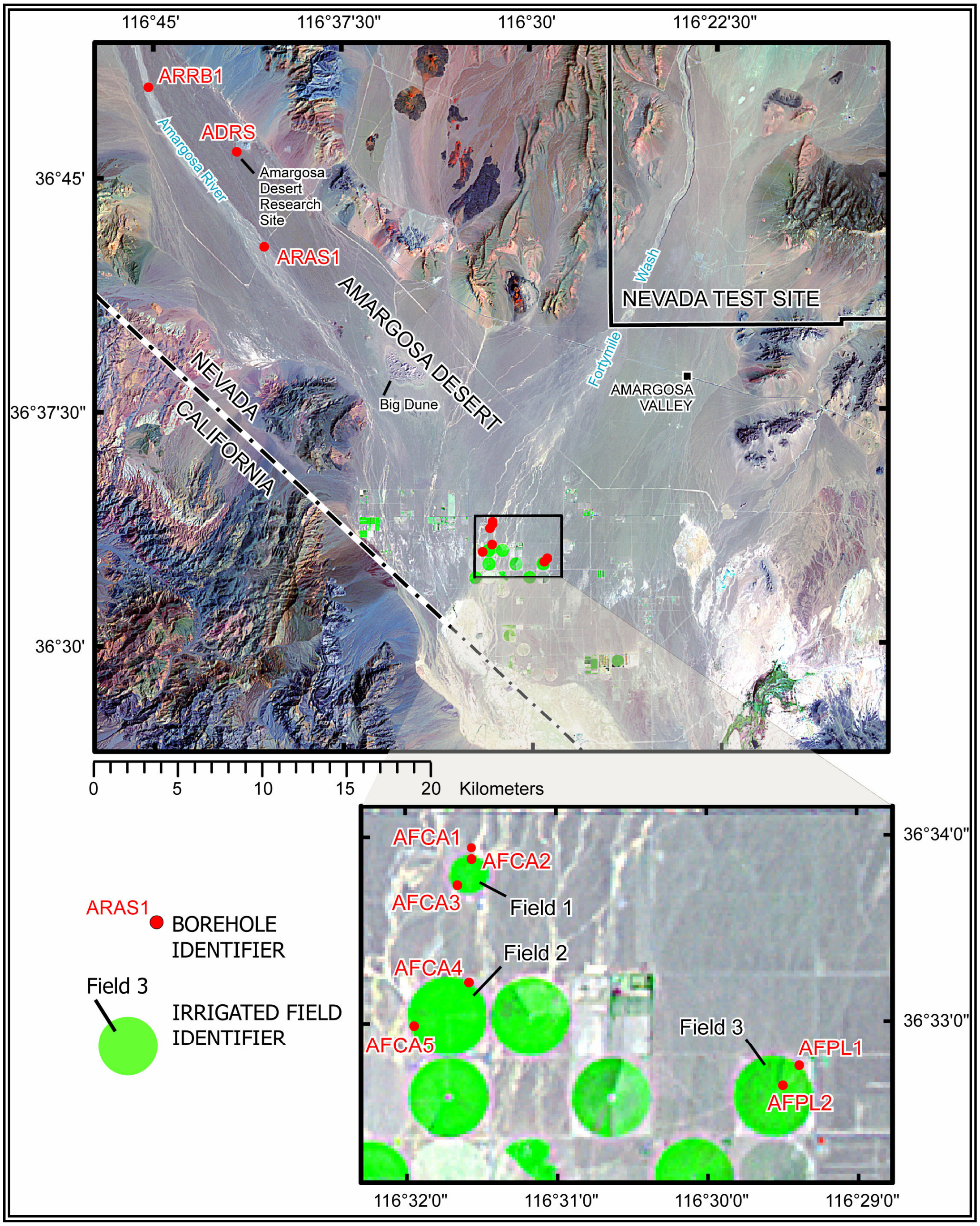
The borehole data collected include gravimetric water content, total water potential, and lithologic description of the samples collected. The data are reported in the tables provided by Stonestrom et al. (2003 [DIRS 165862], Appendices A (lithologic data) and B (other data)). These data are qualified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

