Appendix D

Groundwater Data for Initial Assessment Performed with the System Assessment Capability (Revision 0)

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1.0 INTRODUCTION

This appendix presents data and interpreted information used to simulate radionuclide and chemical contaminant migration through the aquifer system for the initial assessment performed with the System Assessment Capability Revision 0 (SAC Rev. 0). The requirements and design of the SAC Rev. 0 and a description of the initial assessment are presented in the *System Assessment Capability (Revision 0), Assessment Description, Requirements, Software Design, and Test Plan* document (Kincaid et al., 2000). Background information on the development of the SAC is presented in *Preliminary System Assessment Capability Concepts for Architecture, Platform and Data Management*[1] and Kincaid et. al. (2000). These documents can be found at http://www.bhi-erc.com/vadose/sac.htm#info.

2.0 BACKGROUND

For the initial assessment, the groundwater transport component was simulated using a two-dimensional variable-thickness version of the three-dimensional Hanford sitewide groundwater model. The three-dimensional model is described in DOE (1999), Cole et al. (1997), and Wurstner et al. (1995). The two-dimensional model was formulated and used for the SAC Rev. 0 to facilitate executing the large number of simulations required for stochastic analyses within a reasonable time period. Comparisons of groundwater transport simulated by the full three-dimensional and the two-dimensional versions of the model were made as part of the history matching exercise for groundwater.

3.0 INTERACTION WITH OTHER SAC MODULES

The vadose zone module of the SAC provides contaminant flux out of the vadose zone as input to the groundwater module. Contaminant flux out of the groundwater module is used as input to the Columbia River module and concentrations in groundwater a certain locations are used in the risk module. Contaminants are passed from the vadose module to the groundwater module as a dry mass. Water recharge to the aquifer is already accounted for in the groundwater flow model.

4.0 DATA GATHERED

Applicable documents and files containing the data and information are described and referenced rather than listing all information in this data package. A table summarizing those files is included in Section 6 and links are provided to web pages where they can be accessed. All elevations are based on the NGVD29 sea-level datum. All lateral locations are based on the NAD83 datum and expressed in state plane coordinates (m) for FIPSZONE 4602.

A distinction is made between data and interpreted information as recommended by the Groundwater Modeling Project Peer Review Panel (DOE 1999). For example, measured contaminant concentrations in

[1] These documents can be found at http://www.bhi-erc.com/vadose/sac.htm#info

groundwater samples are data, but plume maps or grids of interpolated contaminant concentrations in the aquifer are interpreted information.

4.1 Data and Information for the Two-Dimensional Flow Model

The two-dimensional version of the Hanford sitewide groundwater flow model was used to calculate hydraulic heads and groundwater velocities for transport calculations. This section describes data and information used in the flow model.

<u>Boundary Conditions</u>

The groundwater model domain is defined by boundary conditions at the top, bottom, and lateral perimeter of the model.

The bottom of the model is defined by the top of basalt or the top of the lower Ringold mud unit. It is defined by the top of the lower Ringold mud where this unit either lies directly on top of basalt or completely isolates the underlying basal Ringold gravel unit from the unconfined aquifer system (which is the case in the area north of the Gable Mountain structure). The top of the aquifer is defined by the water table, which changes over time. The thickness of the two-dimensional model is, therefore, defined by the difference between the bottom of the model and the water table at each model node. The elevation of the bottom of the model is contained in a file called bndbot_SAC0.ascii. This file is a regular grid in ARC-INFO ASCII format with a 150m x 150m spacing. This information is based on well data including geologic logs, geophysical logs, and grain size analyses that were used to pick hydrogeologic unit contact depths at wells. Hard copies of these data sources are on file at PNNL. Interpreted elevation picks for the top of each unit, including the unit contacts that define the bottom of the model, are listed in geo_SAC0.xls.

Water table elevations were calculated by the two-dimensional groundwater flow model for each 6-month time plane. The initial condition water table elevations for 1944 are contained in a file called bnd44wt_SAC0.ascii. This file is a regular grid in ARC-INFO ASCII format with a 150m x 150m spacing. This information was based on the 1944 map presented in Kipp and Mud (1974), which was interpreted from back-extrapolation of water-level measurements made in the period 1948-1952. Water-level measurement data are stored in hardcopy and electronic form at PNNL.

