Appendix D
External Groundwater Boundary Conditions

1.0 Purpose

The South Platte Decision Support System (SPDSS) alluvial groundwater flow model includes the key groundwater inflows and outflows that occur within and affect the study area. The flows described in this appendix are from areas external to the active model domain and define external model boundary conditions. The purpose of this appendix is to document and present the input values used to represent boundary condition fluxes in the SPDSS alluvial groundwater flow model. These estimated fluxes include the following:

1. *Alluvial groundwater inflow/outflow at the South Platte mainstem and tributary boundaries*
2. *Bedrock aquifer fluxes from the Denver Basin aquifers*
3. *Lateral boundary inflows from areas not already explicitly accounted for within the model domain*

The external boundary conditions define inflows and outflows at the sides and base of the active model domain. External boundary conditions included in the model include stream and alluvial groundwater inflows at the upstream ends of the simulated streams and rivers, stream and alluvial groundwater outflow at the downstream end of the model, groundwater flux from bedrock aquifers, and lateral boundary inflow from upland areas outside the model domain. The stream inflows are described and presented in Appendix F.

The SPDSS alluvial groundwater model simulates the period 1950 through 2006 with monthly inputs. Calibration of this model was undertaken for two periods: a steady-state period representing average conditions for 1991-1994; and a monthly transient period representing conditions from 1999-2005. Following these calibration steps, model validation was undertaken using monthly inputs for the full study period. The following sections describe the sources, processing and results for alluvial groundwater, bedrock aquifer, and lateral boundary fluxes for of these three model simulation periods.

2.0 Alluvial Groundwater Inflow/Outflow at the South Platte Mainstem and Tributary Boundaries

The active model domain extends upstream along tributary valleys until the estimated saturated thickness of alluvial sediments is less than 10-feet thick. This was done to make the model more stable numerically. To represent any alluvial groundwater inflow at tributary boundaries entering the active model domain from areas outside the active model domain, alluvial groundwater inflow at tributaries have been included as a model input. Inflows from 35 tributary alluvial valleys are represented by this boundary condition. These boundary fluxes are simulated in the model using injection wells. In addition, a general head boundary condition was defined at the most downstream portion of the active model domain to allow groundwater outflow. A general head boundary condition allows the flow rate to vary depending on simulated heads in nearby cells. The groundwater outflow at this location is computed by the model based on simulated heads and not explicitly defined.

2.1 Data Sources

Data used in the alluvial groundwater inflow at tributary boundaries calculations originate from the saturated thickness, aquifer hydraulic conductivity, and water level data evaluated and reported in the Phase 3 Task 42.3, 43.3, and 44.3 Technical Memoranda (SPDSS 2006a-c). Hydraulic conductivity data used for the underflow calculations were obtained from aquifer pumping tests located near the transects, the intersection of the model boundary, and the alluvial aquifer in each tributary.

Many transects did not have enough data to explicitly compute alluvial groundwater inflow. In these cases the groundwater flow entering the model was calculated using the methodology described in lateral boundary inflow discussed in Section 4.0.

2.2 Data Processing

Inflows into the active model domain from tributary alluvial aquifers were calculated using one of two methods, depending on whether or not the tributary valley was simulated as having a perennial stream. In cases where the tributary valley has a perennial stream there is a stream-aquifer interconnection allowing for alluvial underflow to be computed directly. In other cases where a perennial stream is not present the alluvial under flow is related to precipitation and irrigation recharge.

2.2.1 Alluvial Valleys with Perennial Streams at the Upstream Model Boundary

The first method of calculating alluvial groundwater inflows was applied to the South Platte River below Chatfield Reservoir and 11 tributary valleys (Figure D-2), which are represented in the model with perennial streams:

- South Platte River below Chatfield Reservoir
- Bear Creek
- Big Dry Creek
- Big Thompson River
- Boulder Creek
- Cache la Poudre River
- Cherry Creek
- Clear Creek
- Little Thompson River
- Plum Creek
- South Boulder Creek
- St. Vrain River

Alluvial groundwater inflows from these tributaries were calculated using Darcy's Law (Darcy 1856), based on the available data (SPDSS 2006a, SPDSS 2006c) and engineering judgment for estimated parameters. Average monthly flux values were estimated. These values were assumed constant over time.

Groundwater inflow into the model domain through saturated alluvium was estimated using the Darcy equation:

Q=KiA

where:

Q = Groundwater inflow (ft^3/day)
K = Aquifer hydraulic conductivity (ft/day)
i = Water table gradient in the vicinity of the transect (ft/ft)
A = Cross sectional area of the tributary aquifer (ft^2)

Cross-sectional areas were calculated using the saturated thickness data across a transect of the alluvial channel oriented perpendicular to the channel. Figure D-2 presents the transect locations used to estimate groundwater fluxes and Table D-1 lists the tributaries that will receive groundwater flux along with the estimated flux values. The groundwater hydraulic gradients were measured from mapped water level data at the transect locations. This groundwater underflow calculation method is recommended in groundwater inflow evaluations (Freeze and Cherry 1979; Fetter 2001) and has been used in local studies (Duke and Longenbaugh 1966).

Table D-1 Average Monthly Alluvial Groundwater Inflow by Tributary Basin

Tributary Name	Hydraulic Conductivity K (ft/d)	Hydraulic Gradient i (ft/ft)	Cross-sectional Area (ft^2)	Rate (AFY)
South Platte River below Chatfield Reservoir	900	0.00000	139,532	0
Bear Creek	475	0.00423	29,500	490
Big Dry Creek	300	0.00479	51,000	610
Big Thompson River	480	0.00280	197,300	2,220
Boulder Creek	350	0.00352	98,000	1,010
Cache la Poudre River	400	0.00379	80,000	1,010
Cherry Creek	512	0.00222	128,500	1,220
Clear Creek	400	0.00667	30,000	670
Little Thompson River	400	0.00379	20,000	250
Plum Creek	530	0.00323	70,000	1,010
South Boulder Creek	400	0.00500	80,000	1,340
St. Vrain River	480	0.00250	198,012	2,000

2.2.2 Alluvial Valleys without Perennial Streams at the Upstream Model Boundary

A total of 23 tributary alluvial valleys included in the model do not have perennial surface water flows at their upstream model boundary. The lack of perennial stream flow is based on gaging data, rainfall-runoff relationships from nearby tributaries, and engineering judgment. These tributary alluvial valleys, listed below and shown on Figure D-1, are simulated to have inflow only from alluvial groundwater entering the active model domain.

- Badger Creek
- Beaver Creek
- Box Elder Creek
- Boxelder Creek
- Camp Creek
- Cedar Creek
- Comanche Creek
- Crow Creek
- E. Bijou Creek
- Kiowa Creek
- Little Dry Creek
- Lodgepole Creek
- Lonetree Creek
- Middle Bijou Creek
- Muddy Creek
- Owl Creek
- Pawnee Creek
- Ralston Creek
- Sand Creek
- Twentytwo Slough
- W. Bijou Creek
- Wildcat Creek
- Wolf Creek

The flux entering the active model domain through alluvial groundwater inflow from these tributaries is calculated using the lateral boundary inflow method described in Section 4.2, below.

2.3 Model Input

The alluvial groundwater inflow estimates for the South Platte River below Chatfield and 11 tributary alluvial valleys that have perennial surface water flow are presented in the following subsections for the steady-state calibration, transient calibration, and model validation time periods implemented in the model. The alluvial groundwater inflow is estimated to be constant over the period of record for the alluvial valleys with perennial streams. The only variation is in the number of days in a month. The alluvial groundwater inflows for the 24 tributary alluvial valleys without perennial surface water flows are presented in Section 4.0. The alluvial groundwater inflows are input in the model as specified flux values using the Well package of MODFLOW.

2.3.1 Steady State Period

The steady-state model calibration period represents average annual conditions for 1991 through 1994. The basis for selecting this period is described in the *SPDSS Phase 4 Task 48.2 Development of Calibration Targets and Criteria Technical Memorandum* (SPDSS 2008).

The steady-state model input consists of one record for each applicable cell for the average annual alluvial groundwater inflows for 1991 through 1994. The model input value is shown in Table D-2. These values were used in the steady-state model to confirm the estimated alluvial underflow rates were reasonable for each tributary entering the mainstem of the South Platte alluvium.

Table D-2 Average Annual Alluvial Groundwater Inflow, 1991-1994 (AFY)

Model Input	Rate (AFY)
Alluvial Groundwater Inflow, 1991-1994	11,850

2.3.2 Transient Calibration Period

The transient model calibration period represents monthly conditions for the period 1999 through 2005. The basis for selecting this period is described in the *SPDSS Phase 4 Task 48.2 Development of Calibration Targets and Criteria Technical Memorandum* (CDM 2008).

The transient calibration period model inputs consist of 84 monthly values that simulate alluvial groundwater inflow from January 1999 through December 2005. The monthly values are shown on Figure D-3. The simulated alluvial inflow rates are constant over this period, at 32.5 AF/day multiplied by the number of days in a month to account for the minor monthly variations seen in the figure. The average monthly value during this period is 986 AF and the average annual value is 11,850 AF. Table D-3 lists the average annual flux for the South Platte River below Chatfield and each of the 11 tributaries whose inflow was estimated using the Darcy flow equation. The South Platte River below Chatfield Reservoir has no alluvial inflow because the dam creating this reservoir extends into the bedrock and has cut off all alluvial groundwater flow.

Table D-3 Average Monthly Alluvial Groundwater Inflow by Tributary Basin

Tributary	Average Rate (AF/month)
South Platte River below Chatfield Reservoir	0
Bear Creek	41
Big Dry Creek	51
Big Thompson River	185
Boulder Creek	84
Cache la Poudre River	84
Cherry Creek	102
Clear Creek	56
Little Thompson River	21
Plum Creek	84
South Boulder Creek	112
St. Vrain River	167
Total	**986**

2.3.3 Model Validation Period

The model validation period represents monthly conditions the full study period of 1950 through 2006.