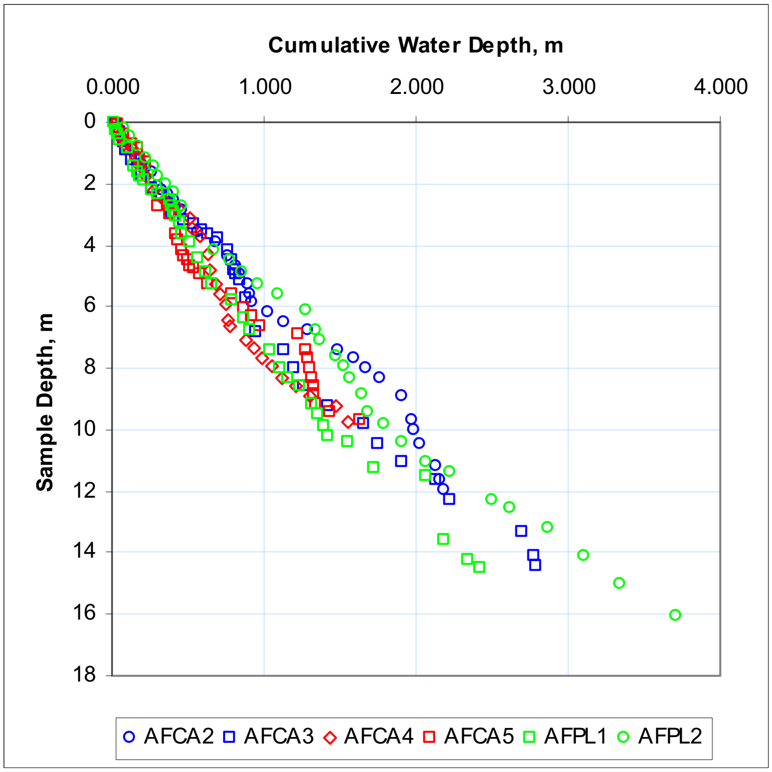
$$s = \frac{\overline{\theta}_v}{\varepsilon} \quad \text{and} \quad \overline{\theta}_v = \frac{D_w}{D_b} \tag{Eq. 6.5-40}$$

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*).

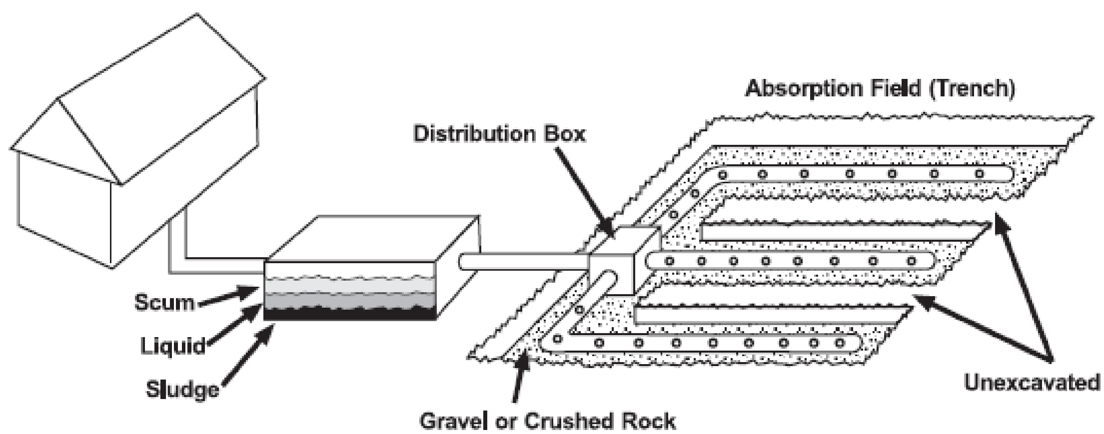
6.5.3.9 Septic Leach Field Parameters

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.

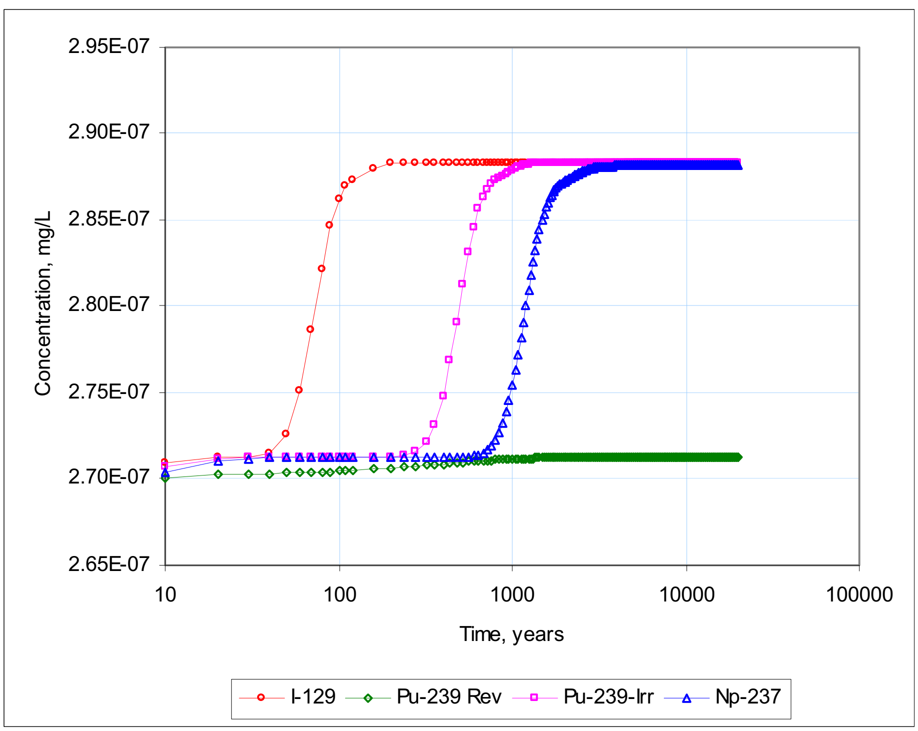
The radionuclide mass fluxes from the saturated zone flow and transport abstraction model at the boundary of the accessible environment were set equal to 1 g/yr for ^{129}I, ^{237}Np, ^{239}Pu reversibly attached to colloids, and ^{239}Pu irreversibly attached to colloids. Other radionuclide mass fluxes 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.

