Documentation of Files for Steady State and Annual Versions of Groundwater Flow Model of Hueco Bolson

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EXECUTIVE SUMMARY

The USGS has completed a groundwater flow model of the Hueco Bolson. Due to the expressed interest of others, and to facilitate consistent use of the model, El Paso Water Utilities (EPWU) has developed this report that documents the model input files that constitute the steady state and annual model. The CD that accompanies this report has all model input and output files for the calibrated model, and the source code and executable file of MODFLOW-96 as modified by the USGS. EPWU has converted the steady state and annual versions of the model for use on a PC, and recompiled the model code. The accompanying CD has all the files necessary to run the steady state and annual versions of the model.

As the model is used by a variety of organizations and individuals, it will become necessary to exchange data, information and ideas regarding the model. In order to facilitate this exchange, it would be beneficial to hold regular (annual) meetings to present results of studies that are relevant to model evolution. These meetings would help all interested parties to learn how the model is being used, and to identify data gaps and model limitations. Most importantly, the meetings would provide a common forum to advance the model by closing data gaps and generally addressing its limitations.

1.0 INTRODUCTION

The USGS has completed a groundwater flow model of the Hueco Bolson. The documentation for the model development, calibration and application is described in a soon-to-be-released report (Heywood and Yager, 2002). In its draft form, the USGS report does not contain a detailed description of the files used to run the model.

Due to the expressed interest of others, and to facilitate consistent use of the model, El Paso Water Utilities (EPWU) has developed this report that documents the model input files that constitute the steady state and annual model. The CD that accompanies this report has all model input and output files for the calibrated model, and the source code and executable file of MODFLOW-96 as modified by the USGS. A monthly model was also developed by the USGS. The documentation of that model will be the subject of a future EPWU report.

The USGS developed the groundwater flow model on a Sun SPARCstation. In order to facilitate the use of the model, EPWU has converted the model files and recompiled the source code for use on a PC. The accompanying CD contains the PC version of the steady state and annual versions of the model.

In the future, EPWU is planning to publish additional reports that will present results from simulations using this model, and document any updates and/or enhancements to the model. In this way, the model will become a tool that is regularly used and improved.

This report is organized around the input files that constitute the model. It is intended to be a supplement to Heywood and Yager (2002). Input files for the steady state model and the annual model are described in separate sections. As appropriate, various graphs and tables are included. Prior to a presentation of the model files, a section on the modified source code is presented.

2.0 MODIFIED MODFLOW SOURCE CODE

As described in Heywood and Yager (2002), the MODFLOW source code was modified in the development of the Hueco Bolson model. Specifically, the Stream Routing package (STR) and the Multi-Aquifer Well (MAW) package were modified to better represent the historical dewatering of the aquifer due to pumping. The STR package was modified to simulate continuing stream leakage to the aquifer to the topmost active cell if the upper layer is dry. The MAW package was modified to support dewatering of model layers by omitting dry layers from the computation of head in the well and apportioning flows to or from the wells in the remaining saturated layers. The source code for these modified packages are included on the accompanying CD.

In addition to those changes made by the USGS, the source code that is included on the accompanying CD include the following modifications:

- All calls to open and write to “unformatted” files in the *bas5.for* and *utl5.for* have been changed to open and write to “binary” files in order to import the results into Groundwater Vistas, a commercially available program to graphically view results and export results to ArcView.
- A screen “counter” has been added to *modflw96.for* so that when the MODFLOW program is running, the stress period, time step and iteration is reported on the screen.
- In order to easily retrieve the volumetric budget, code was added to *bas5.for* that opens a new file as unit 78 named *wb.out*. This file contains the same volumetric water budget (in the same format) that is contained in the standard output file. This file is useful in post-processing total water budget information. The output files for the steady state and annual model are included on the accompanying CD.
- The source code for the MAW package was further modified to facilitate analysis of the model’s allocation of pumping among the layers that are intercepted by a well. With this modified code, if the MAW cell-by-cell terms are saved, a file is opened as unit 77 named *maw.out*. The data that was written to the standard output file in the original version is now written to *maw.out* in order to facilitate analysis.

3.0 STEADY STATE MODEL

The model input and output files are contained in the name file *huecoss.nam*. When MODFLOW is executed, it opens a file named *modflow.bf*, which contains a name file. The accompanying CD includes a *modflow.bf* file in the steady state directory, and it has *huecoss.nam* as its only entry.

The steady state model consists of input files are listed below:

MODFLOW Package	Input File Name
Basic	huecoss.bas
Block Centered Flow	huecoss.bcf
Horizontal Flow Barrier	huecoss.hfb
Flow and Head Boundary	huecoss.fhb
Well	huecoss.wel
Evapotranspiration	huecoss.evt
Recharge	huecoss.rch
Stream Routing	huecoss.str
Output Control	huecoss.oc
Pre-Conditioned Conjugate Gradient (Solver)	huecoss.pcg
Starting Heads	huecossshed.dat

As presented on the accompanying CD, the output files for the steady state model are as follows:

MODFLOW Package	Input File Name
Standard Output	huecoss.out
Head Save	huecoss.hds
Cell-by-Cell Flow	huecoss.cbb

Note that the cell-by-cell flow file is in binary form in order to be read as output files by Groundwater Vistas.

3.1 Basic Package

The *file huecoss.bas* contains the input data that define the model domain, active and no flow cells, the starting heads, and the time discretization. The Hueco groundwater flow model consists of 165 rows, 100 columns and 10 layers. The model grid for layer 1, showing the active and no flow areas is presented in Figure 1. The starting heads are read in the file named *huecossshed.dat.* Because this is a steady state model and time has no meaning, the time step is set to a default of one day.

3.2 Block Centered Flow Package

The file *huecoss.bcf* contains the input data that defines the horizontal anisotropy, and row and column dimensions for the entire model domain. It also includes specification of aquifer hydraulic conductivity, vertical leakance, and top and bottom elevations for each layer.

The horizontal anisotropy is specified as 1.0 (i.e. horizontal hydraulic conductivity is equal in all directions). Row and column spacing ranges from 500 meters by 500 meters to 1000 meters by 1000 meters. The model grid for layer 1 (the upper layer) is presented in Figure 2. Hydraulic conductivity distribution for each layer is presented in Figure 3 through 12. Note that the model domain becomes smaller on the east and west with depth.

Vertical leakance between layers, which is derived by dividing the vertical hydraulic conductivity by the distance between the centers of the layers for each cell, is variable and generally ranges from 10^{-3} day^{-1} to 10^{-4} day^{-1}. The leakance distribution for the model domain is presented in Figures 13 through 21.

In general, the upper surface of the model is the land surface and the bottom of layer 10 is generally 600 meters above sea level. A north-south cross section showing relative layer elevations along model column 49 is presented in Figure 22. East-west cross sections along model row 50 and row 115 are presented in Figures 23 and 24, respectively.

3.3 Horizontal Flow Barrier Package

The file *huecoss.hfb* contains input data related to faults that act as partial barriers to groundwater flow. The locations of these features are presented in Figure 25.

3.4 Flow and Head Boundary Package

The file *huecoss.fhb* contains the specified flux input data associated with inflow from the Tularosa Basin in model row 1, layers 1 through 9.

3.5 Well Package

The file *huecoss.wel* contains specified flux input data associated with inflow from the Mesilla Basin in model row 86, column 6, layer 3.

3.6 Evapotranspiration Package

The file *huecoss.evt* contains head dependent boundary data related to evapotranspiration processes from the groundwater basin. The file contains specifications for the evapotranspiration surface (essentially the land surface), the maximum evapotranspiration rate, and the extinction depth. When groundwater elevations are equal to land surface, the evapotranspiration rate is equal to the maximum rate. When depth to water in a cell is at the extinction depth, the evapotranspiration rate is zero. In between these depths, the evapotranspiration rate is a linearly interpolated. For the steady state model, the entire model domain is subject to this calculation when the depth to water is less than 5 meters.

3.7 Recharge Package

The file *huecoss.rch* contains specified flux input data related to mountain front recharge on the east side of the basin and at the base of the Organ and Franklin Mountains in the United States, and an area at the base of the Sierra Juarez in Mexico. The recharge distribution is presented in Figure 26.

3.8 Stream Routing Package

The file *huecoss.str* contains head dependent boundary data related to seepage between the shallow aquifer and the Rio Grande, Franklin Canal, Acequia Madre, and Ascarte wasteway. The file contains specification for stream stage elevation, stream bottom elevation, streambed conductance, surface flow, channel roughness and channel slope. Figure 27 presents the location of these boundary conditions in the model.

3.9 Output Control Package

The file *huecoss.oc* contains specifications for how output is written. This particular version of the file specifies saving formatted heads.

3.10 Pre-Conditioned Conjugate Gradient Package

The file *huecoss.pcg* contains specifications for the chosen solver package. Note that in this particular implementation that the head closure criterion is 1.0e-04, and the residual closure criterion is 1.00.

3.11 Starting Heads

The starting head file is named *huecossshed.dat*. This particular file is formatted.

3.12 Standard Output

The standard output is contained in the file *huecoss.out*. Note that the volumetric water budget that appears at the end of the standard output file is also contained in the file *wb.out*, as described in Section 2 of this report. For a steady state model, the repetition of the water budget is of limited use, but it becomes more useful for transient runs with many stress periods. The steady state water budget is summarized below.

Steady State Water Budget

	m^3/day	acre-feet/yr	Comments
Inflow			
WEL Package	338	100	Inflow from Mesilla
RCH Package	804	238	Mountain Front Recharge
STR Package	439,265	129,981	Rio Grande Recharge
FHB Package	20,424	6,043	Tularosa Basin Recharge
Total Inflow	460,832	136,363	
Outflow			
EVT Package	460,834	136,363	
Total Outflow	460,834	136,363	
Inflow - Outflow	-3.53	-1.04	

3.13 Head Save and Cell-by-Cell Flow

The model estimated groundwater elevations (heads) are saved in the file *huecoss.hds*, and the cell-be-cell flows are saved in the file *huecoss.cbb*. In this particular application, the heads are saved in a formatted file, and the cell-by-cell flows are saved in a binary file. The steady state head results are presented in Figure 28.

4.0 ANNUAL MODEL

The model input and output files are contained in the name file *huecoann.nam*. When MODFLOW is executed, it opens a file named *modflow.bf*, which contains a name file. The accompanying CD includes a *modflow.bf* file in the steady state directory, and it has *huecoann.nam* as its only entry.

The annual model consists of input files are listed below:

MODFLOW Package	**Input File Name**
Basic	huecoann.bas
Block Centered Flow	huecoann.bcf
Flow and Head Boundary	huecoann.fhb
Horizontal Flow Barrier	huecoann.hfb
Well	huecoann.wel
Multi Aquifer Well	huecoann.maw
Drain	huecoann.drn
Evapotranspiration	huecoann.evt
Recharge	huecoann.rch
Stream Routing	huecoann.str
Output Control	huecoann.oc
Pre-Conditioned Conjugate Gradient (Solver)	huecoann.pcg
Interbed Storage	huecoann.ibs
Starting Heads	huecoss.hds

As presented on the accompanying CD, the output files for the annual state model are as follows:

MODFLOW Package	**Input File Name**
Standard Output	huecoann.out
Head Save	huecoann.hds
Cell-by-Cell Flow	huecoann.cbb

Note that the head save and cell-by-cell flow files are in binary form in order to be read as output files by Groundwater Vistas.

4.1 Basic Package

The *file huecoann.bas* contains the input data that define the model domain, active and no flow cells, the starting heads, and the time discretization. The model domain and active and no flow specifications are identical to the steady state model. The starting heads are read in the file named *huecoss.hds*, which is the steady state head output file. The annual model uses annual time steps and covers the period 1903 to 1996.

4.2 Block Centered Flow Package

The file *huecoann.bcf* contains the input data that defines the horizontal anisotropy, and row and column dimensions for the entire model domain. It also includes specification of aquifer hydraulic conductivity, vertical leakance, specific yield, storativity, and top and bottom elevations for each layer.

The horizontal anisotropy, row and column dimensions, hydraulic conductivity, vertical leakance, and top and bottom elevations are all identical to those of the steady state model. Specific yield is estimated to be 0.177 (dimensionless) for all layers. Storativity for layers 2 through 9 is estimated to be 2.51e-05 (dimensionless). Storativity for layer 10 is estimated to be 8.44e-07 multiplied by the thickness. The estimated areal distribution of storativity for layer 10 is presented in Figure 29.

4.3 Flow and Head Boundary Package

The file *huecoann.fhb* contains the specified flux input data associated with inflow from the Tularosa Basin in model row 1, layers 1 through 9. These data are identical to those used in the steady state model.

4.4 Horizontal Flow Barrier Package

The file huecoann.hfb contains input data related to faults that act as partial barriers to groundwater flow. The locations of these features are identical to those used in the steady state model.

4.5 Well Package

The file *huecoann.wel* contains specified flux input data related to inflow from the Mesilla, as was simulated in the steady state model. In addition, pumping from 32 wells that are screened within a single model layer is included in the well package.

4.6 Multi Aquifer Well Package

The file huecoann.maw contains data related to pumping wells that are screened in multiple layers. A detailed description of the method is provided in Heywood and Yager (2002).

4.7 Drain Package

The file *huecoann.drn* contains head dependent boundary data related to drains. This boundary condition allows water to discharge from the groundwater system if the head is above the drain boundary head. The movement is controlled through a drain conductance term. The location of the drains is presented in Figure 30.

During the simulation, there are no drains from 1903 to 1924. From 1925 to 1996, the 427 drain cells are activated with unchanging boundary elevations and conductance values. The addition of the drains represents the change from essentially nonirrigated and undrained to irrigated and drained agricultural conditions in the Rio Grande Valley in 1925 (Heywood and Yager (2002).

4.8 Evapotranspiration Package

The file *huecoann.evt* contains head dependent boundary data related to evapotranspiration processes from the groundwater basin. As with the steady state model, the file contains specifications for the evapotranspiration surface (essentially the land surface), the maximum evapotranspiration rate, and the extinction depth. The land surface is read from the file *evt.surface-mean_ned*. The maximum evapotranspiration from 1903 to 1924 is read from the file *etratesp0.dat*. This is equivalent to the steady state model (the entire model domain is subject to the evapotranspiration calculation when depth to water is less than 5 meters).

The maximum evapotranspiration rate from 1925 to 1996 is read from the file *etratesp23.dat*. The maximum rate remains the same, but the area of irrigated agriculture is removed from the calculation. The area where the evapotranspiration calculation is made when depth to water is less than 5 meters is presented in Figure 31.

4.9 Recharge Package

The file *huecoann.rch* contains specified flux data related to mountain front recharge on the east side of the basin and at the base of the Organ and Franklin Mountains in the United States, and an area at the base of the Sierra Juarez in Mexico. These recharge estimates are identical to those used in the steady state model.

From 1925 to 1996 (Stress Periods 23 to 94), the recharge package also includes recharge from irrigated fields in the United States and Mexico. The distribution of recharge for this period is presented in Figure 32.

The recharge rates shown in Figure 32 represent the maximum rate. As discussed in Heywood and Yager (2002):

> "The maximum recharge rate is the amount of water typically applied in excess of crop requirements in the United States (Al Blair, oral commun., 2000).. During drought and low-flow years, this maximum

> rate was scaled so that applied irrigation water would not exceed total available surface water."

Figure 33 presents the scaling that is contained in the input file. Note that the scaling factor is not only applied to the recharge from irrigated fields, it is also applied to the mountain front recharge estimates.

4.10 Stream Routing Package

The file *huecoann.str* contains head dependent boundary data related to seepage between the shallow aquifer and the Rio Grande, Franklin Canal, Acequia Madre, and Ascarte wasteway. The file contains specification for stream stage elevation, stream bottom elevation, streambed conductance, surface flow, channel roughness and channel slope. The location of the streams is the same as the steady state model.

4.11 Output Control Package

The file *huecoann.oc* contains specifications for how output is written. This particular version of the file specifies saving heads and cell-by-cell flows for each stress period.

4.12 Pre-Conditioned Conjugate Gradient Package

The file *huecoann.pcg* contains specifications for the chosen solver package. Note that in this particular implementation that the head closure criterion is 1.0e-03, and the residual closure criterion is 1.00.

4.13 Interbed Storage Package

The file *huecoann.ibs* contains data related to elastic and inelastic compaction of the aquifer due to reduction in groundwater elevation. Compaction is assumed to occur in all layers. The preconsolidation head array for layer 1 is read in file *HC1.array*. The preconsolidation head array for layers 2 through 10 is read in file *HC2.array*. The elastic storage factor for all layers is estimated to be 2.1e-04. The inelastic storage factor for all layers is estimated to be 2.0e-03. No previous consolidation is assumed (i.e. Com=0).

4.14 Starting Heads

The starting head file is named *huecoss.hds*, which is the saved steady state head file. This particular file is formatted.

4.15 Standard Output

The standard output is contained in the file *huecoann.out*. Note that the volumetric water budget that appears at the end of each stress period of the standard output file is also contained in the file *wb.out*, as described in Section 2 of this report. A summary of the water budget is presented in Tables 1 and 2. Table 1 presents the annual flows in m^3/day; Table 2 presents the annual flows in acre-feet/yr.

Also note that the standard MAW output that traditionally appears in the standard output file now appears in the file *maw.out*.

4.16 Head Save and Cell by Cell Flows

The model estimated groundwater elevations (heads) are saved in the file *huecoann.hds*, and the cell-be-cell flows are saved in the file *huecoann.cbb*. In this particular application, the heads and the cell-by-cell flows are saved in binary files.

5.0 CONCLUSIONS AND PLANS FOR FUTURE WORK

The groundwater flow model developed by the USGS is the latest in a series of investigations and models by the USGS and other investigators. As more data are collected and additional studies are completed, this model can be updated and enhanced. In the interim, this model can be used to evaluate various scenarios related to managing the groundwater resource.

The most significant new study that is just starting involves the collection, analysis and interpretation of carbon-14, tritium and stable isotope data. This binational investigation is being coordinated by Barry Hibbs of California State University, Los Angeles. This study will provide insight into the flow patterns and recharge in the Hueco Bolson. This study will be an important component in the enhancement and refinement of the conceptual model that underlies the USGS flow model.

As the model is used by a variety of organizations and individuals, it will become necessary to exchange data, information and ideas regarding the model. In order to facilitate this exchange, it would be beneficial to hold regular (annual) meetings to present results of studies that are relevant to model evolution. These meetings would help all interested parties to learn how the model is being used, and to identify data gaps and model limitations. Most importantly, the meetings would provide a common forum to advance the model by closing data gaps and generally addressing its limitations.

REFERENCES

Heywood, C.E. and Yager, R.M., 2002. Simulated Ground-Water Flow in the Hueco Bolson, an Alluvial Basin Aquifer near El Paso, Texas. U.S. Geological Survey Water-Resources Investigations Report 01-XXXX.

