APPENDIX V
RECHARGE SENSITIVITY ANALYSIS

In the *Draft Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington (Draft TC & WM EIS)*, this appendix provided analysis of impacts on the Base Case flow field associated with development of the Black Rock Reservoir west of the Hanford Site. In summary, the analysis involved the development of a variant Base Case flow field with increased recharge along the western boundary of the model domain. The variant flow field was examined to evaluate the potential impacts on general Base Case flow field characteristics and associated *TC & WM EIS* alternatives. In 2008, the U.S. Department of the Interior, Bureau of Reclamation, selected the No Action Alternative within the *Final Planning Report/Environmental Impact Statement, Yakima River Basin Water Storage Feasibility Study* (BOR 2008), in effect canceling the development of the proposed Black Rock Reservoir.

In this *Final TC & WM EIS*, Appendix V includes analysis of multiple boundary recharge variants of the regional-scale groundwater Base Case flow model (this sensitivity analysis is similar to the flow field variant used to evaluate Black Rock Reservoir impacts in the *Draft TC & WM EIS*). This analysis could be used to evaluate potential climate change scenarios resulting from increased precipitation, increased creek and/or mountain-front runoff, or increased Columbia River surface-water elevations. This analysis also includes a general discussion of recharge effects on regional groundwater elevation, Central Plateau groundwater transport patterns, regional groundwater discharge distribution, and maximum technetium-99 concentrations over time within the context of Tank Closure Alternative 2B and Waste Management Alternative 2, Disposal Group 1, Subgroup 1-A.

V.1 BACKGROUND

In the *Draft Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington (Draft TC & WM EIS)*, this appendix provided analysis of impacts on the Base Case flow field related to installation of the Black Rock Reservoir (BRR) west of the Hanford Site (Hanford), as proposed by the U.S. Bureau of Reclamation (BOR). The *Draft TC & WM EIS* analysis in Appendix V included the development of a variant Base Case flow field with increased recharge along the western boundary of the model domain. The variant flow field was examined and compared with the Base Case flow field to determine any impacts on the *TC & WM EIS* alternatives. In 2008, BOR's proposed BRR installation was canceled because BOR selected the "No Action Alternative" within the associated *Yakima River Basin Water Storage Feasibility Study* (BOR 2008). Accordingly, BRR analysis in this *Final TC & WM EIS* is unnecessary.

Although, at this point, the specific BRR scenario and subsequent BRR variant flow field modeling are no longer pertinent or useful, similar variant flow field analysis is useful in assessing the impacts associated with potential climate change scenarios.

Development of the *TC & WM EIS* Base Case flow model used to analyze the long-term groundwater impacts of environmental impact statement (EIS) alternatives and cumulative impacts is described in Appendix L. All flow models, including the *TC & WM EIS* Base Case, are affected by a defined set of model boundary conditions (parameters) that influence flow and transport inside the model domain. Changes in boundary condition recharge parameters (flux into the model from various sources) in the Base Case flow field have the potential to impact groundwater elevations, velocities, and flow patterns beneath Hanford. As such, changes in boundary recharge parameters could affect comparison of the long-term impacts of various alternatives examined in this *TC & WM EIS*. Examining these potential effects is the subject of this appendix.

V.2 RECHARGE SENSITIVITY ANALYSIS PURPOSE AND SCOPE

V.2.1 Purpose of Analysis

The overall goal of this analysis is to illustrate the impacts of regional and focused recharge changes (potential climate change scenarios limited to boundary recharge sensitivity) on the *TC & WM EIS* Base Case regional flow field model, as well as to evaluate the potential differences among selected *TC & WM EIS* alternatives with respect to long-term groundwater impacts.

Specifically, this sensitivity analysis involved the use of three recharge sensitivity–variant models of the *TC & WM EIS* Base Case to evaluate (1) impacts on general flow field characteristics, such as the change in water table elevation; (2) Central Plateau particle flow direction; (3) regional volumetric discharge of water along selected pathways to the Columbia River; and (4) potential changes in long-term groundwater technetium–99 concentrations resulting from the models' recharge sensitivity–variant flow fields in the context of selected Tank Closure and Waste Management alternatives evaluated in Chapter 5 of this *TC & WM EIS* (specifically, Tank Closure Alternative 2B and Waste Management Alternative 2, Disposal Group 1, Subgroup 1-A).

Unlike most other analyses in this EIS, the analyses presented in this appendix do not include evaluation of impacts on human health.

V.2.2 Scope of Modeling Effort

The scope of the recharge sensitivity modeling effort included the following:

- Development of three recharge sensitivity–variant transport models of the *TC & WM EIS* Base Case that support potential scenarios associated with long-term regional climate change
- Insertion of boundary recharge fluxes into the *TC & WM EIS* Base Case MODFLOW [modular three-dimensional finite-difference groundwater flow model] to simulate changes in the water table elevation, particle flow direction, and volumetric discharge rates of selected routes (water budget zones) to the Columba River
- Comparison of the overall characteristics of each recharge model's flow field with the *TC & WM EIS* Base Case model flow field
- Comparison of the three variant models with the Base Case flow field for specific *TC & WM EIS* alternatives with respect to long-term maximum technetium–99 concentrations at the Core Zone Boundary, Columbia River nearshore, and selected disposal facility barriers
- Evaluation of the results of each recharge sensitivity variant to determine the potential differential impacts on selected *TC & WM EIS* alternatives

V.3 RECHARGE SENSITIVITY–VARIANT MODEL DEVELOPMENT AND IMPACT ASSESSMENT METHODOLOGY

V.3.1 Relationship to the *TC & WM EIS* Modeling Framework

The *TC & WM EIS* Base Case groundwater flow model was developed for input to the *TC & WM EIS* groundwater transport model, which was used to simulate the fate and transport of contaminants for the purpose of analyzing the EIS alternatives and cumulative impacts. The Base Case groundwater flow model development and the associated flow field extraction methods are discussed in Appendix L. The *TC & WM EIS* Base Case groundwater transport model development and application are discussed in Appendix O.

The Base Case groundwater flow and transport models are calibrated to historical field observations of groundwater hydraulic heads and contaminant concentrations. Calibration to historical field observations provides a level of confidence that the Base Case model can reasonably predict future hydraulic heads and contaminant concentrations. The calibrated results produced in the Base Case groundwater modeling simulations are used as inputs to the long-term impacts analysis in this *TC & WM EIS*.

Three recharge flow and transport models are presented in this appendix. Each of the models is a variant of the Base Case groundwater flow model presented in Appendix L. Table V–1 describes each recharge model variant, the parameter changes made, and the purpose (potential climate change scenario) of the variant.

Table V–1. Description of Each *TC & WM EIS* Base Case Flow and Transport Recharge Sensitivity Model Variant

Recharge Sensitivity Variant	*TC & WM EIS* Base Case Recharge Parameter Changed and Purpose of Change
Background recharge model variant (increased yearly regional precipitation)	This variant changed the background recharge value from 3.5 millimeters per year to 35 millimeters per year, beginning at calendar year 2100, to evaluate the flow field changes that may occur if precipitation is higher in the future than assumed in the Base Case model simulations presented in this *TC & WM EIS*.
Generalized Head Boundary recharge model variant (increased western boundary creek and watershed slope runoff discharge)	This variant increased the Base Case flow model Generalized Head Boundary (GHB) head values by 10 meters (32.8 feet) for all GHB cells in the model, beginning at calendar year 2100, to evaluate the flow field changes that may occur if water influx into the model along the western highlands is higher in the future than assumed in the Base Case flow model used in this *TC & WM EIS*. This includes increasing the discharge from various points along the western boundary border–Cold Creek, Dry Creek, and Rattlesnake Mountain slope eastern runoff. Increased water influx at these various locations could come from increased precipitation runoff, increased agricultural irrigation, or other unknown sources of water affected by climate change.
Columbia River recharge model variant (increased Columbia River surface water elevation)	This variant increased the Base Case flow model Columbia River surface-water head values by 5 meters (16.4 feet) for all Columbia River cells in the model, beginning at calendar year 2100, to evaluate the flow field changes that may occur if the Columbia River surface-water elevations are higher in the future than assumed in the Base Case flow model. Increased Columbia River surface-water head values could come from changes in precipitation or runoff patterns near the Columbia River headwaters in various British Columbia watersheds or other unknown sources of water affected by climate change.

Key: *TC & WM EIS=Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington*.

Sections V.3.2 and V.3.3 describe the methodology and application of the three recharge sensitivity variant flow field models listed in Table V–1.

V.3.2 Methodology for Evaluating Changes in the Flow Field and Transport Patterns

The recharge variant flow fields summarized in Table V–1 add recharge (flux) to various locations across the model domain. In general, the background recharge model variant covers the entire model (increased yearly regional precipitation flux). The Generalized Head Boundary (GHB) recharge model variant affects most of the western model boundary (increased creek and watershed slope runoff flux). The Columbia River recharge model variant affects the entire northern and eastern model boundaries (increased riverhead elevation). In all model variants, the boundary condition changes were added into the model at 100 percent starting at calendar year (CY) 2100 (no stepped-in flux over the first few years of the boundary condition change).

To evaluate and characterize the variant flow fields listed in Table V–1, the following investigative methods were used:

1. **Steady state flow field head distribution analysis generated by MODFLOW.** The three recharge variant flow field head distributions were compared with the head distributions in the *TC & WM EIS* Base Case flow field. Using Groundwater Vistas (ESI 2004), standard color ramp scales were developed to compare model hydraulic head values. For each variant, model cell head information was provided from model layer 19 at CY 2200 (long-term steady state) for all models. The results of this analysis are presented in Section V.4.1.

2. **Hanford Central Plateau directional flow field tracers (particle path line) analysis.** Central Plateau–originating directional particle flow path lines (generated by MODPATH [MODFLOW particle-tracking postprocessing package]) from the long-term steady state flow field for each of the recharge variant flow field models were compared with those from the long-term steady state flow path lines of the Base Case flow model. By means of MODDATA, a uniformly distributed set of particles was released across the Central Plateau area. The results of this analysis are presented in Section V.4.2.

3. **Zone Budget Hydrograph Analysis.** A zone budget analysis was completed for each of the recharge flow model variants. To complete the analysis, identical zones (or gates) were defined in each recharge variant to measure the water flow (volumetric discharge) from the western region of the model (where all GHB water sources originate) to (1) the northwest through Umtanum Gap, (2) the north through Gable Gap, and (3) the south and east toward the Columbia River. A comparison of the water flow through these three gates for each of the three recharge flow model variants is presented in Section V.4.3.

V.3.3 Methodology for Evaluating Changes to Peak Concentrations Over Time at the Core Zone, Columbia River, and Disposal Facility Barriers

Groundwater flow and transport analysis was performed using each of the recharge variant flow fields described in Table V–1 and the *TC & WM EIS* Base Case flow field for the purpose of evaluating maximum concentration over time at the Core Zone, Columbia River, and applicable disposal facility barriers. Particle-tracking computer code was used to simulate the migration of technetium-99 through each flow field (aquifer). A comprehensive discussion of the Base Case flow field development and extraction for use is included in Appendix L. Detailed groundwater transport information can be found in Appendix O.

Contaminant transport analysis was performed to compare the concentrations of technetium-99 and long-term impacts thereof at the Core Zone Boundary, Columbia River nearshore, and selected disposal facility barriers within the Base Case model and the three recharge model variant flow fields listed in Table V–1. This included particle-tracking transport runs from CY 2200 to CY 11,940. This comparison was performed within the contexts of Tank Closure Alternative 2B (expanded Waste Treatment Plant vitrification, landfill closure) and Waste Management Alternative 2, Disposal Group 1, Subgroup 1-A (disposal of waste associated with Tank Closure Alternative 2B in the proposed 200-East Area Integrated Disposal Facility [IDF-East] and the River Protection Project Disposal Facility [RPPDF]). Further details regarding each EIS alternative evaluated in this recharge sensitivity analysis can be found in Chapters 2 and 5 of this *TC & WM EIS*.