The model validation period model inputs consist of 684 monthly values that simulate agricultural pumping from January 1950 through December 2006. The annual alluvial groundwater inflow values for this time period are shown on Figure D-4. The annual inflow values have a narrow range, and average 11,850 AFY, with no significant changes over time.

Average monthly alluvial groundwater inflow values for the model validation period are shown on Figure D-5 and listed in Table D-4. The small range in average monthly inflows, from 916 AF/month to 1,006 AF/month, is due to the difference in number of days in a month multiplied by the constant rate of 32.5 AF/day.

Table D-4 Average Monthly Alluvial Groundwater Inflow, 1950-2006 (AF/month)

Time Period	Average Rate (AF/month)
January	1,006
February	916
March	1,006
April	973
May	1,006
June	973
July	1,006
August	1,006
September	973
October	1,006
November	973
December	1,006

3.0 Bedrock Aquifer Flux from the Denver Basin Aquifers

Denver Basin bedrock aquifers underlie approximately the southern half of the alluvial aquifer system included in the SPDSS groundwater model. Inflows to and outflows from the base of the alluvial aquifer and the underlying bedrock aquifers is a component of the external boundary conditions included in the model. The boundary fluxes are simulated in the model using either injection or pumping wells.

3.1 Data Sources

Monthly transient bedrock flux was derived from a numerical model of the Denver Basin aquifers developed by the U.S. Geological Survey (USGS). This is a 12-layer model that explicitly represents the six Denver Basin aquifers (from bottom to top: Laramie-Fox Hills, Lower Arapahoe, Upper Arapahoe, Denver, Lower Dawson and Upper Dawson), their overlying confining layers, and the surficial alluvial aquifer (USGS 2011). The Division of Water Resources (DWR) and Colorado Water Conservation Board (CWCB) worked closely with the USGS in model development to ensure consistency in data sources and outlines of the active domain for the alluvial aquifer between the USGS and

SPDSS models. The bedrock-alluvial aquifer fluxes from the calibrated USGS Denver Basin model were made available for use as an external boundary flux in the SPDSS alluvial groundwater model.

3.2 Data Processing

Monthly transient bedrock flux was derived from the USGS Denver Basin Model (Denver Basin Model) using the G2GFLOW tool developed by USGS (Banta et al. 2008). The G2GFLOW tool allocates cell-by-cell flows generated in the Denver Basin Model to the SPDSS alluvial model (SPDSS Model) using both spatial and temporal proportioning, as the USGS and SPDSS models have different grids and cell sizes, as well as different stress period durations. G2GFLOW generates a MODFLOW Well package file that lists flow for each cell in the SPDSS model where the Denver Basin Model simulates non-zero flow between the alluvium and the bedrock.

Spatial apportionment to each SPDSS Model cell is based on area and percent of SPDSS Model cell that is contained within the Denver Basin Model cell. In cases where the SPDSS model grid falls outside of the active cells and are within the Denver Basin Model grid, G2GFLOW assigns a flux of 0. Bedrock fluxes from the Denver Basin Model that fall outside the SPDSS Model domain were incorporated into the model by locating the nearest active model cell and adding the flux to that cell. The bedrock fluxes computed by the Denver Basin model were incorporated in the nearest active model cell because of the course representation of the alluvium in the Denver Basin Model (1-mile cells) as compared to the SPDSS Alluvial Groundwater Model (uniform 1,000-foot cells).

Temporal apportionment consisted of using the G2GFLOW code to assign Denver Basin flux to the SPDSS model based on the SPDSS model stress period length and percent of overlap between the Denver Basin Model and SPDSS model stress periods. The Denver Basin Model simulation runs through 2003. The SPDSS Model runs through 2006, with monthly stress periods. Monthly bedrock flux for the SPDSS Model was determined for the overlapping time period from 1950 to 2003. Monthly fluxes determined for 2003 were repeated for 2004 through 2006.

3.3 Model Input

The following subsections present the results for the steady-state calibration, transient calibration, and model validation time periods implemented in the model. The bedrock aquifer fluxes are input in the model as specified flux values using the Well package of MODFLOW. Flow from the bedrock aquifers into the alluvial aquifer are positive fluxes and flow from the alluvial aquifer into the bedrock aquifers are negative fluxes.

3.3.1 Steady-State Period

The steady-state model calibration period represents average annual conditions for 1991 through 1994. The basis for selecting this period is described in the *SPDSS Phase 4 Task 48.2 Development of Calibration Targets and Criteria Technical Memorandum* (SPDSS 2008).

The steady-state model input consists of one set of values containing the average monthly agricultural pumping for 1991 through 1994. The model input value is shown in Table D-4. The model input uses a negative value to indicate a flux out of the alluvial aquifer system. The net flux is positive, indicating on overall flow from the bedrock aquifers into the alluvial aquifer. However, as shown on Figure D-6, there is considerable spatial variation in flux across the study area, both in magnitude and whether it is positive (upward) or negative (downward) flux.

For the steady-state time period there is a bedrock aquifer flux into the alluvial aquifer of 19,300 AFY and a flux from the alluvial aquifer into the bedrock aquifers of over a quarter of this amount, 5,500 AFY, to yield the net flux of 13,800 AFY (19.1 cfs). As shown in Figure D-6, during the steady-state period bedrock flux is into the alluvial aquifer in three groupings of areas:

1. Upstream portions of Boulder Creek, St. Vrain Creek, Cherry Creek, Wolf Creek, Comanche Creek, each of the tributaries of Bijou Creek, and Muddy Creek, overlying the Dawson and Denver Aquifers;

2. Alluvial areas overlying the Arapahoe Aquifer; and

3. Alluvial areas at the northern end of the model active area overlying the Laramie - Fox Hills Aquifer.

3.3.2 Transient Calibration Period

The transient model calibration period represents monthly conditions, for all input data, for the period 1999 through 2005. The basis for selecting this period is described in the *SPDSS Phase 4 Task 48.2 Development of Calibration Targets and Criteria Technical Memorandum* (SPDSS 2008).

The transient calibration period model boundary inflow inputs consist of 84 monthly values for each applicable cell to represent bedrock aquifer flux from January 1999 through December 2005. The net monthly flux values are shown on Figure D-7. The net bedrock inflow rates obtained from the Denver Basin Model decline approximately 10 percent from 1999 through 2002; the bedrock inflow rates are similar for 2002 and 2003. Bedrock fluxes were not available from the Denver Basin Model after 2003; therefore, monthly fluxes determined for 2003 were repeated for 2004 and 2005. The lowest monthly values (give a value) occur in February while the highest monthly inflow value (give a value) occurs in many months. The average monthly value during this period is 1039 AF and the average annual value is 12,473 AF. As with the steady-state period, there is a net positive flux into the alluvial aquifer during the transient calibration period but also considerable spatial variation in the magnitude and direction of flow between the alluvial and bedrock aquifers in approximately the same distribution as shown on Figure D-6.

3.3.3 Model Validation Period

The model validation period represents monthly conditions for the full study period of 1950 through 2006. The basis for selecting this period is described in the *SPDSS Phase 4 Task 48.2 Development of Calibration Targets and Criteria Technical Memorandum* (SPDSS 2008).

The model validation period model inputs consist of 684 monthly values for each applicable cell to represent bedrock aquifer flux to and from the alluvial aquifer from January 1950 through December 2006. The annual bedrock aquifer inflow values for this time period are shown on Figure D-8. The annual inflow values show an overall decline beginning in the mid-1950s, with a period of stable bedrock inflow during 1985-1994. The average annual net bedrock flux into the alluvium is 15,427 AF (21.3 cfs), although there are locations where flow is from the alluvium into the bedrock aquifers, comparable to the distribution shown on Figure D-6. The average annual net bedrock flux for the validation period is larger by approximately 20 percent than that for the transient calibration period due to the larger bedrock flux values that occurred in the early part of the study period.

Average monthly bedrock flux values for the model validation period are shown on Figure D-9 and listed in Table D-5. There is a small range in average monthly inflows, from 1,195 AF in February to 1,311 AF in January.

Table D-5 Average Monthly Bedrock Aquifer Inflow, 1950-2006 (acre-ft/month)

Time Period	Average Rate (AF/month)
January	1,312
February	1,195
March	1,311
April	1,269
May	1,311
June	1,268
July	1,309
August	1,308
September	1,266
October	1,308
November	1,265
December	1,307

4.0 Lateral Boundary Inflows

A review of SPDSS irrigated acreage mapping of the South Platte River watershed (SPDSS 2006d) indicates that there are considerable areas located outside the active model domain in which irrigated agricultural activity is occurring. The subsurface return flow from these irrigated areas and also subsurface inflow from the upstream portions of selected tributaries located outside the alluvial model are important components contributing to the aquifer mass balance. The boundary fluxes are simulated in the model by adding injection wells in the nearest active cell. These external boundary conditions are included in the model and are described below.

4.1 Data Sources

To calculate the lateral boundary inflows for the South Platte Alluvial Groundwater Model, data on the spatial and temporal distribution of recharge from irrigation and precipitation in the South Platte watershed was first collected. This data was compiled and provided by the SPDSS Consumptive Use contractor. Soil property data was also collected for the areas where irrigation was present. Managed recharge areas in the South Platte Basin were included in this analysis since in recent years these recharge areas have become a significant source of recharge. Managed recharge areas are discussed in Appendix M.

4.2 Data Processing

Using the data described above and the spatial relationship between the irrigated and native areas outside the active model area and the flow model boundary, the lateral boundary flow was calculated using the Glover method, an equation that estimates the lagging and attenuation of an infiltrated flow on a boundary at a known distance.

The following assumptions are made in this analysis:

- Infiltrated irrigation water and water from excess precipitation within the South Platte River watershed will flow towards the river (and therefore the model boundary that surrounds the river) either within an alluvial or weathered mantle, or within permeable bedrock deposits.

- Soil properties (transmissivity and storativity) are continuous and homogenous over the portion of soils in which the infiltrated irrigation water travels towards the model boundary, given the basin scale of the modeling area.