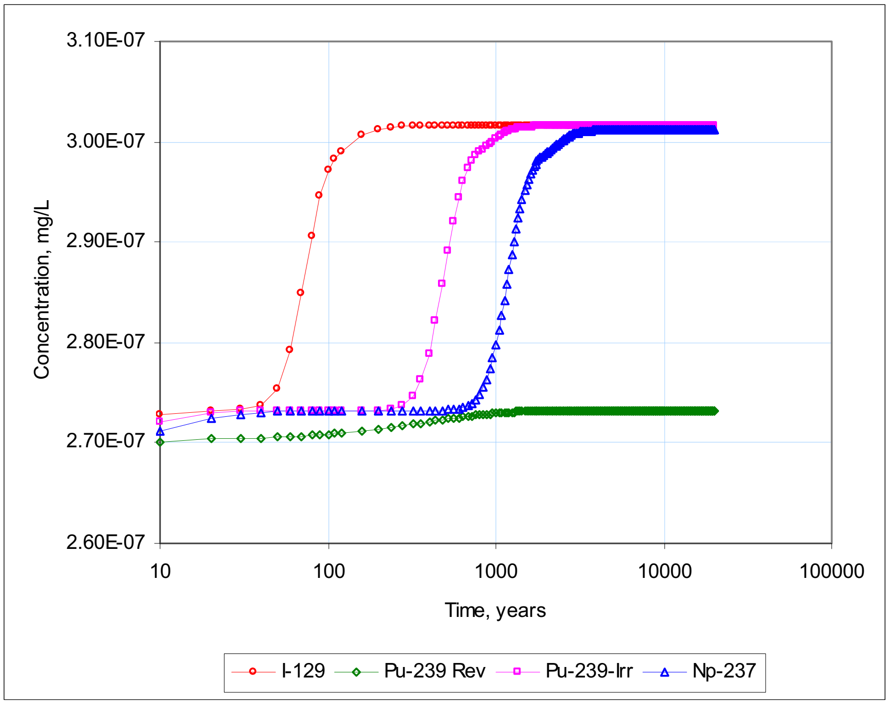
The parameter values used in the third run corresponded to the maximum values of parameters F_c, F_{res}, and F_{ind}. These values are 0.357, 0.831, and 0.591, respectively. This is based on the distributions obtained for these parameters in Sections 6.5.3.4 and 6.5.3.5. The purpose of this run was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



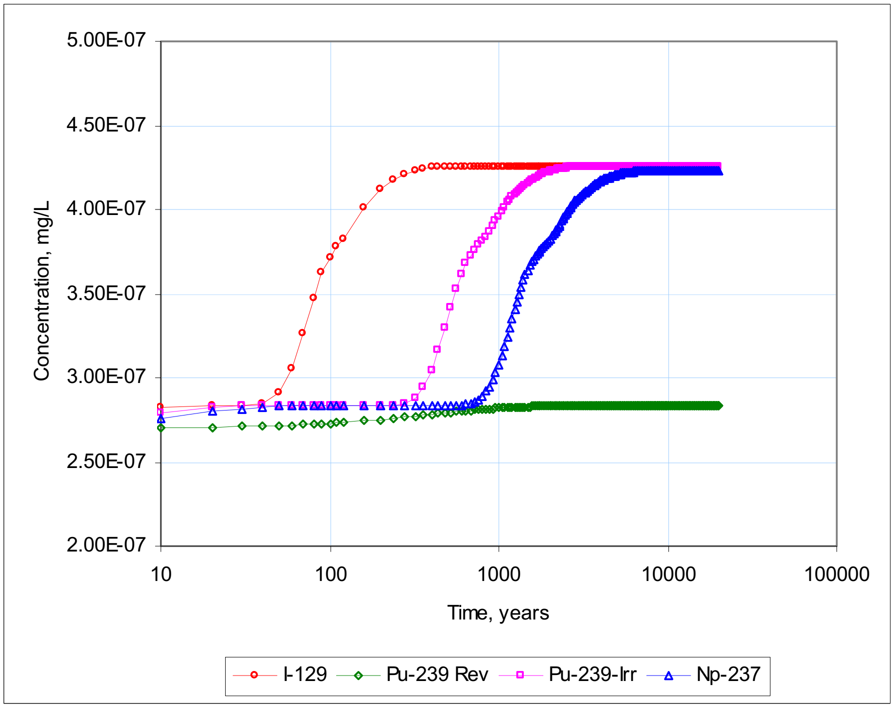
Source: Output DTN: SN0703PASZIRMA.001 (directory *Results,* file: *Modeling_Results.xls*).