Lateral flow model boundaries are shown in Figure 1, together with the model grid used for the SAC Rev. 0. This figure also shows the type of each lateral boundary condition. Information used in defining these boundary conditions includes the following:

- Columbia and Yakima River hydraulic head conditions over time
- inflow from Cold Creek, Dry Creek, and Rattlesnake Hills constant flux boundaries
- natural surface recharge from precipitation
- artificial recharge from Hanford disposal practices and the Richland well field
- locations of no flow boundaries

Specified head conditions over time for the model nodes that form the Columbia River and the Yakima River specified-head boundaries are contained in the file bndHH_SAC0.xls. These head conditions were based on historical river stage measurements which are discussed in Appendix E. A constant-head condition was selected and assigned to each node.

Fluxes at the constant-flux boundaries along the western side of the model domain were determined during the calibration process for the three-dimensional Hanford sitewide groundwater model as described in Cole et al. (1997). The fluxes across the boundaries are listed in Table D-1.

Recharge to the water table from precipitation varies both temporally and areally across the Hanford Site (Gee and Heller 1985, Gee et al. 1992). Recharge used in the flow model was based on estimates made by Fayer and Walters (1995) and is shown in Figure 2. Recharge to the water table from precipitation varies

Table D-1. Fluxes at Constant-Flux Boundaries

Cold Creek Valley	2881 m^3/d
Dry Creek Valley (north)	1207 m^3/d
Dry Creek Valley (east)	328 m^3/d
Rattlesnake Hills	3104 m^3/d

both temporally and areally across the Hanford Site (Gee and Heller 1985, Gee et al. 1992). Recharge used in the flow model was based on estimates made by Fayer and Walters (1995) and is shown in Figure 2. The recharge was based on average climatic conditions and 1979 soil and vegetation conditions. It was assumed to be constant over time. The recharge information is contained in the file called rech79_SAC0.ascii. This file is a regular grid in ARC-INFO ASCII format with a 50m x 50m spacing. The recharge values are in mm/y. Fayer and Walters (1995) used several types of field data and computer modeling results to estimate the areal distribution of mean recharge rates for the soil and vegetation conditions at the Hanford Site. Their estimates ranged from 2.6 mm/yr for several soil and vegetation combinations to 127.1 mm/yr for basalt outcrops with no vegetation at the crest of Rattlesnake Mountain. However, these basalt outcrops are outside the model domain and recharge occurring outside the model domain was not included as an input to the model. The annual volume of estimated recharge from precipitation was calculated to be 8.47 x 10^9 liters for the portion of the Site bounded by Highway 240 and the Columbia River, which approximates the model domain. The magnitude of recharge at a particular location is influenced by five main factors: climate, soils, vegetation, topography, and springs (from the basalt confined aquifer system) and influent stream reaches. Additional data and information on the development of the estimates for natural recharge are available in Fayer and Walters. (1995).

Artificial recharge is important information for groundwater modeling at Hanford because the volumes of artificial recharge since 1944 have been significantly greater than the volume of recharge from natural sources. Artificial recharge information for the groundwater flow model is contained in the EXCEL file a_rech_SAC0.xls. This file lists the volume of recharge over time for each discharge site. These values were applied at the nearest model node. The values are based on data presented in quarterly discharge reports for Hanford facilities. The file also includes net recharge at the North Richland well field where water is pumped from the Columbia River into recharge basins and then a smaller volume is extracted from nearby wells. Artificial recharge used in the groundwater model at some sites may differ from the liquid waste discharge volumes applied in the SAC rev. 0 vadose zone module. The vadose discharge volumes were compiled under the SAC rev. 0 inventory module, whereas the values in the a_rech_SAC0.xls table are from earlier calibration of the groundwater flow model. Contaminants are passed from the vadose module to the groundwater module as a dry mass because recharge from waste discharges is already accounted for in the groundwater flow model. Changing the artificial recharge volumes is not valid unless the groundwater flow model is recalibrated. The groundwater flow model assumes no delay of waste discharge between the waste facility and the water table. However, delay of contaminants in the vadose zone is accounted for by the vadose zone module.