- The Glover method is valid in the thin aquifers outside the alluvial aquifer. The Glover method is routinely used to estimate the effect of infiltrated (or extracted) water on a neighboring surface water body. The flow model boundary is assumed to approximate the terminal surface water boundary in the Glover method.

Figure D-10 shows the South Platte River watershed and the outline of the alluvial groundwater flow model. Any irrigated areas outside the active model area and within the watershed will contribute flow to the alluvial model. The watersheds for tributaries that do not have a perennial surface water flow are also accounted for using the Glover method and are shown in blue shading. Watershed areas whose inflow are accounted for in streamflow and alluvial groundwater inflow estimates made at points where the main tributaries meet the model boundary are shown in a red hatch color in Figure D-10.

Figure D-11 displays the spatial distribution of irrigated land outside the active model area and within the South Platte watershed in the year 2001. Similar irrigated area coverages are available for years 1956, 1976, and 1987. These coverages can be combined, along with data on how much water is applied to the irrigated land, into a time series of applied irrigation for a specific area in the watershed.

For each month (the groundwater flow model has a monthly time step) of available data, the irrigated area will be converted to a model cell-based format by intersecting the irrigated areas with model cells outside the alluvial boundary. This will create a cell-based, monthly time series of available water to use in the lateral boundary flow calculations. Irrigated cells are identified by their model layer, row, and column properties. The time step and the amount of available water from irrigation is also included in the database table. Finally, fields that contain the aquifer transmissivity and specific yield for each irrigated cell are included in the table.

The return flow from each irrigated cell is routed to the nearest model boundary cell. The uniform grid used in the SPDSS groundwater model simplifies the distance computation between two cells. Note that this relationship does not change with time and changing irrigation and that one boundary cell could have multiple irrigation cells contributing to it. The calculated distance between the cells is also used in the Glover method.

The return flow for each boundary cell is calculated using the Glover method for each irrigated cell paired with the selected boundary cell. If a boundary cell is paired with more than one irrigated cell, the total boundary flow will be the sum of the individually calculated boundary flows.

The Glover equation (Glover and Balmer 1954) for cumulative return flow as a fraction of the cumulative applied flow (v/Qt) is shown below. This equation assumes an upgradient impermeable boundary that will be positioned at the area of recharge in our analysis (W = a).

$$\frac{v}{Qt} = \sum_{n=0}^{i} [(-1)^n C + (-1)^n D]$$

where

$$C = \left(\frac{(2nW+a)^2}{2tT/S} + 1\right)\operatorname{erfc}\left(\frac{2nW + a}{\sqrt{4tT/S}}\right) - \frac{2nW + a}{\sqrt{4tT/S}}\frac{2}{\sqrt{\pi}}\exp\left(-\frac{(2nW+a)^2}{4tT/S}\right)$$

$$D = \left(\frac{(2W+2nW-a)^2}{2tT/S} + 1\right)\operatorname{erfc}\left(\frac{2W + 2nW - a}{\sqrt{4tT/S}}\right) - \frac{2W + 2nW - a}{\sqrt{4tT/S}}\frac{2}{\sqrt{\pi}}\exp\left(-\frac{(2W+2nW-a)^2}{4tT/S}\right)$$

The variables in this solution are defined as follows:

a = distance from irrigated area to model boundary

W = distance from assumed impermeable boundary to model boundary (assumed to be equal to "a" in our analysis)

T = aquifer transmissivity

S = aquifer storativity

t = time

A conceptual illustration of lateral boundary inflow parameters is shown in Figure D-12.

Glover "Return Flow Factors" (RFF) are developed for each recharge cell and multiplied by the recharge in each time step for the specified cell. Summing the resulting data gives the lateral boundary inflow for each model boundary cell.

4.3 Model Input

The following sections present the results for the steady-state calibration, transient calibration and model validation time periods implemented in the model. The lateral boundary inflows are input in the model as specified flux values using the MODFLOW Well package.

4.3.1 Steady-State Period

The steady-state model calibration period represents average annual conditions for 1991 through 1994. The basis for selecting this period is described in the *SPDSS Phase 4 Task 48.2 Development of Calibration Targets and Criteria Technical Memorandum* (SPDSS 2008).

The average annual lateral groundwater inflow for 1991 through 1994 for the entire model domain was 478,780 AFY.

4.3.2 Transient Calibration Period

The transient model calibration period represents monthly conditions for the period 1999 through 2005. The basis for selecting this period is described in the *SPDSS Phase 4 Task 48.2 Development of Calibration Targets and Criteria Technical Memorandum* (SPDSS 2008).

The transient calibration period model inputs consist of 84 monthly values that simulate lateral boundary inflow from January 1999 through December 2005. The monthly values are shown on Figure D-13. The simulated lateral boundary inflow rates exhibit a 10 to 15 percent range over a year, with the minimum values being in February and the maximum values in October. This annual cycle of lateral boundary inflows suggests that lag times are approximately 1 to 3 months for the return flow from irrigated lands located outside the active model domain. Although there is a seasonal component to the estimated inflow pattern, there is also variability from year to year that is derived from differences in annual irrigation patterns. The average monthly inflow during this period is 40,660 AF and the average annual value is 487,940 AF.

4.3.3 Model Validation Period

The model validation period represents monthly conditions for the full study period of 1950 through 2006.

The model validation period model inputs consist of 684 monthly values that simulate lateral boundary inflows from January 1950 through December 2006. The annual alluvial groundwater inflow values for this time period are shown on Figure D-14. The average annual inflow for the entire model domain is 463,280 AFY. There is a slight trend of increasing inflows during the study period; this is likely due to the cumulative effects of lateral inflow moving towards the model boundary. With a long enough "warm-up period," or period of estimating boundary inflow prior to the validation period, the effect should be minimized. A warm-up period of 80 years was used for the lateral boundary inflows.

Average monthly lateral boundary inflow values for the model validation period are shown on Figure D-15 and listed in Table D-6. The monthly averages range from 36,110 AF to 41,480 AF, a 13 percent of variance over the course of a year, with the lowest values occurring in the spring and early summer.

Table D-6 Average Monthly Lateral Boundary Inflow, 1950-2006 (acre-ft/month)

Time Period	Average Rate (AF/month)
January	40,170
February	36,109
March	39,067
April	37,408
May	38,549
June	37,657
July	39,763
August	40,659
September	39,975
October	41,476
November	39,915
December	40,804

5.0 References

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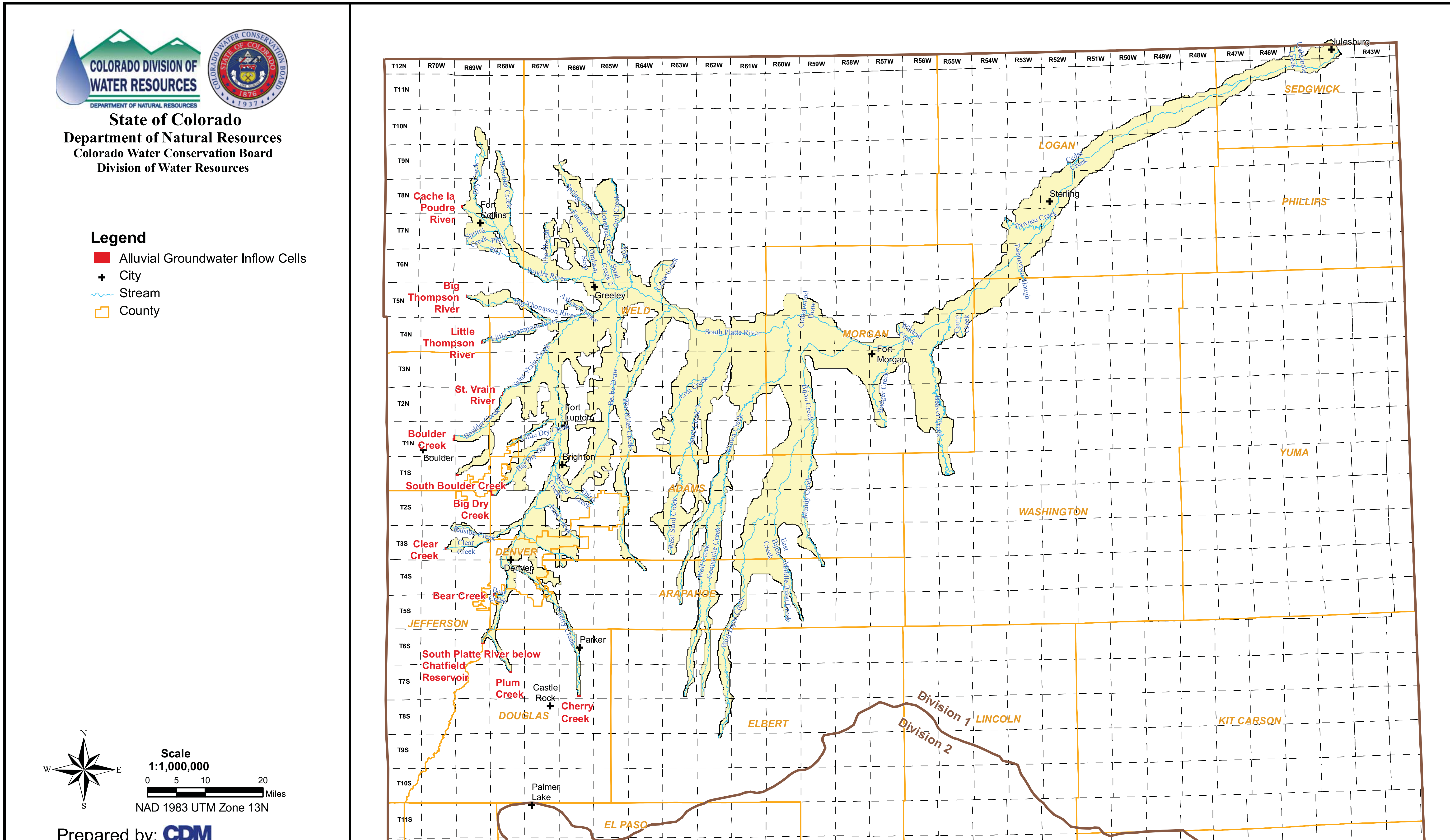
SPDSS Alluvial Groundwater Model Report