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}

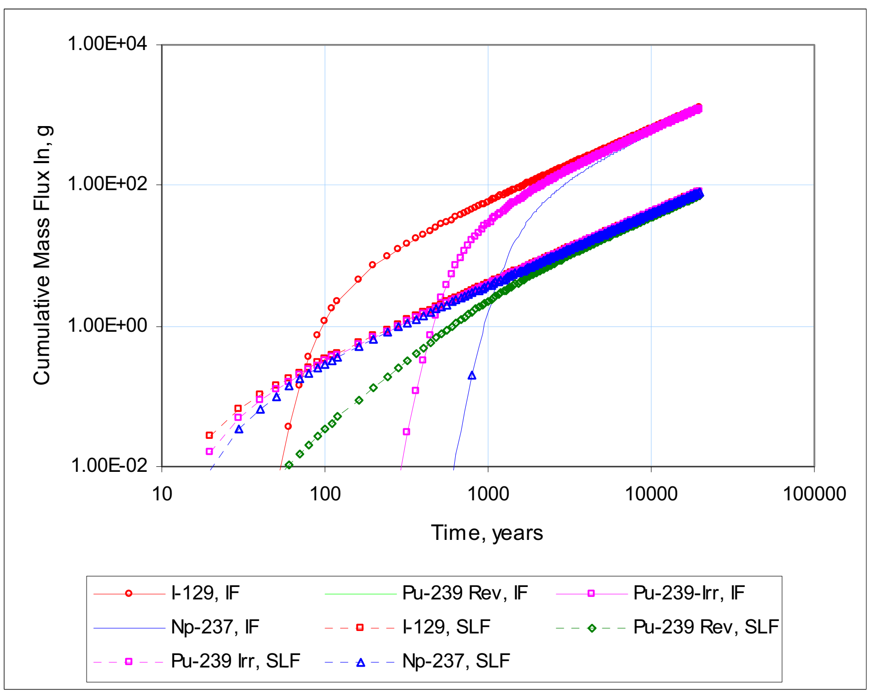


Source: Output DTN: SN0703PASZIRMA.001 (directory Results, file: *Modeling_Results.xls*).

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.

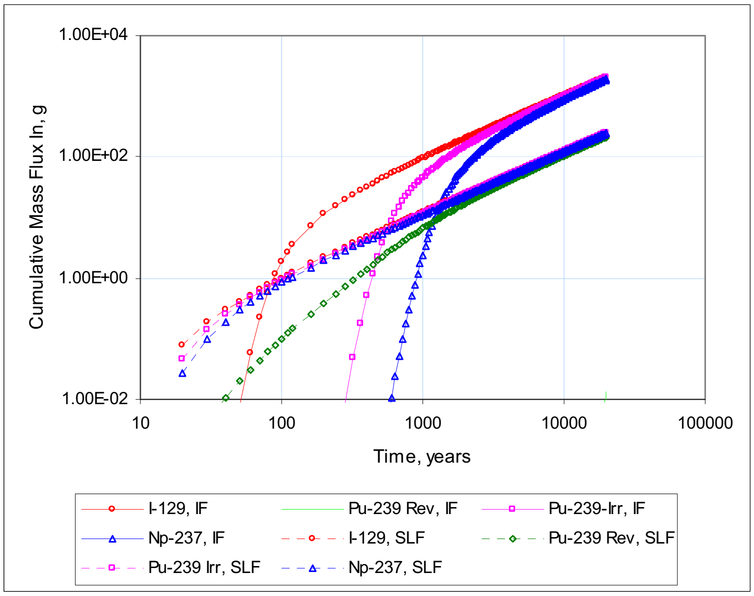
The effectiveness of the removal processes is shown in Figure 6.6-7 for ^{237}Np. The most effective removal mechanism is with the irrigation water that is not recaptured by the pumping well that accounts for 87% (minimum and median parameter values) to 88% (maximum parameter values) of the mass removed.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