Wells used for water supply on the Hanford Site and the adjacent Arid Lands Ecology Reserve are described in Poston et al. (2000). Within the Hanford Site boundary, only the FFTF water supply wells are accounted for in the flow model. The volume of withdrawal at the other Hanford Site wells is too low to affect the model results. Other water-supply wells located south of the Hanford Site, but within the model domain were also accounted for in the flow model. Extraction volumes for wells are listed as negative values in the file a_rech_SAC0.xls, which lists the artificial recharge applied in the model.

Lateral perimeter boundary segments not identified as constant-flux or constant-head boundaries in Figure 1 are no-flow boundaries in the model. Except the short segment between Umtanum Ridge and the Columbia River, these boundaries represent basalt rising above the water table. For the segment between Umtanum Ridge and the Columbia River, flow is assumed to be predominantly toward the river and little flow is expected across the boundary. Inflow from precipitation on Rattlesnake Mountain is accounted for by the Rattlesnake Hills constant-flux boundary (Figure 1). No-flow boundaries also occur within the model domain where basalt subcrops above the water table. Potential runoff from elevated basalt areas within the model domain, such as Gable Mountain, is not accounted for in the current model.

Hydraulic Parameters

Transmissivity values for the two-dimensional flow model resulted from a model-calibration process based on assumed steady-state conditions for 1979, which followed a period of relatively steady waste-water discharges on the Hanford Site. The model calibration is described in Wurstner et al. (1995). Figure 3 shows the resulting transmissivity distribution. The transmissivity values for each model element are listed in file elemtrans_SAC0.xls. The grid node and element locations are given in the file elem_nod_SAC0.xls. For calibration of the flow model, a specific yield of 0.1 was assumed. Hydraulic property data from aquifer tests were used in the calibration process. These data are described in Thorne and Newcomer (1992), Thorne et al. (1993 and 1994), and Wurstner et al. (1995).

4.2 Data and Interpreted Information for the Two-Dimensional Transport Model

The three-dimensional version of the Hanford sitewide groundwater model consists of up to 7 geologic layers below the water table, which are further divided into transport layers. However, for the two-dimensional version of the model, flow and transport take place through the entire aquifer thickness. In general, contamination in the Hanford Site unconfined aquifer remains in the upper part of the aquifer (Eddy et al. 1978). Concentrations calculated by the groundwater model at any particular point were, therefore, corrected by multiplying by the thickness of the aquifer and dividing by the assumed thickness of the contaminant plume. Limited vertical contaminant data (Eddy et al. 1978; Wurstner et al. 1995) show that plume thickness varies across the site. However, to simplify the correction a constant plume thickness was assumed. The groundwater history matching exercise showed that a plume thickness of 20 m resulted in the best match to monitoring data for the tritium plume from the PUREX cribs. This 20-m thickness was assumed for all groundwater plumes. At locations where the aquifer thickness is less than 20 m, the correction factor was 1 and the concentration was unchanged.

Contaminant transport was modeled based on the discharge velocity field calculated by the groundwater flow model and specified transport properties. The initial conditions assumed that concentrations of modeled contaminants were negligible in 1944, prior to the start of Hanford Site operations. Transport properties used in the model include the following:

- effective porosity
- dispersivity
- radioactive decay coefficients (or half-lives)
- retardation factors for sorbed contaminants

Effective porosity was assumed to be 0.25 for the two-dimensional transport calculations. This value is in the range from measurements for Ringold and Hanford formation gravel sediments (Wurstner et al. 1995).