The maximum concentrations of technetium-99 at the Core Zone Boundary, Columbia River nearshore, and selected waste disposal facility barriers for the *TC & WM EIS* Base Case model and three recharge variant flow fields are further discussed in Section V.4.4.

V.4 MODEL RESULTS

This section describes the results of the analyses described in Sections V.3.2 and V.3.3. In all analyses, the three recharge variant flow field models summarized in Table V–1 were compared with and differentiated from the *TC & WM EIS* Base Case flow model.

V.4.1 Changes to Steady State Groundwater Head Distribution

Hydraulic head differences in flow model long-term steady state groundwater head values are illustrated in Figure V–1 (hydraulic head difference between the Base Case flow model and the background recharge model variant); Figure V–2 (hydraulic head difference between the Base Case flow model and GHB recharge model variant); and Figure V–3 (hydraulic head difference between the Base Case flow model and Columbia River recharge model variant).

The distribution of head values in the *TC & WM EIS* Base Case is higher in the west, with elevations ranging between 125 and 160 meters (410 and 525 feet) above mean sea level (amsl). In general, the higher hydraulic head in the west progressively slopes north, east, and south to the Columbia River. The highly conductive geology in the central region of the site from Gable Gap through the eastern part of the 200-East Area, then south and east for several kilometers, results in an essentially flat water table in the center of the model. Hydraulic heads in the central regions of the model range between 120 and 122 meters (394 and 400 feet) amsl. Moderately conductive geology is typical of the northern, eastern, and southern portions of the site, and results in a gently sloping water table as groundwater moves to the Columbia River. Hydraulic heads in these regions range between 104 and 122 meters (341 and 400 feet) amsl. Hydraulic heads in areas near the Columbia River are heavily influenced by the river stage, which is simulated as a constant head boundary that ranges between 122 meters (400 feet) amsl in the northwest to 104 meters (341 feet) amsl in the southeast.

Background Recharge Model Variant Compared with *TC & WM EIS* Base Case Model

Hydraulic head distribution across the background recharge model variant is similar to that of the Base Case. Increased head elevations (up to a maximum of plus 3 meters [9.84 feet]) are noted in the background recharge variant in the western region of the Central Plateau between Cold and Dry Creeks and in the southern region of the model near the 300 Area. The majority of the head differences across the model are between plus 0.5 meters (1.64 feet) and plus 2 meters (6.56 feet), both of which are below the calibrated Base Case flow model root mean square (RMS) error value of 2.28 meters (7.48 feet) (see Appendix L for Base Case flow model calibration specifics). Similar to the Base Case flow field, the background recharge model variant flow field head values indicate a progressive slope (somewhat flat distribution in the center of the model) from west to east to the Columbia River boundary.

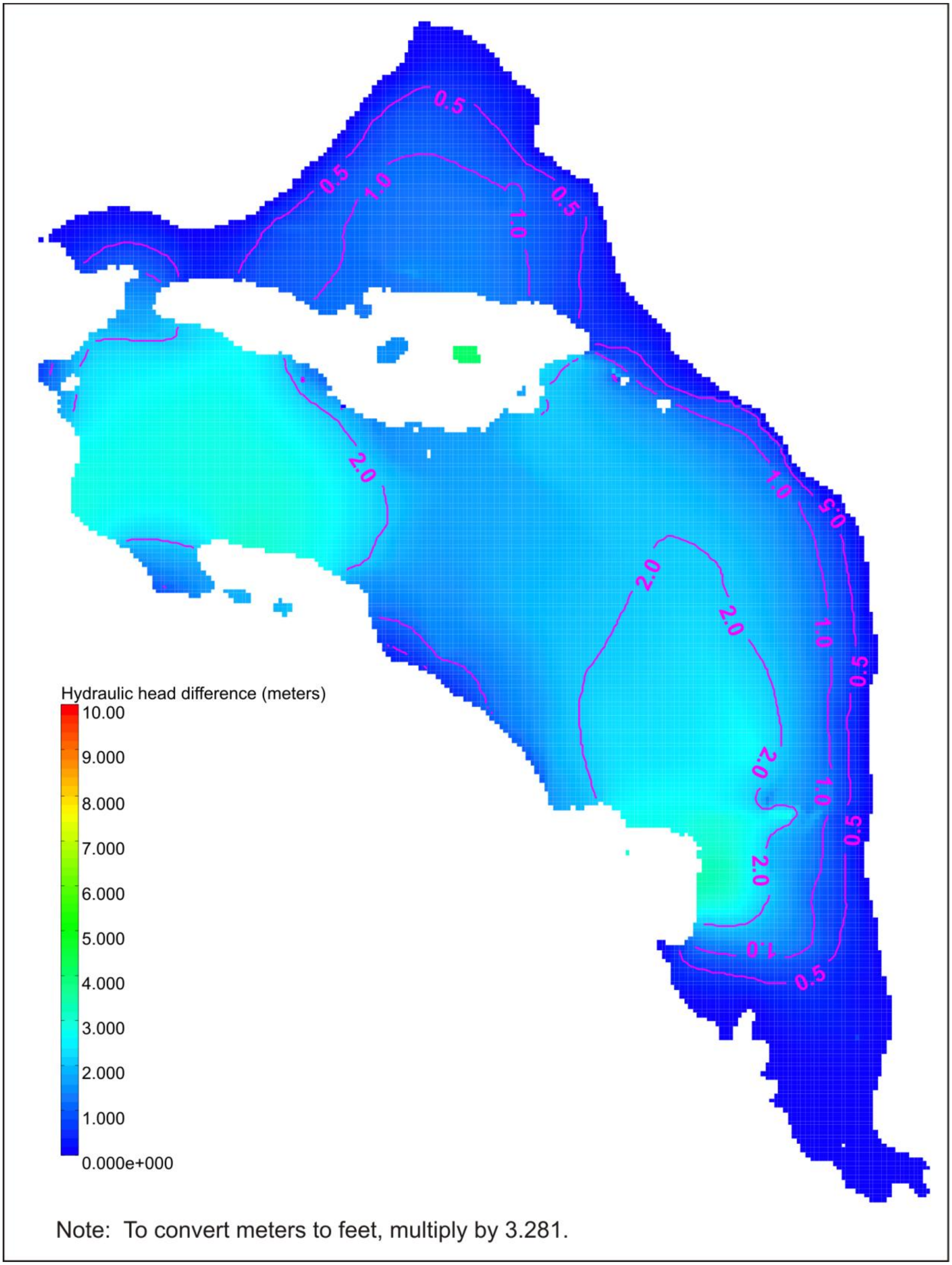


Figure V–1. Hydraulic Head Difference Between Base Case Flow Model and the Background Recharge Model Variant (from Model Layer 19, 105 to 110 meters above mean sea level)

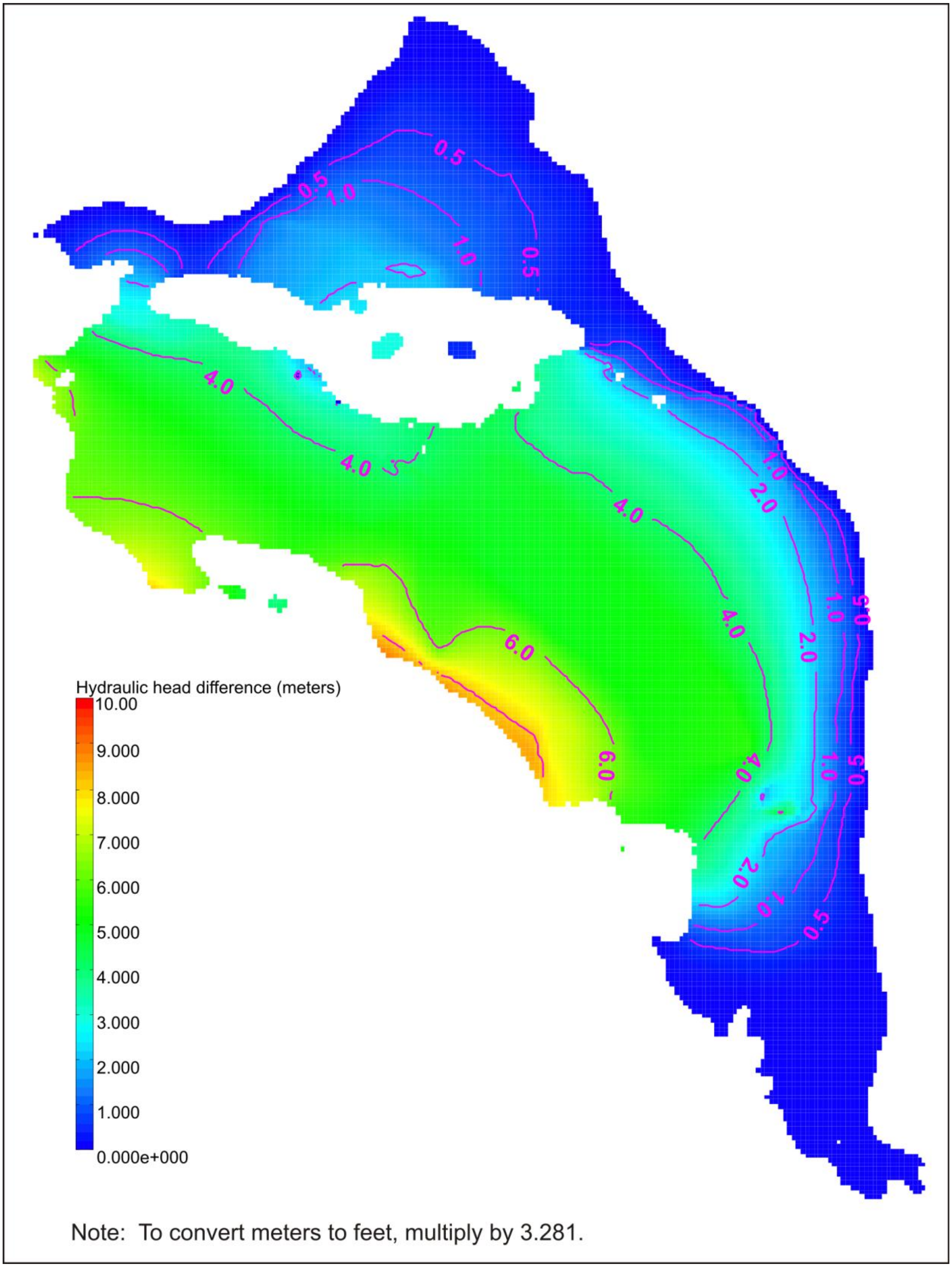


Figure V–2. Hydraulic Head Difference Between Base Case Flow Model and the Generalized Head Boundary Recharge Model Variant (from Model Layer 19, 105 to 110 meters above mean sea level)