Figure 1
Model Domain
Layer 1

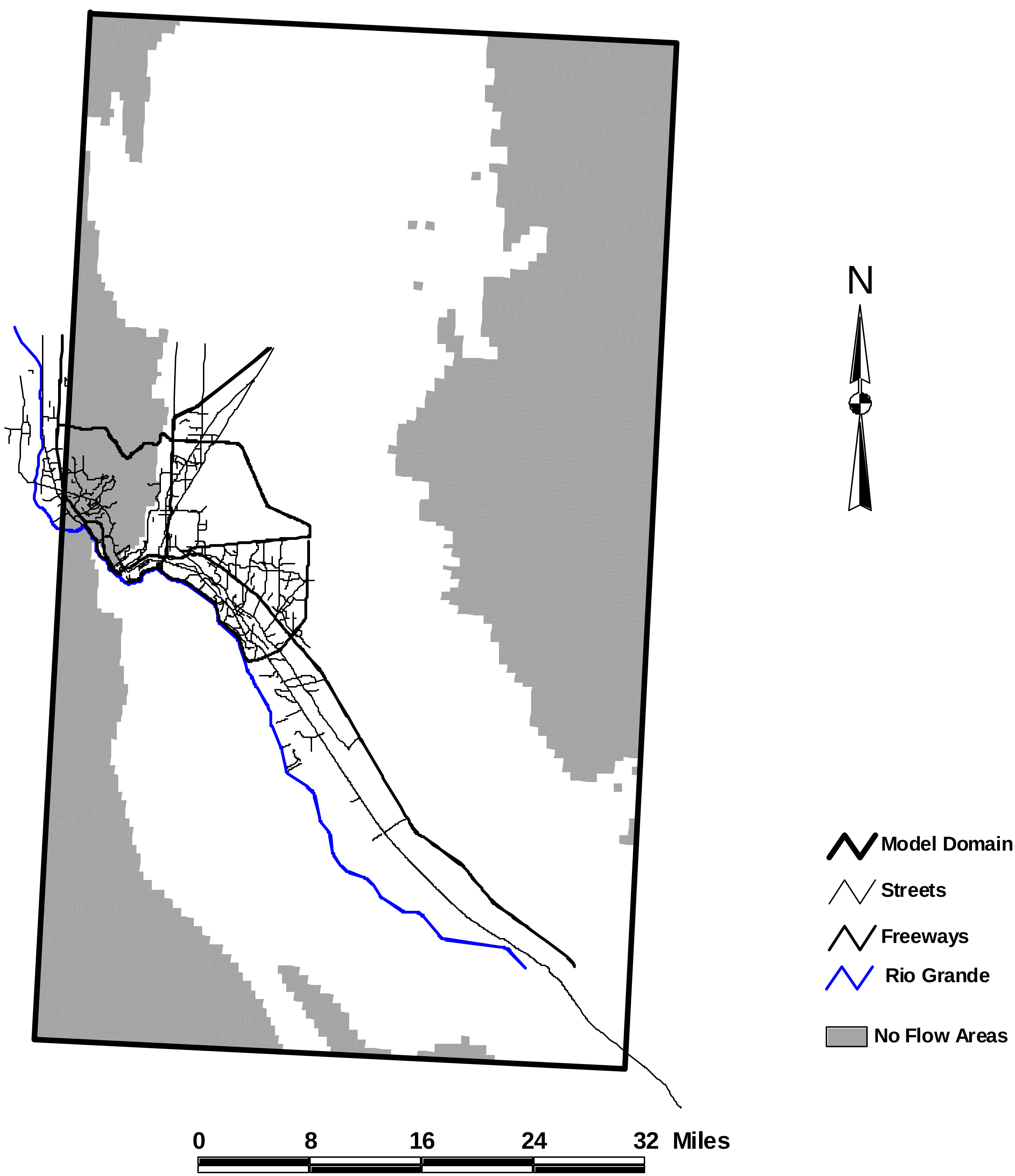

Figure 2
Model Grid
Layer 1

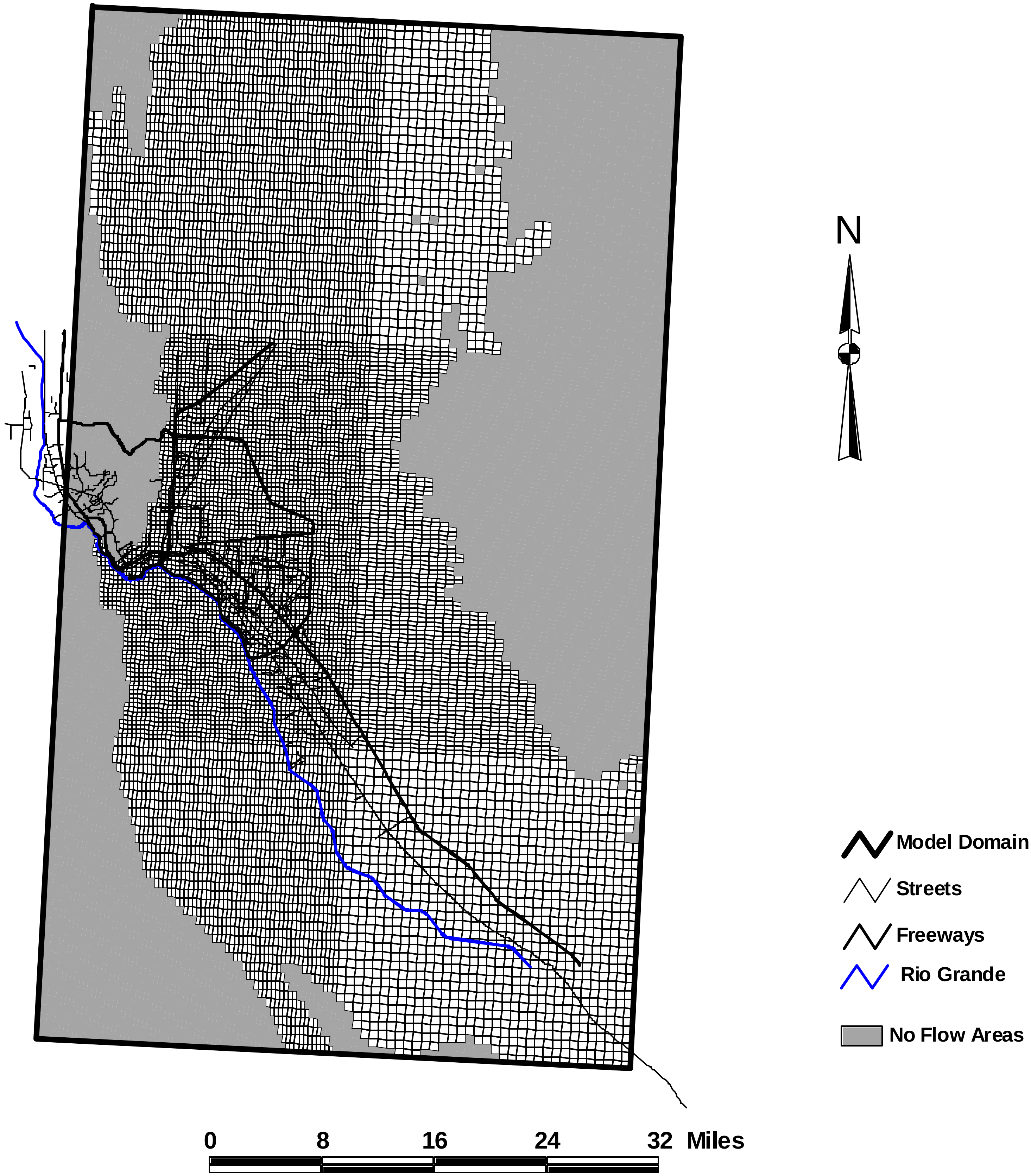

Figure 3
Hydraulic Conductivity Distribution
Layer 1

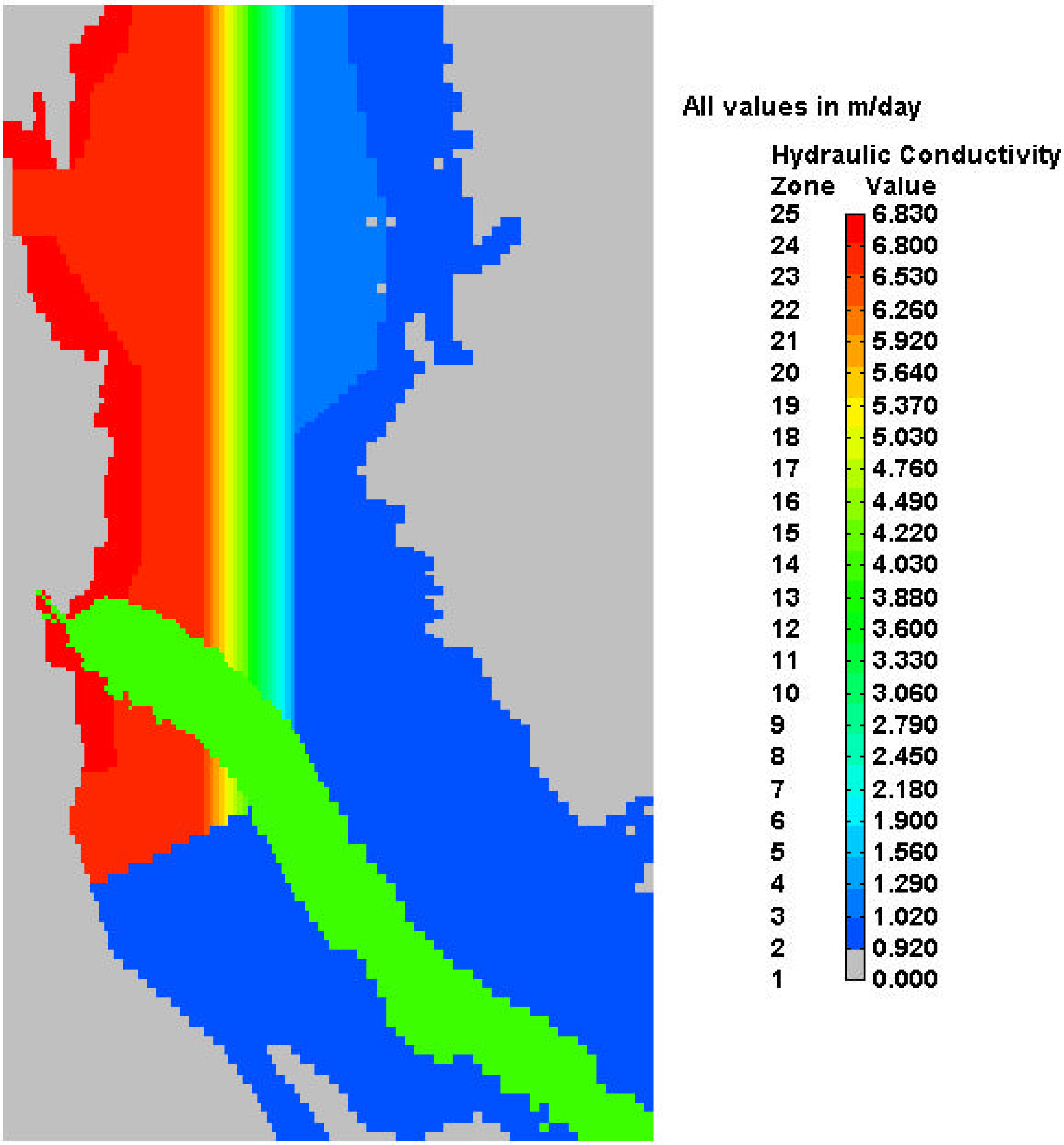

Figure 4
Hydraulic Conductivity Distribution
Layer 2

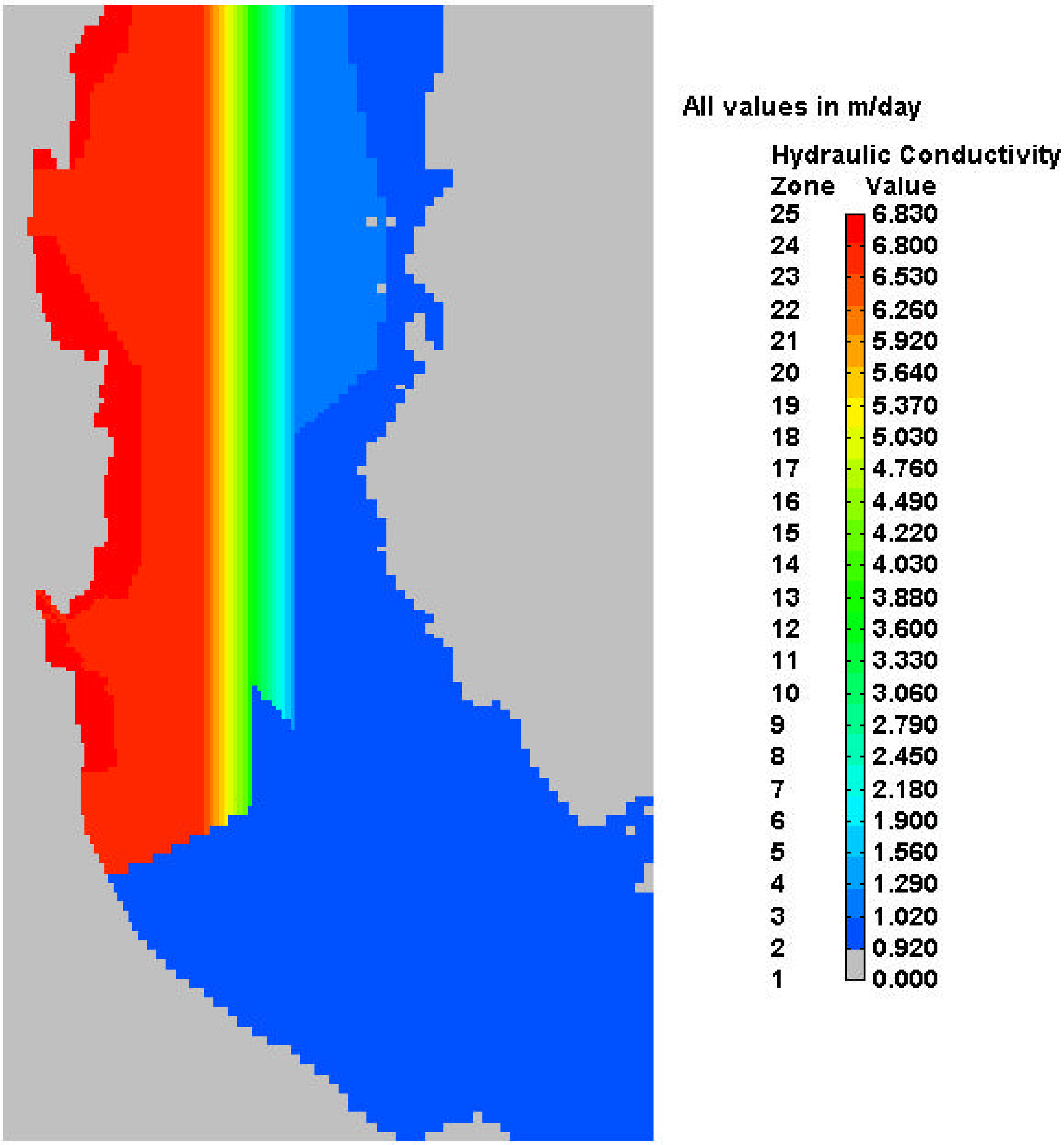

Figure 5
Hydraulic Conductivity Distribution
Layer 3

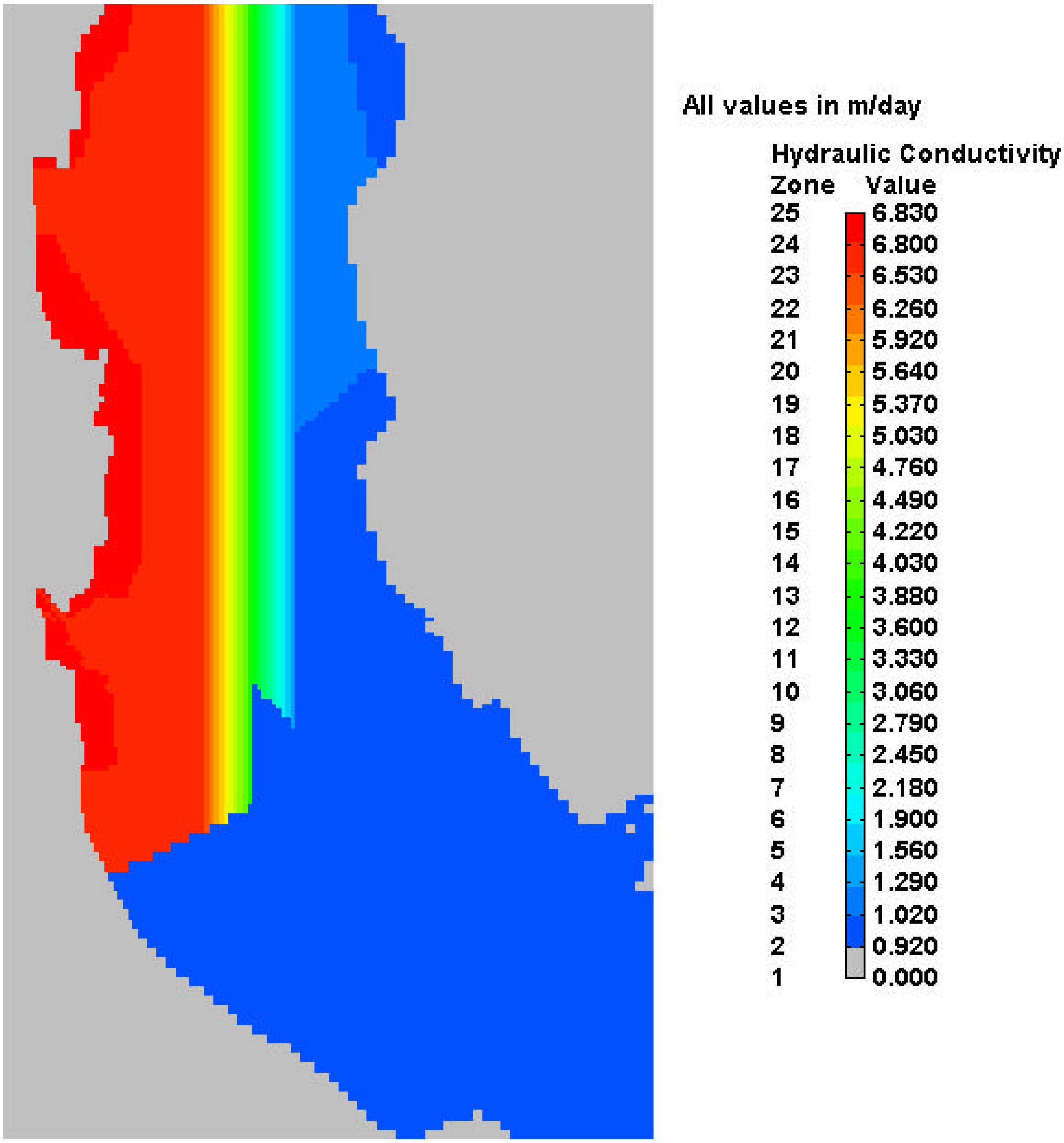

Figure 6
Hydraulic Conductivity Distribution
Layer 4

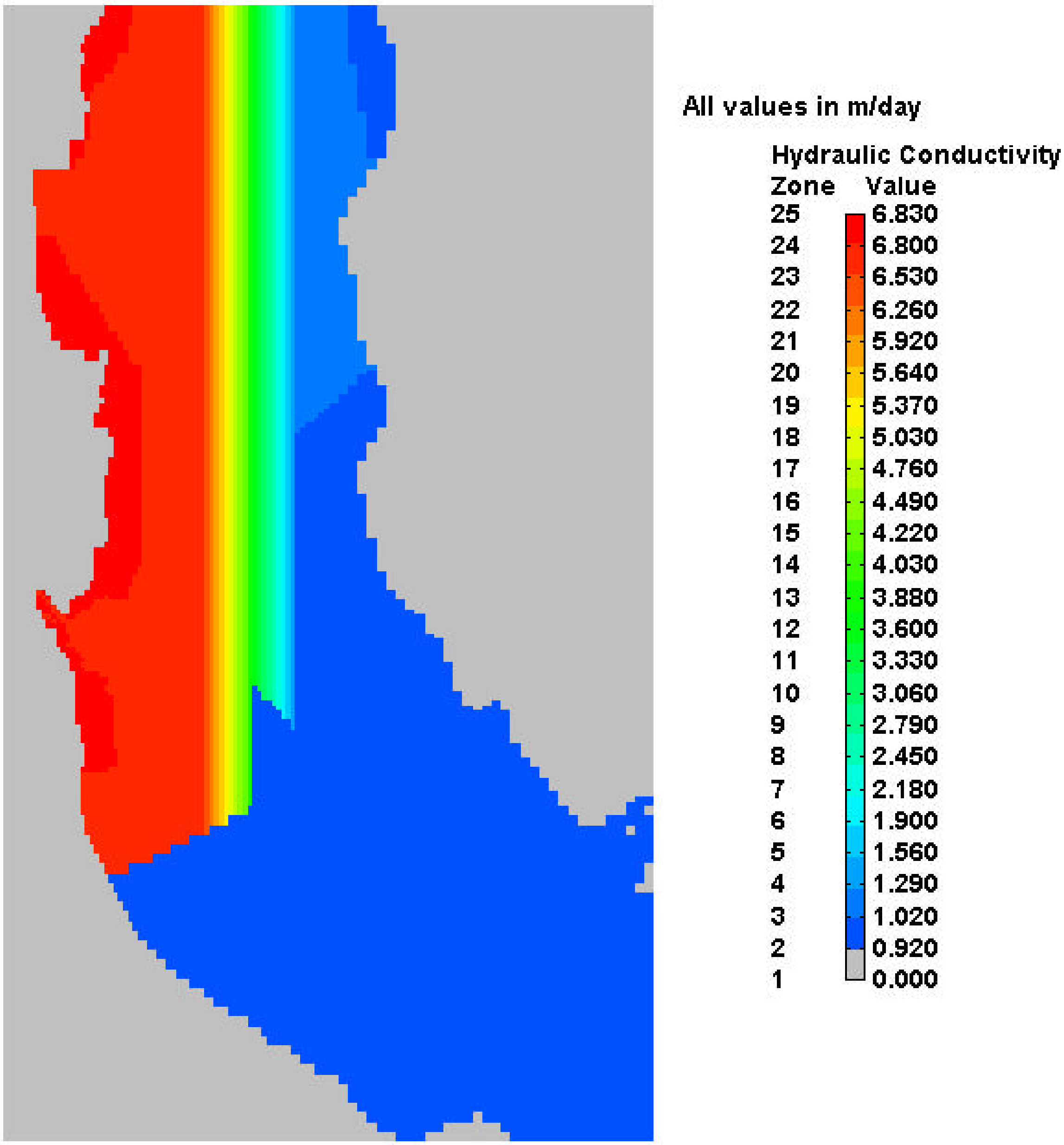

Figure 7
Hydraulic Conductivity Distribution