Figure D-1: Alluvial Groundwater Inflow Locations with Perennial Streams



SPDSS Alluvial Groundwater Model Report

Figure D-2: Alluvial Groundwater Inflow Locations without Perennial Streams

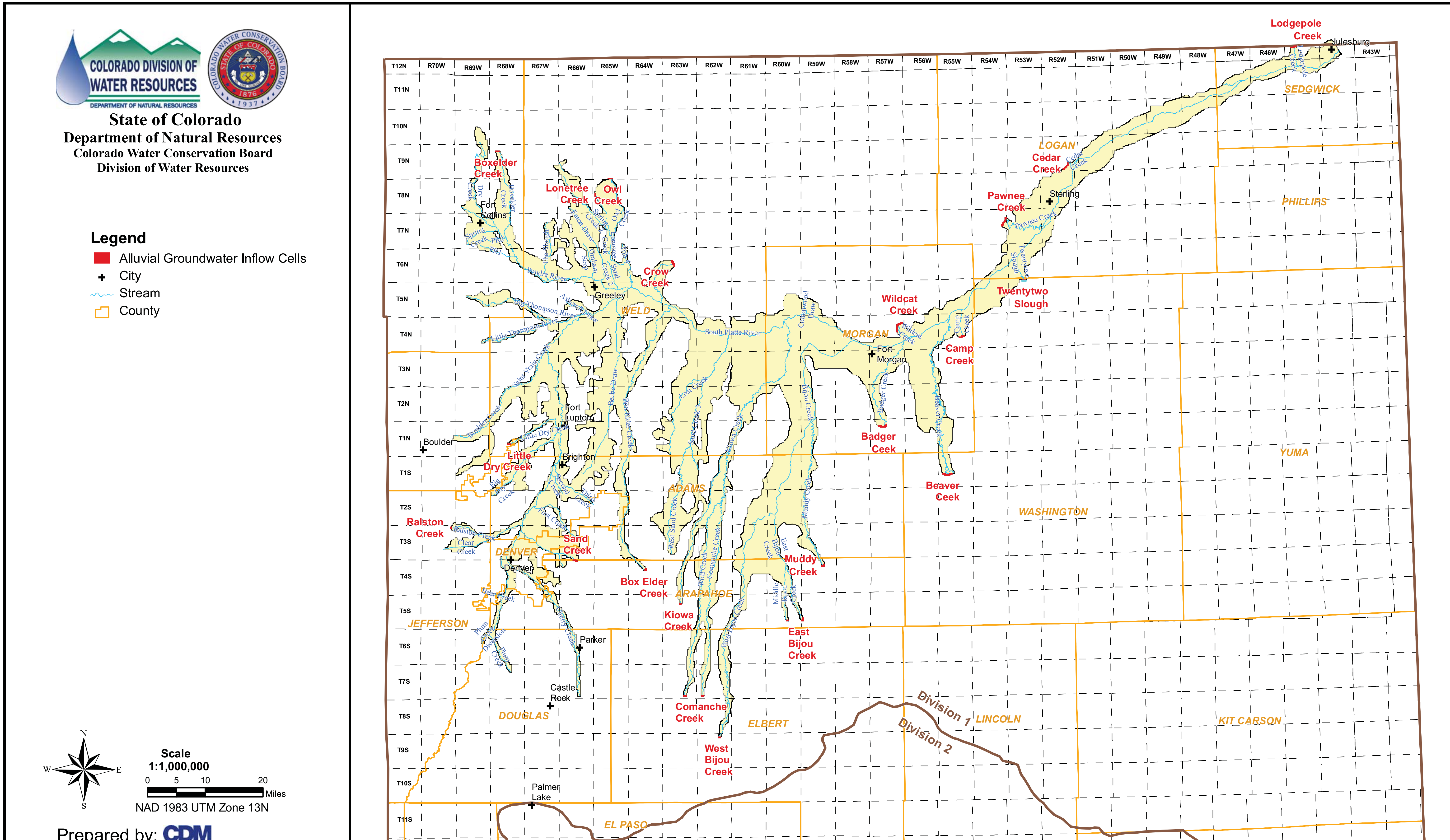
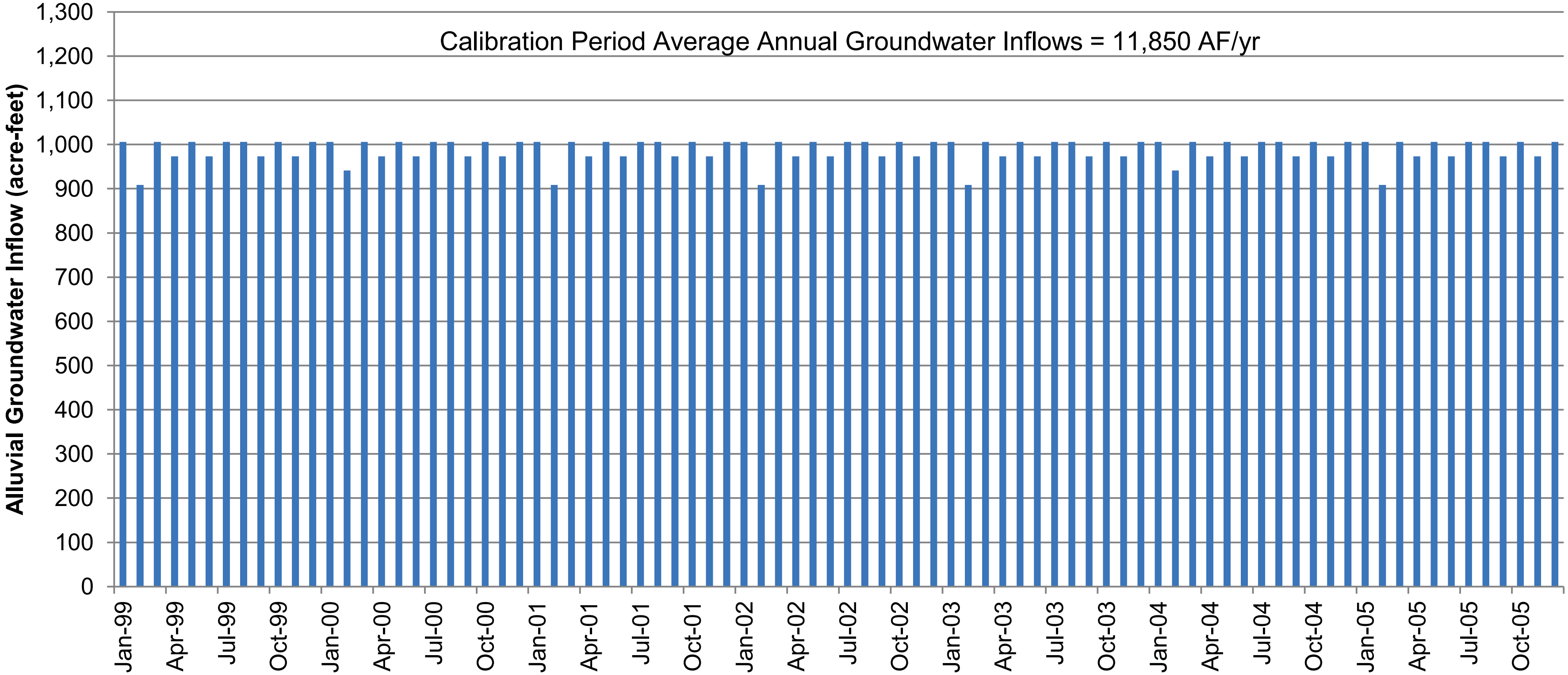


Figure D-3. Average Monthly Alluvial Groundwater Inflow - Transient Calibration Period (1999 - 2005)



State of Colorado
Department of Natural Resources
Colorado Water Conservation Board
Division of Water Resources

Prepared by: CDM

Figure D-4. Average Annual Alluvial Groundwater Inflow – Validation Period (1950 - 2006)