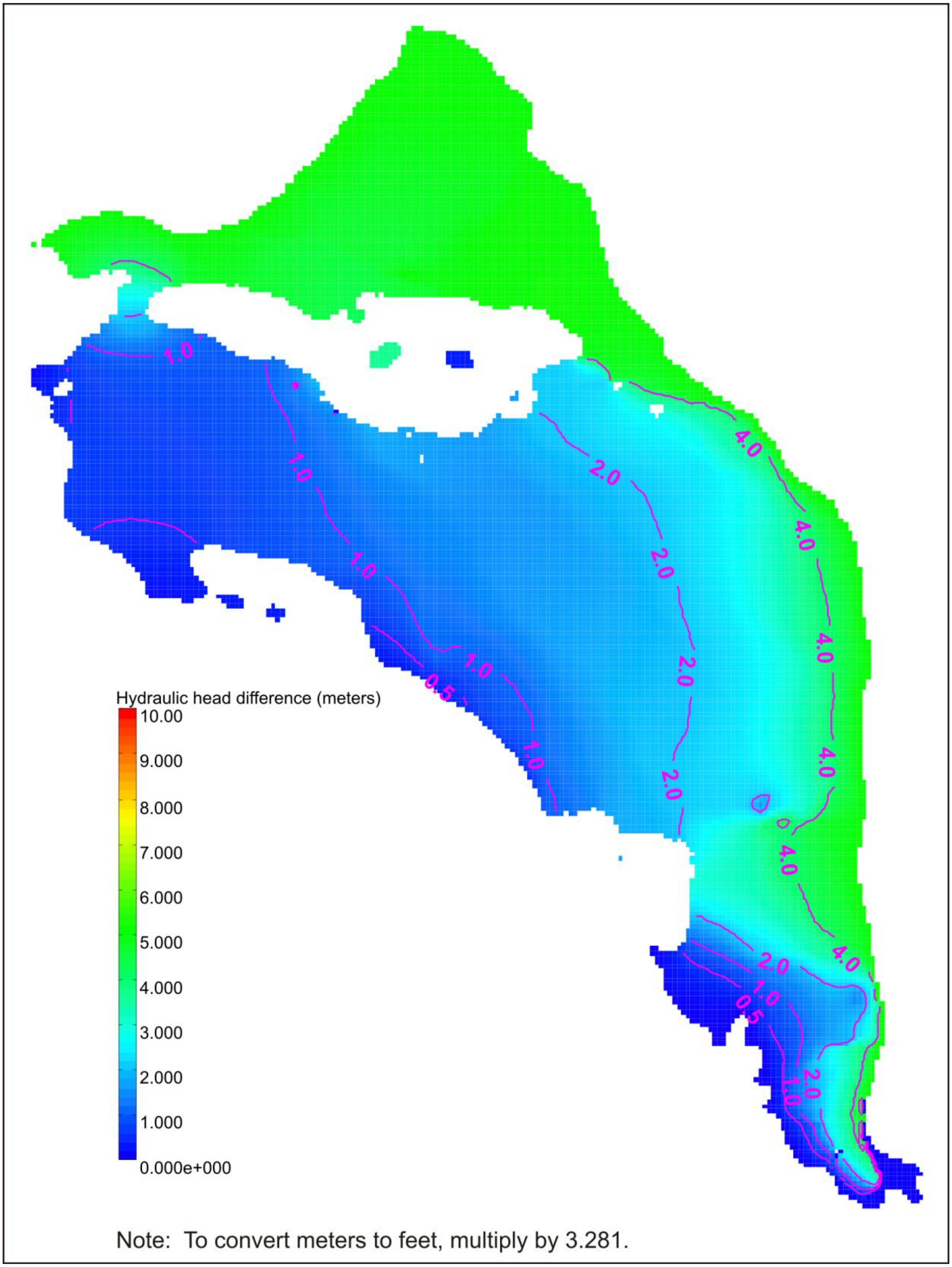


Figure V–3. Hydraulic Head Difference Between Base Case Flow Model and the Columbia River Recharge Model Variant (from Model Layer 19, 105 to 110 meters above mean sea level)

GHB Recharge Model Variant Compared with the *TC & WM EIS* Base Case Model

Most hydraulic head elevations across the GHB recharge model variant are higher than the Base Case head elevations. The head differences are especially higher along the western boundary of the GHB recharge model variant (where the GHB boundary condition cells are encoded into the model), where mounding of groundwater is observed (a difference of approximately plus 8.5 meters [27.88 feet]) in the Ringold geologic formations east of the Rattlesnake Mountain watershed slope. Both models indicate a progressive slope of head elevations, from higher in the west to lower in the east across the model, with only minor head elevation differences (between plus 0.5 meters [1.64 feet] and plus 1.0 meter [3.28 feet]) along the Columbia River boundary and southern 300 Area. The GHB recharge model variant exhibits a steeper west-to-east slope than the more moderate slope in the western region of the Base Case model. Within the Core Zone Boundary, the GHB recharge model variant shows increased head elevations of approximately plus 4.0 to 5.0 meters (13.12 to 16.4 feet). Just north of the Core Zone, across Gable Gap and extending north to the Columbia River, the head elevation differences are approximately plus 1.0 meter (3.28 feet).

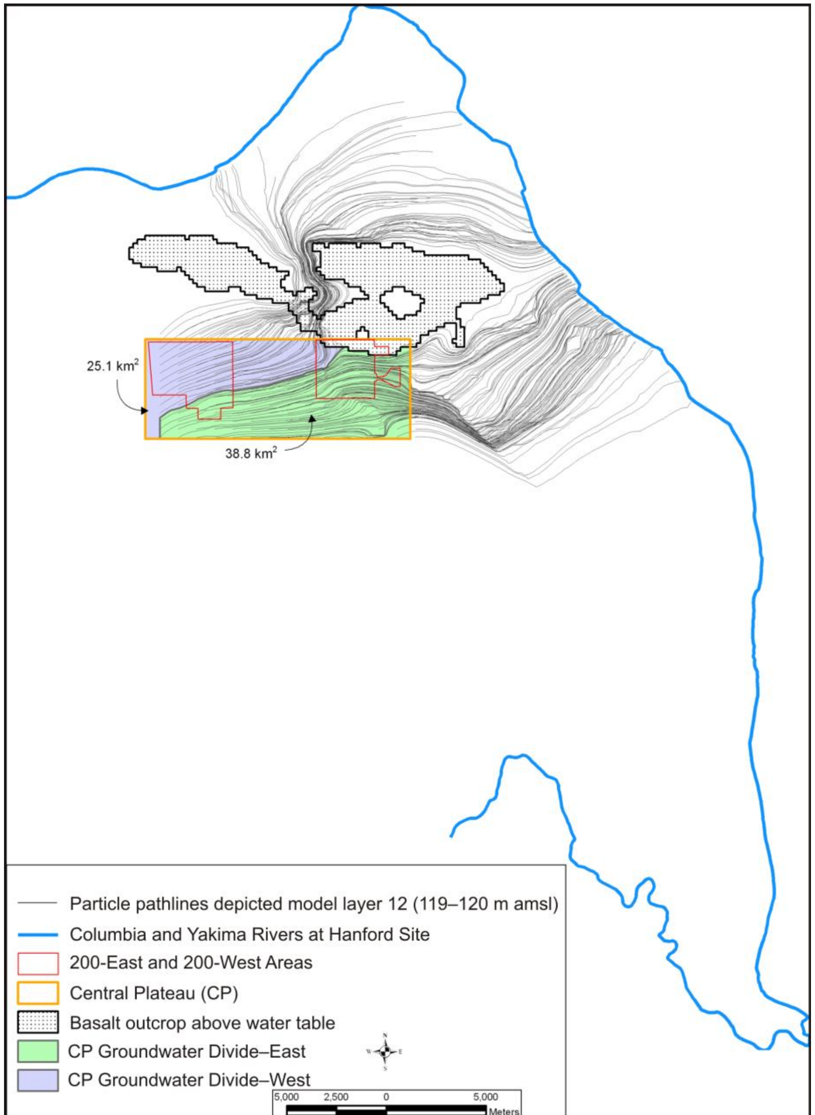
Columbia River Recharge Model Variant Compared with *TC & WM EIS* Base Case Model

Hydraulic head elevations across the Columbia River recharge model variant are, in general, higher than the head elevations associated with the Base Case. The differences in heads are below the calibrated Base Case RMS error value of 2.28 meters (7.48 feet) in the eastern, southern, and central regions (including the Core Zone) of the variant model. Along the Columbia River boundary and in the northern reaches of the model, north of Gable Gap, the differences in head elevation are around plus 4 meters (13.12 feet) and exhibit less slope west to east toward the river than the Base Case flow field. The west-to-east slope in this recharge model variant's eastern regions and the Central Plateau is about the same as that observed in the Base Case flow field, with hydraulic head differences of plus 0.5 to 2 meters (1.64 to 6.56 feet).

For comparison it is important to note that, on average, the Hanford operational period increased the groundwater head elevations beneath the Core Zone more than 20 meters (66 feet) in the 200-West Area and approximately 10 meters (33 feet) in the 200-East Area due to wastewater discharges at the ground surface (Freedman 2008) as well as some direct injections to groundwater. For this recharge model variant, the increases in hydraulic head in the Core Zone (compared with head values for the *TC & WM EIS* Base Case flow field) are less than the head elevation changes observed during the Hanford operational period.

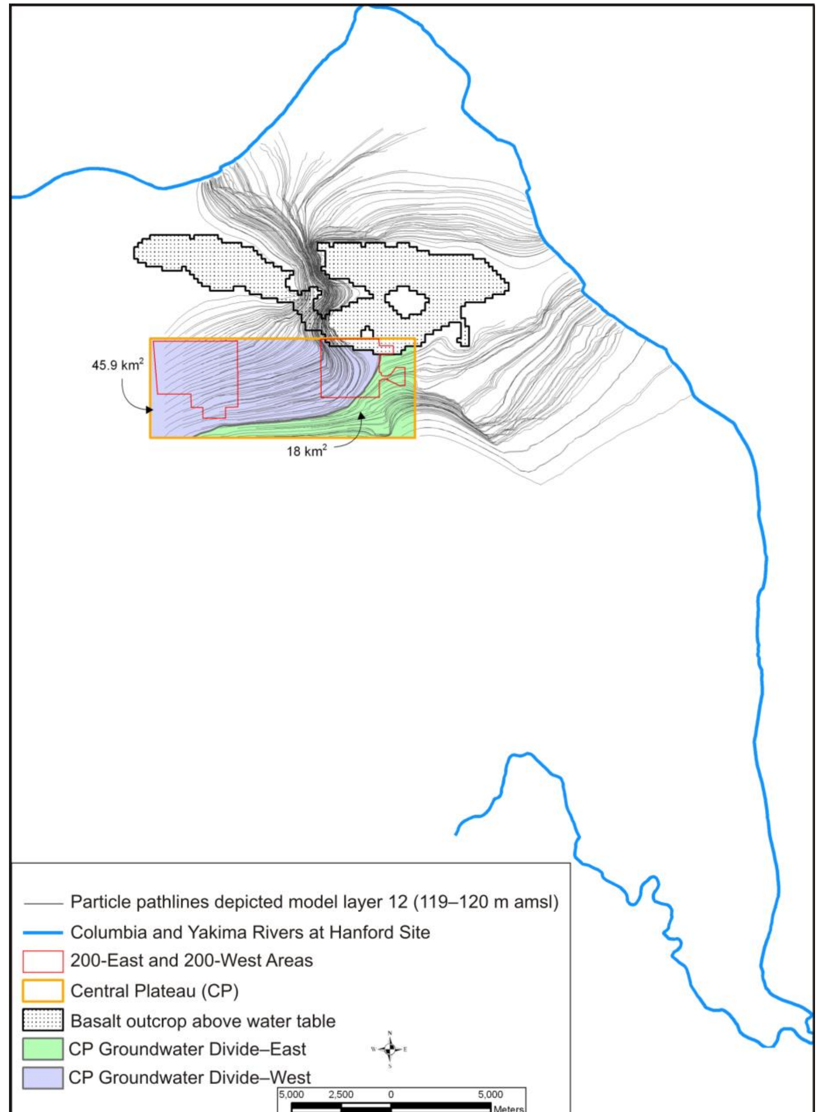
V.4.2 Changes to Central Plateau Transport Patterns (Particle Path Lines)

Results of the directional flow field tracers analysis (particle path lines) of particles released within the Hanford Central Plateau fixed regional box (64 square kilometers [24.7 square miles]) are illustrated in Figure V–4 (*TC & WM EIS* Base Case flow field), Figure V–5 (background recharge model variant flow field), Figure V–6 (GHB recharge model variant flow field), and Figure V–7 (Columbia River recharge model variant flow field). Further, a summary of analytical results associated with the bifurcating groundwater divide in the Central Plateau area, including particle paths through Gable Gap or east to the Columbia River, is presented in Table V–2.