Dispersivity is a scale dependent parameter and can only be determined from inverse modeling of tracer tests on the scale of interest. Because very few such large-scale tracer tests have been conducted and none have been conducted at the Hanford Site, the longitudinal dispersivity, α_L, of 95 m and transverse dispersivity, α_T, of 20 m used in the groundwater transport model were not based on Hanford Site data. However, α_L is in the range of 60 m to 120 m determined by Van der Kamp et al. (1994) for a plume that moved 7.7 km at an average pore velocity of 380 m/y. By comparison, the distance moved by the tritium plume from 200 East Area to the Columbia River was about 14 km at a velocity of about 800 m/y (Freshley and Graham 1988). Dispersivity values used in the Hanford sitewide groundwater model also satisfy the following constraints:

- The grid Peclet number, P_e=(grid spacing)/α_L must be less than 4 for acceptable solutions in finite element simulations (Campbell, Longsine, and Reeves 1981). The 95-m dispersivity value meets this criterion for the 375 m by 375 m grid spacing where most contaminant transport occurs. A larger value was not selected because large values of α_L are not conservative in transport calculations.

- At the grid scale of 375 m, the flow system is homogeneous. Heterogeneities at scales less than 375 meters are uncharacterized and the selected α_L of 95 m is less than this distance.

- The ratio of α_L• /α_T = 4.75 is within the range of 1 to 24 cited by Walton (1985) and slightly less than the range of 5 to 20 indicated by Freeze and Cherry (1979).

The U. S. Environmental Protection Agency (Mills et al. 1995) indicates that "A rough estimate of longitudinal dispersivity in saturated porous media may be made by setting α_L equal to 10% of the mean travel distance". The distance from the closest source in the 200 East Area to the Columbia River is about 17 km. Using the 10% rule-of-thumb would suggest a value of 1700 m for α_L for this simulation. However, this is much larger than the scale of uncharacterized heterogeneity within the model. Also, large values of dispersivity are not conservative in that they tend to reduce maximum contaminant concentrations too much at smaller distances. Using the 95-m value for α_L, estimates of concentration at 950 m from the source should be accurate and for greater distances, they should be conservative. This is also the smallest value that could be used with the grid spacing selected and meet the condition for the Peclet number described above.

Decay of radioactive constituents is controlled by the specific activity, which is related to the half-life of the radioactive isotope. Consistent values are used in all of the SAC Rev. 0 modules and are listed in Table D-2.

Table D-2. Half-lives and Specific Activities for Radioactive Contaminants

CONTAMINANT	HALF-LIFE (y)	SPECIFIC ACTIVITY (Ci/g)
Tritium	12.3	9.681E+3
Tc-99	2.13E+5	1.697E-2
I-129	1.70E+7	1.632E-4
U-238	4.51E+09	3.363E-7
Sr-90	28.9	1.366E+2
Cs-137	30.2	8.706E+1
Pu-239/240	2.44E+04	6.209E-2

Retardation of sorbed contaminants was calculated based on a linear isotherm model. The effective retardation factors assigned to each contaminant are listed in Table D-3 and were based on distribution coefficients (K_d) also listed below. These values were consistently used in all SAC Rev. 0 modules. The K_d was treated as a stochastic parameter for the non-zero K_d contaminants in the initial assessment. Therefore, the minimum, maximum, and type of population distribution for each parameter is also listed. The K_d values used for groundwater transport assume low ionic strength and near neutral acidity with low organic content. Retardation factors were calculated by assuming a matrix particle density of 2.65 g/cm^3 and a porosity of 0.25, which results in a bulk density value of 1.99 gm/cm^3.

5.0 ASSESSMENT DATA

Data and information used in the groundwater module of the initial assessment is summarized in Table D-4. Large files used in groundwater flow and transport modeling that could not be practically listed in this appendix are available on the web. Table D-4 gives a description and name for each of the files mentioned in the previous section. These files can be found on the web at http://www.bhi-erc.com/vadose/sac.htm#info

Table D-3. Distribution Coefficients and Effective Retardation Factors

Waste Chemistry/Source Category 6: Low Organic/Low Salt/Near Neutral - Groundwater