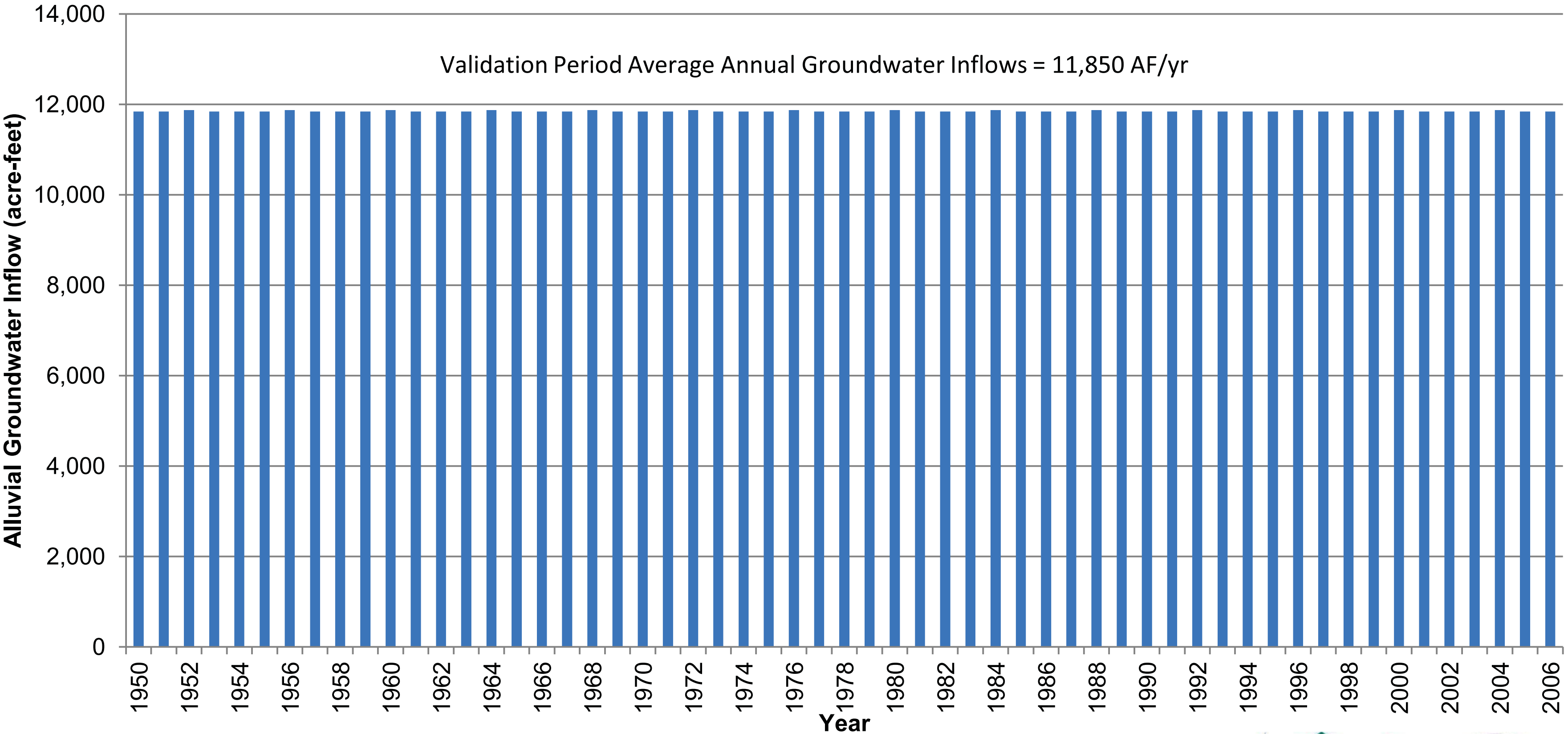


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Figure D-5. Average Monthly Alluvial Groundwater Inflows – Validation Period (1950 - 2006)

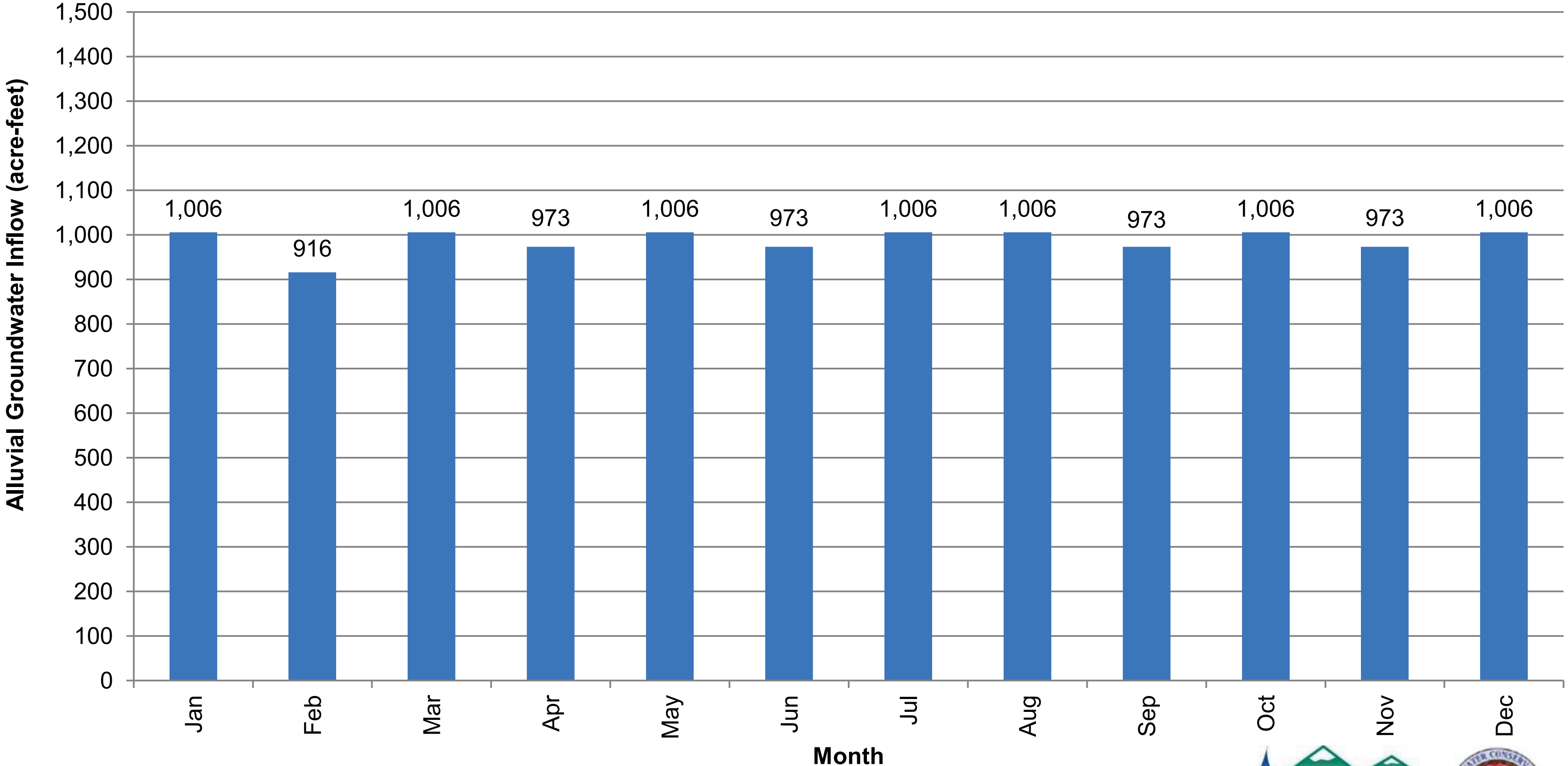

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Figure D-6: Bedrock Aquifer Flux - Steady State Period (1991-1994)

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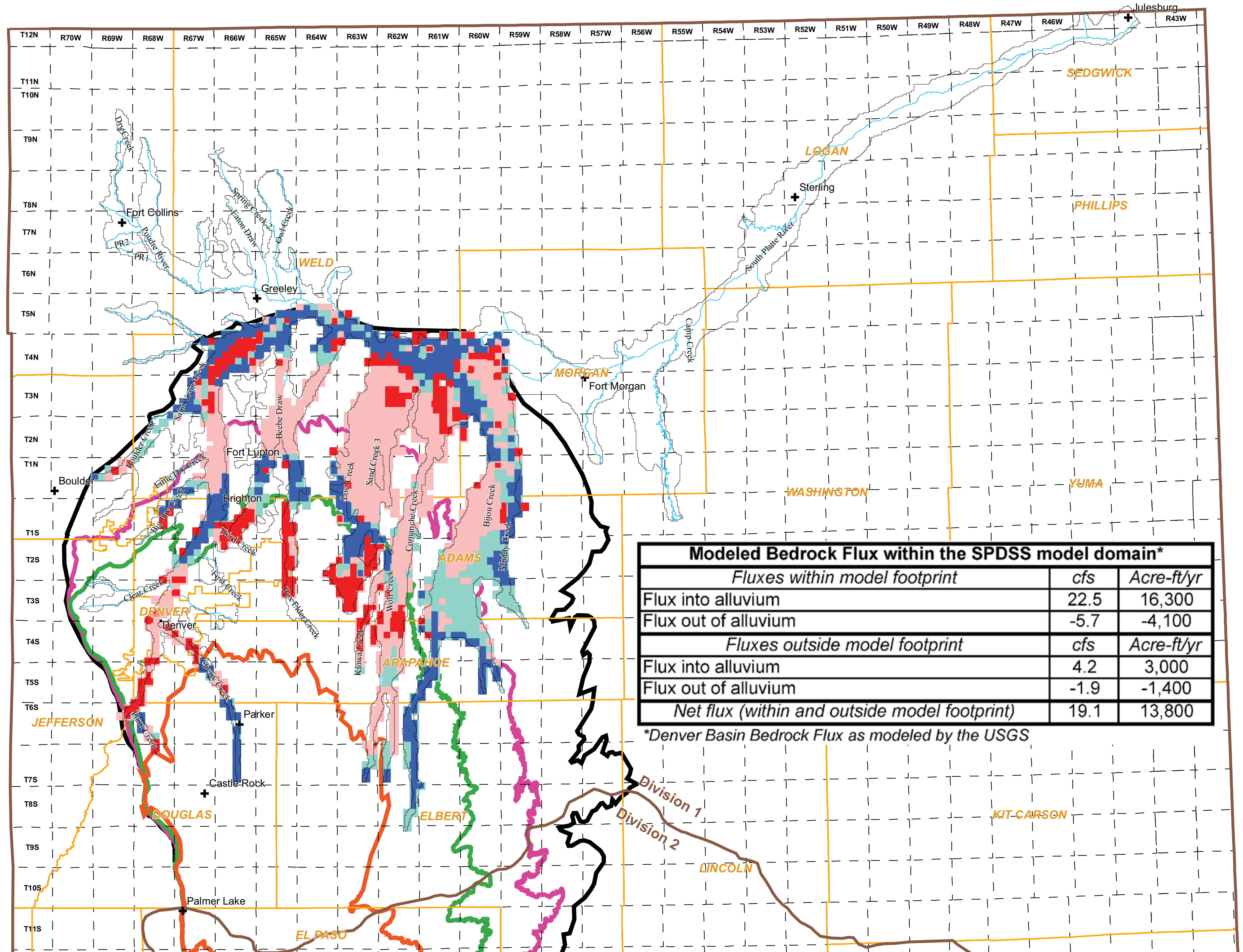
Legend

- Alluvial Aquifer Extent

Bedrock Aquifer Flux per Model Cell

- < -0.00025 (out of alluvium)
- -0.00025 - 0.00000 (out of alluvium)
- 0.00000 - 0.00025 (into alluvium)
- > 0.00025 (into alluvium)
- City
- Stream
- County
- Dawson Aquifer
- Denver Aquifer
- Arapahoe Aquifer
- Denver Basin Extent
- Complex Area