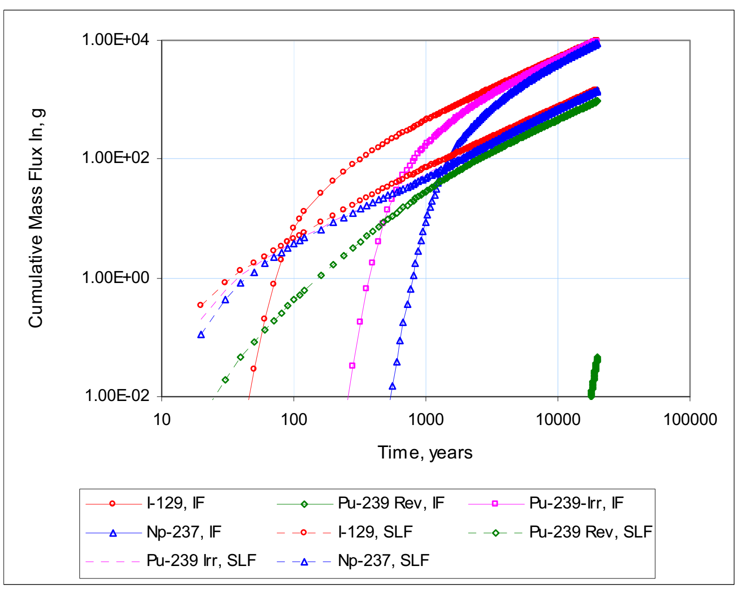
Figure 6.6-4. Cumulative Radionuclide Mass Fluxes into the Representative Groundwater Volume Cell from the Irrigated Fields Path and Septic Leach Fields Path Corresponding to the Minimum Values of F_c, F_{ind}, and F_{res}



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.

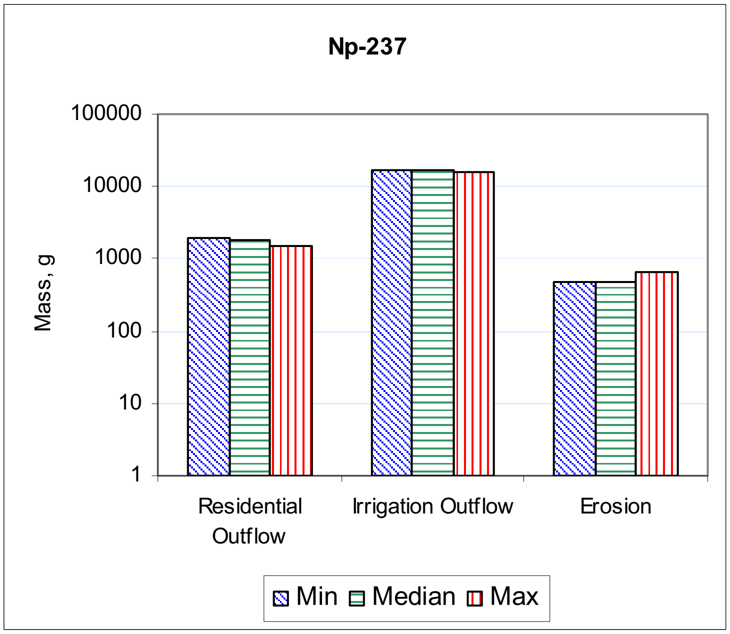
Figure 6.6-5. Cumulative Radionuclide Mass Fluxes into the Representative Groundwater Volume Cell from the Irrigated Fields Path and Septic Leach Fields Path Corresponding to the Median Values of F_c, F_{ind}, and F_{res}



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:

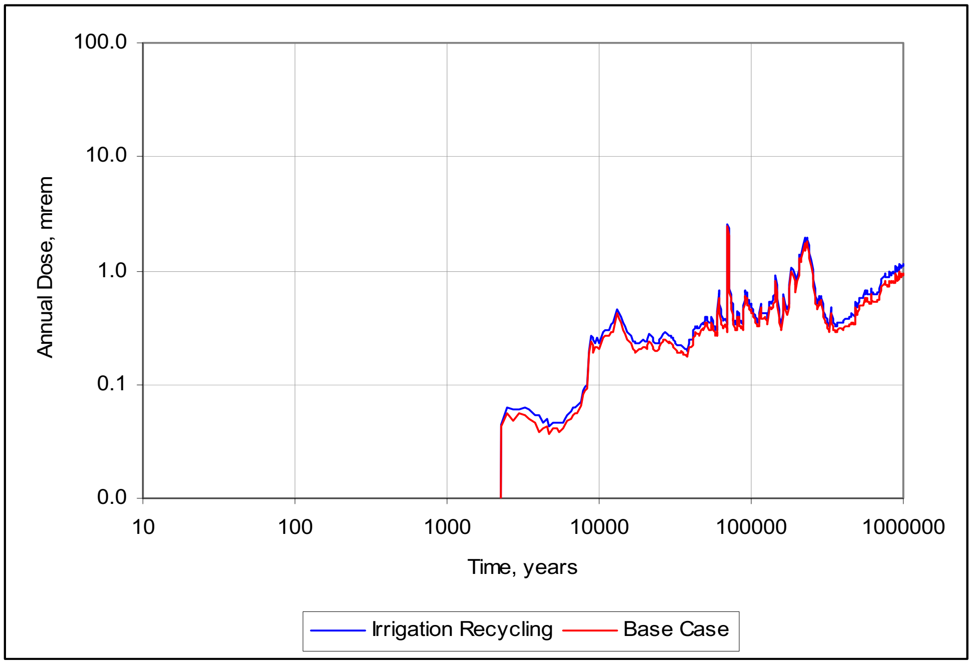
- v5.000_GS_9.60.100_SZ_Recycle_Prototype_Igneous_1Myr.gsm – Igneous scenario with irrigation recycling