Layer 5

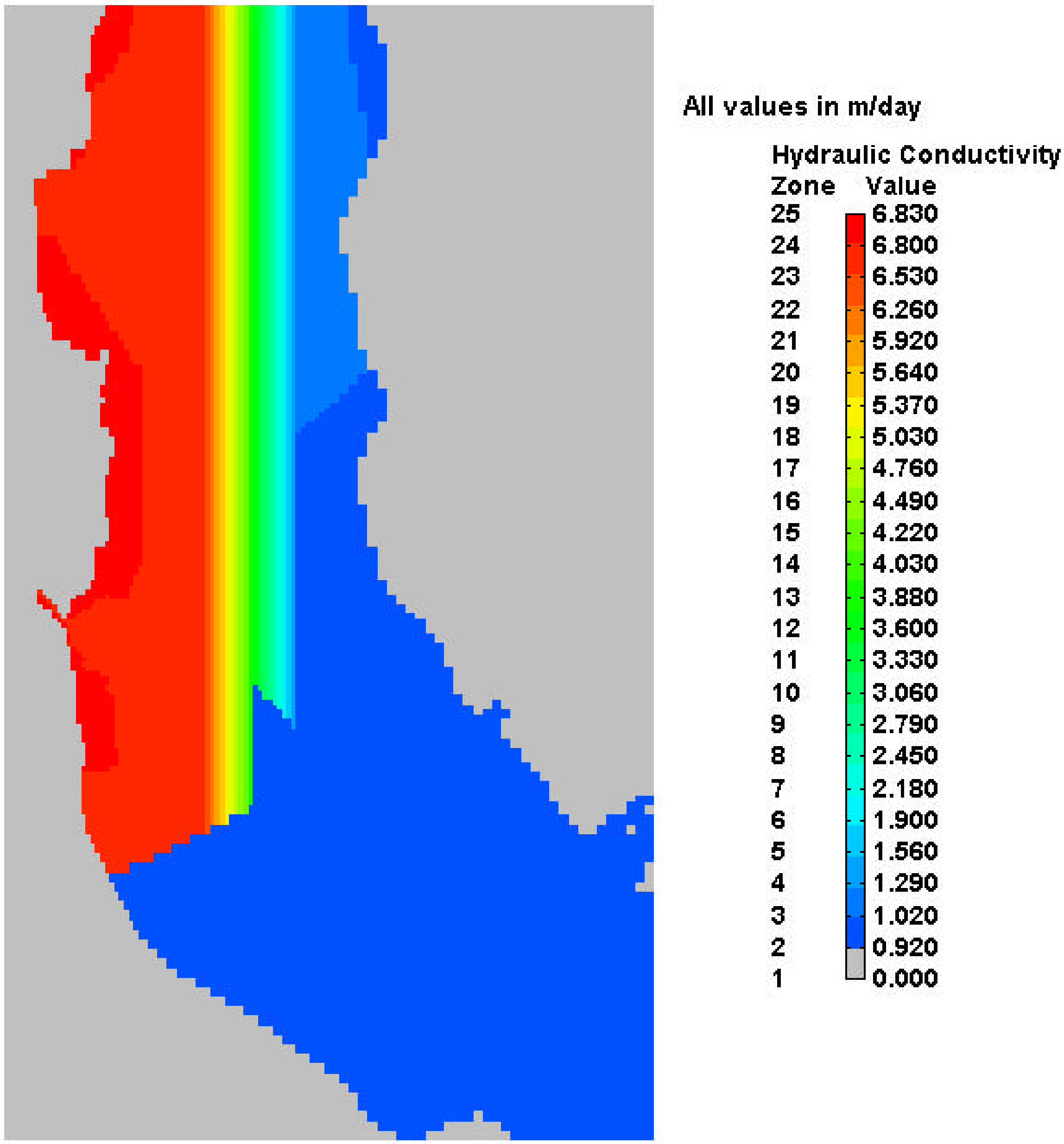

Figure 8
Hydraulic Conductivity Distribution
Layer 6

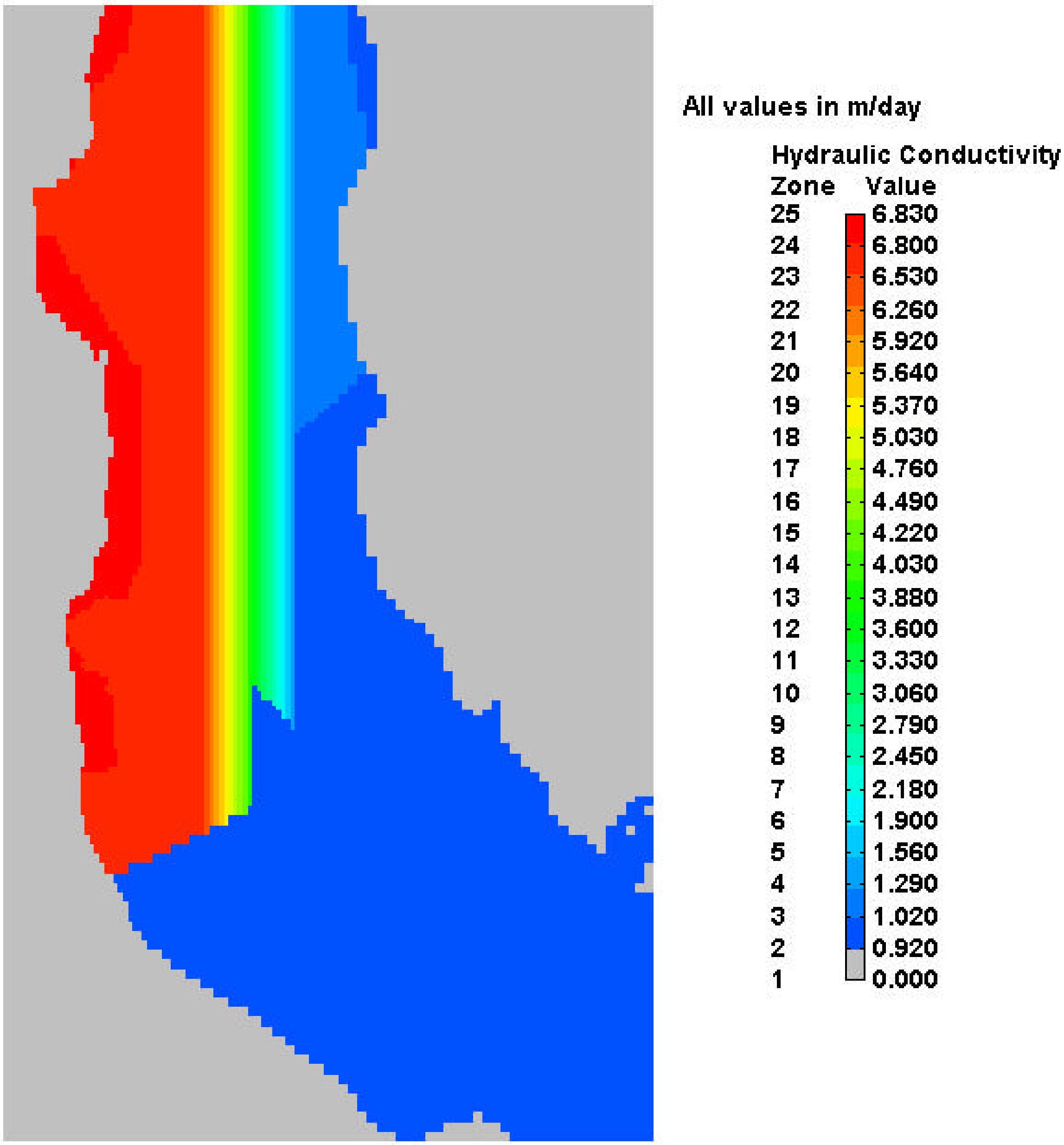

Figure 9
Hydraulic Conductivity Distribution
Layer 7

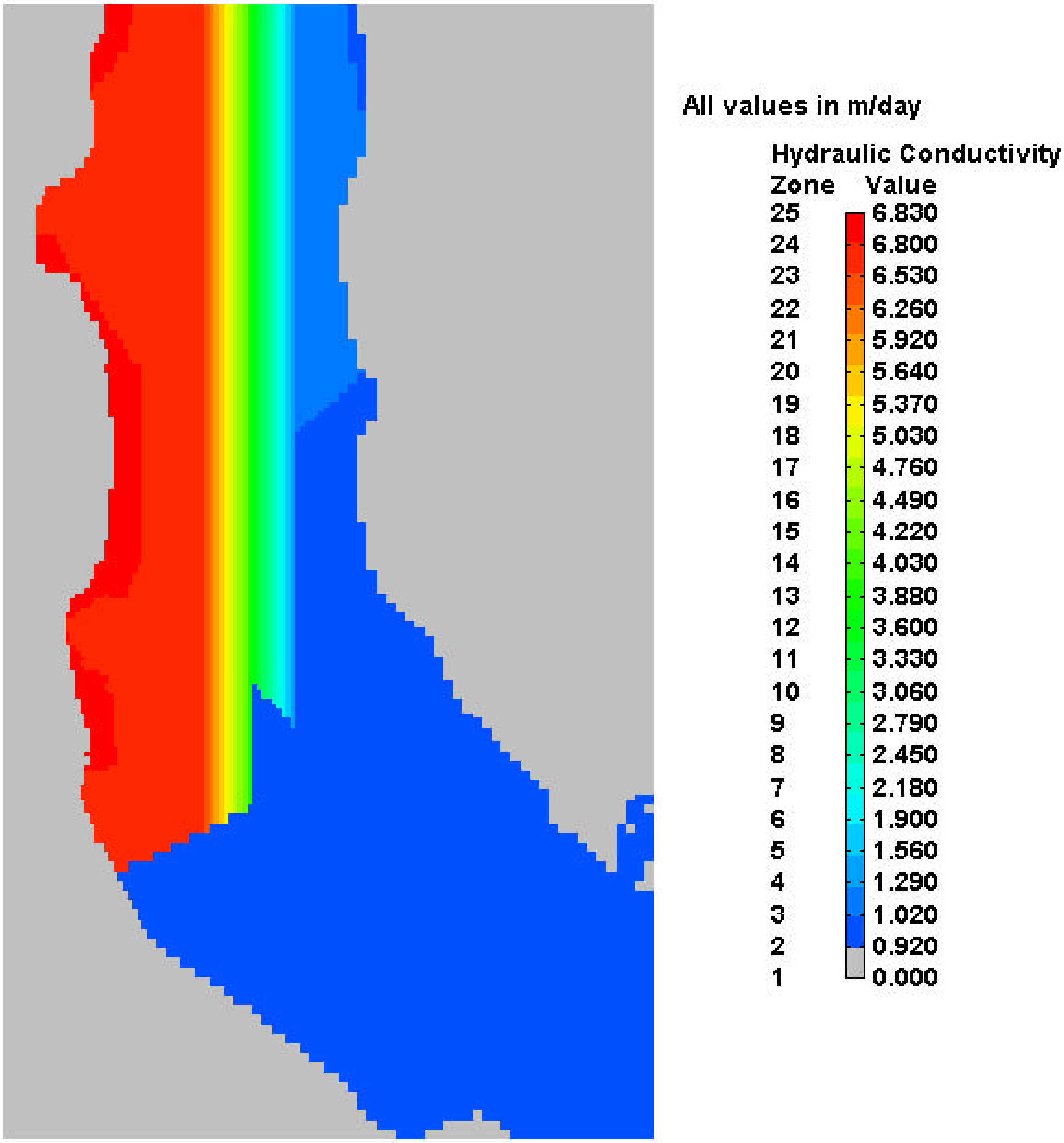

Figure 10
Hydraulic Conductivity Distribution
Layer 8

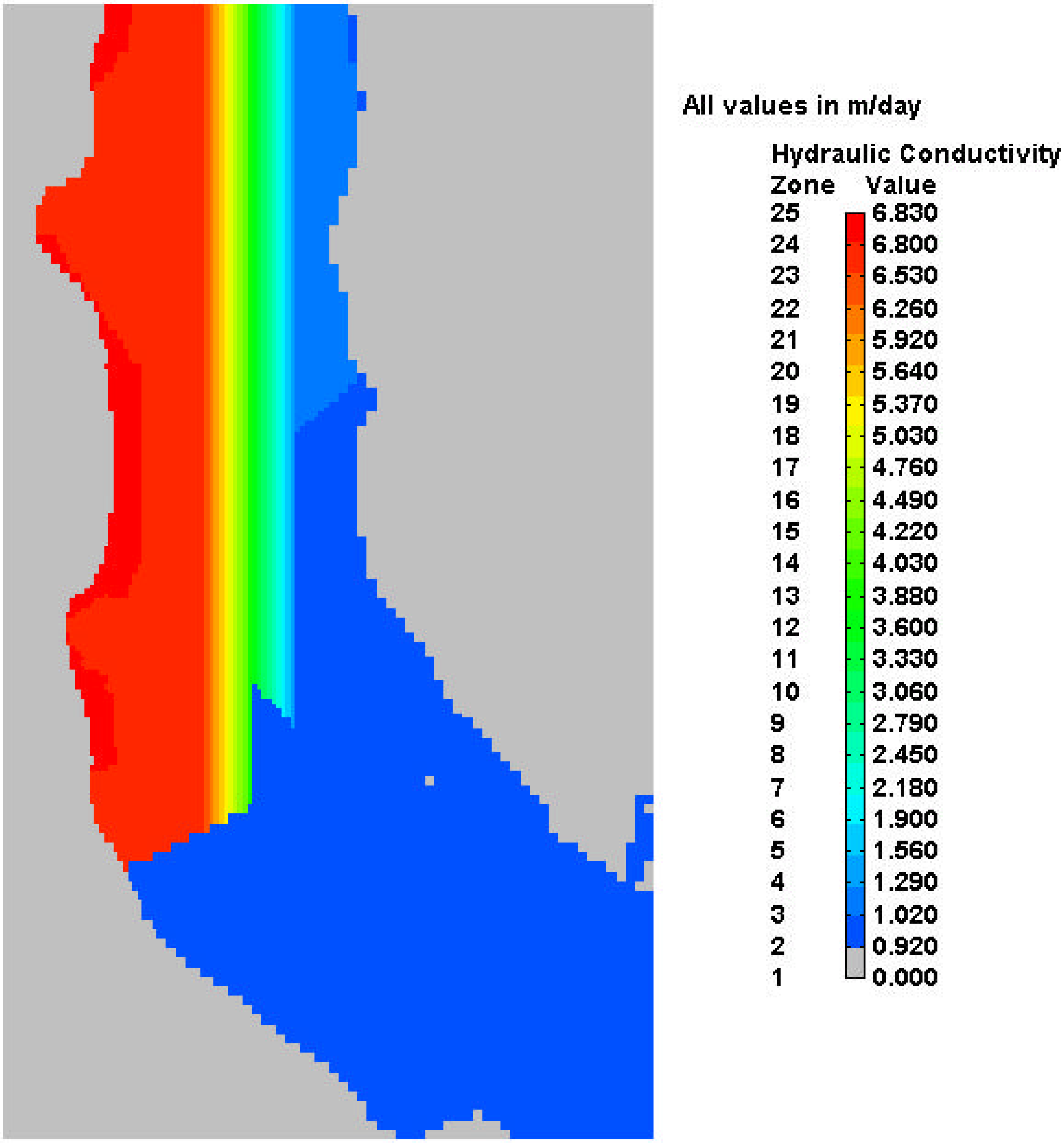

Figure 11
Hydraulic Conductivity Distribution
Layer 9

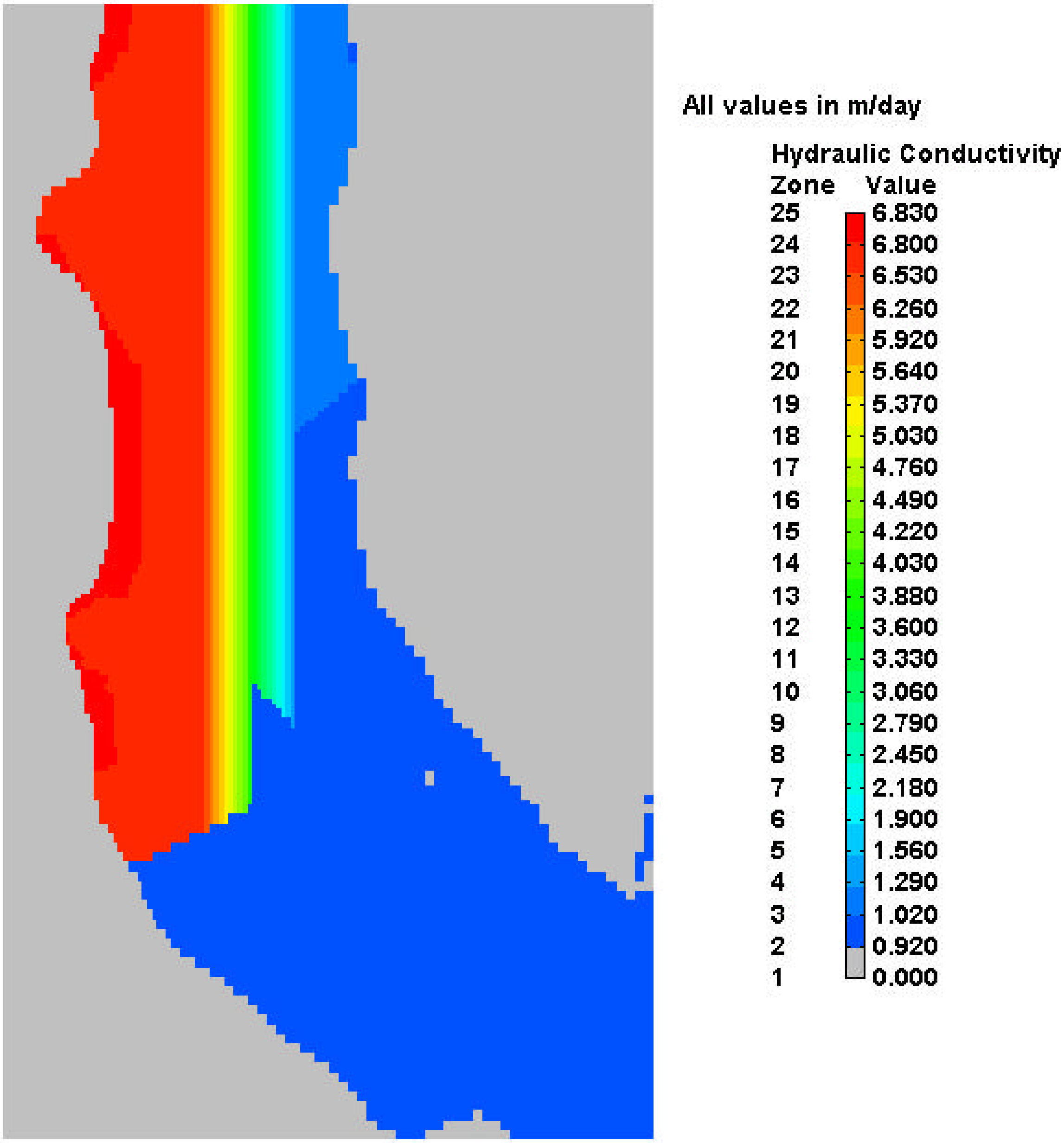

Figure 12
Hydraulic Conductivity Distribution
Layer 10

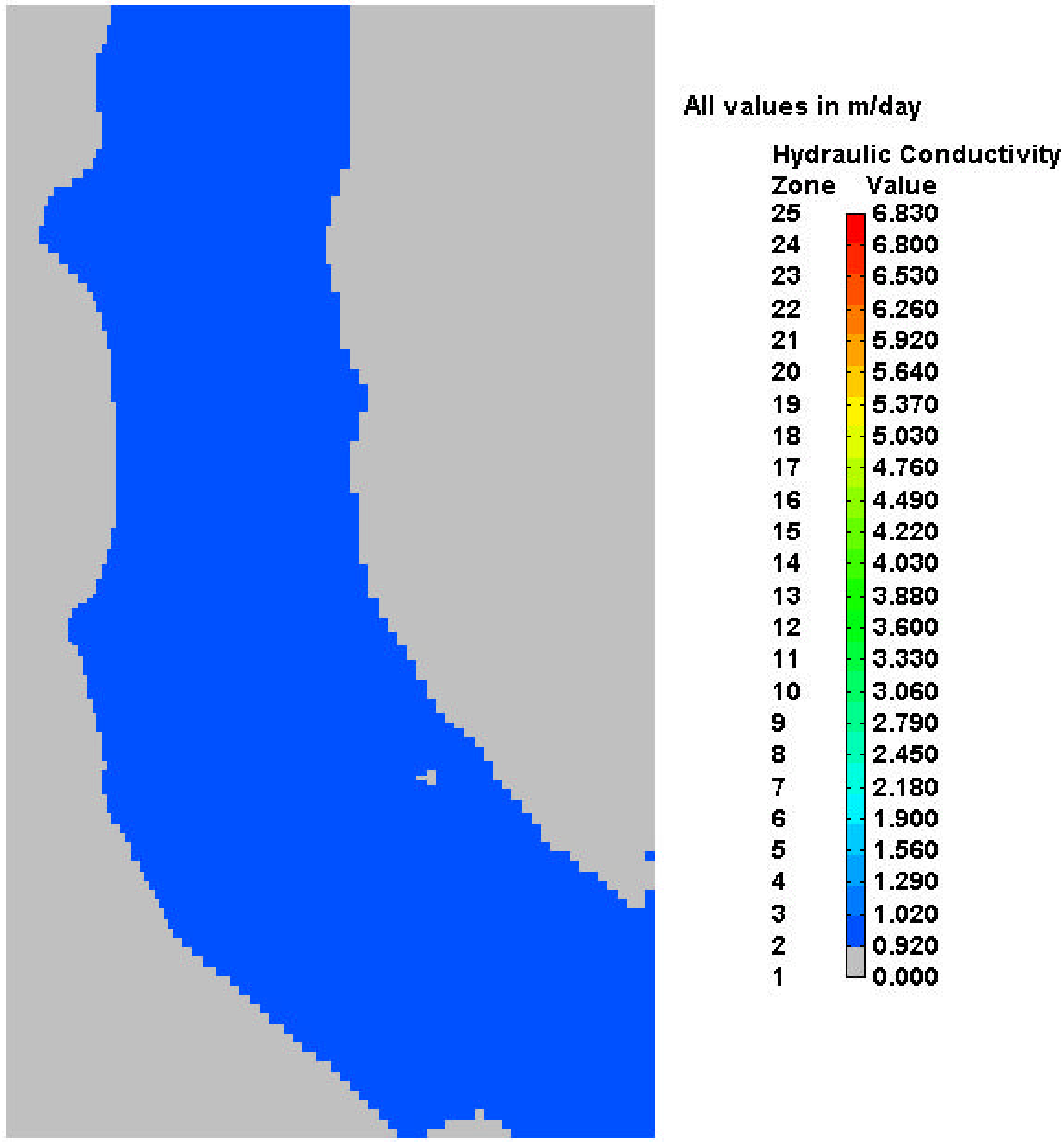

Figure 13