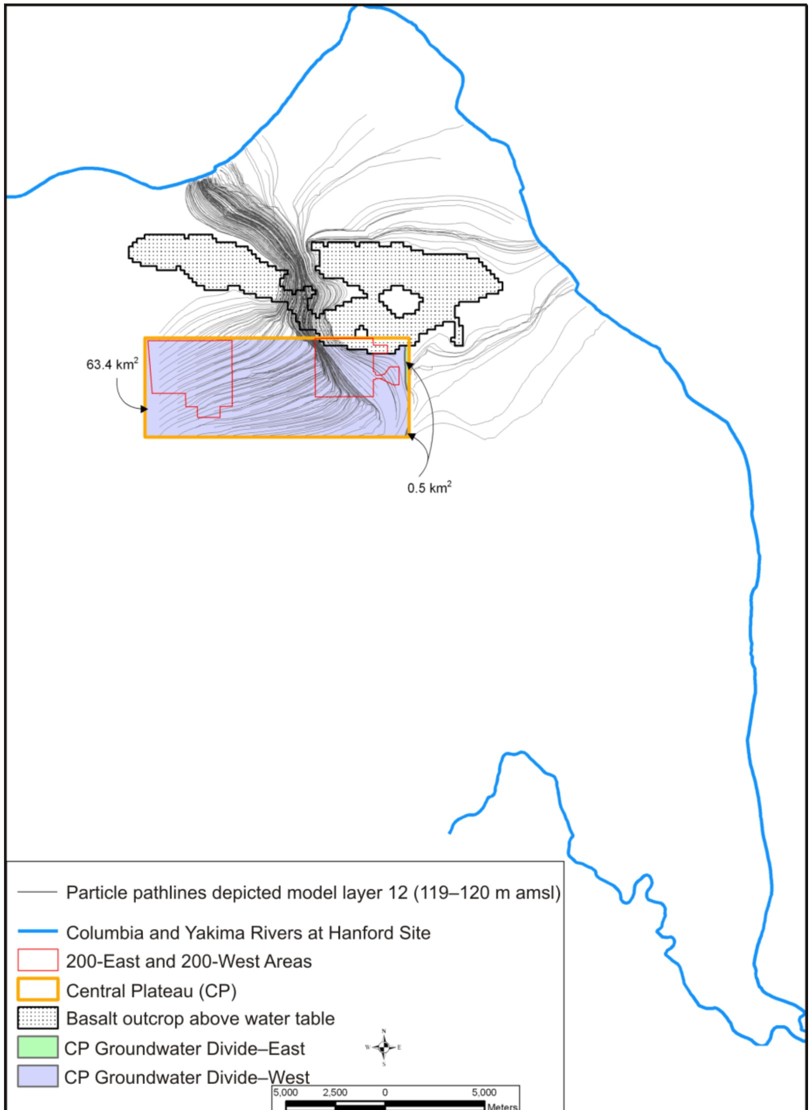
Note: To convert meters to feet, multiply by 3.281; square kilometers to square miles, by 0.3681.
Key: amsl=above mean sea level; km^2=square kilometers; m=meters.

Figure V–4. *TC & WM EIS* Base Case Flow Field, Central Plateau–Delineated Particle Path Lines



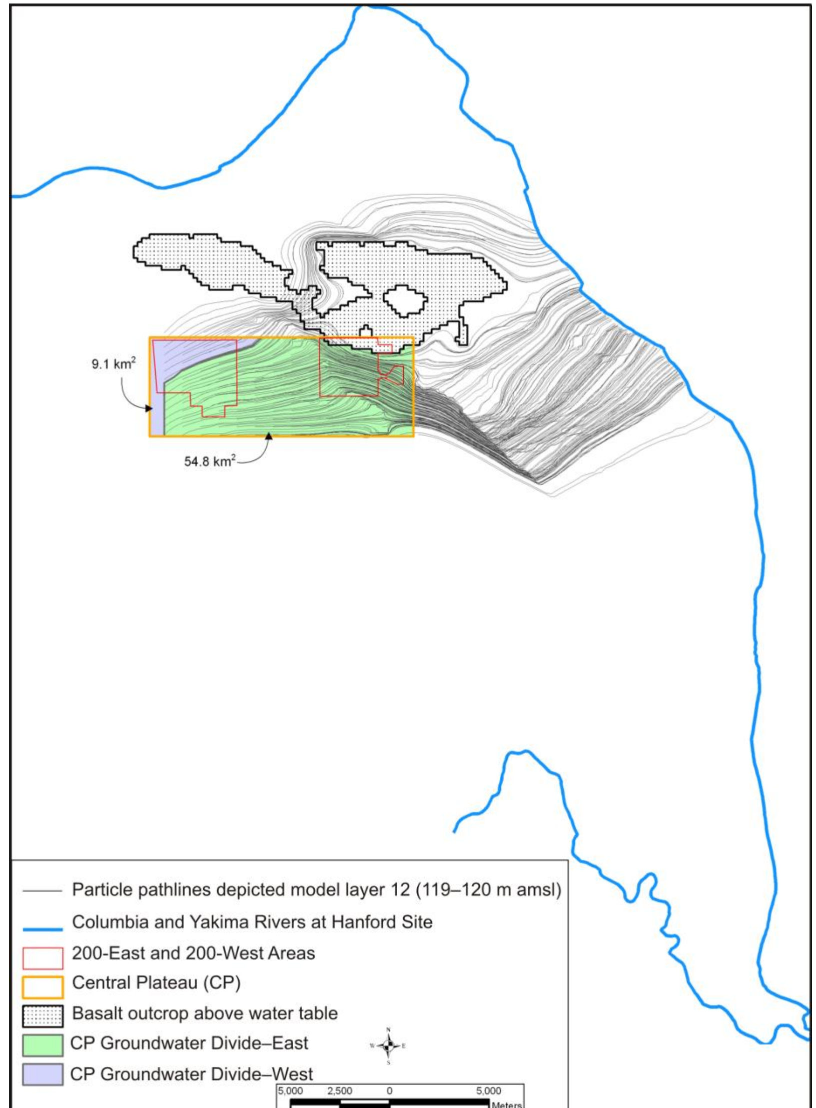
Note: To convert meters to feet, multiply by 3.281; square kilometers to square miles, by 0.3681.
Key: amsl=above mean sea level; km^2=square kilometers; m=meters.

Figure V–5. Background Recharge Model Variant Flow Field, Central Plateau–Delineated Particle Path Lines



Note: To convert meters to feet, multiply by 3.281; square kilometers to square miles, by 0.3681.
Key: amsl=above mean sea level; km²=square kilometers; m=meters.

Figure V–6. Generalized Head Boundary Recharge Model Variant Flow Field, Central Plateau–Delineated Particle Path Lines



Note: To convert meters to feet, multiply by 3.281; square kilometers to square miles, by 0.3681.
Key: amsl=above mean sea level; km²=square kilometers; m=meters.

Figure V–7. Columbia River Recharge Model Variant Flow Field, Central Plateau–Delineated Particle Path Lines

Table V–2. Central Plateau Particle Path Line Direction to the Columbia River

Flow Field Model	Central Plateau Area with Particles Directed North Through Gable Mountain–Gable Butte Gap to the Columbia River		Central Plateau Area with Particles Directed East to the Columbia River	
	Area (square kilometers)	Area (percent)	Area (square kilometers)	Area (percent)
TC & WM EIS Base Case flow field	25.1	39	38.8	61
Background recharge model variant (increased yearly regional precipitation)	45.9	72	18.0	28
Generalized Head Boundary recharge model variant (increased creek and watershed slope runoff discharge)	63.4	99	0.5	1
Columbia River recharge model variant (increased surface water elevation)	9.1	14	54.8	86

Note: To convert square kilometers to square miles, multiply by 0.3861.

Key: *TC & WM EIS=Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington*.

The Central Plateau is an area located just south of Gable Gap. The Hanford Core Zone, which includes the 200-East and 200-West Areas, is that part of the Central Plateau identified by the polygons in Figures V–4 through Figure V–7.

There are differences in the bifurcating groundwater divide between each of the three recharge model variant flow fields and the *TC & WM EIS* Base Case flow field. As such, there are differences in the amount of area within the Central Plateau where released particles either flow north through Gable Gap or east toward the Columbia River.

In the *TC & WM EIS* Base Case flow field, the majority of uniformly distributed particles released in the Central Plateau area travel east toward the Columbia River (see Figure V–4). In general, particles released in the 200-East Area and the southern reaches of the 200-West Area are directed east. Approximately 61 percent (39 square kilometers [15 square miles]) of the particles released from the Central Plateau area move to the east. For the remaining 39 percent (25 square kilometers [9.65 square miles]) of the Central Plateau, which includes most of the 200-West Area, particles flow north through Gable Gap. Once through Gable Gap, the majority move east toward the Columbia River, with a small quantity continuing in a northern direction toward the Columbia River.

In contrast to the *TC & WM EIS* Base Case flow field, the background recharge model variant flow field shows more of the uniformly distributed particles in the Central Plateau area directed north through Gable Gap (see Figure V–5). In the background recharge variant, the bifurcating groundwater divide shifts several miles east and south moving into the far eastern region of 200-East Area. Approximately 28 percent (18 square kilometers [5.9 square miles]) of the particles released from the Central Plateau move east toward the Columbia River, and approximately 72 percent (46 square kilometers [17.7 square miles], including all of the 200-West and most of the 200-East Areas) move north through Gable Gap. Once through Gable Gap, most of the particles in the background recharge variant flow field continue north toward the Columbia River rather than taking the longer track of turning east toward the Columbia River.

In contrast to the *TC & WM EIS* Base Case flow field, the GHB recharge model variant flow field shows just about all particles in the Central Plateau directed north through Gable Gap (see Figure V–6). The bifurcating groundwater divide seen in the Base Case flow field is hardly observable inside the Central Plateau of the GHB recharge variant. Less than 1 percent (0.5 square kilometers [0.164 square miles]) of the particles released from the Central Plateau move east toward the Columbia River, and approximately 99 percent (63 square kilometers [20.6 square miles]) of particles released in the Central Plateau move north through Gable Gap. Once through Gable Gap, virtually all of the particles in the GHB recharge variant flow field continue north toward the Columbia River (the shortest route to the river from the Central Plateau) rather than turning east toward the Columbia River.

In contrast to all other recharge model variant flow fields and the *TC & WM EIS* Base Case flow field, the Columbia River recharge model variant shows the majority of particles originating from the Central Plateau heading directly east toward the Columbia River (see Figure V–7). In comparison with the *TC & WM EIS* Base Case, the Columbia River recharge model variant's bifurcating groundwater divide moves to the northwest corner of the Central Plateau, splitting the 200-West Area. Most of the particles released in the Central Plateau in the Columbia River recharge model variant flow east toward the river; their path lines cover approximately 86 percent (55 square kilometers [18 square miles]) of the Central Plateau area. The remaining area, 14 percent (9 square kilometers [2.9 square miles]) of the Central Plateau (exclusive to the northwest corner and northern boundary of the 200-West Area), has particle path lines moving north through Gable Gap. Once through Gable Gap, the few particles that are headed north in the Columbia River variant actually turn east toward the river rather than continuing on the shorter track to the north.