Modeled Bedrock Flux within the SPDSS model domain*		
Fluxes within model footprint	*cfs*	*Acre-ft/yr*
Flux into alluvium	22.5	16,300
Flux out of alluvium	-5.7	-4,100
Fluxes outside model footprint	*cfs*	*Acre-ft/yr*
Flux into alluvium	4.2	3,000
Flux out of alluvium	-1.9	-1,400
Net flux (within and outside model footprint)	19.1	13,800

**Denver Basin Bedrock Flux as modeled by the USGS*

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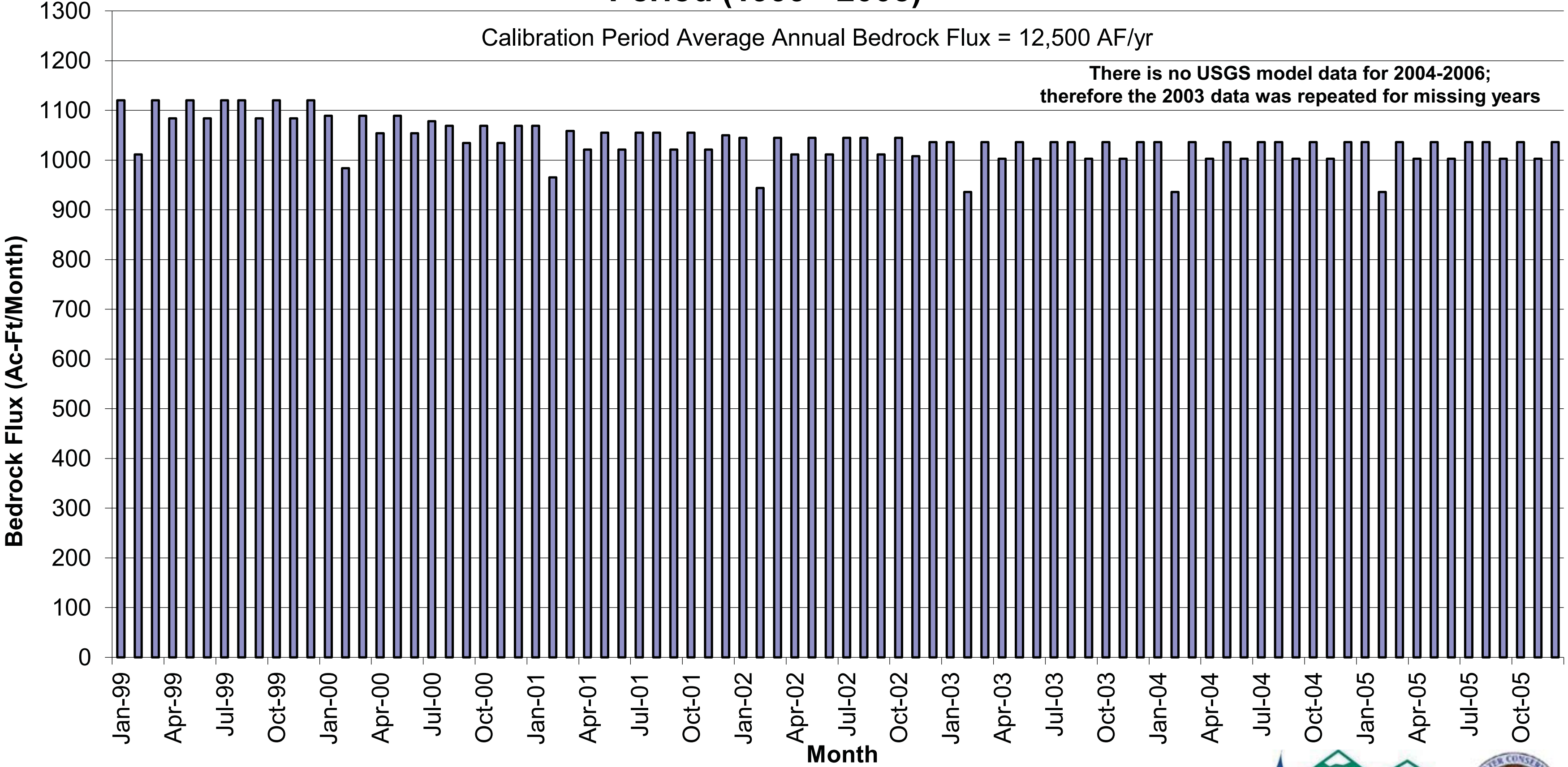
Figure D-7 Net Monthly Bedrock Flux into Alluvium - Transient Calibration Period (1999 - 2005)



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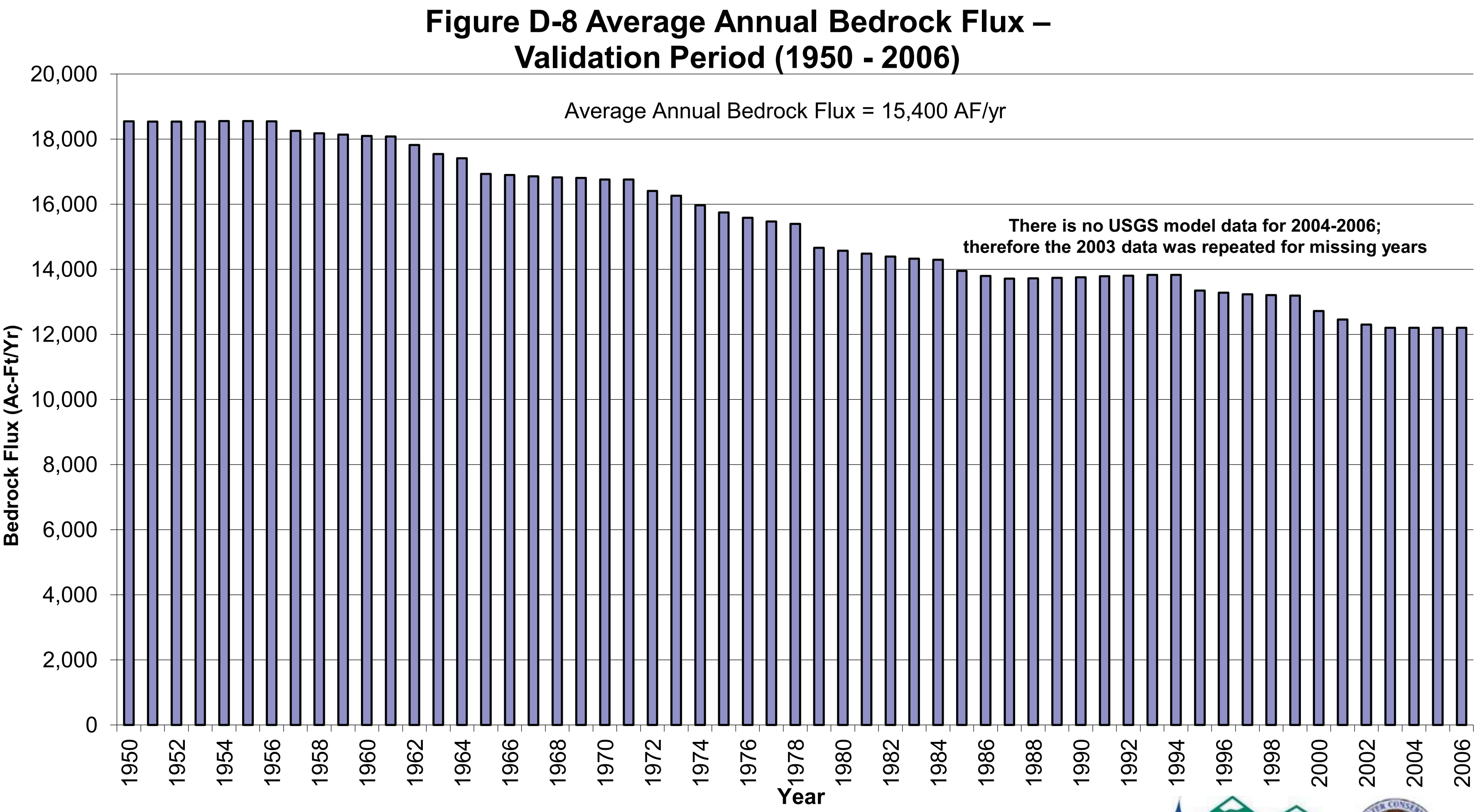

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Figure D-9 Average Monthly Bedrock Flux – Validation Period (1950 - 2006)