Vertical Leakance Distribution
Layers 1 and 2

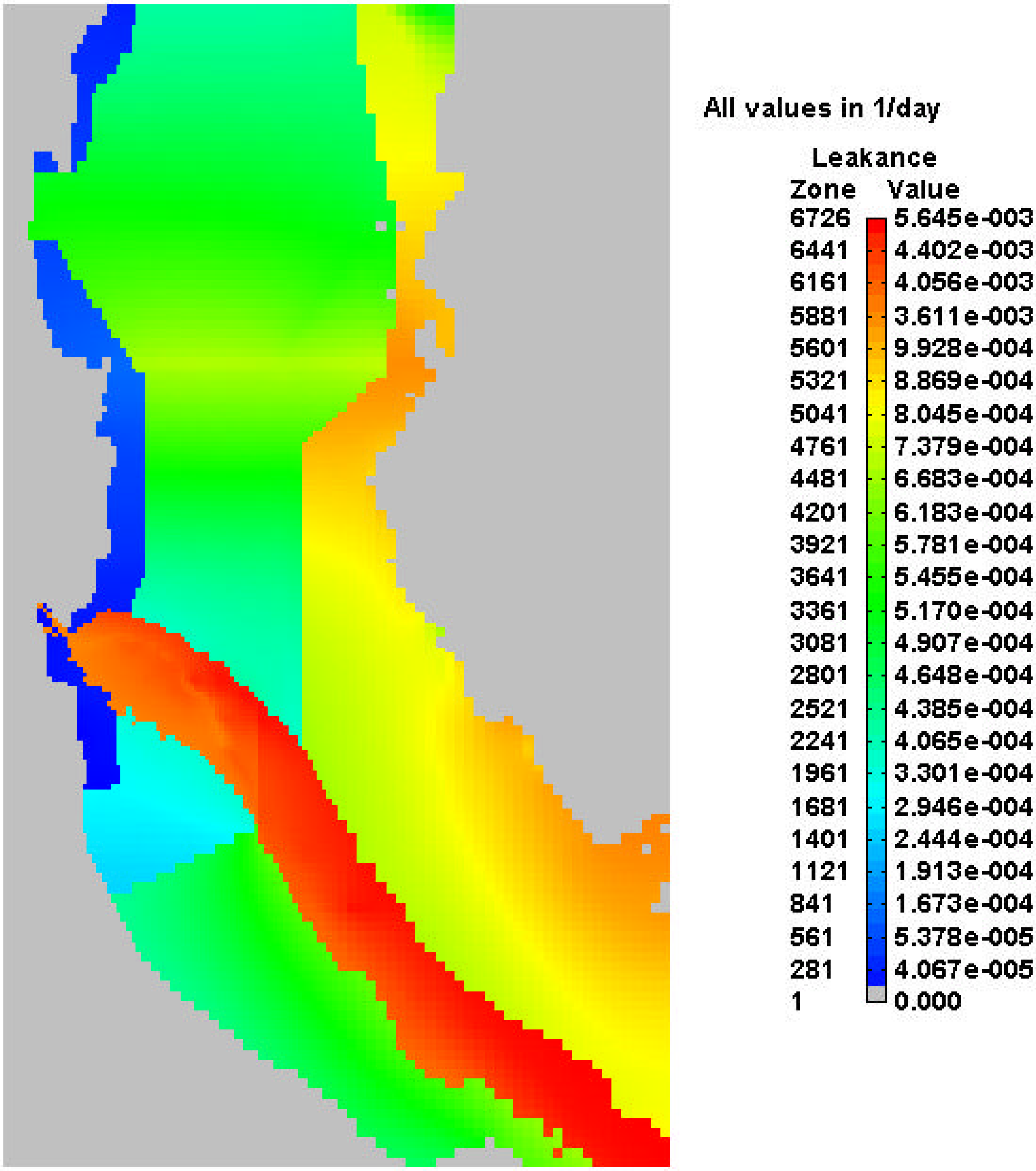

Figure 14
Vertical Leakance Distribution
Layers 2 and 3

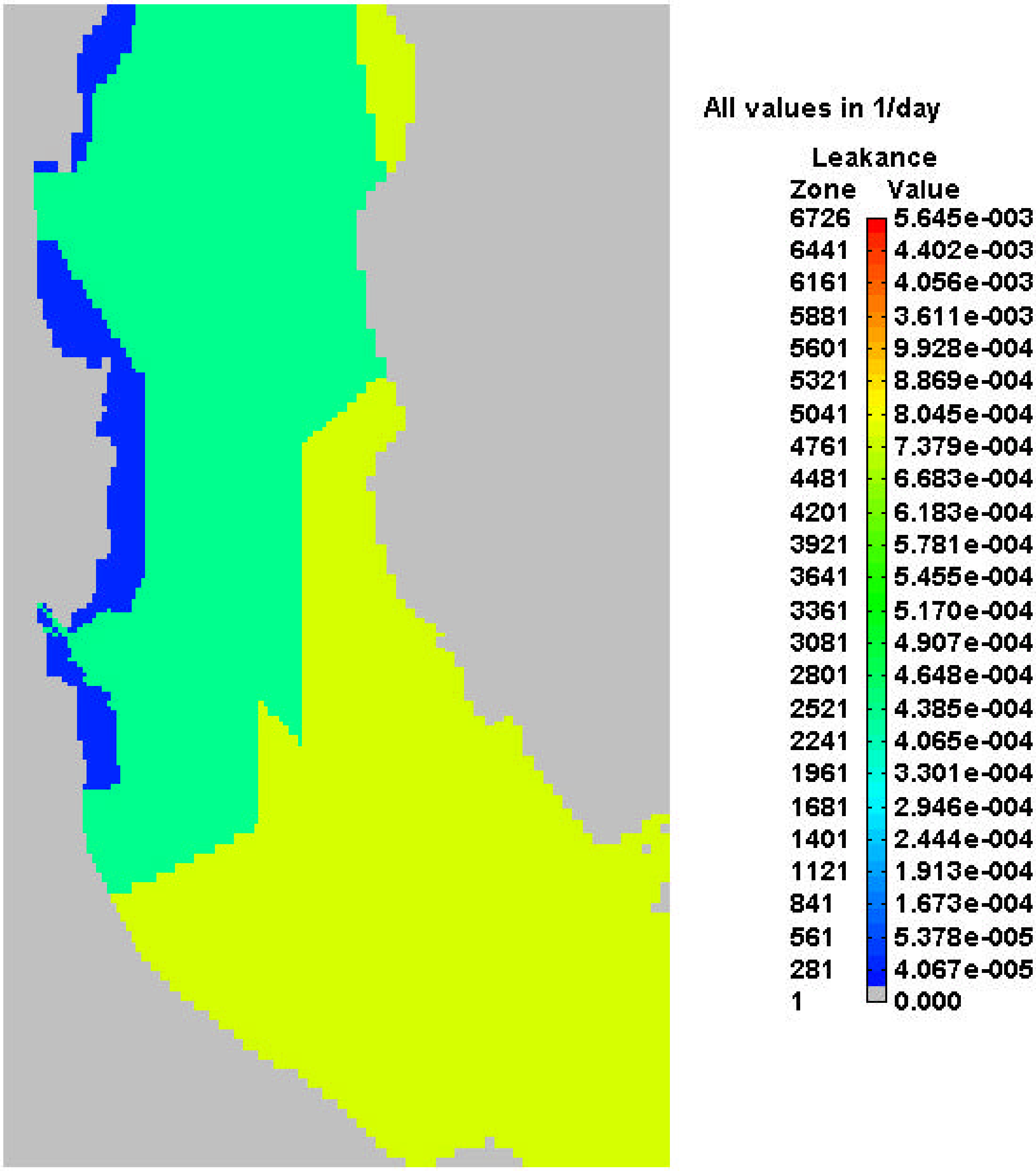

Figure 15
Vertical Leakance Distribution
Layers 3 and 4

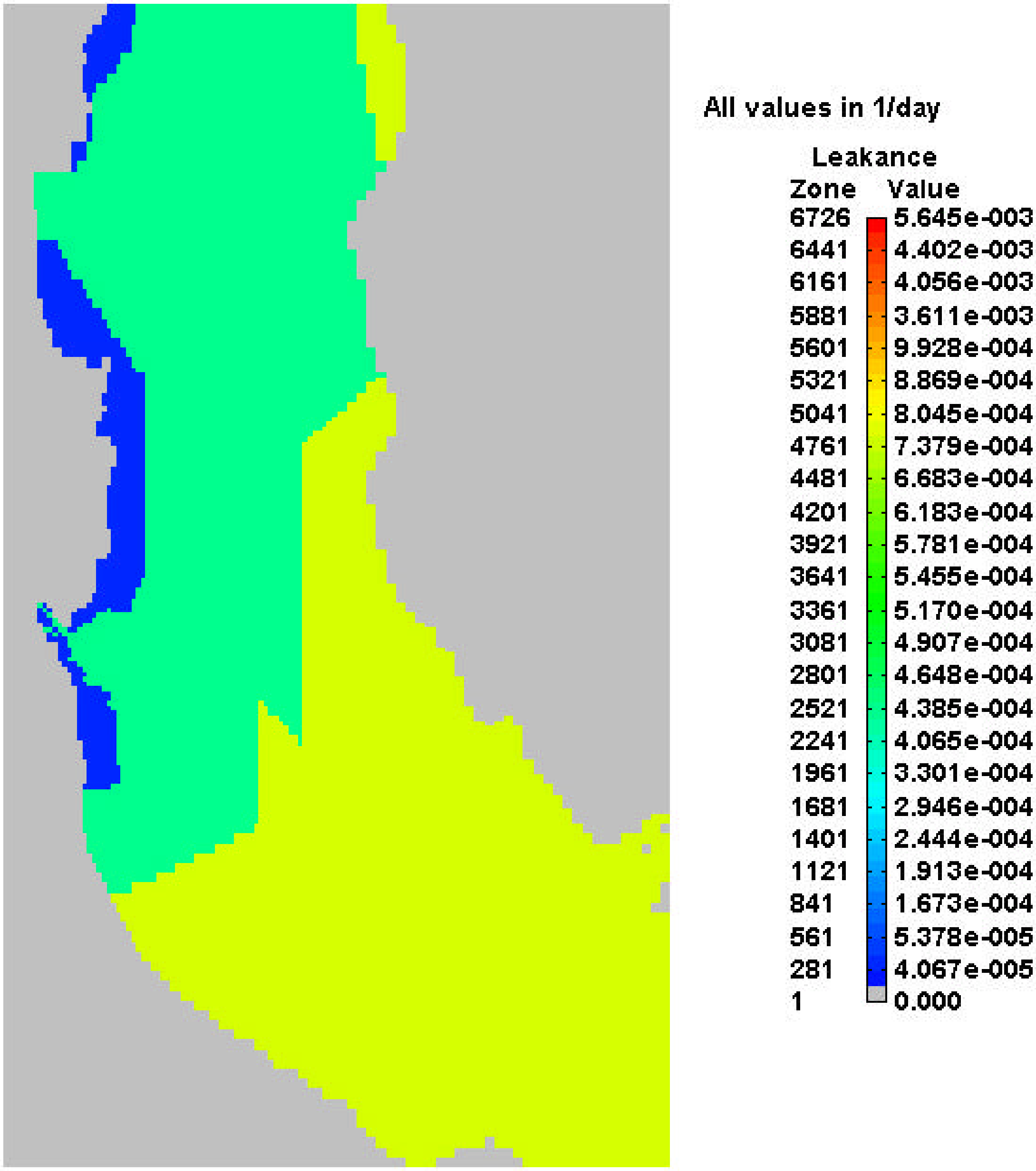

Figure 16
Vertical Leakance Distribution
Layers 4 and 5

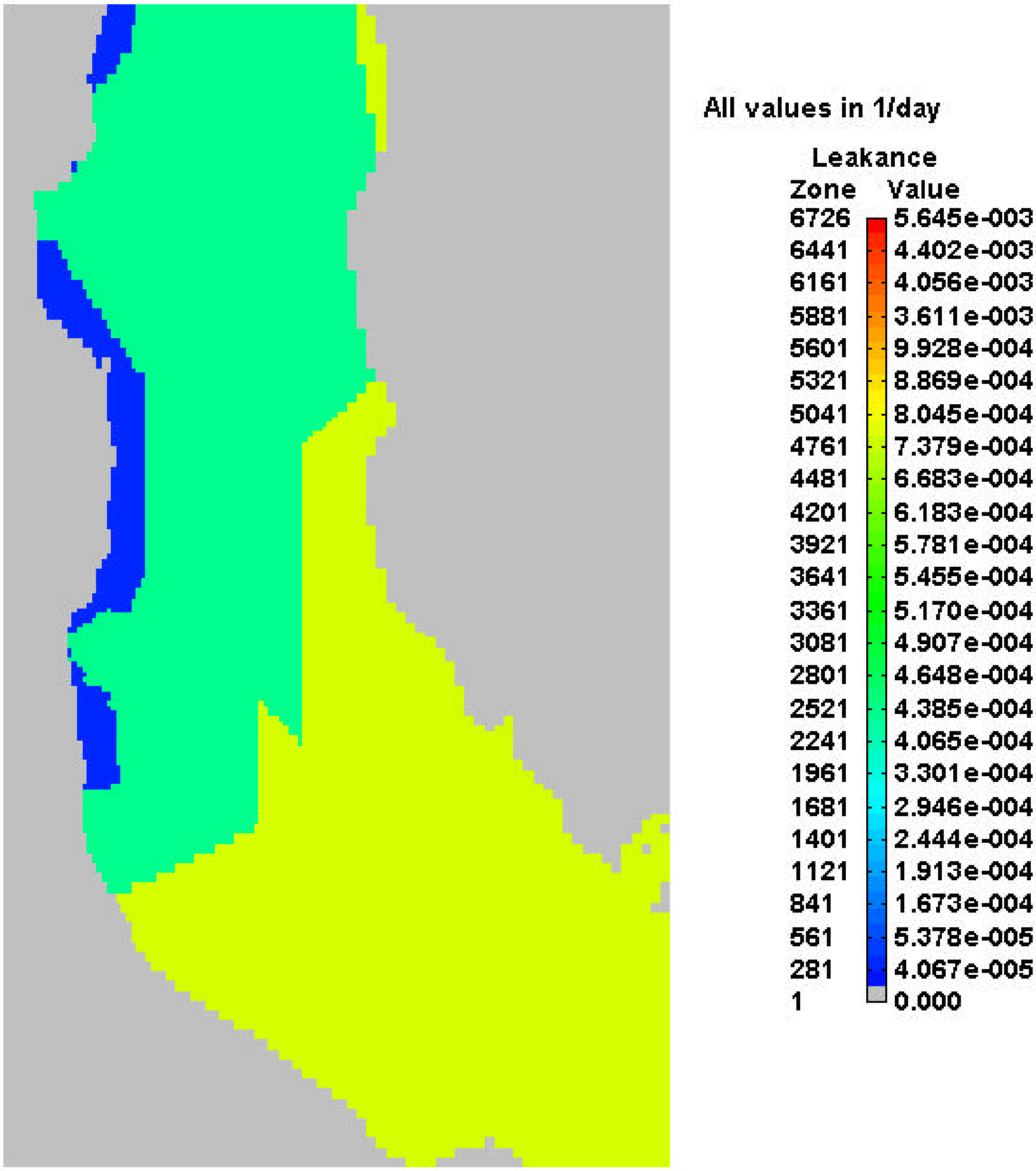

Figure 17
Vertical Leakance Distribution
Layers 5 and 6

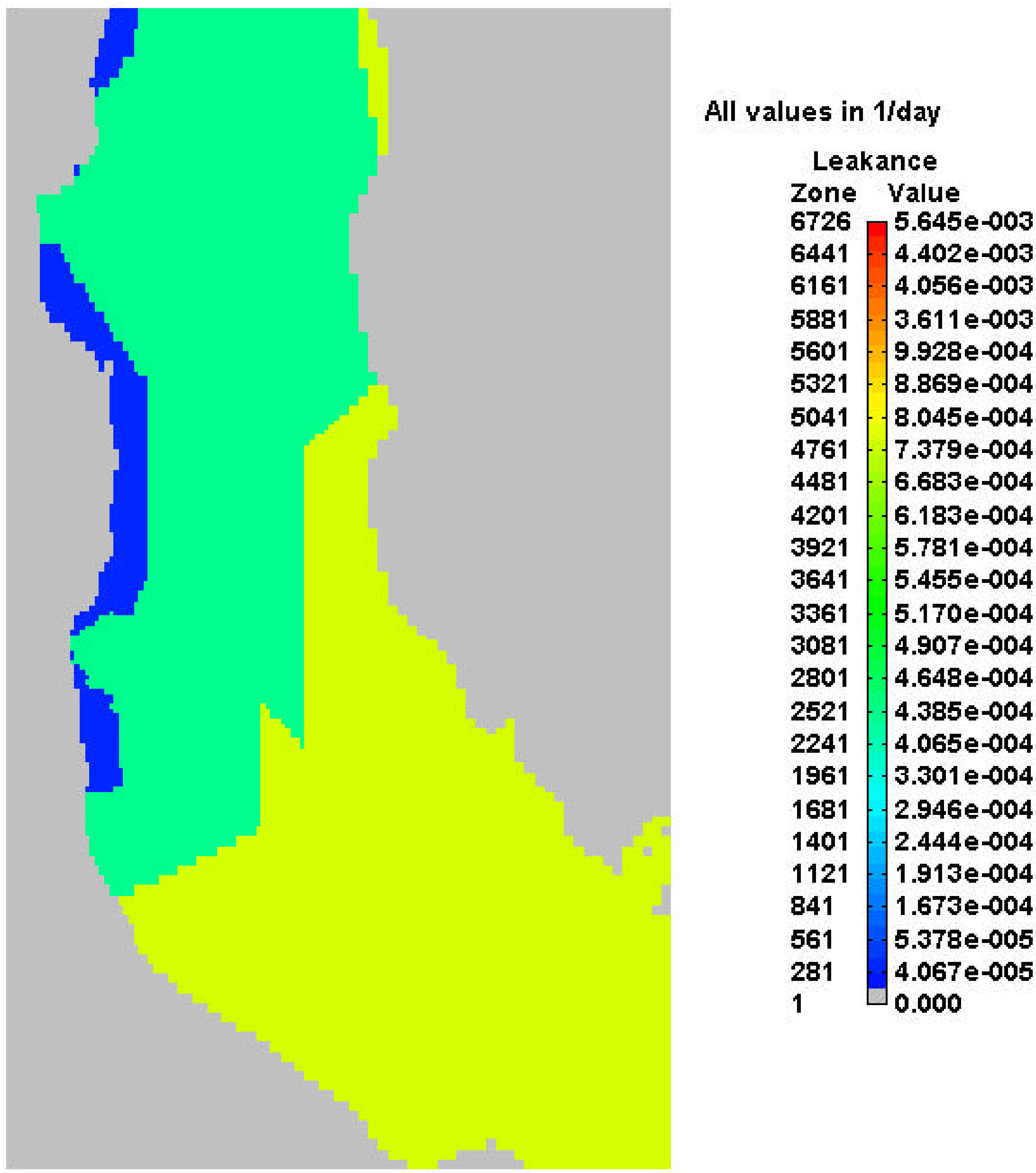

Figure 18
Vertical Leakance Distribution
Layers 6 and 7

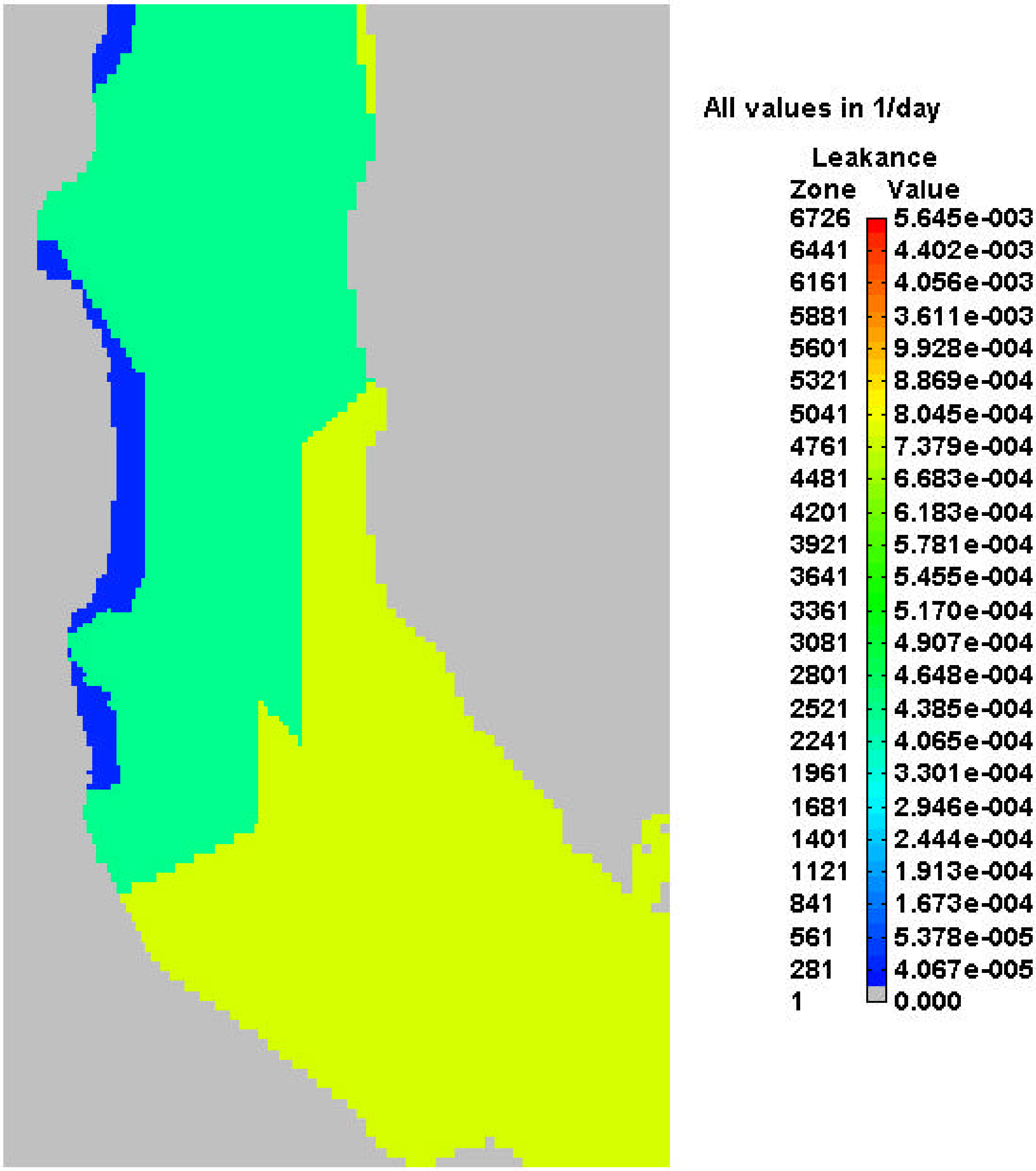