Element	Best K_d (mL/g)	Min K_d (mL/g)	Max K_d (mL/g)	Best Retardation Factor	Min Retardation Factor	max Retardation Factor	Probability Distribution
Tritium	0	0	0	1	1	1	NA
Technetium	0	0	0	1	1	1	NA
Iodine	0.5	0	15	2.33	1	40.8	Ln normal
Uranium	3	0.1	500	8.95	1.27	1326	Ln normal
Strontium	20	0.2	173	54	1.53	459	Ln normal
Cesium	300	40	2000	796	107	5301	Ln normal
Plutonium	200	80	1980	531	213	5248	Ln normal
Carbon Tetrachloride	0.2	0.1	0.6	1.53	1.27	2.59	Ln normal
Chromium	0	0	0	1	1	1	NA

Note: Ln normal = natural log (base-e) normal distribution

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Table D-4 Summary of Groundwater Data and Information Used for the SAC Rev. 0 Initial Assessment

DESCRIPTION	VALUE / TABLE / FILE NAME	FILE TYPE / INFO LOCATION
Elevation of the bottom of the model domain	bndbot_SAC0.ascii	ARC-INFO ascii file
Interpreted elevation for the top of each hydrogeologic unit	geo_SAC0.xls	EXCEL file
Initial condition water table elevations for 1944	bnd44wt_SAC0.ascii	ARC-INFO ascii file
Fluxes at constant flux boundaries	Table D-1	Table in text
Specified-head conditions for rivers	bndHH_SAC0.xls	EXCEL file
Natural recharge from precipitation	rech79_SAC0.ascii	ARC-INFO ascii file
Artificial recharge / discharge	a_rech_SAC0.xls	EXCEL file
Transmissivity values for each model element	elemtrans_SAC0.xls	EXCEL file
Specific yield	0.1	
Grid node and element locations	elem_nod_SAC0.xls	EXCEL file
Effective porosity	0.25	
Longitudinal dispersivity	95 m	
Transverse dispersivity	20 m	
Radionuclide half-life / specific activity	Table D-2	Table in text
Distribution coefficients for sorbed contaminants (linear sorption isotherm)	Table D-3	Table in text

6.0 REFERENCES

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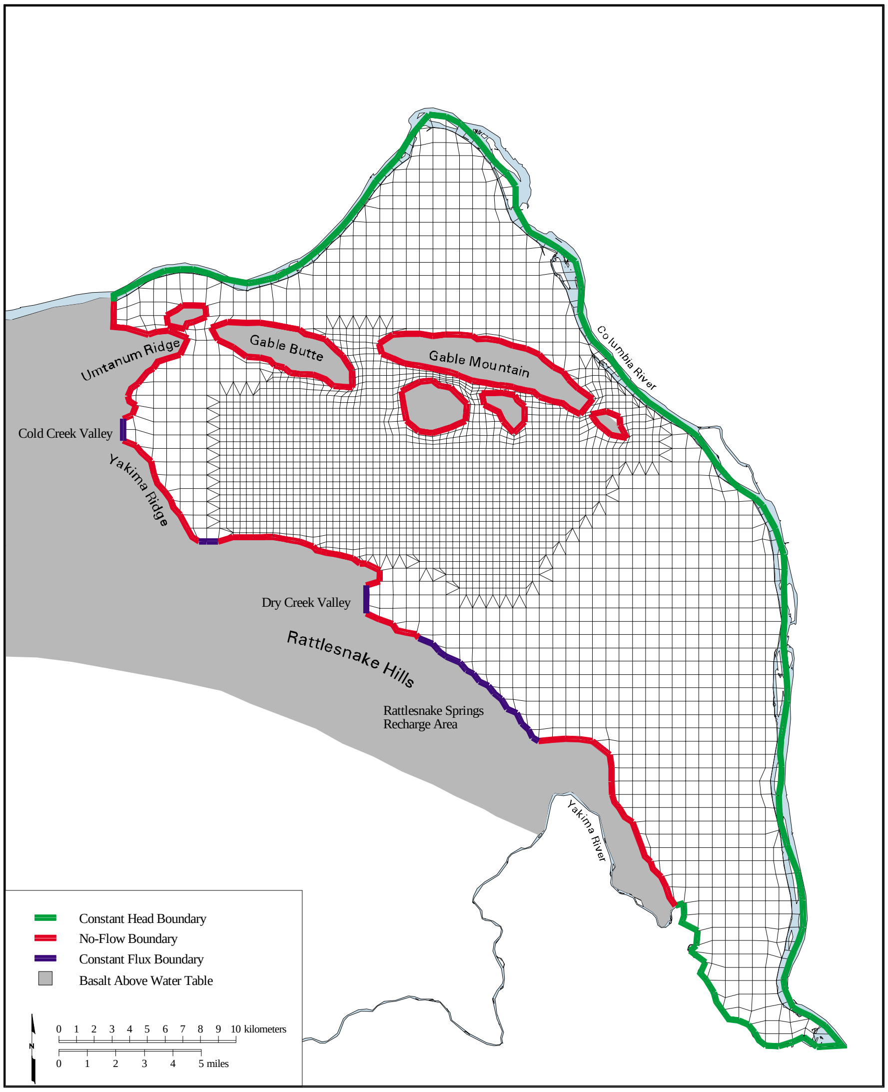