In summary, depending on the type and location of recharge parameter variation, recharge can have a significant effect on the bifurcating groundwater divide position in the Central Plateau. Regarding this specific form of analysis—particle path transport patterns—it is clear that the *TC & WM EIS* Base Case model is sensitive to boundary recharge parameters. Unlike the *TC & WM EIS* Base Case, except for the Columbia River recharge model variant, all recharge model variant flow fields exhibit a shift in the groundwater divide to the east, resulting in a greater number of particles reaching the Columbia River in a shorter distance (directly north through Gable Gap). These additional redirected portions in the 200-East Area include the B, BX, and BY tank farms (and associated cribs and trenches [ditches]), as well as the proposed location of the RPPDF in the northern part of the Central Plateau between the 200-East and 200-West Areas.

V.4.3 Changes in Groundwater Discharge Rates in Selected Model Zones (Water Budget Hydrograph Analysis)

To complete the hydrographic analysis, each recharge model variant was measured for one model year (model year 261, CY 2200) at identical water budget zones (or gates) to determine volumetric groundwater flow through each gate. Water budget zones were positioned to capture groundwater flow originating with areal recharge fluxes from above, as well as GHB fluxes along the western domain boundary (where all GHB sources originate). These gate locations included (1) northwest through Umtanum Gap, (2) north through Gable Gap, and (3) south and east toward the Columbia River. An illustration of the location of each of the three groundwater flow measurement zones or gates is shown in Figure V–8.

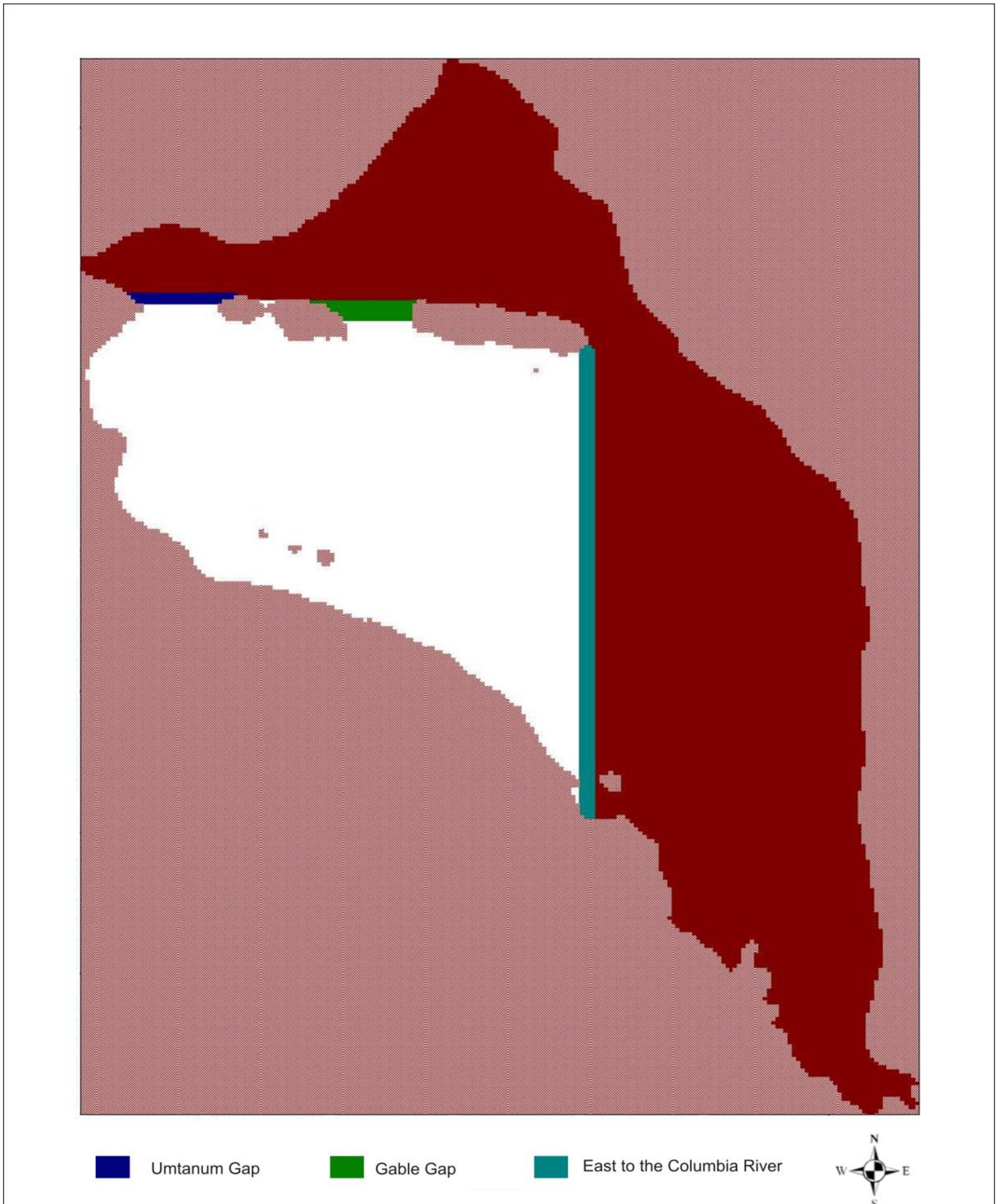


Figure V–8. Yearly Volumetric Discharge Measurement Locations (Gates) in Hanford Site Regional Groundwater Model

Results of the selected water zone budget hydrographs (yearly volumetric discharge) are included as Figure V–9 (*TC & WM EIS* Base Case), Figure V–10 (background recharge model variant), Figure V–11 (GHB recharge model variant), and Figure V–12 (Columbia River recharge model variant). Further, a summary of analytical results associated with the hydrographic analysis, including the annual volumetric discharge through selected gates, is presented in Table V–3.

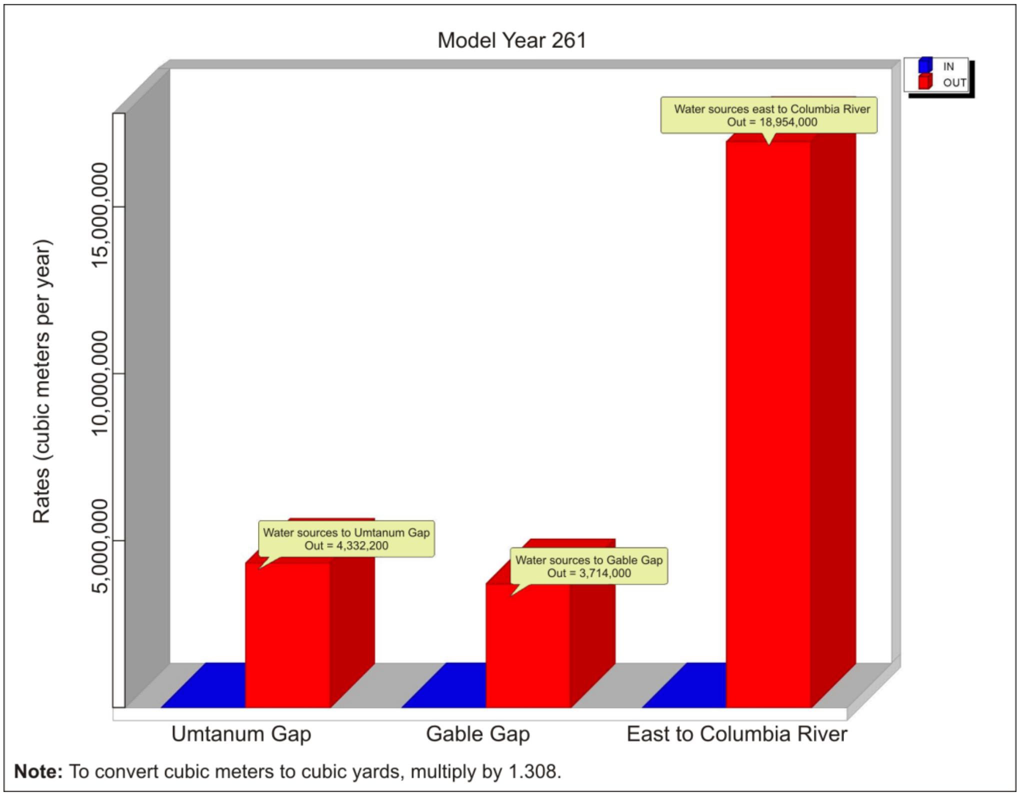


Figure V–9. Yearly Volumetric Discharge Measurements for Selected Zones, *TC & WM EIS* Base Case Flow Field