- 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.

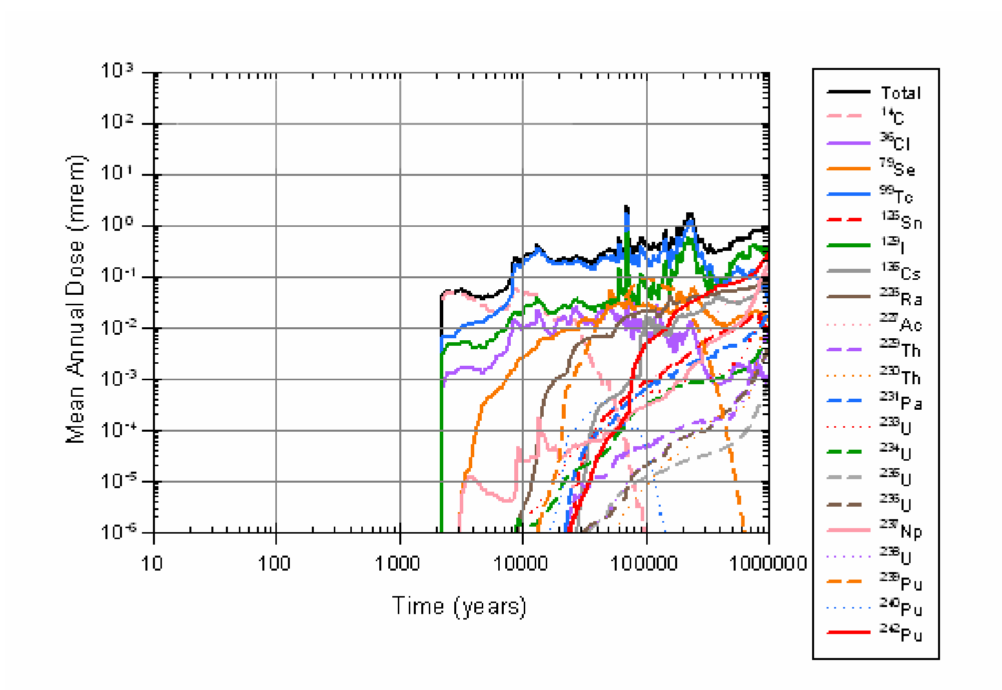
Seismic-Ground Motion (GM) Scenario

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

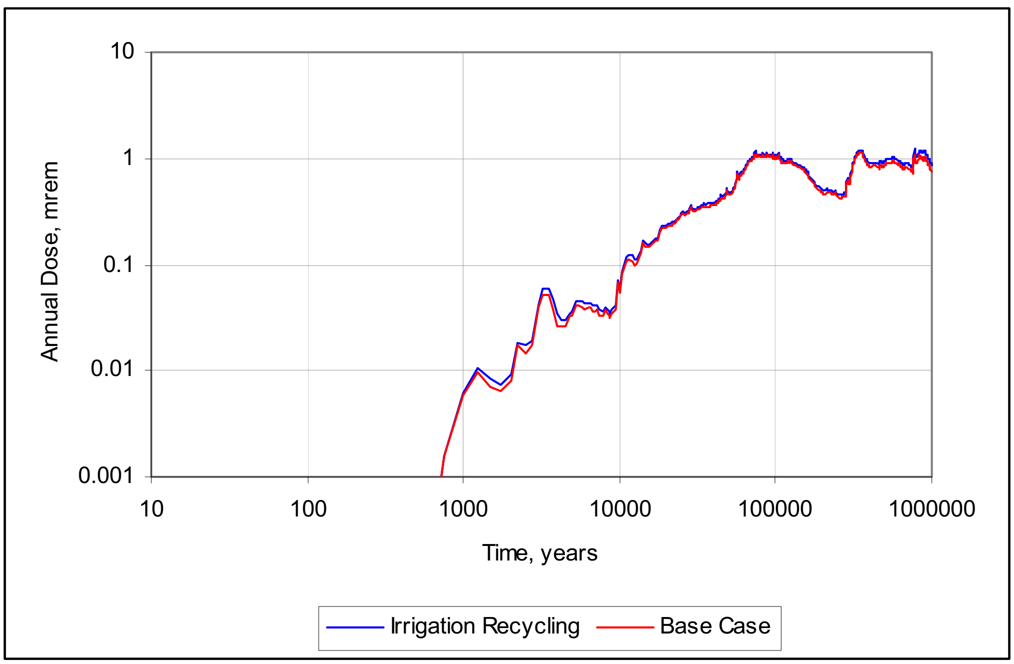