Figure 19
Vertical Leakance Distribution
Layers 7 and 8

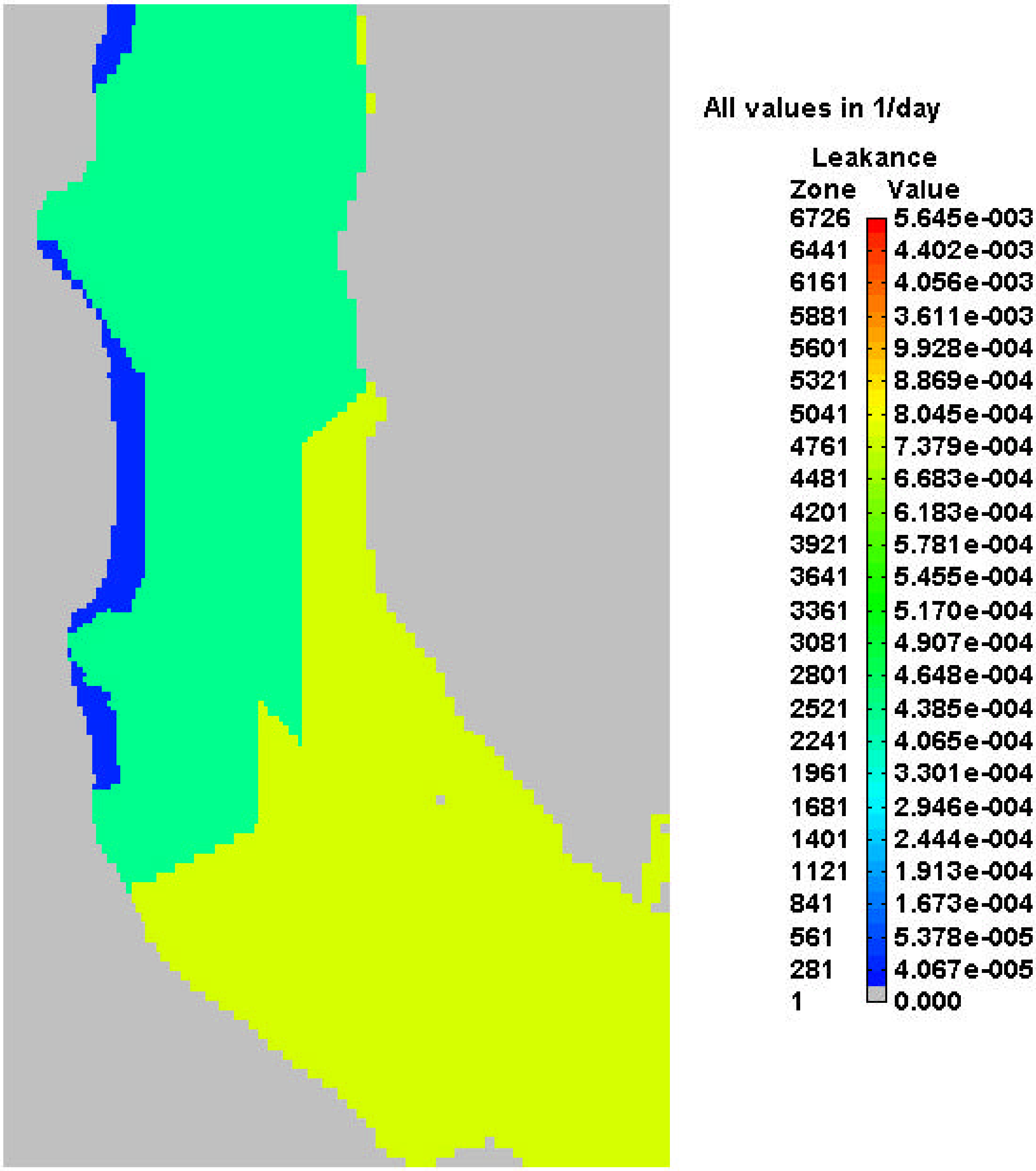

Figure 20
Vertical Leakance Distribution
Layers 8 and 9

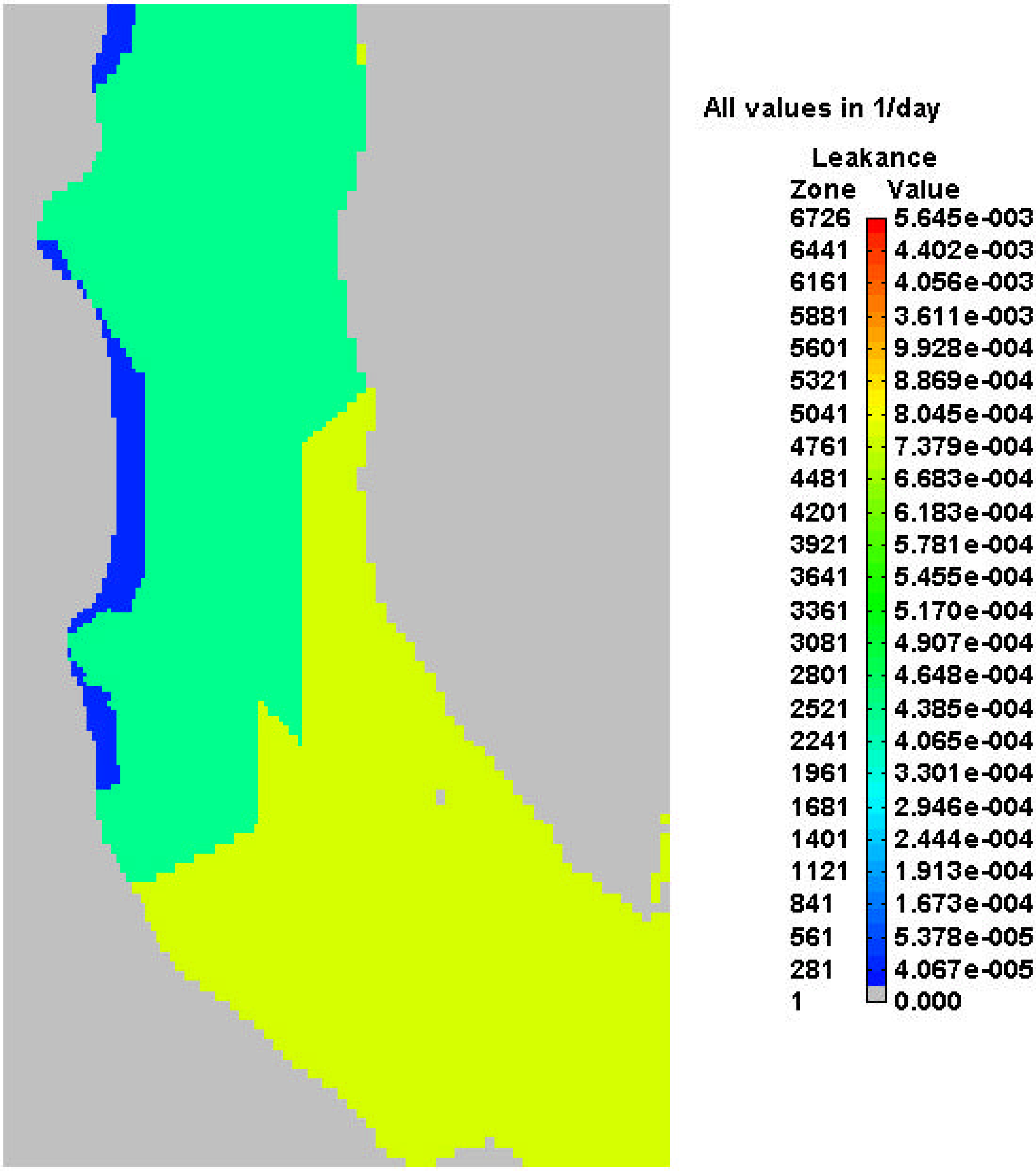

Figure 21
Vertical Leakance Distribution
Layers 9 and 10

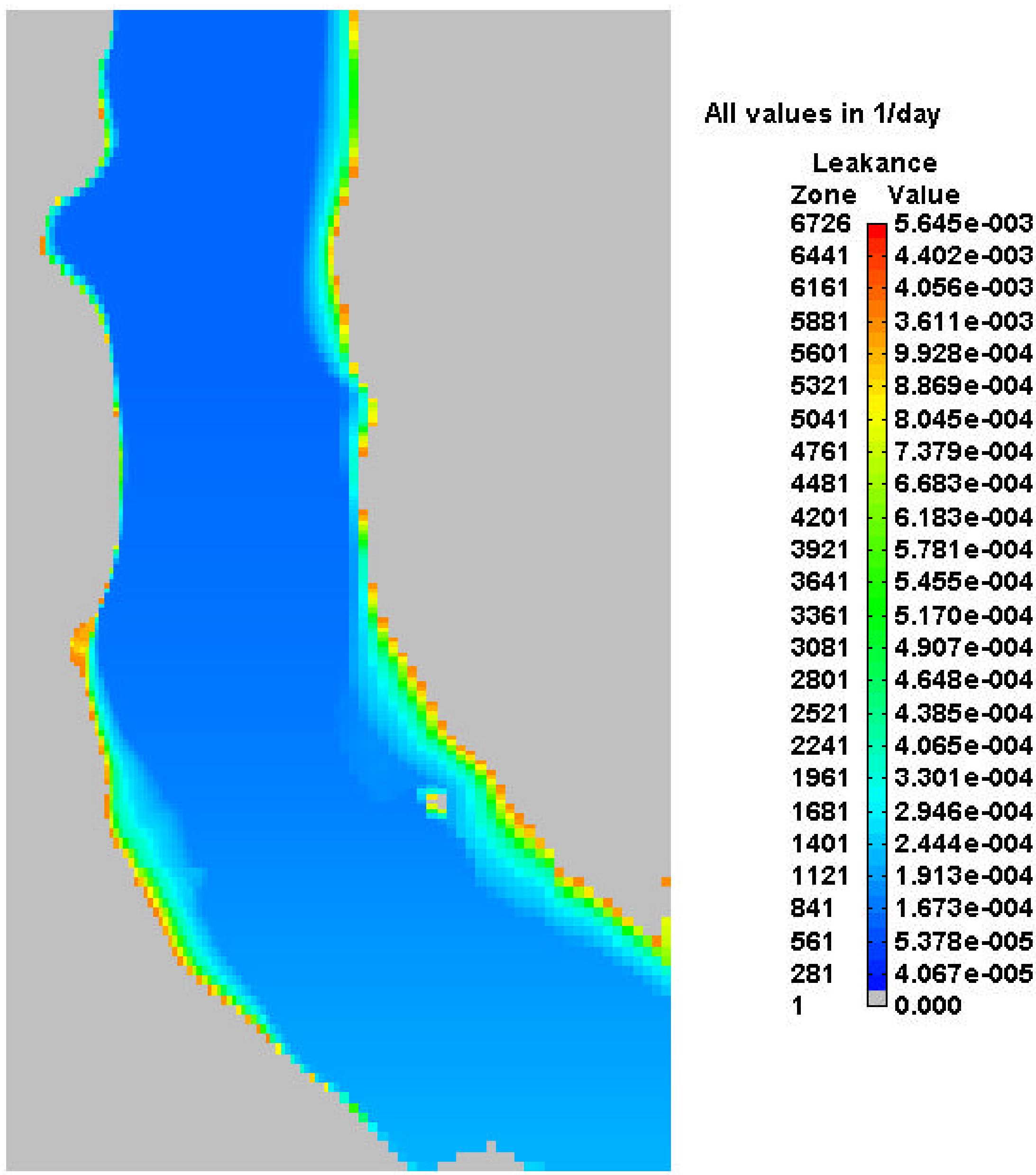

Figure 22
North South Cross Section
Model Column 49

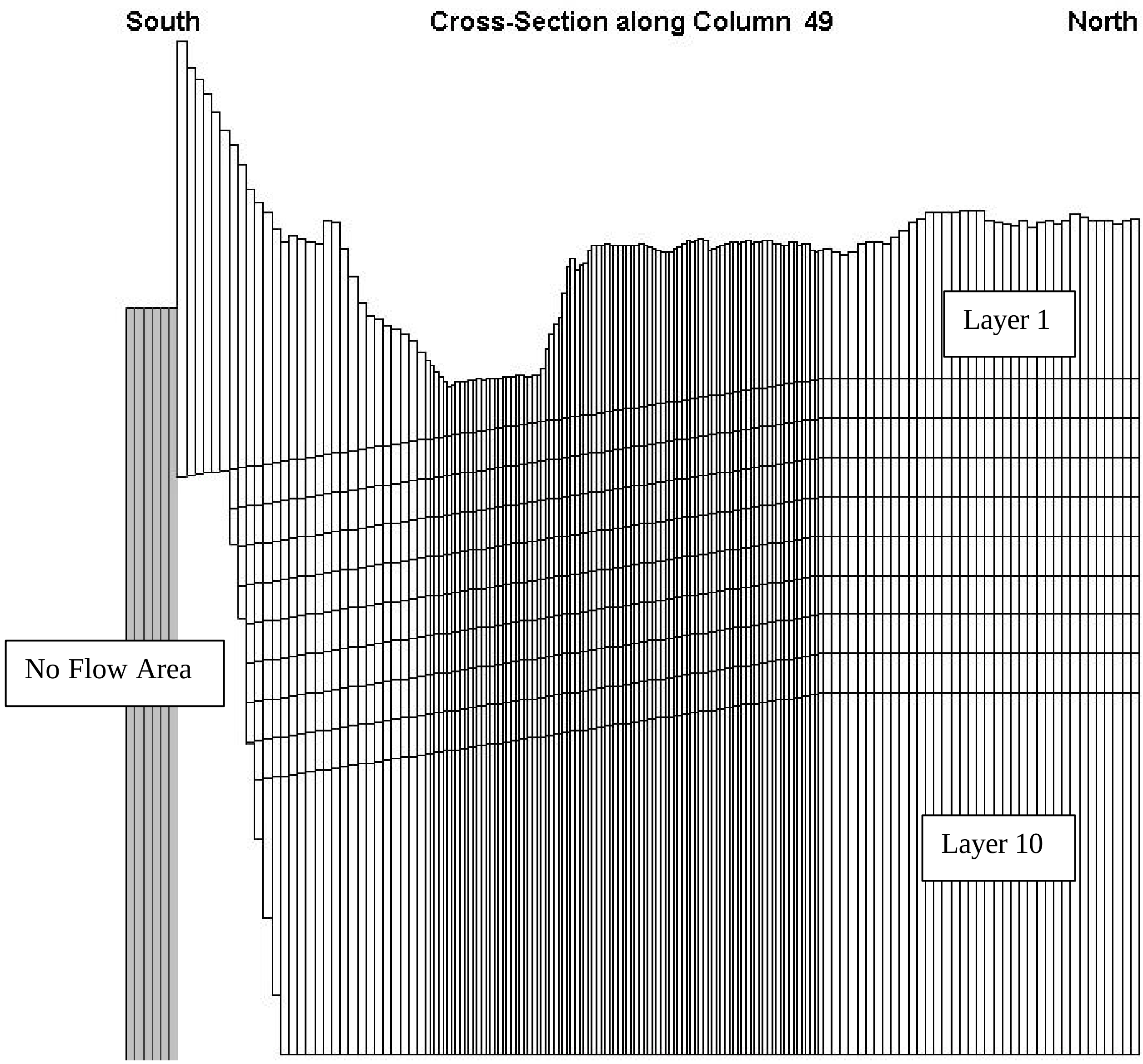

Figure 23
East West Cross Section
Model Row 50

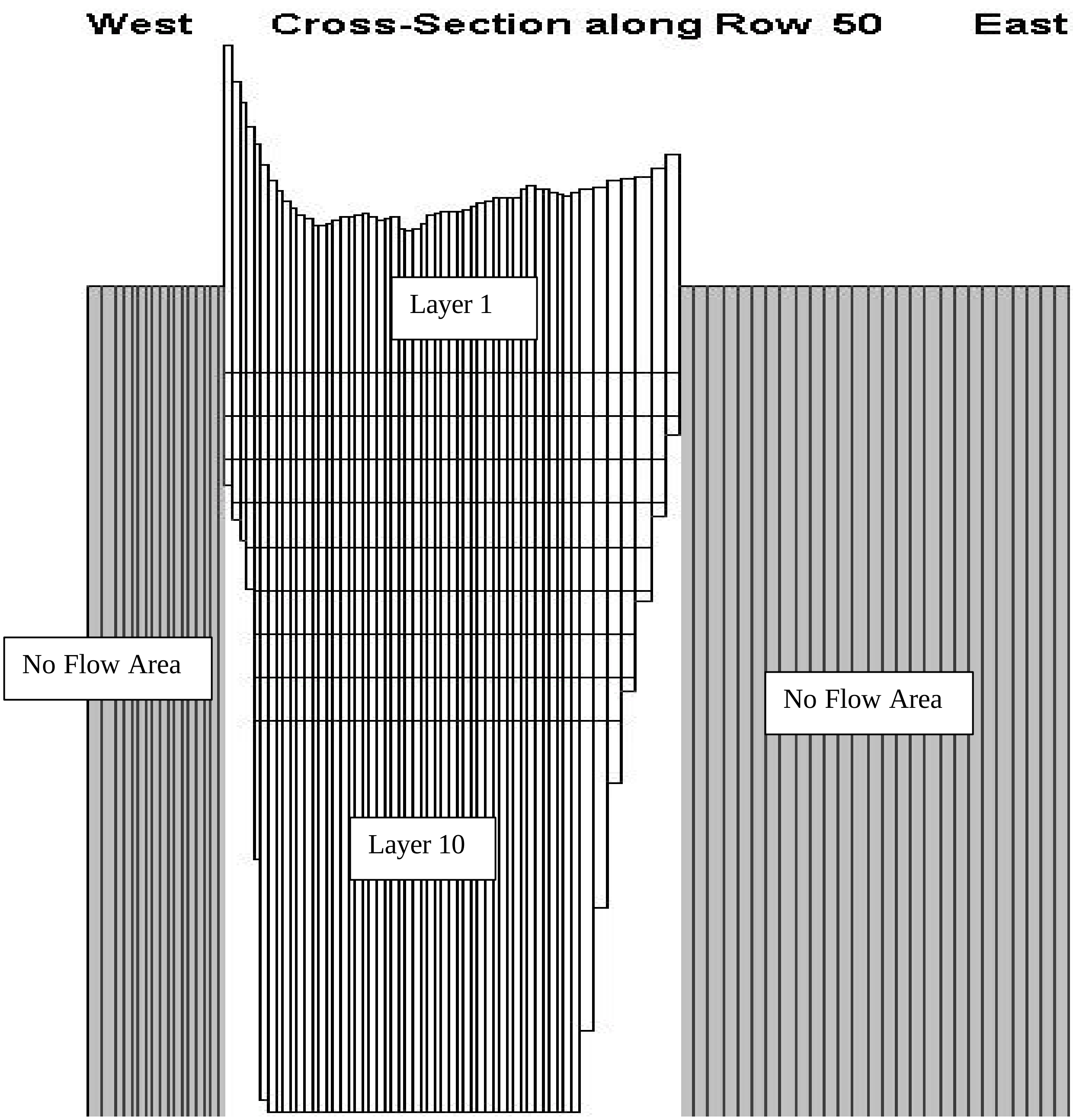

Figure 24
East West Cross Section
Model Row 115

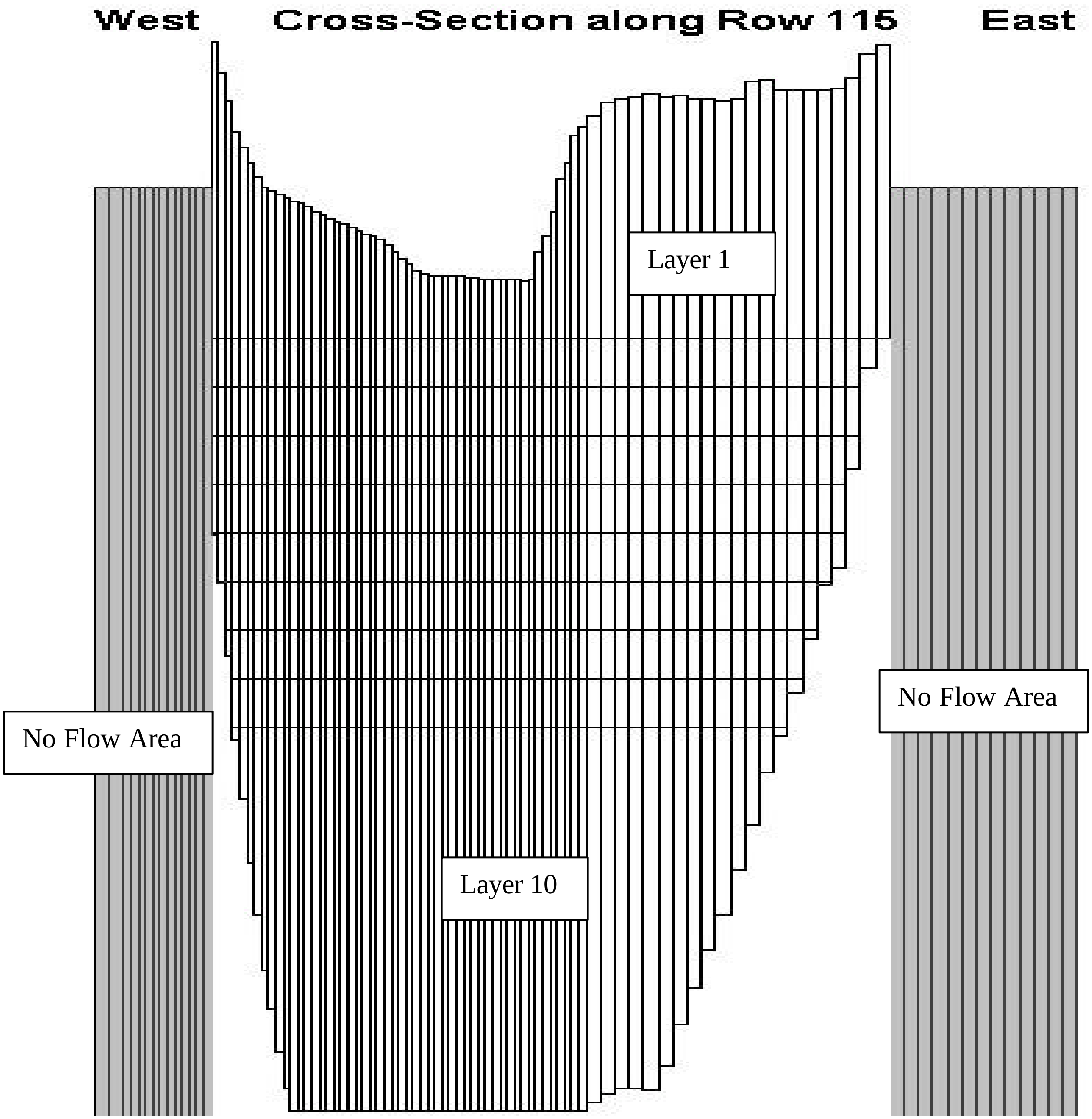