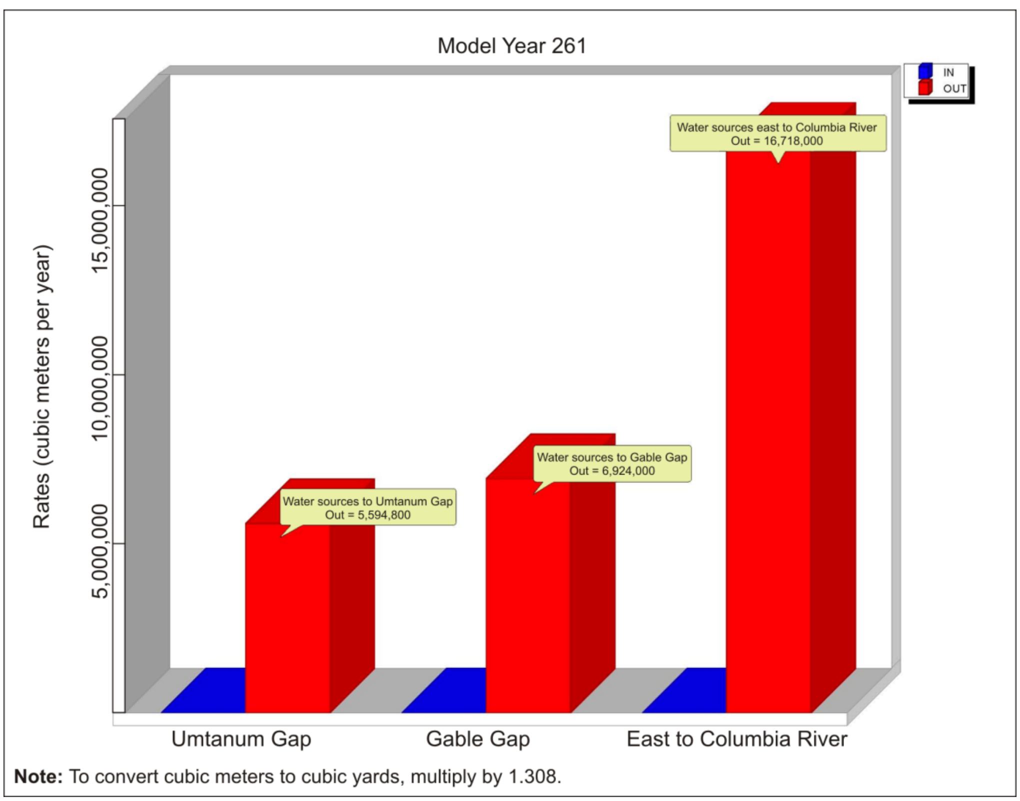
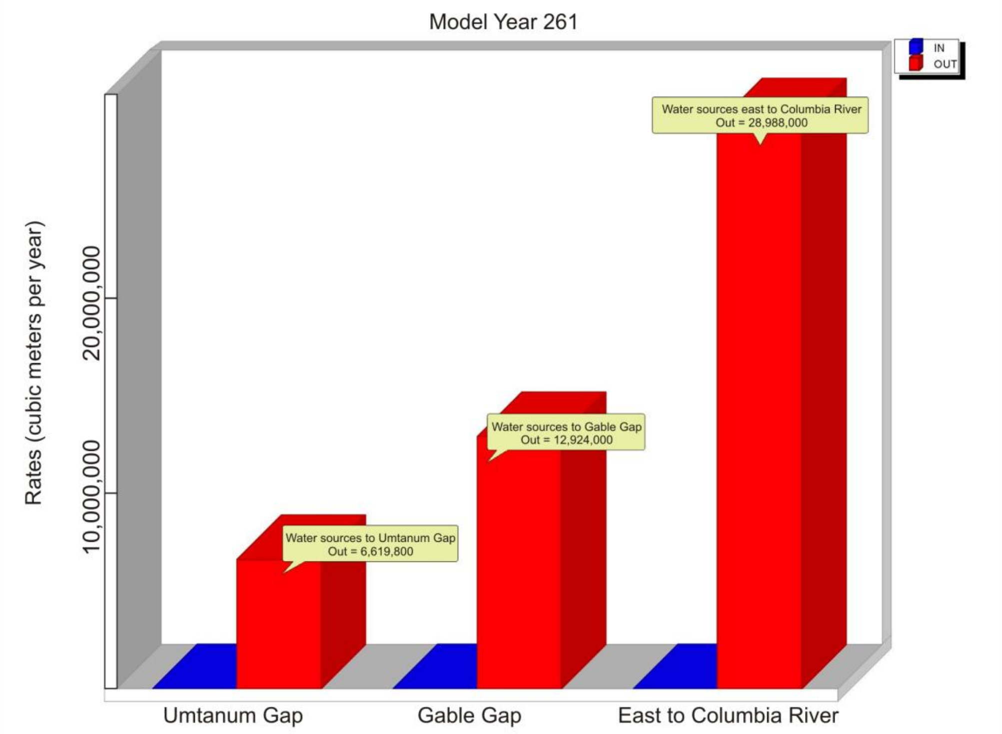
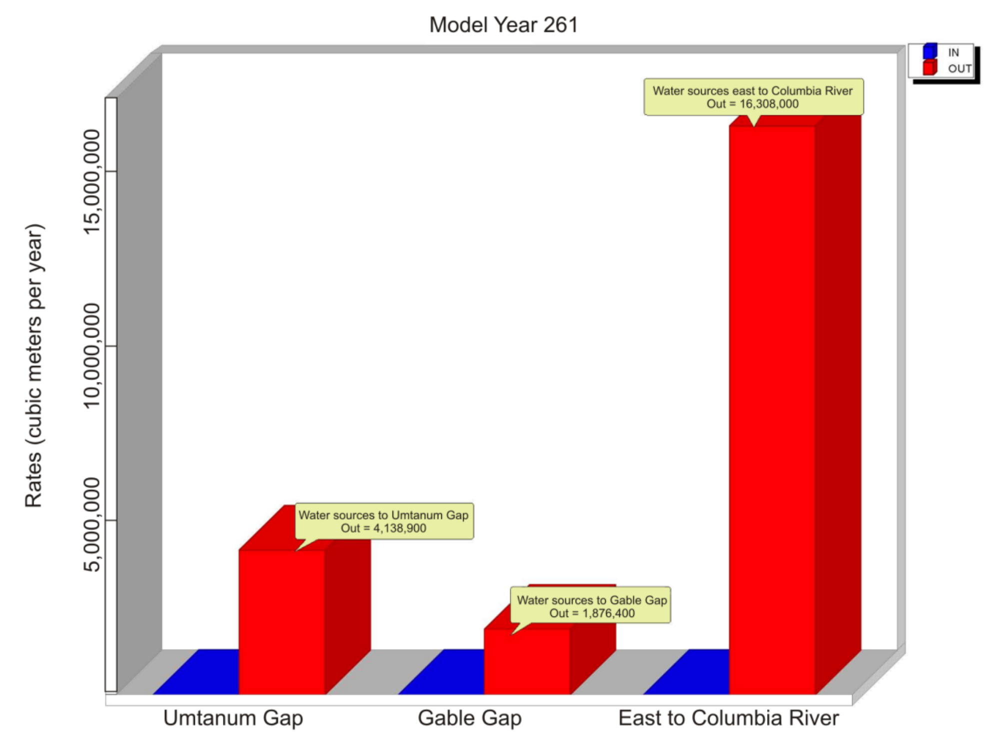


Figure V–10. Yearly Volumetric Discharge Measurements for Selected Zones, Background Recharge Model Variant Flow Field



Note: To convert cubic meters to cubic yards, multiply by 1.308.

Figure V–11. Yearly Volumetric Discharge Measurements for Selected Zones, Generalized Head Boundary Recharge Model Variant Flow Field



Note: To convert cubic meters to cubic yards, multiply by 1.308.

Figure V–12. Yearly Volumetric Discharge Measurements for Selected Zones, Columbia River Recharge Model Variant Flow Field

Table V–3. Summary of Water Budget Hydrographic Analysis

Recharge Variant Flow Field	Total Volumetric Discharge (cubic meters per year)	Umtanum Gap	Gable Gap	East to Columbia River
		Discharge in cubic meters per year (percent of total)		
TC & WM EIS Base Case flow field	25,000,200	4,332,200 (17%)	3,714,000 (15%)	16,954,000 (68%)
Background recharge model variant (increased yearly regional precipitation)	29,236,800	5,594,800 (19%)	6,924,000 (24%)	16,718,000 (57%)
Generalized Head Boundary recharge model variant (increased creek and watershed slope runoff discharge)	48,531,800	6,619,800 (14%)	12,924,000 (27%)	28,988,000 (60%)
Columbia River recharge model variant (increased surface water elevation)	22,323,300	4,138,900 (19%)	1,876,400 (8%)	16,308,000 (73%)

Note: To convert cubic meters to cubic yards, multiply by 1.308.
Key: *TC & WM EIS=Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington*.

In the *TC & WM EIS* Base Case flow field, nearly 25 million cubic meters (32.7 million cubic yards) per year (at CY 2200) of groundwater are discharged through all three gates. For comparison, there was a 14 percent increase in total discharge (to 29.2 million cubic meters [38.2 million cubic yards] per year) in the background recharge model variant, a 48 percent increase in total discharge (to 48.5 million cubic meters [63.4 million cubic yards] per year) in the GHB recharge model variant, and an 11 percent decrease in total discharge (to 22.3 million cubic meters [29.1 million cubic yards] per year) in the Columbia River recharge model variant.

As summarized in Table V–3, of the 25 million cubic meters (32.7 million cubic yards) per year of total groundwater discharge in the *TC & WM EIS* Base Case, 68 percent passed through the "East to the Columbia River" measurement gate, 15 percent through Gable Gap, and 17 percent through Umtanum Gap. Although the total volumetric discharges associated with the background recharge and GHB recharge model variants were higher than that of the *TC & WM EIS* Base Case, the ratio and percentage of discharge through each of these measurement gates were about the same as for the Base Case (the percentage of total discharge through each of the three measurement gates was within 10 percent that of the Base Case).

In contrast to the *TC & WM EIS* Base Case flow field, the Columbia River recharge model variant exhibited both an overall decrease in total volumetric discharge and a decrease in the percentage of discharge though Gable Gap (only 8 percent of the total discharge). Further, the Columbia River recharge model variant flow field exhibited an increase in the percentage of discharge east to the Columbia River (73 percent of the total discharge) compared with that of the GHB recharge model variant (60 percent of the total discharge) and the background recharge model variant (57 percent of the total discharge).

V.4.4 Changes to Long-Term Groundwater Peak Concentrations at Selected Lines of Analysis

Groundwater flow and transport analysis was performed using each of the recharge variant flow fields outlined in Table V–1 and the *TC & WM EIS* Base Case flow field to evaluate long-term peak concentrations over time at the Core Zone Boundary, Columbia River nearshore, and applicable waste storage facility barriers, as defined in Chapters 2 and 5. Particle-tracking computer code was used to simulate the migration of technetium-99 through each flow field (aquifer). This included particle-tracking transport runs from CY 2200 to CY 11,940.

The technetium-99 groundwater flow and transport analysis was performed within the contexts of Tank Closure Alternative 2B (peak concentration results and variances are summarized in Table V–4) and Waste Management Alternative 2, Disposal Group 1, Subgroup 1-A (peak concentration results and variances are summarized in Table V–5).

Table V–4. Tank Closure Alternative 2B, Technetium-99 Peak Concentration at Core Zone Boundary and Columbia River Nearshore

	Core Zone Boundary			Columbia River Nearshore		
Flow Field Scenario	**Peak Concentration (picocuries per liter)**	**Peak Year**	**Peak Year Variance[a]**	**Peak Concentration (picocuries per liter)**	**Peak Year**	**Peak Year Variance[a]**
TC & WM EIS Base Case flow field	1,210	2209	Not applicable	396	2254	Not applicable
Background recharge model variant (increased yearly regional precipitation)	1,710	3663	1,454	871	2487	233
Generalized Head Boundary recharge model variant (increased creek and watershed slope runoff discharge)	100	2248	39	187	2322	68
Columbia River recharge model variant (increased surface water elevation)	107	2205	–4	251	2203	–51

[a] Difference between the peak year of the selected recharge model variant and that of the *TC & WM EIS* Base Case model.

Key: *TC & WM EIS=Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington*.

Table V–5. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-A, Technetium-99 Peak Concentration at Core Zone Boundary and Columbia River Nearshore

	Core Zone Boundary			Columbia River Nearshore		
Flow Field Scenario	**Peak Concentration (picocuries per liter)**	**Peak Year**	**Peak Year Variance[a]**	**Peak Concentration (picocuries per liter)**	**Peak Year**	**Peak Year Variance[a]**
TC & WM EIS Base Case flow field	497	7709	Not applicable	377	8130	Not applicable
Background recharge model variant (increased yearly regional precipitation)	7,743	7942	215	1,484	8839	709
Generalized Head Boundary recharge model variant (increased creek and watershed slope runoff discharge)	237	8350	641	335	8157	27
Columbia River recharge model variant (increased surface water elevation)	354	7796	87	246	7681	–449

[a] Difference between the peak year of the selected recharge model variant and that of the *TC & WM EIS* Base Case model.

Key: *TC & WM EIS=Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington*.

Graphs illustrating peak concentrations versus time (calendar year) of technetium-99 (picocuries per liter) at the Core Zone Boundary and Columbia River nearshore within the context of Tank Closure Alternative 2B are included as Figure V–13 (*TC & WM EIS* Base Case flow field), Figure V–14 (background recharge model variant flow field), Figure V–15 (GHB recharge model variant flow field), and Figure V–16 (Columbia River recharge model variant flow field).