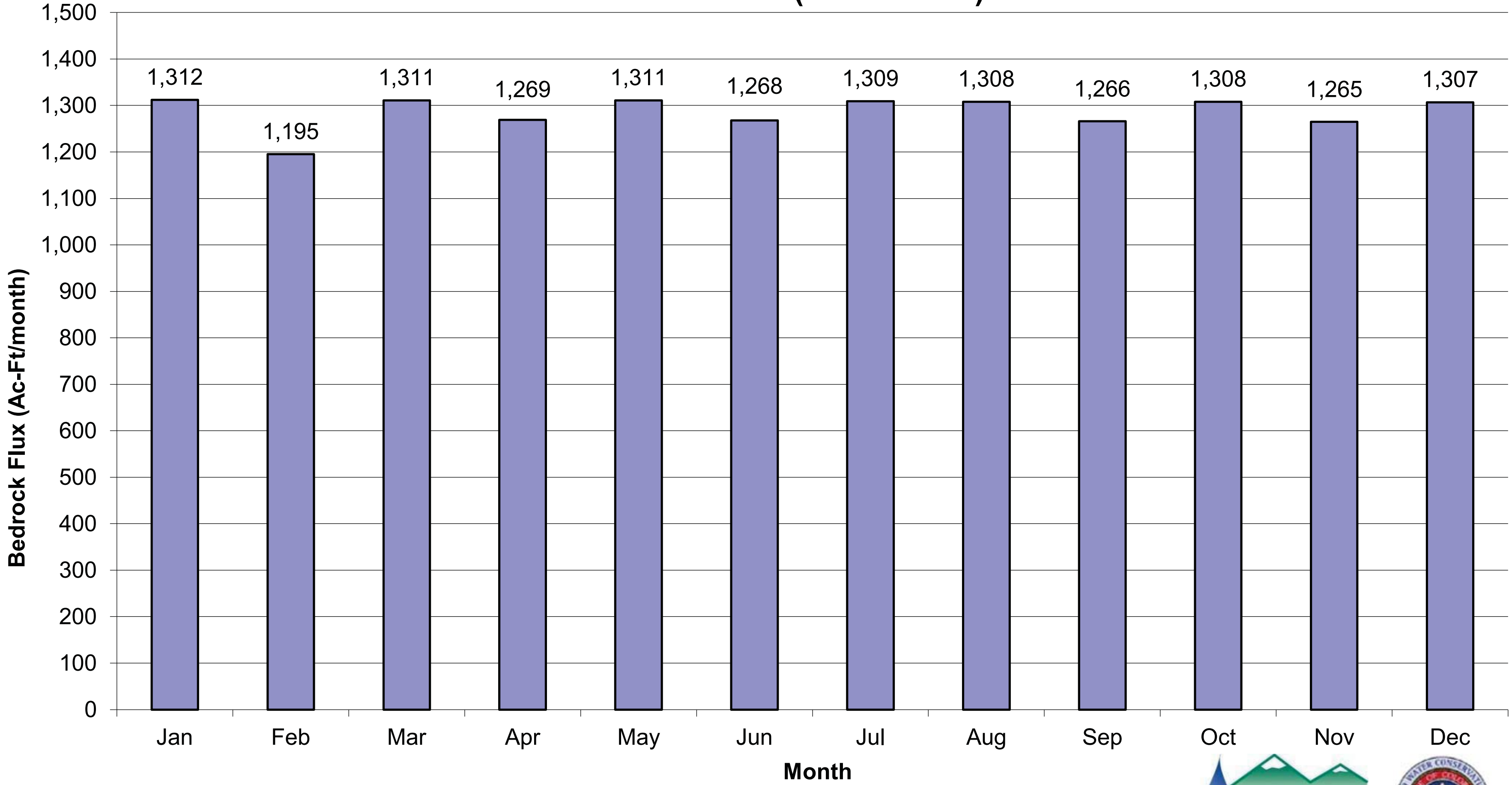

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Figure D-10: Active Model Domain and Lateral Boundary Inflows

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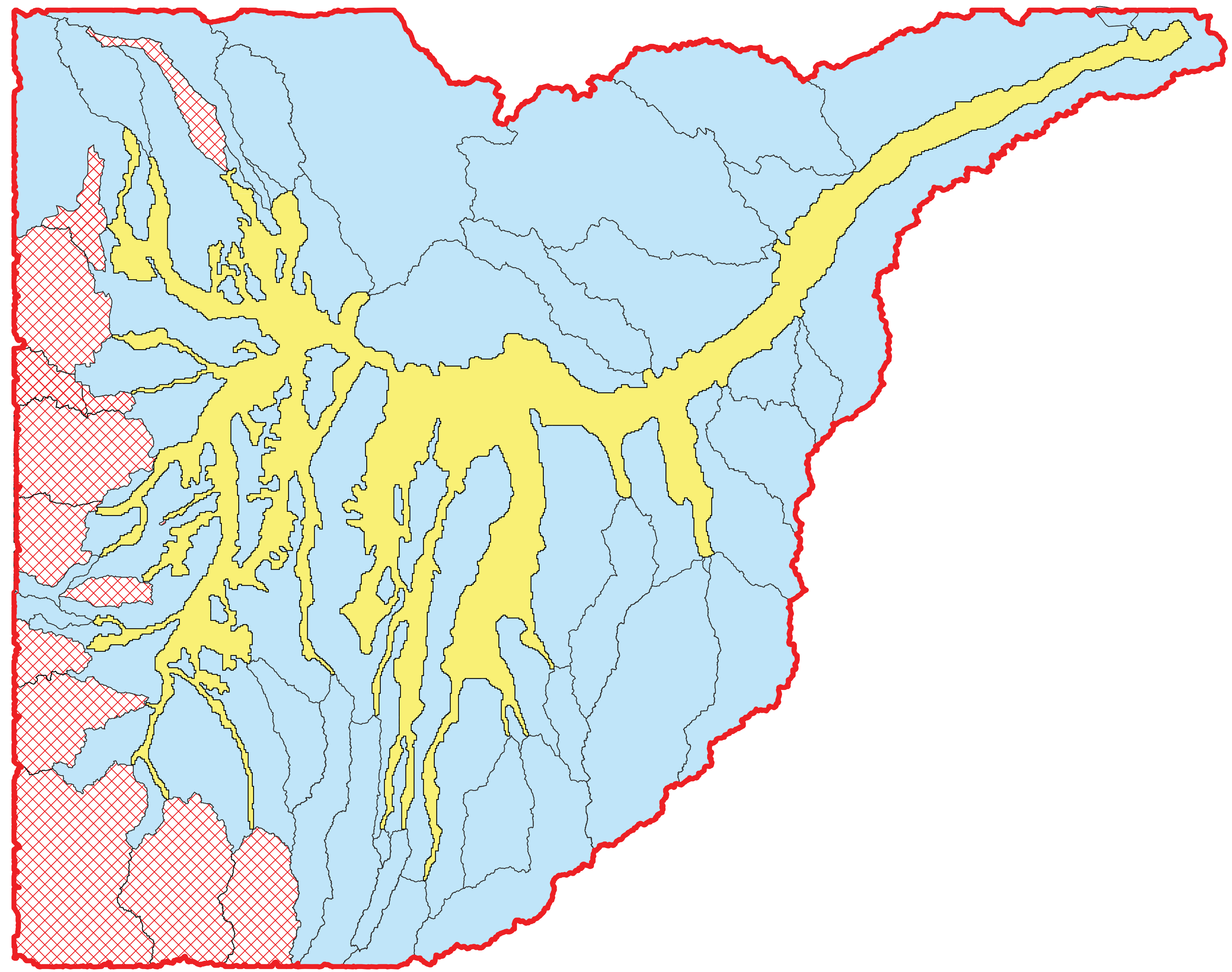
Legend

- Active Model Area
- Areas Contributing to SW/GW Inflow
- South Platte Watershed
- Areas Contributing to Lateral Boundary Inflows



Scale
1:1,100,000
0 5 10 20 Miles

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Figure D-11: Irrigated Areas in the South Platte Watershed in 2001

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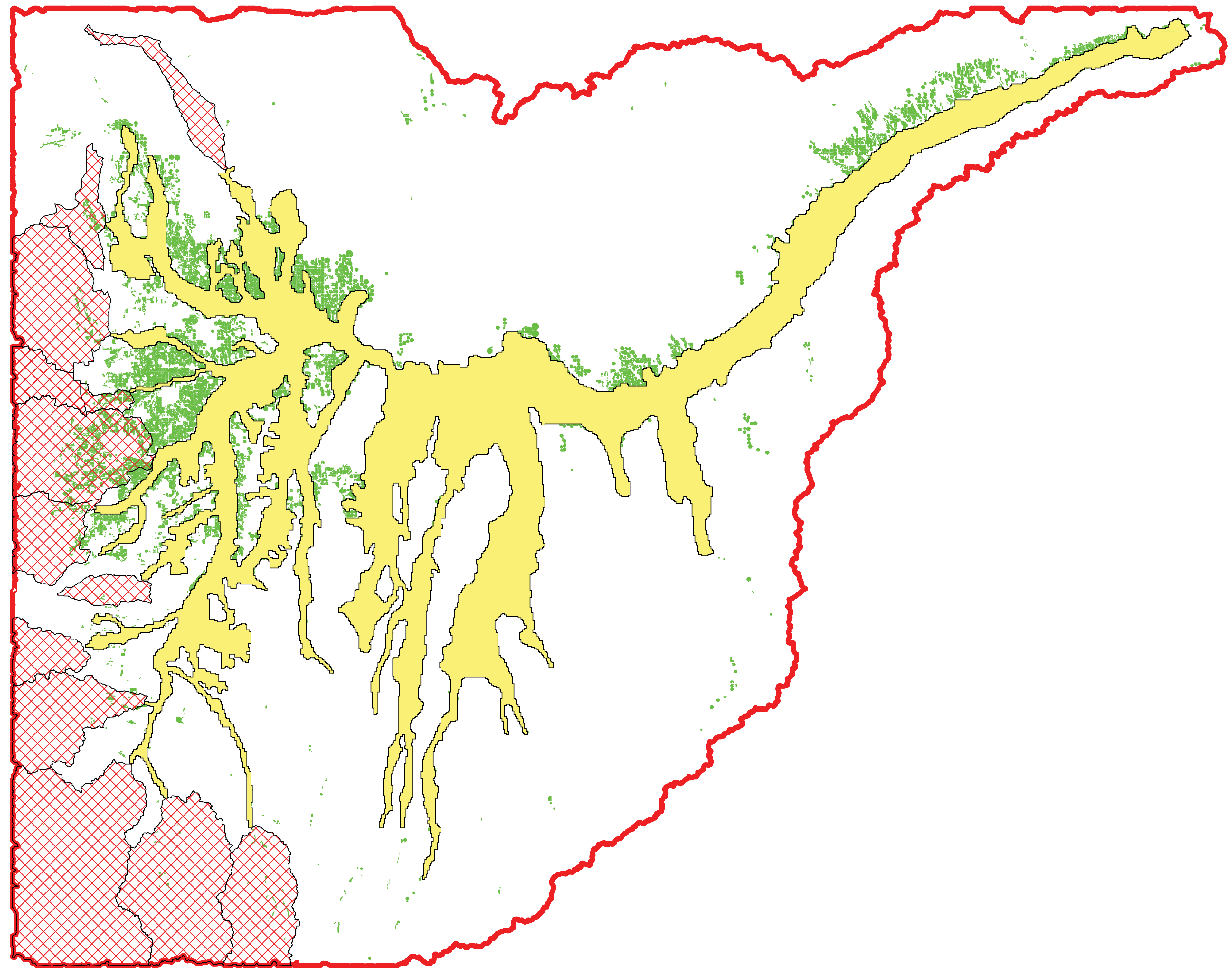
Legend