Figure 25
Location of Horizontal Flow Barriers (Faults)

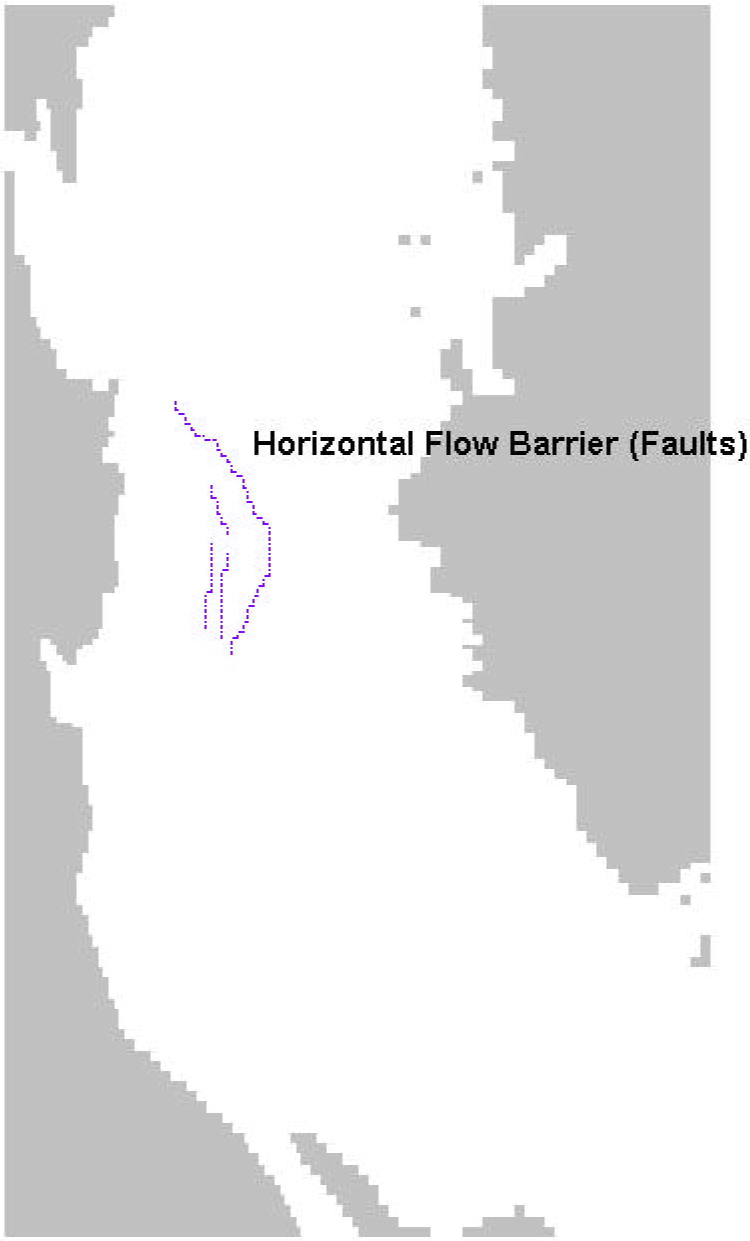

Figure 26
Steady State Recharge Distribution

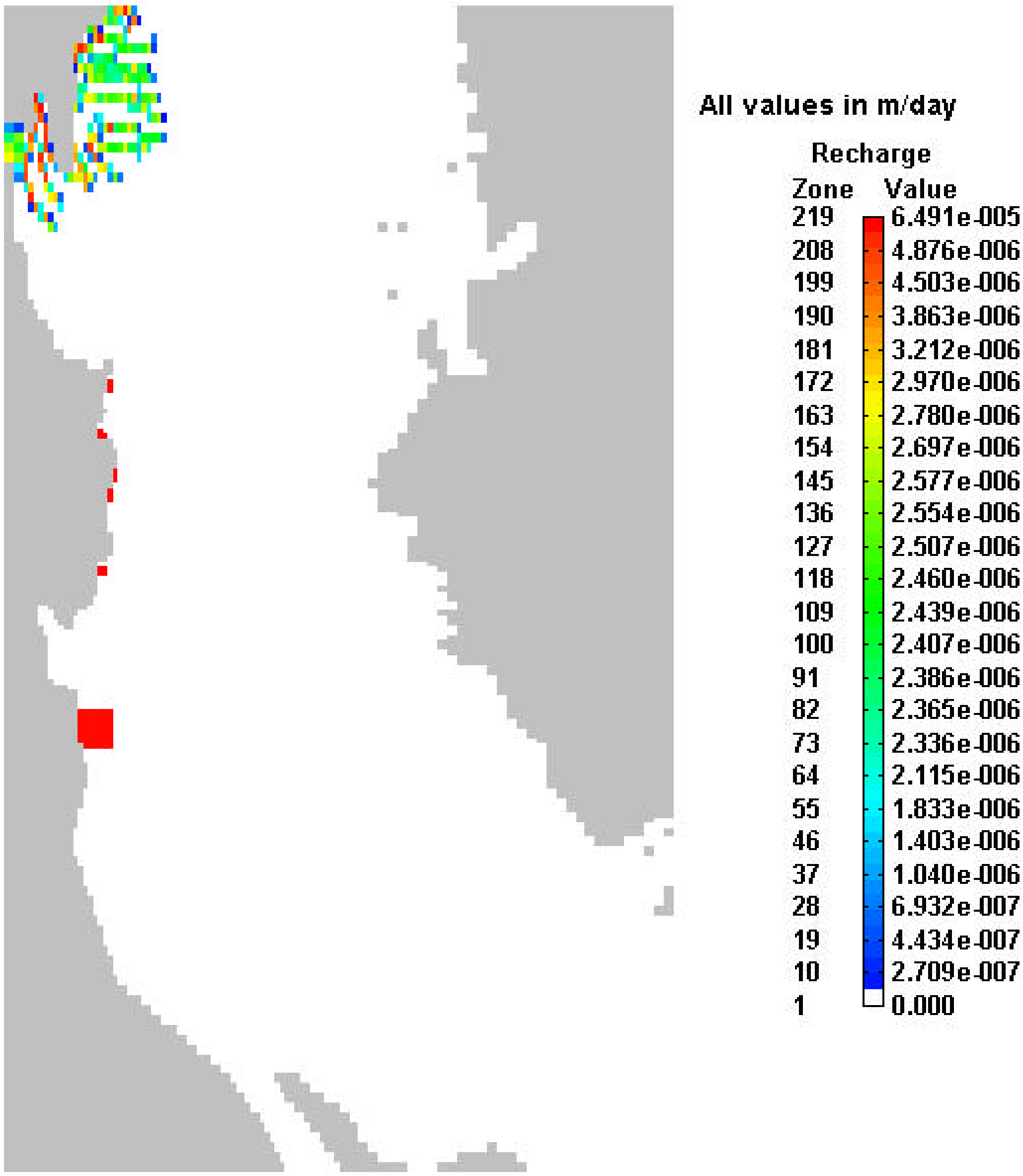

Figure 27
Location of Stream Cells

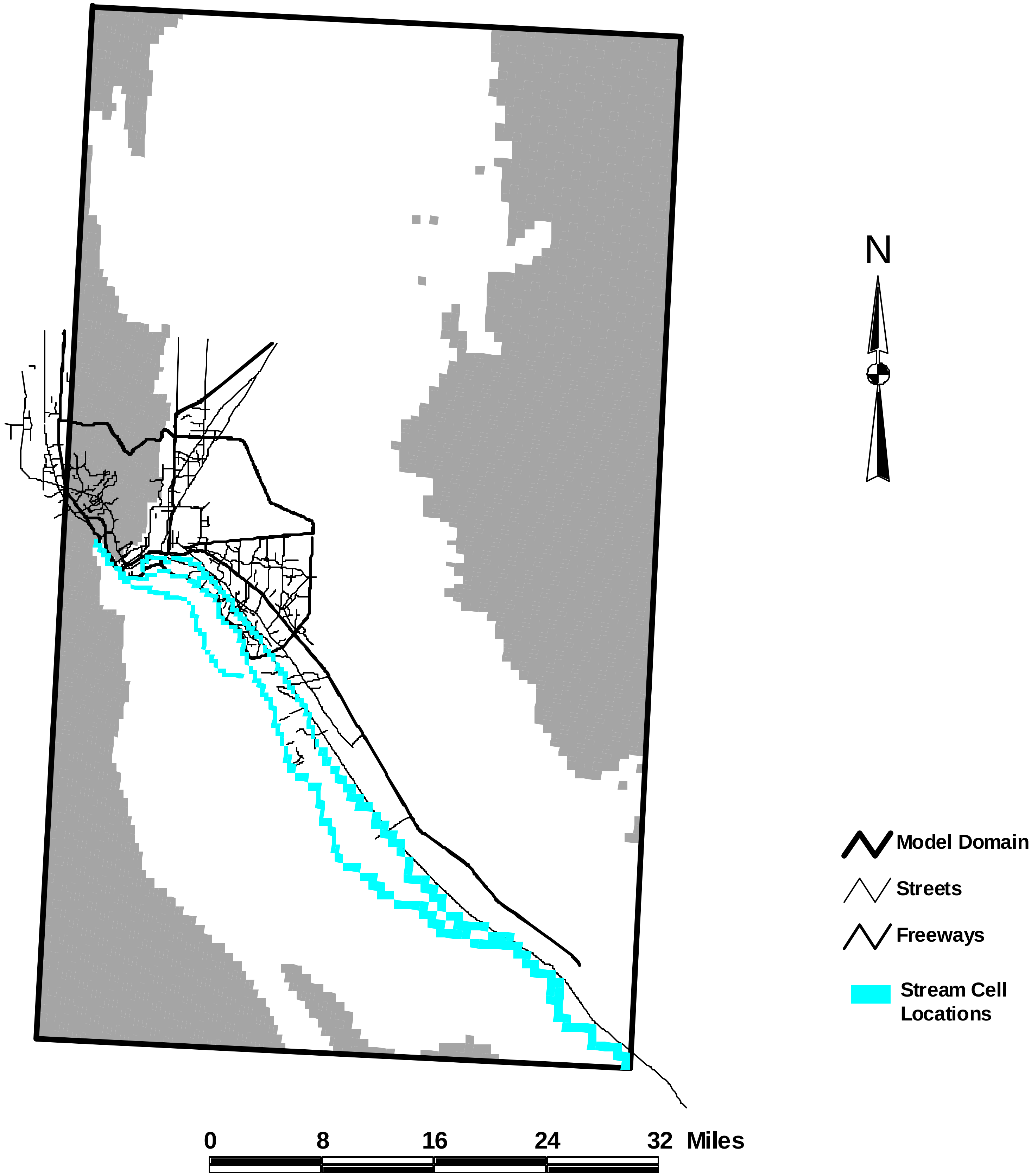

Figure 28
Pre-Development Groundwater Elevations
Estimated by Steady State Model
(5 meter contour interval)

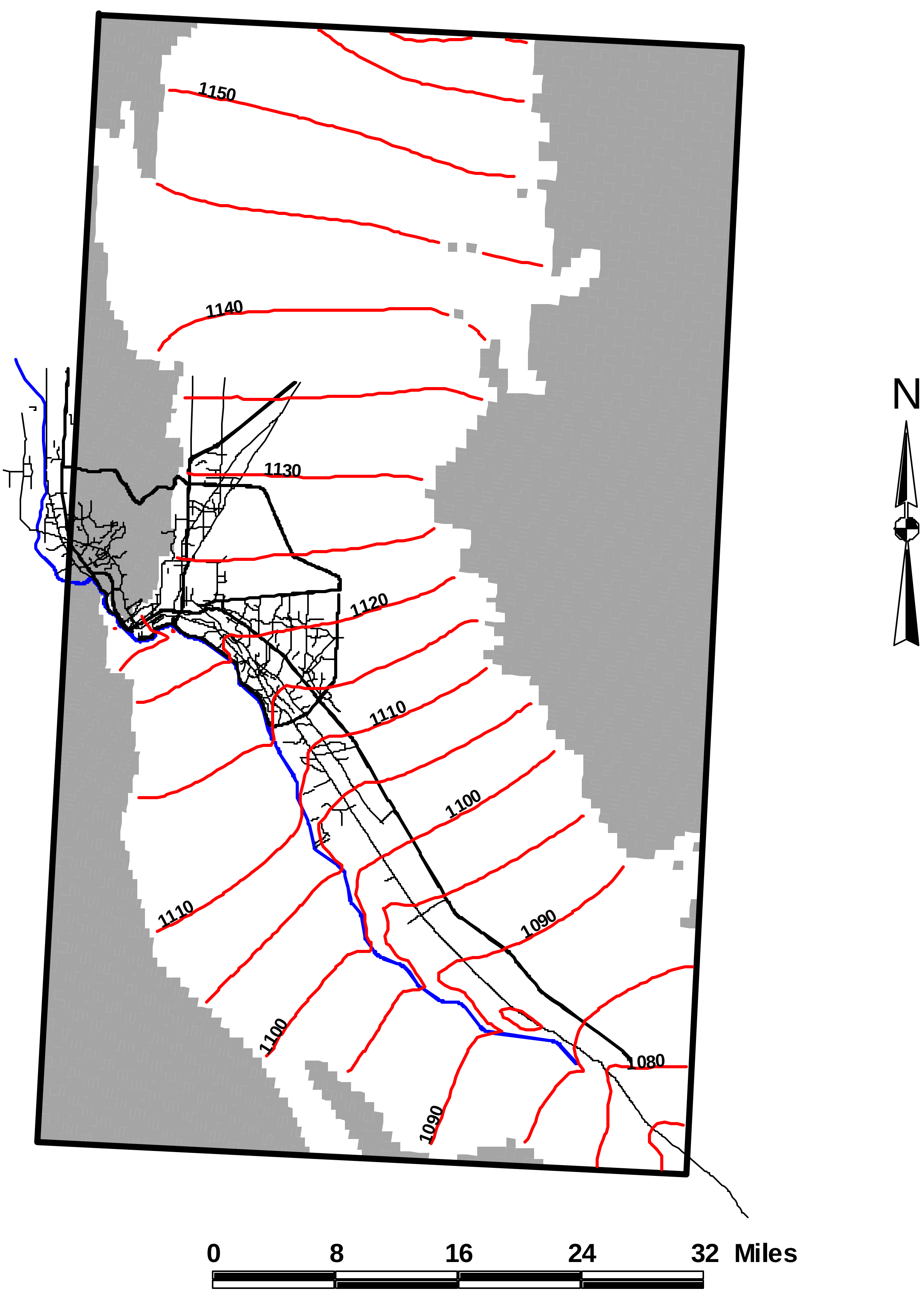

Figure 29
Storativity Distribution – Layer 10

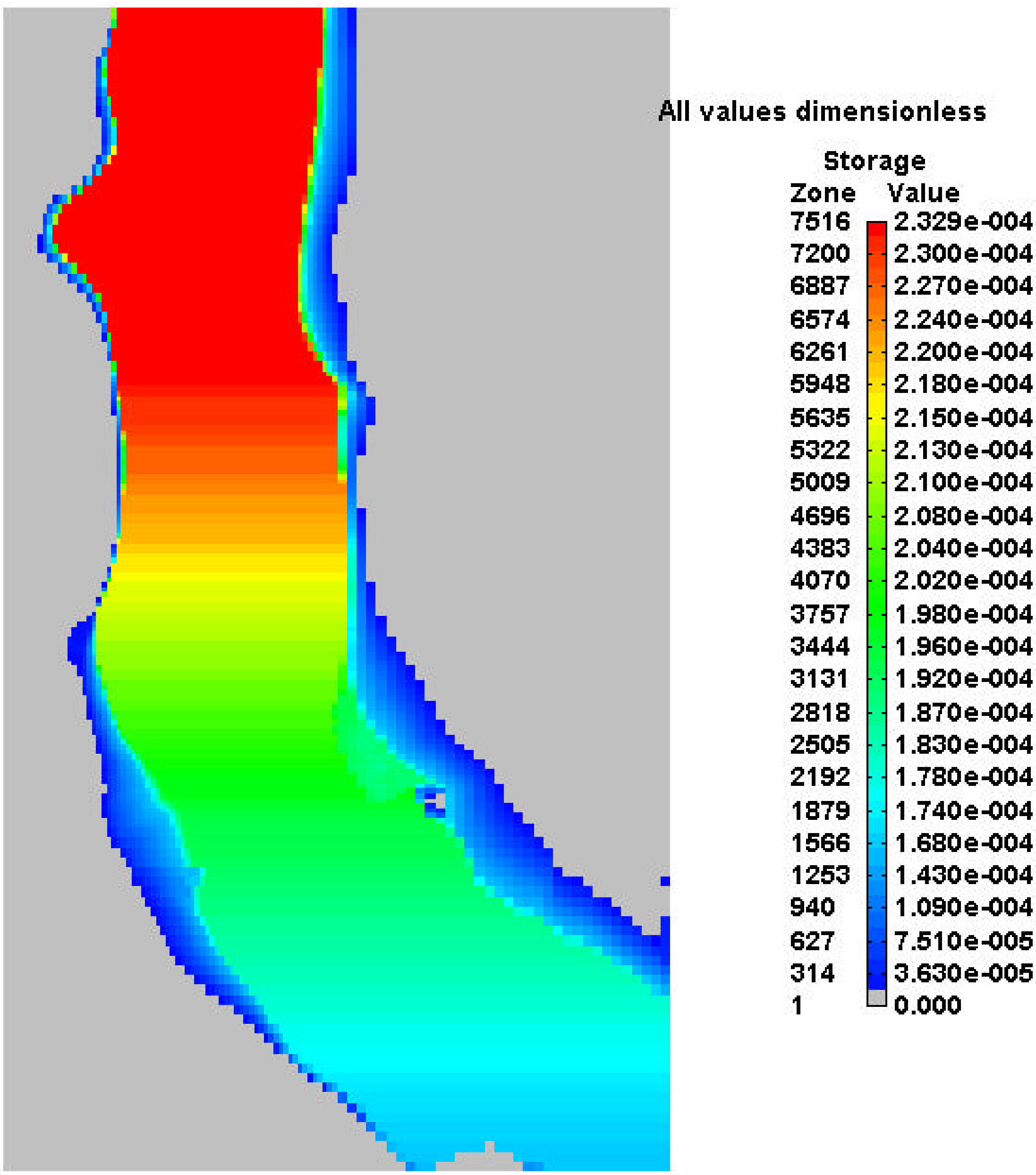

Figure 30
Drain Location
(active after 1925)