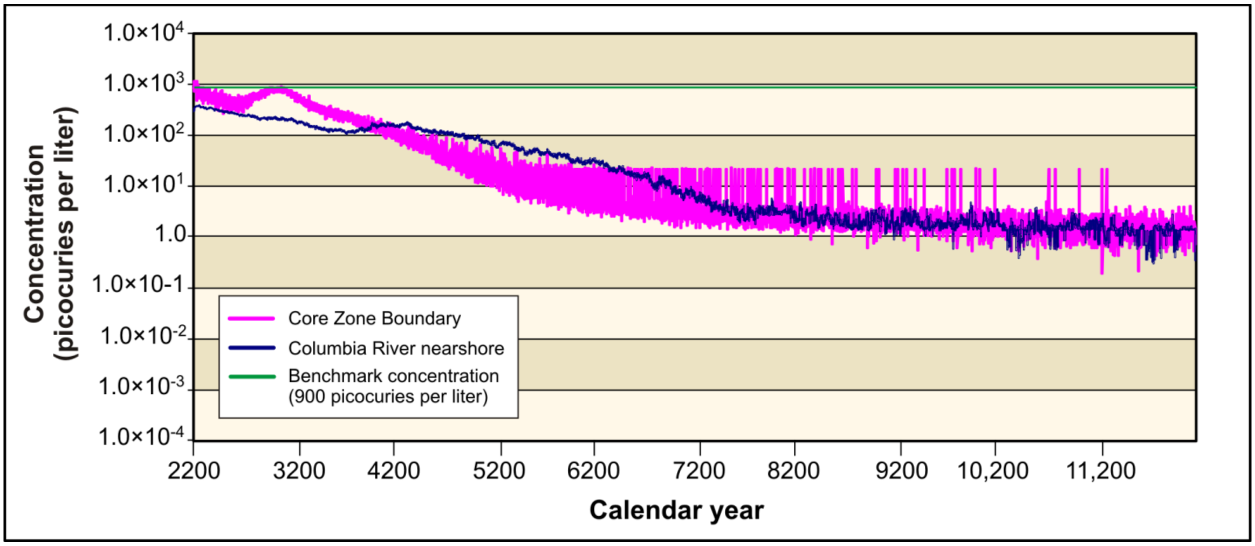


Figure V–13. Tank Closure Alternative 2B Technetium-99 Maximum Concentrations at Selected Barriers, *TC & WM EIS* Base Case Flow Field

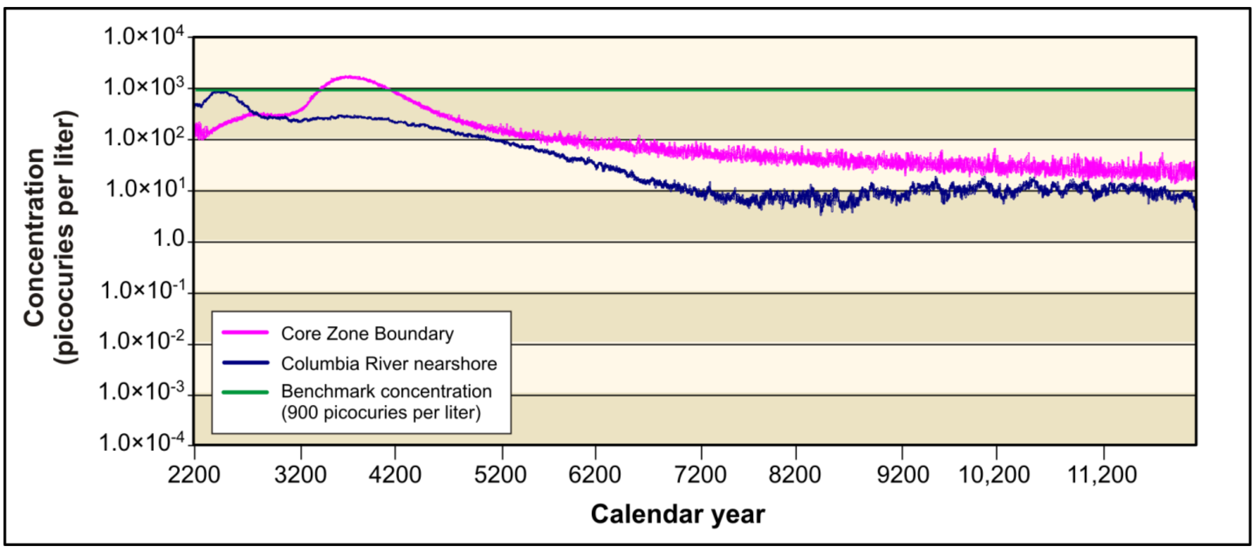


Figure V–14. Tank Closure Alternative 2B Technetium-99 Maximum Concentrations at Selected Barriers, Background Recharge Variant Flow Field

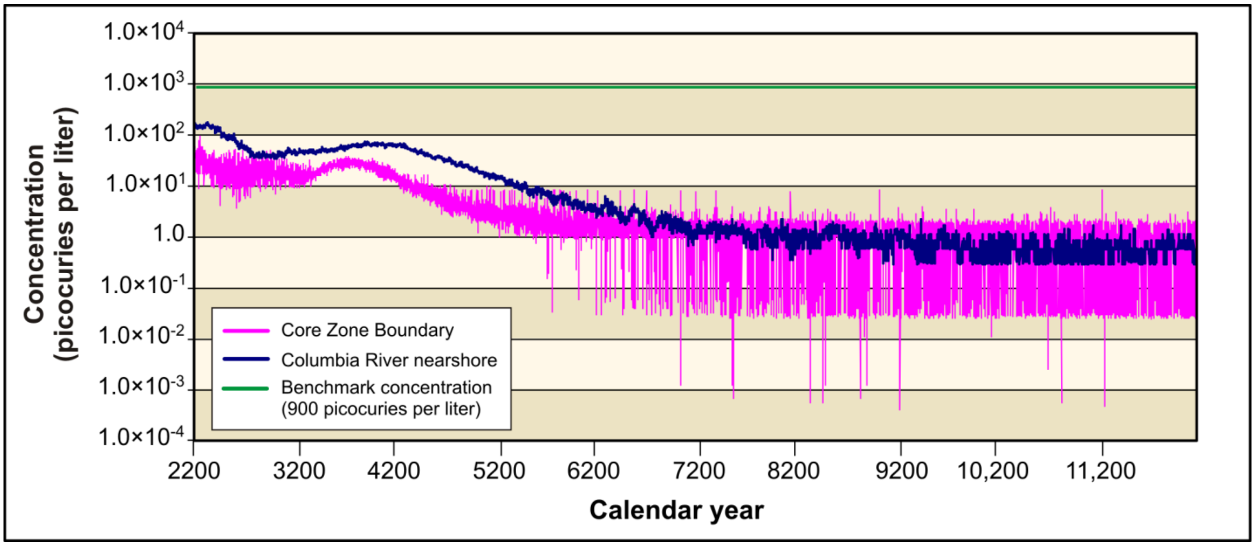


Figure V–15. Tank Closure Alternative 2B Technetium-99 Maximum Concentrations at Selected Barriers, Generalized Head Boundary Recharge Variant Flow Field

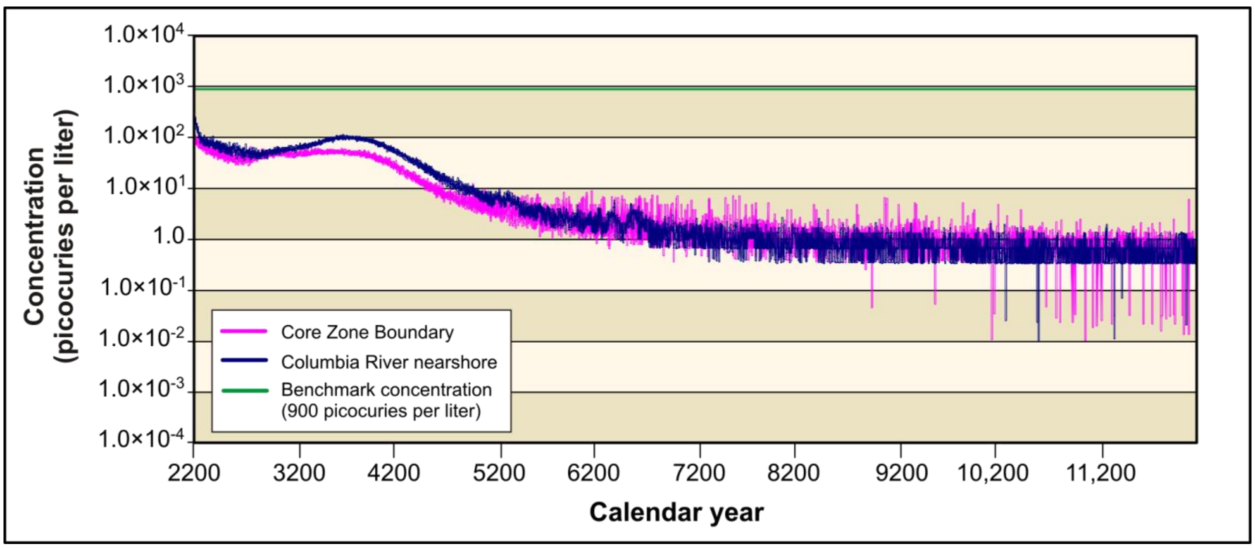


Figure V–16. Tank Closure Alternative 2B Technetium-99 Maximum Concentrations at Selected Barriers, Columbia River Recharge Variant Flow Field

Further, concentration versus time (calendar year) graphs illustrating peak technetium-99 concentrations (picocuries per liter) at the Core Zone Boundary, Columbia River nearshore, RPPDF, and IDF-East within the context of Waste Management Alternative 2, Disposal Group 1, Subgroup 1-A, are included as Figure V–17 (*TC & WM EIS* Base Case flow field), Figure V–18 (background recharge model variant flow field), Figure V–19 (GHB recharge model variant flow field), and Figure V–20 (Columbia River recharge model variant flow field).

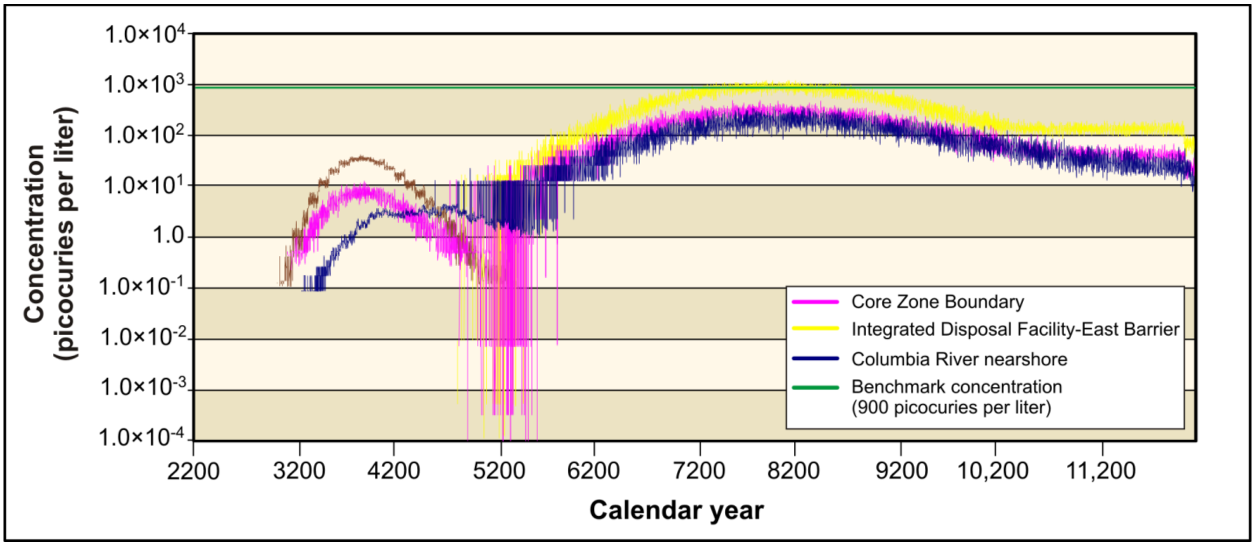


Figure V–17. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-A, Technetium-99 Maximum Concentrations at Selected Barriers, *TC & WM EIS* Base Case Flow Field