skw98003.eps January 02, 1998

Figure 1. Model grid and lateral boundary conditions.

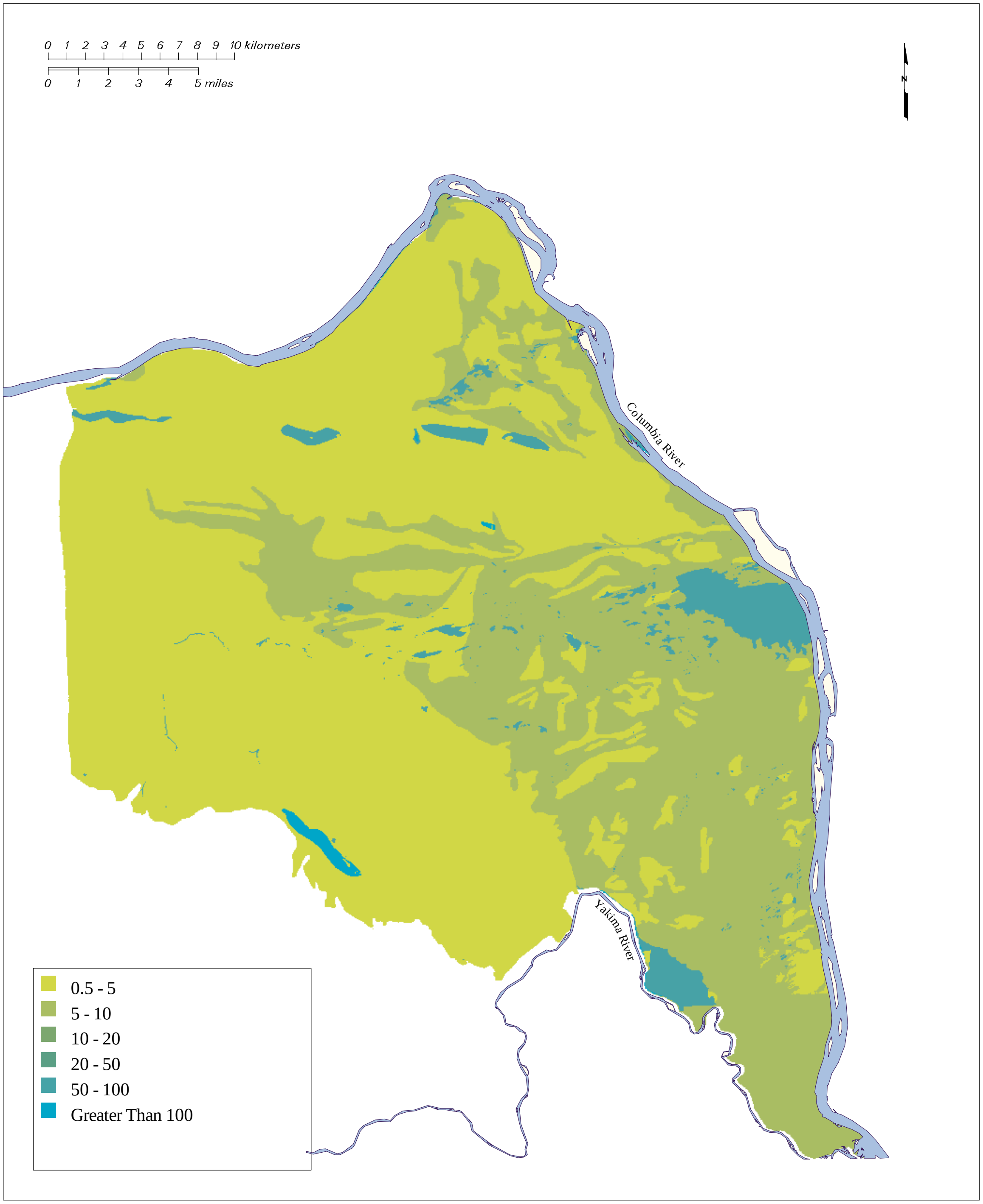