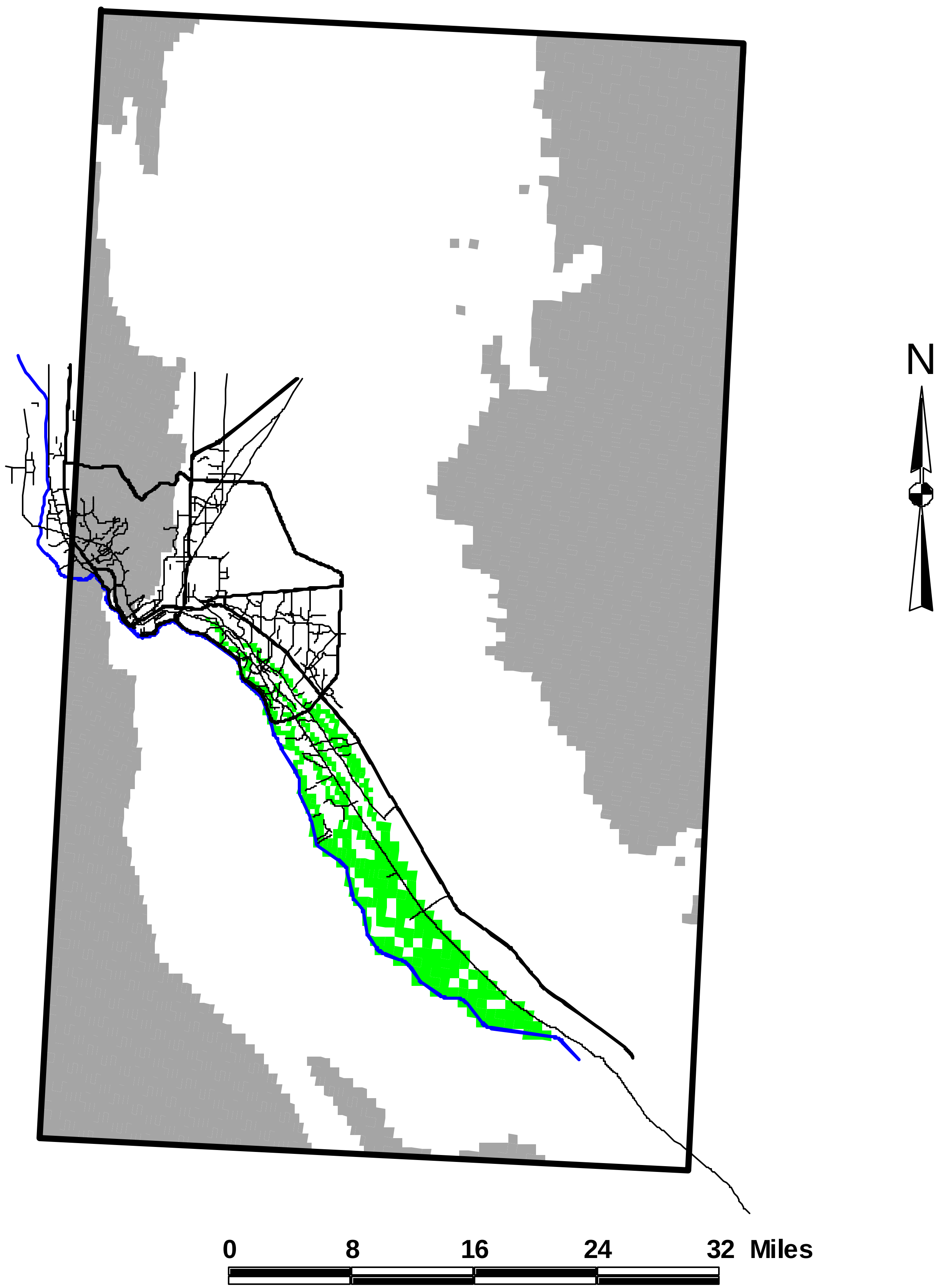

Figure 31
Evapotranspiration Area
1925 - 1996

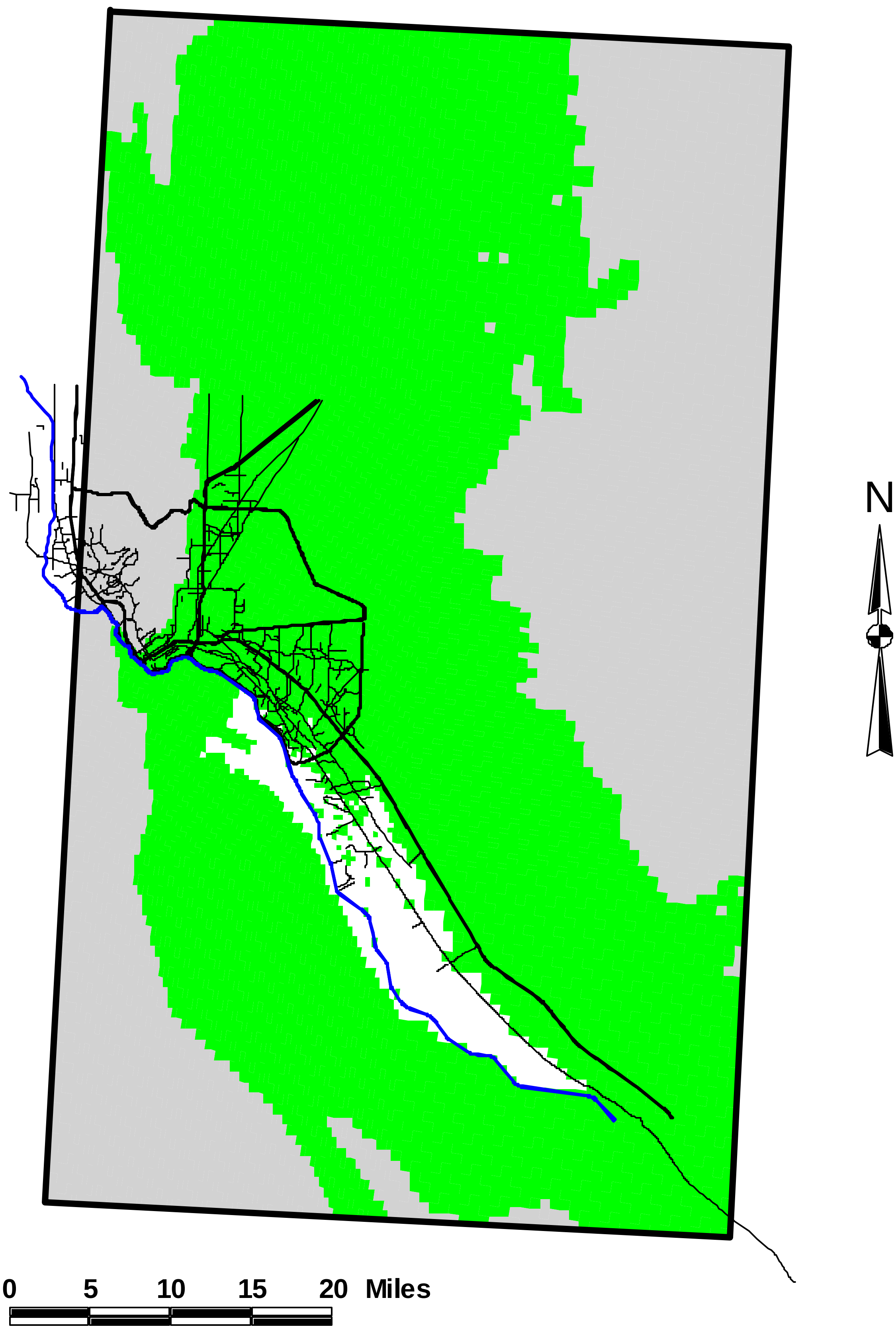

Figure 32
1925 to 1996 Base Recharge Distribution

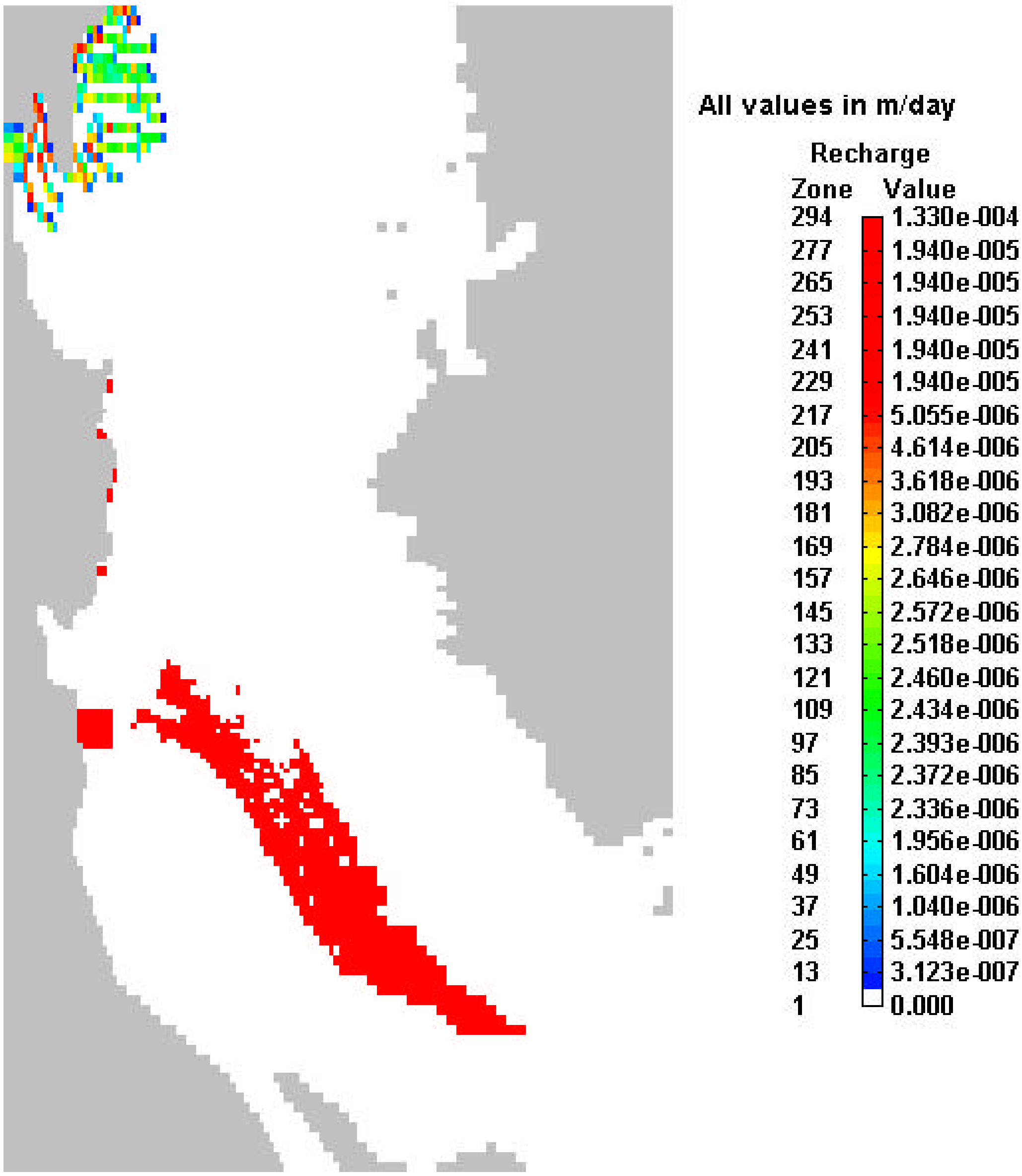

Figure 33
Multiplication Factor for Recharge Distribution
1925-1996

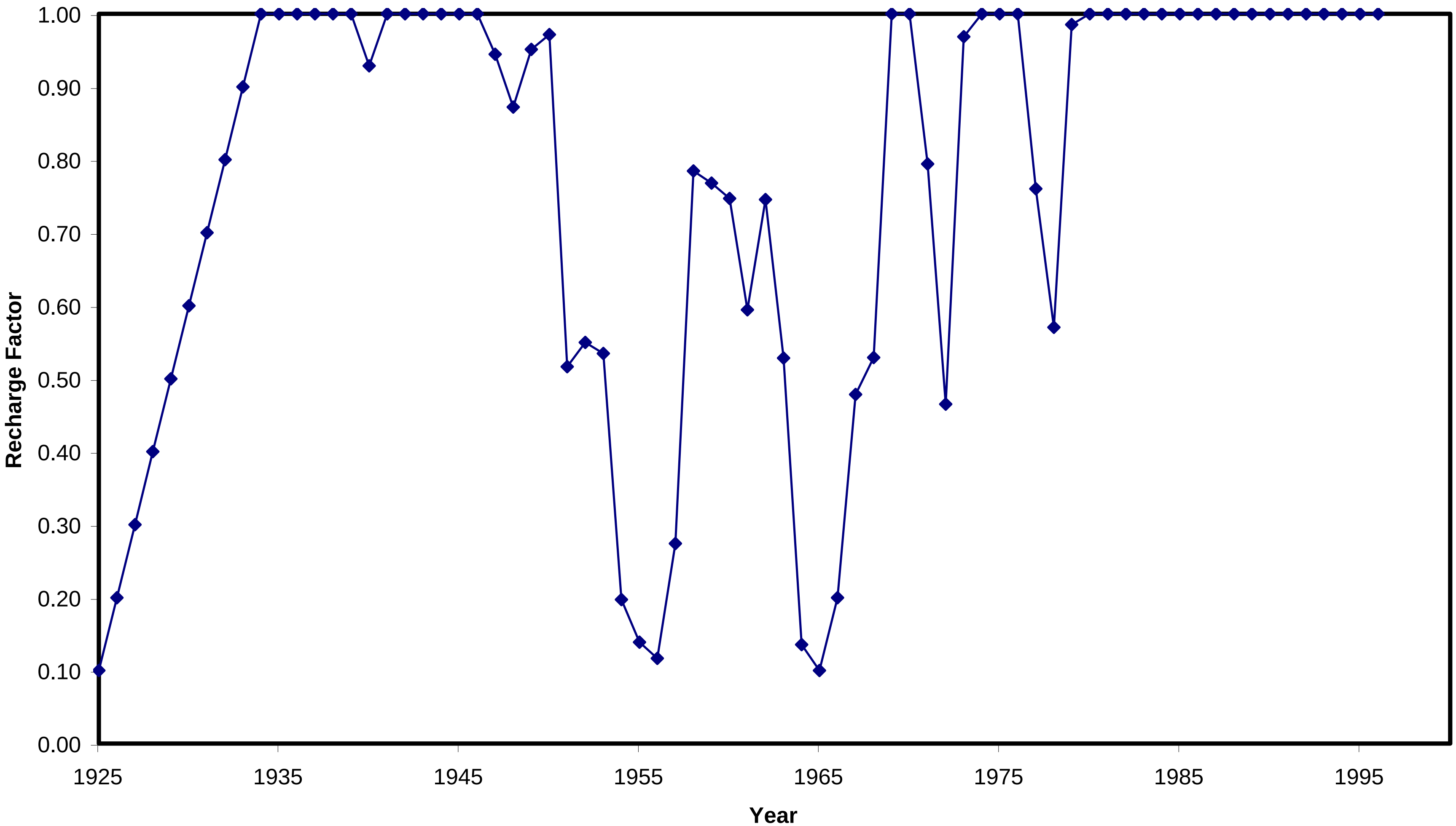

Table 1
Summary of Annual Water Budget (all values in m^3/yr)

	Inflow								Outflow									
Year	Storage	WEL	MAW	RCH	STR	IBS	FHB	Total	Storage	WEL	MAW	DRN	ET	STR	IBS	Total	In-Out	% Error
1903	1298	338	0	804	497935	30	20425	520831	39540	0	378	0	480136	0	740	520794	37	0.01
1904	160078	338	20	804	106689	2873	20425	291228	12349	0	520	0	277930	409	105	291312	-84	-0.03
1905	794	338	0	804	677685	0	20425	700047	188857	0	504	0	507327	0	3336	700023	24	0.00
1906	24116	338	3	804	466696	287	20425	512670	20206	0	4822	0	487354	0	267	512649	20	0.00
1907	3809	338	0	804	548914	74	20425	574365	47393	0	5853	0	520273	0	828	574348	17	0.00
1908	46812	338	7	804	418119	733	20425	487239	8999	0	6380	0	471707	203	54	487344	-105	-0.02
1909	5120	338	7	804	469676	61	20425	496431	12859	0	6377	0	477030	0	149	496414	17	0.00
1910	12744	338	10	804	448038	226	20425	482586	6178	0	7624	0	468710	0	57	482569	17	0.00
1911	5836	338	14	804	493738	118	20425	521274	24308	0	8871	0	487685	0	395	521260	14	0.00
1912	9010	338	240	804	541094	257	20425	572168	39381	0	13494	0	518715	0	676	572266	-98	-0.02
1913	71290	338	243	804	378657	1308	20425	473066	4275	0	15299	0	452596	875	17	473062	3	0.00
1914	11358	338	270	804	488179	210	20425	521585	26032	0	17276	0	477909	0	358	521574	10	0.00
1915	12338	338	297	804	469693	264	20425	504160	6032	0	18851	0	479173	0	95	504150	10	0.00
1916	21868	338	419	804	454168	534	20425	498557	3687	0	23014	0	471930	0	27	498658	-101	-0.02
1917	20919	338	585	804	466199	645	20425	509915	5590	0	30151	0	474103	0	64	509909	7	0.00
1918	35913	338	456	804	427132	649	20425	485719	2622	0	27532	0	455513	24	24	485715	3	0.00
1919	20273	338	426	804	441110	429	20425	483806	2808	0	26934	0	454036	0	20	483799	7	0.00
1920	20662	338	395	804	452600	757	20425	495982	5732	0	32463	0	457825	0	57	496077	-95	-0.02
1921	18175	338	460	804	473738	645	20425	514586	12670	0	33010	0	468689	0	193	514562	24	0.00
1922	15143	338	507	804	474397	412	20425	512028	8134	0	30767	0	472951	0	155	512007	20	0.00
1923	19780	338	585	804	460974	703	20425	503609	4079	0	32365	0	467108	0	51	503603	7	0.00
1924	14927	338	652	804	472907	547	20425	510601	7387	0	33490	0	469747	0	84	510710	-108	-0.02
1925	21821	338	838	3944	425588	531	20425	473485	66173	0	36211	144972	225011	0	1112	473478	7	0.00
1926	21341	338	919	7888	406741	304	20425	457956	45308	1997	36819	151112	221756	57	889	457939	17	0.00
1927	20037	338	1294	11831	414649	575	20425	469149	37522	4860	42094	160923	223020	47	679	469146	3	0.00
1928	17016	338	1291	15775	417261	280	20425	472387	32179	4596	42017	168445	224585	57	591	472471	-84	-0.02
1929	18411	338	1653	19719	405909	233	20425	466689	25336	4322	43014	170500	222882	132	477	466662	27	0.01
1930	22913	338	1541	23666	399279	794	20425	468956	21706	4042	50972	171517	220161	176	382	468956	0	0.00
1931	17871	338	1825	27610	404554	341	20425	472964	21706	3771	49823	175938	221053	159	483	472934	30	0.01
1932	12717	338	1700	31554	411807	135	20425	478676	25045	3508	43203	182109	224220	139	537	478760	-84	-0.02
1933	15518	338	2055	35498	399918	233	20425	473985	17969	3234	46826	182615	222753	243	328	473968	17	0.00
1934	22585	338	2328	39442	386863	608	20425	472589	15755	2944	53223	180784	219212	406	264	472586	3	0.00
1935	19567	338	1963	39442	393027	277	20425	475039	14616	4089	53561	182632	219157	338	608	475002	37	0.01
1936	20240	338	2207	39442	401401	703	20425	484755	15204	4076	58400	185934	220709	267	267	484857	-101	-0.02
1937	22146	338	2964	39442	404632	737	20425	490683	13430	4076	63040	188080	221564	257	237	490683	0	0.00
1938	38499	338	2646	39442	442864	331	20425	544545	58174	4123	55900	192700	230387	2072	1149	544504	41	0.01
1939	50570	338	3214	39442	361845	1010	20425	476844	27029	3991	64189	165309	214169	1798	355	476841	3	0.00
1940	35842	338	4451	36630	355762	852	20425	454300	14187	4359	68319	158760	207096	1484	196	454401	-101	-0.02
1941	22467	338	3491	39442	453465	446	20425	540074	39046	4724	67667	197117	229752	1037	730	540074	0	0.00
1942	28289	338	3805	39442	603786	1217	20425	697303	78069	5130	84696	259833	268258	0	1315	697299	3	0.00
1943	105990	338	3832	39442	341277	2535	20425	513839	11436	5732	95361	172599	225355	3217	132	513832	7	0.00
1944	45822	338	3599	39442	366654	564	20425	476844	11294	6306	78589	163170	214960	1696	902	476918	-74	-0.02
1945	61367	338	3630	39442	296104	1402	20425	422709	7583	5312	80600	121613	206363	1115	108	422695	14	0.00
1946	46839	338	3984	39442	308933	1058	20425	421019	10105	5096	81823	120214	202280	1375	115	421009	10	0.00
1947	38952	338	3180	37258	306574	554	20425	407281	9618	4731	74449	117399	199067	1480	497	407241	41	0.01
1948	35971	338	3305	34399	309044	493	20425	403976	9108	5140	74301	117091	196566	1402	436	404044	-68	-0.02
1949	45626	338	4062	37519	352423	2247	20425	462640	19922	5252	98356	138558	198999	1217	321	462623	17	0.00
1950	45710	338	4681	38313	347310	1044	20425	457821	10067	5650	99721	142025	198837	1335	172	457808	14	0.00
1951	87234	338	4572	20365	263702	1632	20425	398268	4387	5380	103709	98555	185417	747	64	398258	10	0.00
1952	72969	338	5931	21686	276216	1818	20425	399384	5269	5309	115314	90684	182399	466	61	399502	-118	-0.03
1953	77832	338	5343	21088	277054	2244	20425	404324	4380	5296	127206	87193	179716	463	57	404311	14	0.00
1954	126706	338	5803	7776	216133	3940	20425	381121	3940	5363	148240	64646	158503	321	81	381094	27	0.01