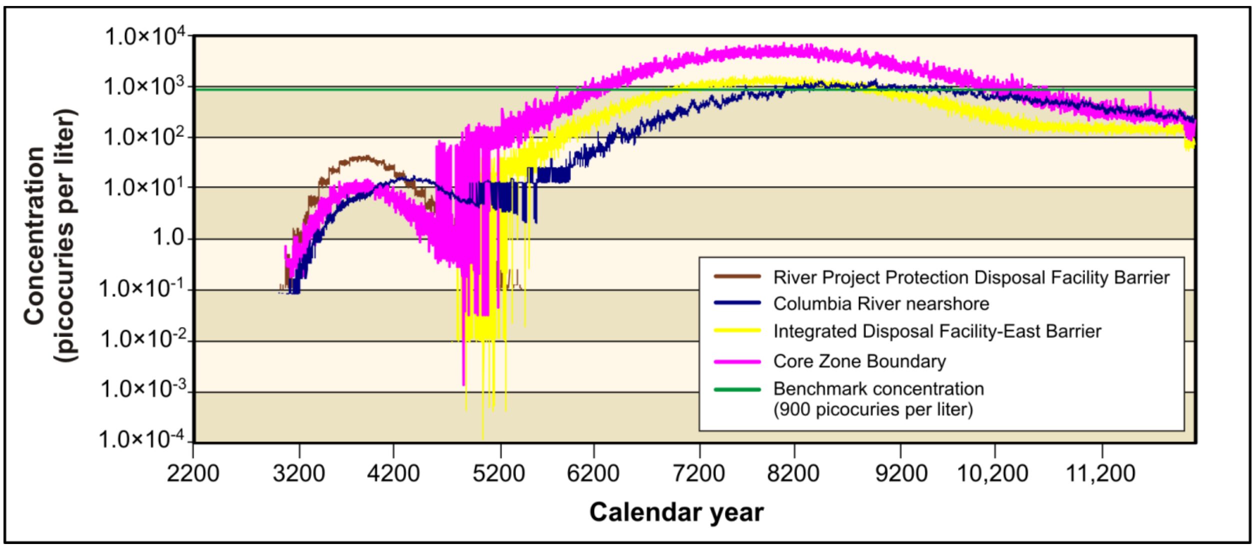


Figure V–18. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-A, Technetium-99 Maximum Concentrations at Selected Barriers, Background Recharge Variant Flow Field

Within the context of Tank Closure Alternative 2B (expanded Waste Treatment Plant vitrification, landfill closure) and regarding long-term (beyond CY 2100) flow and transport, peak technetium-99 concentrations and peak year variances associated with each of the recharge model variants are minimally impacted considering the overall period of waste release and the length of the *TC & WM EIS* Base Case transport simulation (10,000 years). None of the three recharge model variants changed the peak technetium-99 concentrations at the lines of analysis more than an order of magnitude. In general, the background recharge model variant exhibited slightly higher peak concentrations at the lines of analysis and longer travel times to the Columbia River than the Base Case flow field (see Figure V–14). Further, in general, the GHB recharge and Columbia River recharge model variants exhibited slightly lower peak concentrations than the Base Case flow field (see Figures V–15 and V–16). Long-term transport times of peak technetium-99 concentrations to the Columbia River nearshore were about the same for the GHB recharge and Columbia River recharge model variants as for the Base Case flow field.

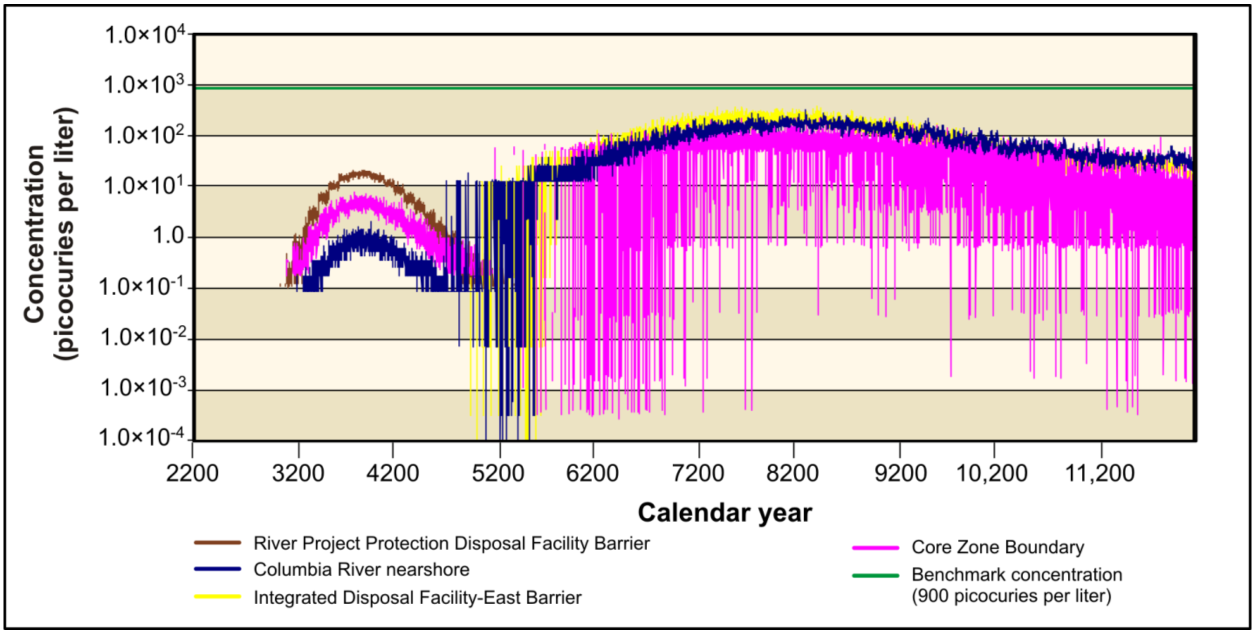


Figure V–19. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-A, Technetium-99 Maximum Concentrations at Selected Barriers, Generalized Head Boundary Recharge Variant Flow Field

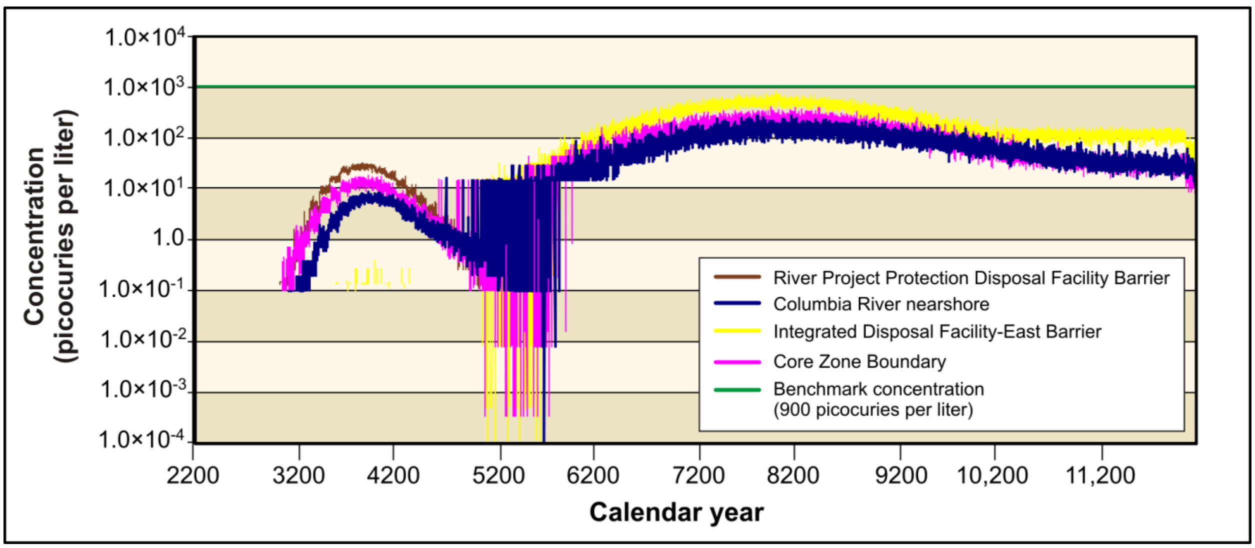


Figure V–20. Waste Management Alternative 2, Disposal Group 1, Subgroup 1-A, Technetium-99 Maximum Concentrations at Selected Barriers, Columbia River Recharge Variant Flow Field

Within the context of Waste Management Alternative 2, Disposal Group 1, Subgroup 1-A (disposal of waste associated with Tank Closure Alternative 2B in the proposed IDF-East and RPPDF), and regarding long-term (beyond CY 2100) flow and transport, peak technetium-99 concentrations and peak year variances associated with each of the recharge model variants are minimally impacted considering the overall period of waste release and the length of the transport simulation (10,000 years). None of the three recharge model variants changed the peak technetium-99 concentrations at the lines of analysis more than an order of magnitude. However, the background recharge model variant did exhibit Core Zone Boundary, IDF-East barrier, and Columbia River nearshore peak concentrations exceeding the benchmark technetium-99 concentration of 900 picocuries per liter. In addition, the background recharge model variant exhibited higher concentrations and longer travel times to the Columbia River nearshore than the Base Case flow field (see Figure V–18).

Overall, within the context of Waste Management Alternative 2, Disposal Group 1, Subgroup 1-A, the GHB recharge and Columbia River recharge model variants exhibited lower peak concentrations than the Base Case flow field (see Figures V–19 and V–20). Long-term travel times of peak technetium-99 concentrations to the Columbia River nearshore were about the same for the GHB recharge and Columbia River recharge model variants as for the Base Case flow field.

V.5 SUMMARY OF RESULTS AND POTENTIAL IMPLICATIONS FOR THE *TC & WM EIS* ALTERNATIVES

In summary, based on results presented in Section V.4, the following observations were made regarding each of the developed recharge model variant flow fields (described in Table V–1) relative to the *TC & WM EIS* Base Case flow field:

Background Recharge Model Variant (increased regional yearly precipitation)

- The increased yearly precipitation (to 35 millimeters per year) increases groundwater head elevations 1 to 3 meters (3.28 to 9.84 feet) across the model (most changes are below the calibrated *TC & WM EIS* Base Case RMS error value of 2.28 meters [7.48 feet]). The most significant effect is the shift of the bifurcating groundwater divide several kilometers east within the Core Zone. Thus, most of the particles released within the Central Plateau flow north through Gable Gap and continue north to the Columbia River.

- The background recharge model variant does not significantly change the maximum technetium-99 concentrations at the Core Zone Boundary and Columbia River nearshore within the context of the selected *TC & WM EIS* alternatives.

GHB Recharge Model Variant (increased western boundary, creek, and Rattlesnake Mountain watershed slope runoff discharge flux)

- The increased GHB recharge along the western boundary increases localized groundwater head elevations (6 to 9 meters [19.68 to 29.52 feet]) along the western model boundary. Included is a 4-meter (13.12-foot) increase in groundwater elevation within the Core Zone.

- The groundwater divide within the Core Zone shifts several kilometers to the east, almost out of the Central Plateau area. Thus, almost all of the particles released in the Core Zone travel north through Gable Gap and continue north to the Columbia River.

- The GHB recharge model variant does not significantly change the maximum technetium-99 concentrations at the Core Zone Boundary and Columbia River nearshore within the context of the selected *TC & WM EIS* alternatives.

Columbia River Recharge Model Variant (increased Columbia River surface water elevation)

- The increased Columbia River surface-water elevation moderately increases localized groundwater head elevations (approximately 4 meters [13.12 feet]) along the eastern and northern model boundary. Core Zone groundwater head elevations are increased roughly 1 meter (3.28 feet), which is below the calibrated *TC & WM EIS* Base Case RMS error value of 2.28 meters (7.48 feet).

- The bifurcating groundwater divide within the Core Zone shifts several kilometers to the west, crossing through the middle of the 200-West Area. As such, most of the particles released in the Core Zone travel east to the Columbia River in this model variant.

- The Columbia River recharge model variant does not significantly change the maximum technetium-99 concentrations at the Core Zone Boundary and Columbia River nearshore river barrier within the context of the selected *TC & WM EIS* alternatives.

V.6 REFERENCES

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