Figure 2. Distribution of recharge (mm/y) from precipitation.

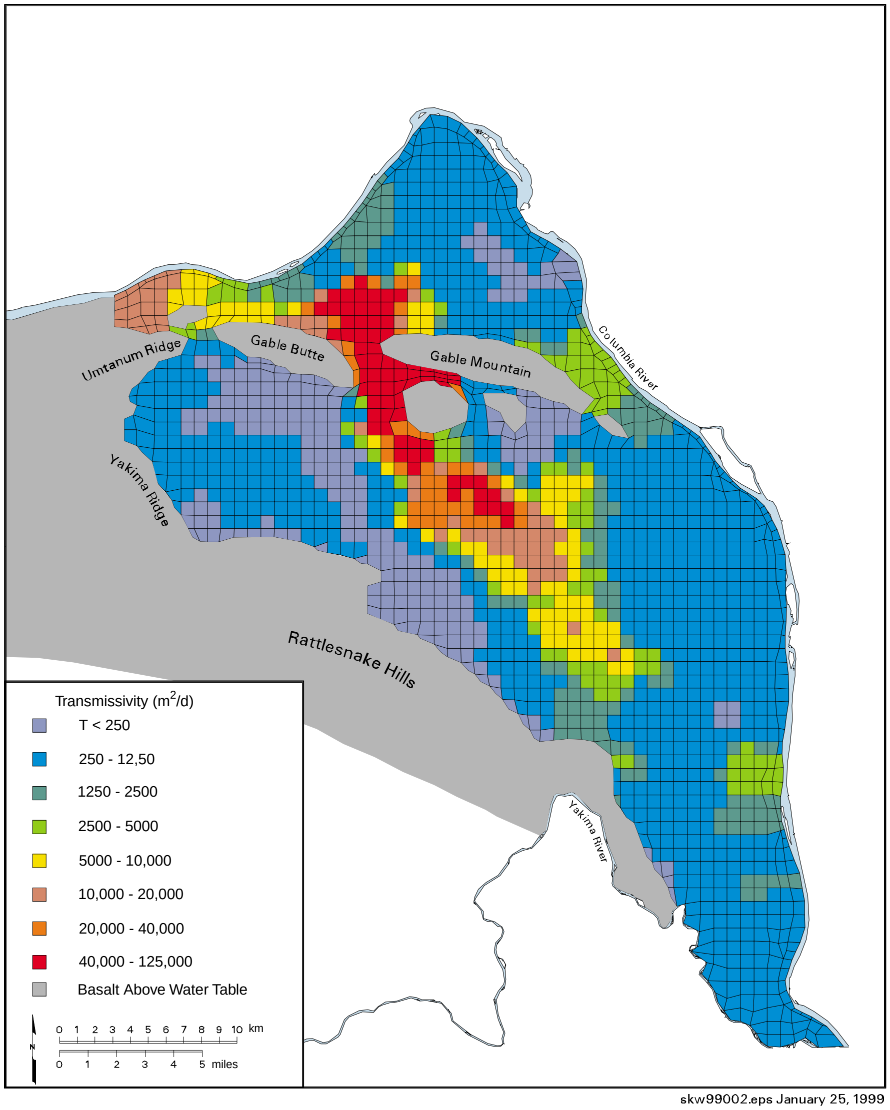

Figure 3. Transmissivity distribution of the two-dimensional model.