Table 1

Summary of Annual Water Budget (all values in m^3/yr)

	Inflow								Outflow									
Year	Storage	WEL	MAW	RCH	STR	IBS	FHB	Total	Storage	WEL	MAW	DRN	ET	STR	IBS	Total	In-Out	% Error
1955	143339	338	7959	5475	200155	3937	20425	381628	4356	4488	170206	55839	146553	145	41	381628	0	0.00
1956	160598	338	7712	4599	185255	4150	20425	383078	3109	4447	183879	51415	140237	74	41	383203	-125	-0.03
1957	118788	338	9882	10814	252489	2501	20425	415237	19283	3288	188661	56281	147533	14	182	415243	-7	0.00
1958	96544	338	10919	30949	463367	1490	20425	624033	103404	4174	190800	145570	178188	159	1724	624019	14	0.00
1959	108115	338	13312	30290	408251	2460	20425	583192	32622	3096	208962	157134	180250	541	598	583202	-10	0.00
1960	131761	338	12693	29469	430255	3403	20425	628345	31277	4437	224298	178408	188955	547	541	628463	-118	-0.02
1961	134472	338	14359	23450	440454	3315	20425	636814	19303	4630	238586	181287	192206	551	257	636821	-7	0.00
1962	132377	338	13842	29394	467544	2778	20425	666698	24795	4289	245977	190165	200537	564	378	666705	-7	0.00
1963	165404	338	16100	20834	410205	4268	20425	637574	13325	3099	259569	173406	187438	595	145	637578	-3	0.00
1964	266514	338	17678	5346	204038	6668	20425	521007	3116	6512	271265	85375	154468	365	34	521135	-128	-0.02
1965	211952	338	18459	3944	276010	4626	20425	535755	14839	9013	276182	80238	155032	301	149	535755	0	0.00
1966	151356	338	20456	7888	382047	2099	20425	584608	47096	5532	254311	113448	162964	243	987	584581	27	0.00
1967	152995	338	21855	18867	423706	3406	20425	641592	40537	5877	274945	148564	170777	297	612	641609	-17	0.00
1968	157618	338	27860	20858	480916	3788	20425	711804	35599	8739	298047	179601	189205	152	575	711919	-115	-0.02
1969	221935	338	25559	39442	473279	5650	20425	786628	41179	10561	325326	208039	200719	108	706	786638	-10	0.00
1970	206555	338	22960	39442	462715	3934	20425	756369	19503	11233	308155	214190	202740	179	378	756379	-10	0.00
1971	244301	338	25988	31321	435892	6823	20425	765088	8060	12605	341673	205839	196505	291	122	765094	-7	0.00
1972	290308	338	27461	18344	410049	7840	20425	774766	5356	10601	382034	190686	185850	311	61	774898	-132	-0.02
1973	277629	338	27154	38205	461633	6924	20425	832308	21581	10142	400485	205690	193967	108	341	832315	-7	0.00
1974	278916	338	26397	39442	481886	6874	20425	854278	20044	13680	403777	216396	199986	64	348	854295	-17	0.00
1975	279836	338	25491	39442	475986	5955	20425	847472	12947	16400	400732	217623	199442	81	250	847475	-3	0.00
1976	279751	338	24690	39442	489686	6195	20425	860527	14008	21585	401678	221513	201561	30	280	860655	-128	-0.01
1977	326803	338	26498	29989	441779	10182	20425	856015	7387	18134	434280	205349	190659	132	95	856035	-20	0.00
1978	347370	338	28681	22497	431384	12251	20425	862946	5275	18181	463154	193754	182497	34	54	862950	-3	0.00
1979	319923	338	29570	38864	475732	11480	20425	896332	16853	16556	467682	206485	188502	0	260	896339	-7	0.00
1980	312853	338	29185	39442	486367	10142	20425	898752	13001	16461	465536	212274	191358	0	253	898884	-132	-0.01
1981	321295	338	31236	39442	481967	12156	20425	906859	7360	13535	484161	211922	189743	0	145	906866	-7	0.00
1982	353075	338	35028	39442	481579	15721	20425	945608	5907	14261	527556	210638	187171	0	84	945618	-10	0.00
1983	347245	338	32615	39442	486780	11909	20425	938754	6326	11524	524477	210641	185600	0	193	938761	-7	0.00
1984	338841	338	32355	39442	501457	16144	20425	949001	8202	11162	530503	212787	186117	0	182	948954	47	0.00
1985	344937	338	39719	39442	502812	15833	20425	963505	6688	12115	546339	212165	185123	0	152	962583	923	0.10
1986	322785	338	47576	39442	620849	13271	20425	1064686	48380	14488	550253	246707	204085	0	757	1064669	17	0.00
1987	360594	338	49350	39442	612698	20402	20425	1103249	17181	13663	612637	251715	207252	0	294	1102742	507	0.05
1988	403851	338	44930	39442	542612	19354	20425	1070952	7489	10963	627132	229938	195410	0	105	1071036	-84	-0.01
1989	432519	338	50067	39442	526218	25755	20425	1094763	5610	10023	672998	217900	188148	0	57	1094736	27	0.00
1990	438470	338	51652	39442	487885	20517	20425	1058728	12156	10693	657425	196393	181632	0	135	1058434	294	0.03
1991	405571	338	50966	39442	512244	20909	20425	1049894	18695	10821	643427	197360	178837	0	355	1049496	399	0.04
1992	401972	338	42118	39442	550915	24558	20425	1079769	16336	13450	657114	208397	183636	0	253	1079187	581	0.05
1993	340463	338	45832	39442	587731	15066	20425	1049296	27330	12112	596622	222118	190084	0	879	1049144	152	0.01
1994	353788	338	51554	39442	613874	22328	20425	1101749	26904	16330	628274	233736	196052	0	385	1101681	68	0.01
1995	351041	338	48120	39442	581431	25826	20425	1066623	24173	1568	620674	226734	192767	0	612	1066528	95	0.01
1996	331910	338	42510	39442	581509	19645	20425	1035778	11723	1108	605588	226160	190963	0	189	1035731	47	0.00
Average	139761	338	14107	23539	430880	5143	20425	634193	21202	5936	213606	132584	260143	329	378	634178	15	0.00

Table 2
Summary of Annual Water Budget (all values in acre-feet/yr)

	Inflow								Outflow									
Year	Storage	WEL	MAW	RCH	STR	IBS	FHB	Total	Storage	WEL	MAW	DRN	ET	STR	IBS	Total	In-Out	% Error
1903	384	100	0	238	147342	9	6044	154117	11700	0	112	0	142075	0	219	154106	11	0.01
1904	47368	100	6	238	31570	850	6044	86176	3654	0	154	0	82241	121	31	86201	-25	-0.03
1905	235	100	0	238	200531	0	6044	207148	55884	0	149	0	150121	0	987	207141	7	0.00
1906	7136	100	1	238	138098	85	6044	151702	5979	0	1427	0	144211	0	79	151696	6	0.00
1907	1127	100	0	238	162427	22	6044	169958	14024	0	1732	0	153952	0	245	169953	5	0.00
1908	13852	100	2	238	123724	217	6044	144177	2663	0	1888	0	139581	60	16	144208	-31	-0.02
1909	1515	100	2	238	138980	18	6044	146897	3805	0	1887	0	141156	0	44	146892	5	0.00
1910	3771	100	3	238	132577	67	6044	142800	1828	0	2256	0	138694	0	17	142795	5	0.00
1911	1727	100	4	238	146100	35	6044	154248	7193	0	2625	0	144309	0	117	154244	4	0.00
1912	2666	100	71	238	160113	76	6044	169308	11653	0	3993	0	153491	0	200	169337	-29	-0.02
1913	21095	100	72	238	112047	387	6044	139983	1265	0	4527	0	133926	259	5	139982	1	0.00
1914	3361	100	80	238	144455	62	6044	154340	7703	0	5112	0	141416	0	106	154337	3	0.00
1915	3651	100	88	238	138985	78	6044	149184	1785	0	5578	0	141790	0	28	149181	3	0.00
1916	6471	100	124	238	134391	158	6044	147526	1091	0	6810	0	139647	0	8	147556	-30	-0.02
1917	6190	100	173	238	137951	191	6044	150887	1654	0	8922	0	140290	0	19	150885	2	0.00
1918	10627	100	135	238	126391	192	6044	143727	776	0	8147	0	134789	7	7	143726	1	0.00
1919	5999	100	126	238	130527	127	6044	143161	831	0	7970	0	134352	0	6	143159	2	0.00
1920	6114	100	117	238	133927	224	6044	146764	1696	0	9606	0	135473	0	17	146792	-28	-0.02
1921	5378	100	136	238	140182	191	6044	152269	3749	0	9768	0	138688	0	57	152262	7	0.00
1922	4481	100	150	238	140377	122	6044	151512	2407	0	9104	0	139949	0	46	151506	6	0.00
1923	5853	100	173	238	136405	208	6044	149021	1207	0	9577	0	138220	0	15	149019	2	0.00
1924	4417	100	193	238	139936	162	6044	151090	2186	0	9910	0	139001	0	25	151122	-32	-0.02
1925	6457	100	248	1167	125934	157	6044	140107	19581	0	10715	42898	66582	0	329	140105	2	0.00
1926	6315	100	272	2334	120357	90	6044	135512	13407	591	10895	44715	65619	17	263	135507	5	0.00
1927	5929	100	383	3501	122697	170	6044	138824	11103	1438	12456	47618	65993	14	201	138823	1	0.00
1928	5035	100	382	4668	123470	83	6044	139782	9522	1360	12433	49844	66456	17	175	139807	-25	-0.02
1929	5448	100	489	5835	120111	69	6044	138096	7497	1279	12728	50452	65952	39	141	138088	8	0.01
1930	6780	100	456	7003	118149	235	6044	138767	6423	1196	15083	50753	65147	52	113	138767	0	0.00
1931	5288	100	540	8170	119710	101	6044	139953	6423	1116	14743	52061	65411	47	143	139944	9	0.01
1932	3763	100	503	9337	121856	40	6044	141643	7411	1038	12784	53887	66348	41	159	141668	-25	-0.02
1933	4592	100	608	10504	118338	69	6044	140255	5317	957	13856	54037	65914	72	97	140250	5	0.00
1934	6683	100	689	11671	114475	180	6044	139842	4662	871	15749	53495	64866	120	78	139841	1	0.00
1935	5790	100	581	11671	116299	82	6044	140567	4325	1210	15849	54042	64850	100	180	140556	11	0.01
1936	5989	100	653	11671	118777	208	6044	143442	4499	1206	17281	55019	65309	79	79	143472	-30	-0.02
1937	6553	100	877	11671	119733	218	6044	145196	3974	1206	18654	55654	65562	76	70	145196	0	0.00
1938	11392	100	783	11671	131046	98	6044	161134	17214	1220	16541	57021	68173	613	340	161122	12	0.01
1939	14964	100	951	11671	107072	299	6044	141101	7998	1181	18994	48916	63374	532	105	141100	1	0.00
1940	10606	100	1317	10839	105272	252	6044	134430	4198	1290	20216	46978	61281	439	58	134460	-30	-0.02
1941	6648	100	1033	11671	134183	132	6044	159811	11554	1398	20023	58328	67985	307	216	159811	0	0.00
1942	8371	100	1126	11671	178664	360	6044	206336	23101	1518	25062	76886	79379	0	389	206335	1	0.00
1943	31363	100	1134	11671	100986	750	6044	152048	3384	1696	28218	51073	66684	952	39	152046	2	0.00
1944	13559	100	1065	11671	108495	167	6044	141101	3342	1866	23255	48283	63608	502	267	141123	-22	-0.02
1945	18159	100	1074	11671	87619	415	6044	125082	2244	1572	23850	35986	61064	330	32	125078	4	0.00
1946	13860	100	1179	11671	91415	313	6044	124582	2990	1508	24212	35572	59856	407	34	124579	3	0.00
1947	11526	100	941	11025	90717	164	6044	120517	2846	1400	22030	34739	58905	438	147	120505	12	0.01
1948	10644	100	978	10179	91448	146	6044	119539	2695	1521	21986	34648	58165	415	129	119559	-20	-0.02
1949	13501	100	1202	11102	104284	665	6044	136898	5895	1554	29104	41000	58885	360	95	136893	5	0.00
1950	13526	100	1385	11337	102771	309	6044	135472	2979	1672	29508	42026	58837	395	51	135468	4	0.00
1951	25813	100	1353	6026	78031	483	6044	117850	1298	1592	30688	29163	54866	221	19	117847	3	0.00
1952	21592	100	1755	6417	81734	538	6044	118180	1559	1571	34122	26834	53973	138	18	118215	-35	-0.03
1953	23031	100	1581	6240	81982	664	6044	119642	1296	1567	37641	25801	53179	137	17	119638	4	0.00

Table 2
Summary of Annual Water Budget (all values in acre-feet/yr)

	Inflow								Outflow									
Year	Storage	WEL	MAW	RCH	STR	IBS	FHB	Total	Storage	WEL	MAW	DRN	ET	STR	IBS	Total	In-Out	% Error
1954	37493	100	1717	2301	63955	1166	6044	112776	1166	1587	43865	19129	46902	95	24	112768	8	0.01
1955	42415	100	2355	1620	59227	1165	6044	112926	1289	1328	50365	16523	43366	43	12	112926	0	0.00
1956	47522	100	2282	1361	54818	1228	6044	113355	920	1316	54411	15214	41497	22	12	113392	-37	-0.03
1957	35150	100	2924	3200	74713	740	6044	122871	5706	973	55826	16654	43656	4	54	122873	-2	0.00
1958	28568	100	3231	9158	137113	441	6044	184655	30598	1235	56459	43075	52727	47	510	184651	4	0.00
1959	31992	100	3939	8963	120804	728	6044	172570	9653	916	61833	46497	53337	160	177	172573	-3	0.00
1960	38989	100	3756	8720	127315	1007	6044	185931	9255	1313	66371	52792	55913	162	160	185966	-35	-0.02
1961	39791	100	4249	6939	130333	981	6044	188437	5712	1370	70599	53644	56875	163	76	188439	-2	0.00
1962	39171	100	4096	8698	138349	822	6044	197280	7337	1269	72786	56271	59340	167	112	197282	-2	0.00
1963	48944	100	4764	6165	121382	1263	6044	188662	3943	917	76808	51312	55464	176	43	188663	-1	0.00
1964	78863	100	5231	1582	60376	1973	6044	154169	922	1927	80269	25263	45708	108	10	154207	-38	-0.02
1965	62718	100	5462	1167	81673	1369	6044	158533	4391	2667	81724	23743	45875	89	44	158533	0	0.00
1966	44787	100	6053	2334	113050	621	6044	172989	13936	1637	75252	33570	48222	72	292	172981	8	0.00
1967	45272	100	6467	5583	125377	1008	6044	189851	11995	1739	81358	43961	50534	88	181	189856	-5	0.00
1968	46640	100	8244	6172	142306	1121	6044	210627	10534	2586	88194	53145	55987	45	170	210661	-34	-0.02
1969	65672	100	7563	11671	140046	1672	6044	232768	12185	3125	96266	61560	59394	32	209	232771	-3	0.00
1970	61121	100	6794	11671	136920	1164	6044	223814	5771	3324	91185	63380	59992	53	112	223817	-3	0.00
1971	72290	100	7690	9268	128983	2019	6044	226394	2385	3730	101103	60909	58147	86	36	226396	-2	0.00
1972	85904	100	8126	5428	121336	2320	6044	229258	1585	3137	113046	56425	54994	92	18	229297	-39	-0.02
1973	82152	100	8035	11305	136600	2049	6044	246285	6386	3001	118506	60865	57396	32	101	246287	-2	0.00
1974	82533	100	7811	11671	142593	2034	6044	252786	5931	4048	119480	64033	59177	19	103	252791	-5	0.00
1975	82805	100	7543	11671	140847	1762	6044	250772	3831	4853	118579	64396	59016	24	74	250773	-1	0.00
1976	82780	100	7306	11671	144901	1833	6044	254635	4145	6387	118859	65547	59643	9	83	254673	-38	-0.01
1977	96703	100	7841	8874	130725	3013	6044	253300	2186	5366	128506	60764	56417	39	28	253306	-6	0.00
1978	102789	100	8487	6657	127649	3625	6044	255351	1561	5380	137050	57333	54002	10	16	255352	-1	0.00
1979	94667	100	8750	11500	140772	3397	6044	265230	4987	4899	138390	61100	55779	0	77	265232	-2	0.00
1980	92575	100	8636	11671	143919	3001	6044	265946	3847	4871	137755	62813	56624	0	75	265985	-39	-0.01
1981	95073	100	9243	11671	142617	3597	6044	268345	2178	4005	143266	62709	56146	0	43	268347	-2	0.00
1982	104477	100	10365	11671	142502	4652	6044	279811	1748	4220	156107	62329	55385	0	25	279814	-3	0.00
1983	102752	100	9651	11671	144041	3524	6044	277783	1872	3410	155196	62330	54920	0	57	277785	-2	0.00
1984	100265	100	9574	11671	148384	4777	6044	280815	2427	3303	156979	62965	55073	0	54	280801	14	0.00
1985	102069	100	11753	11671	148785	4685	6044	285107	1979	3585	161665	62781	54779	0	45	284834	273	0.10
1986	95514	100	14078	11671	183713	3927	6044	315047	14316	4287	162823	73002	60390	0	224	315042	5	0.00
1987	106702	100	14603	11671	181301	6037	6044	326458	5084	4043	181283	74484	61327	0	87	326308	150	0.05
1988	119502	100	13295	11671	160562	5727	6044	316901	2216	3244	185572	68040	57823	0	31	316926	-25	-0.01
1989	127985	100	14815	11671	155711	7621	6044	323947	1660	2966	199144	64478	55674	0	17	323939	8	0.00
1990	129746	100	15284	11671	144368	6071	6044	313284	3597	3164	194536	58114	53746	0	40	313197	87	0.03
1991	120011	100	15081	11671	151576	6187	6044	310670	5532	3202	190394	58400	52919	0	105	310552	118	0.04
1992	118946	100	12463	11671	163019	7267	6044	319510	4834	3980	194444	61666	54339	0	75	319338	172	0.05
1993	100745	100	13562	11671	173913	4458	6044	310493	8087	3584	176544	65726	56247	0	260	310448	45	0.01
1994	104688	100	15255	11671	181649	6607	6044	326014	7961	4832	185910	69164	58013	0	114	325994	20	0.01
1995	103875	100	14239	11671	172049	7642	6044	315620	7153	464	183661	67092	57041	0	181	315592	28	0.01
1996	98214	100	12579	11671	172072	5813	6044	306493	3469	328	179197	66922	56507	0	56	306479	14	0.00
Average	41356	100	4174	6965	127500	1522	6044	187661	6274	1757	63207	39232	76978	97	112	187657	5	0.00