Source: Output DTN: SN0703PASZIRMA.001 (*Results**TSPA Runs*, file: *v5.000_SZ_Recycle_Seismic_1Myr_RN_Dose_WT.txt*).

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

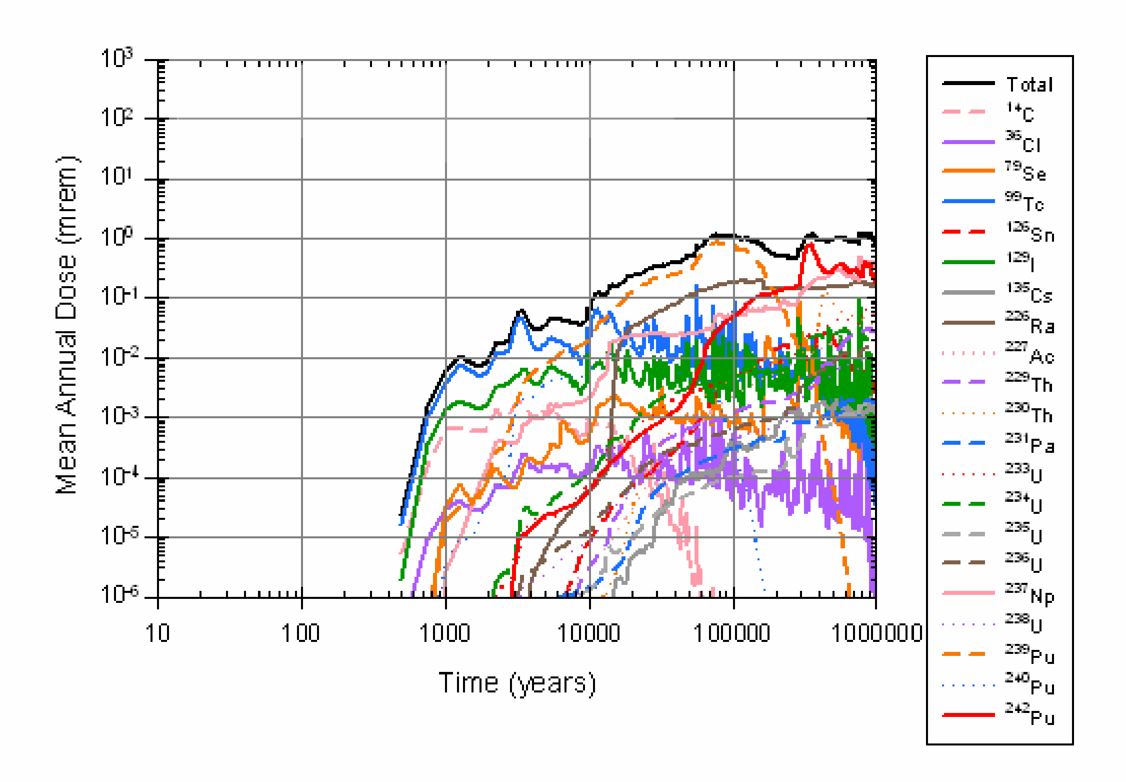
Igneous Scenario

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:

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

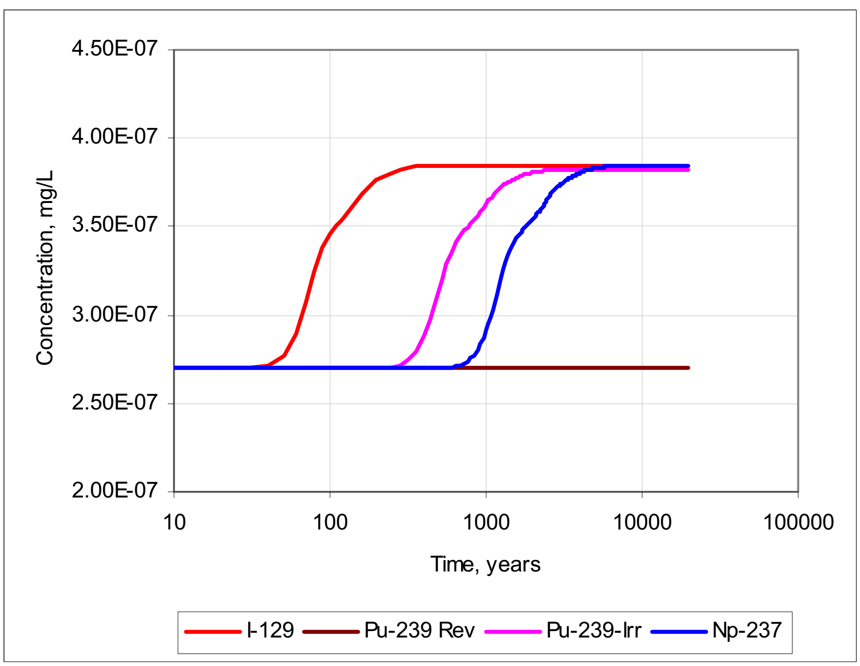
Equations 7.1-1 through 7.1-3 were used to calculate the equilibrium concentrations in both cases with and without irrigation recycling and the increase in concentration due to recycling. The following parameter values were used:

- $Q_T = 3{,}000$ 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

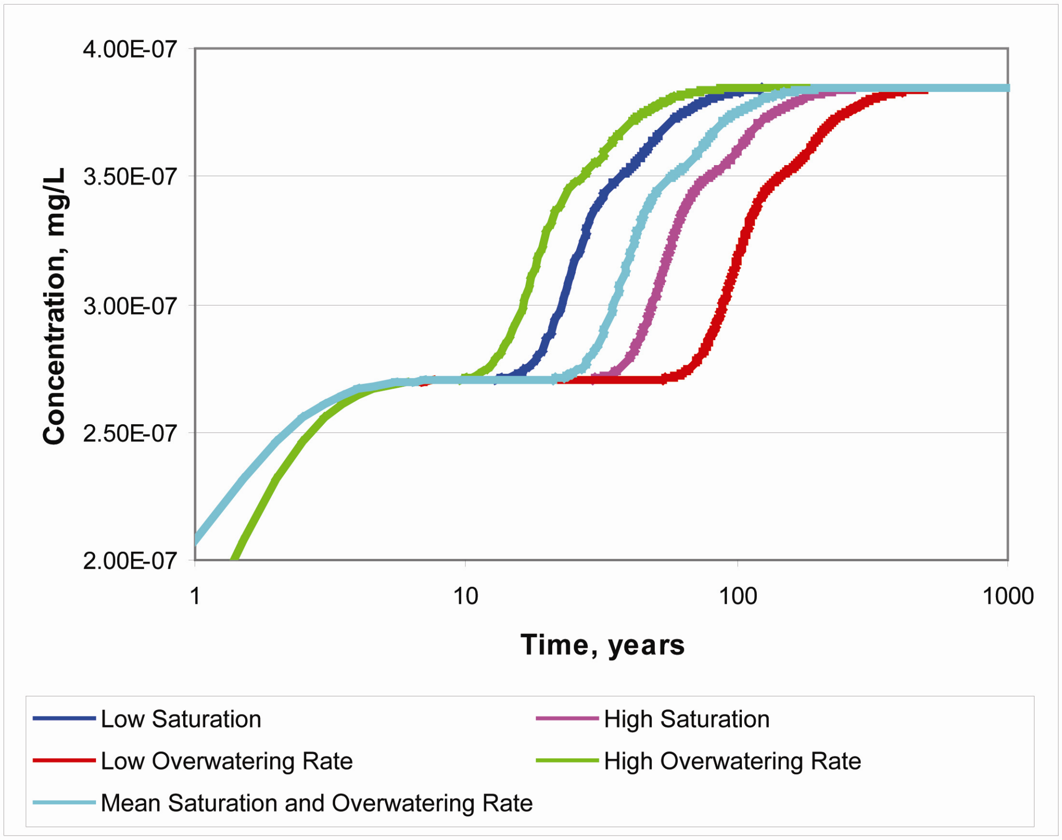
Source: Stonestrom et al. 2003 [DIRS 165862], Table 4.

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.

9. INPUTS AND REFERENCES

9.1 DOCUMENTS CITED

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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

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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.

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

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9.4 OUTPUT DATA, LISTED BY DATA TRACKING NUMBER

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

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9.5 SOFTWARE CODES

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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

QA: QA
Page 1 of 1

Complete only applicable items.

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

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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 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 for Stephanie Kuzio	Date 7/12/07

SCI-PRO-001.1-R1

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