- Active Model Area
- Areas Contributing to SW/GW Inflow
- South Platte Watershed
- Irrigated Land 2001 Outside Active Model Area



N W E S

Scale
1:1,100,000
0 5 10 20 Miles

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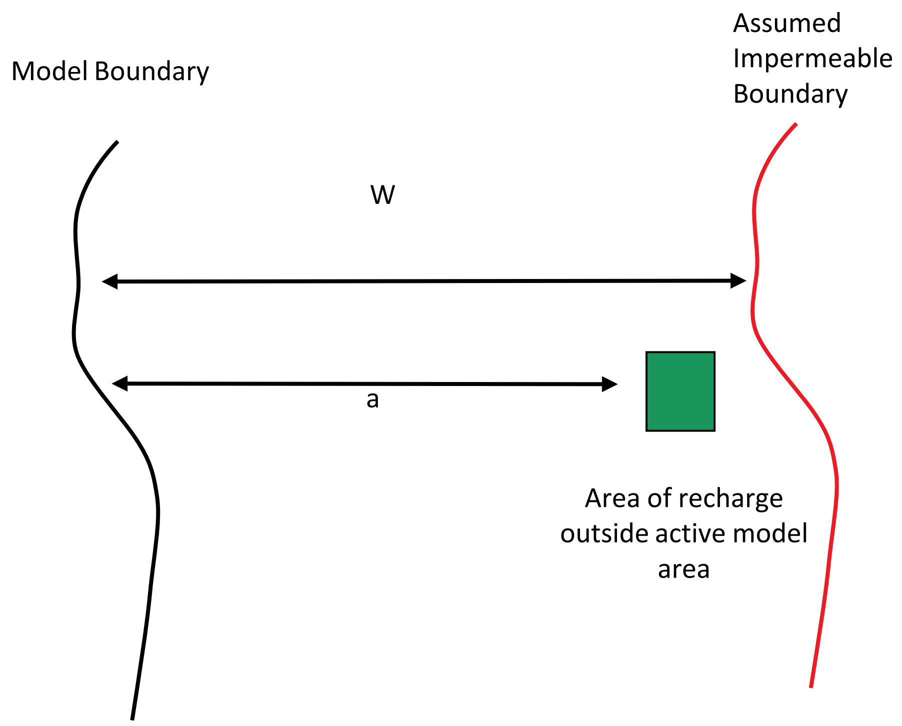
Figure D-12 Example Lateral Boundary Inflow Diagram



Where

W is the distance from the Model Boundary to the Assumed Impermeable Boundary

a is the distance from the Model Boundary to the Area of recharge outside active model area

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Figure D-13. Monthly Lateral Boundary Inflow - Transient Calibration Period (1999 - 2005)

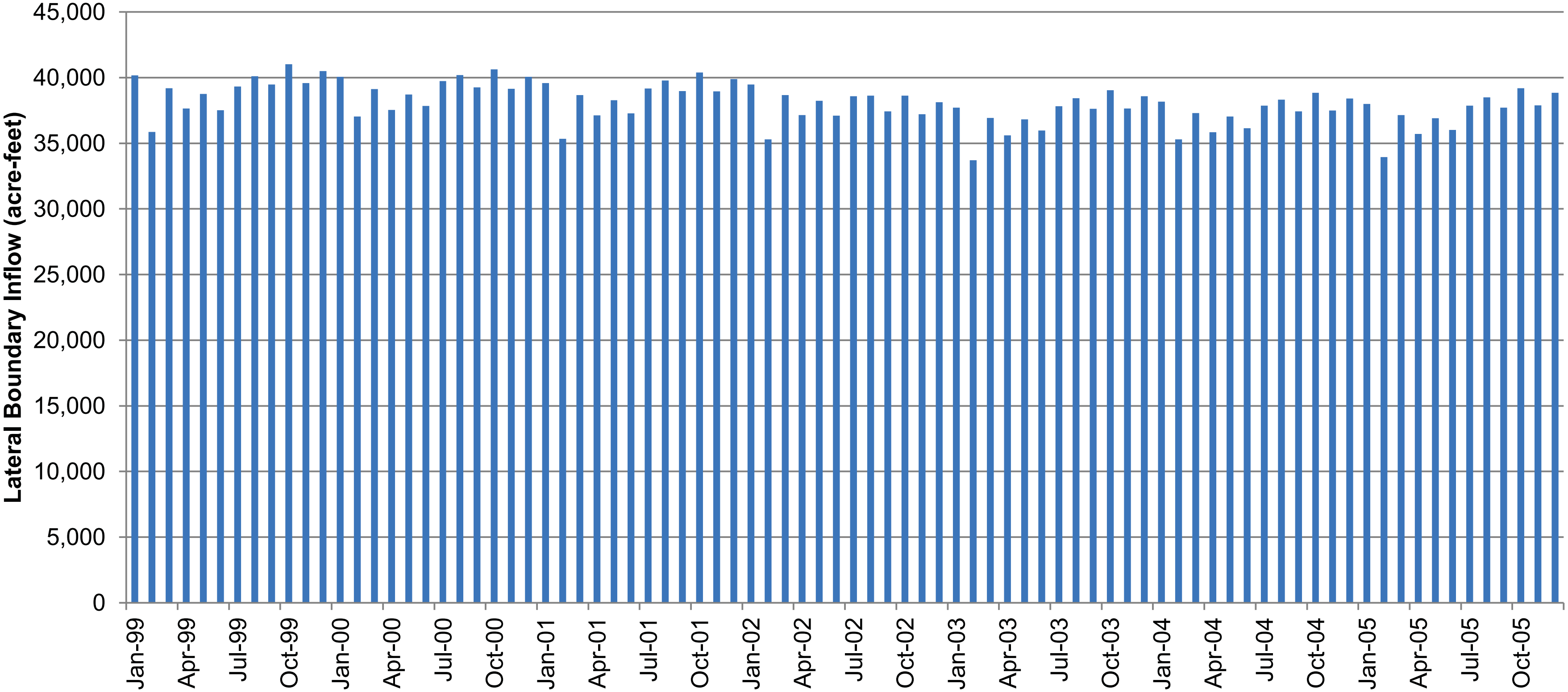

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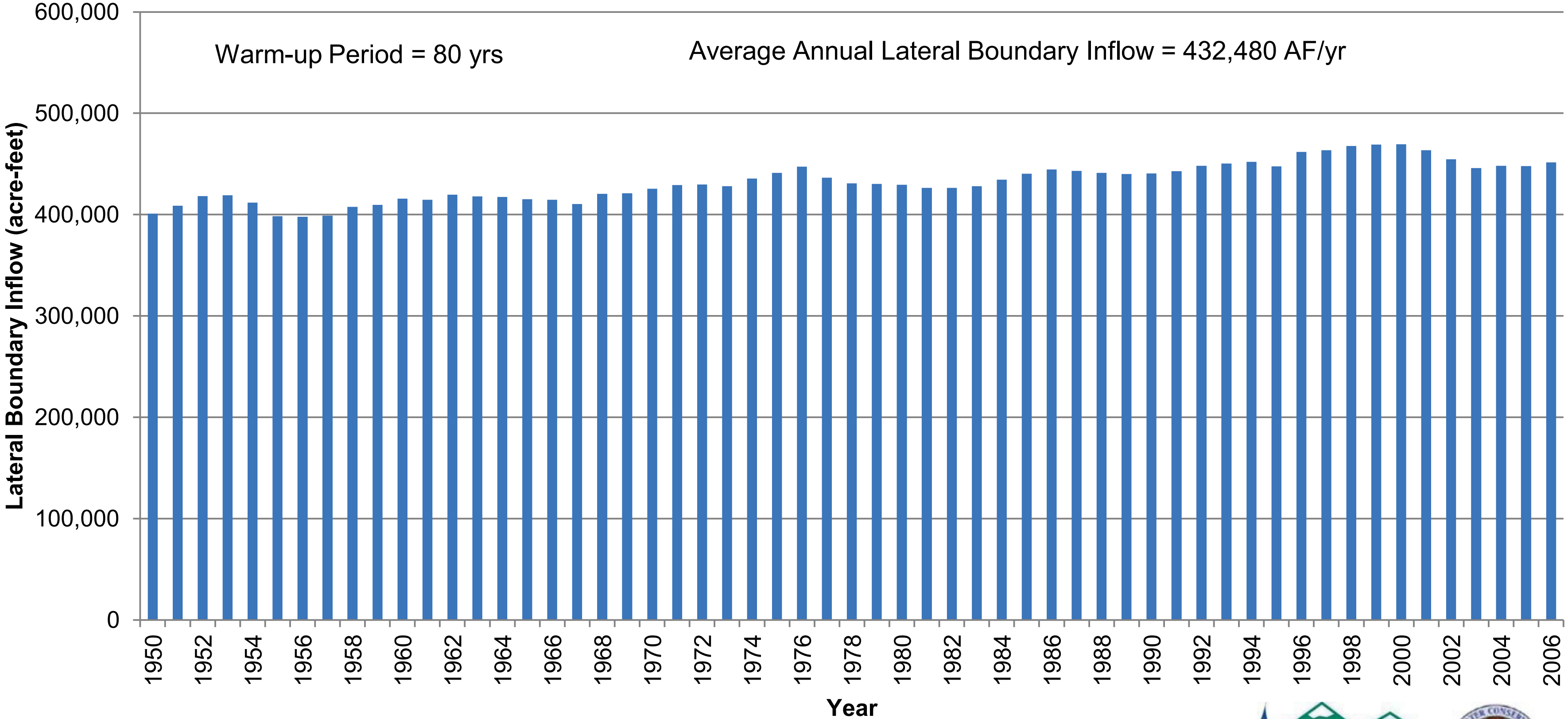
Figure D-14. Annual Lateral Boundary Inflow – Validation Period (1950 - 2006)



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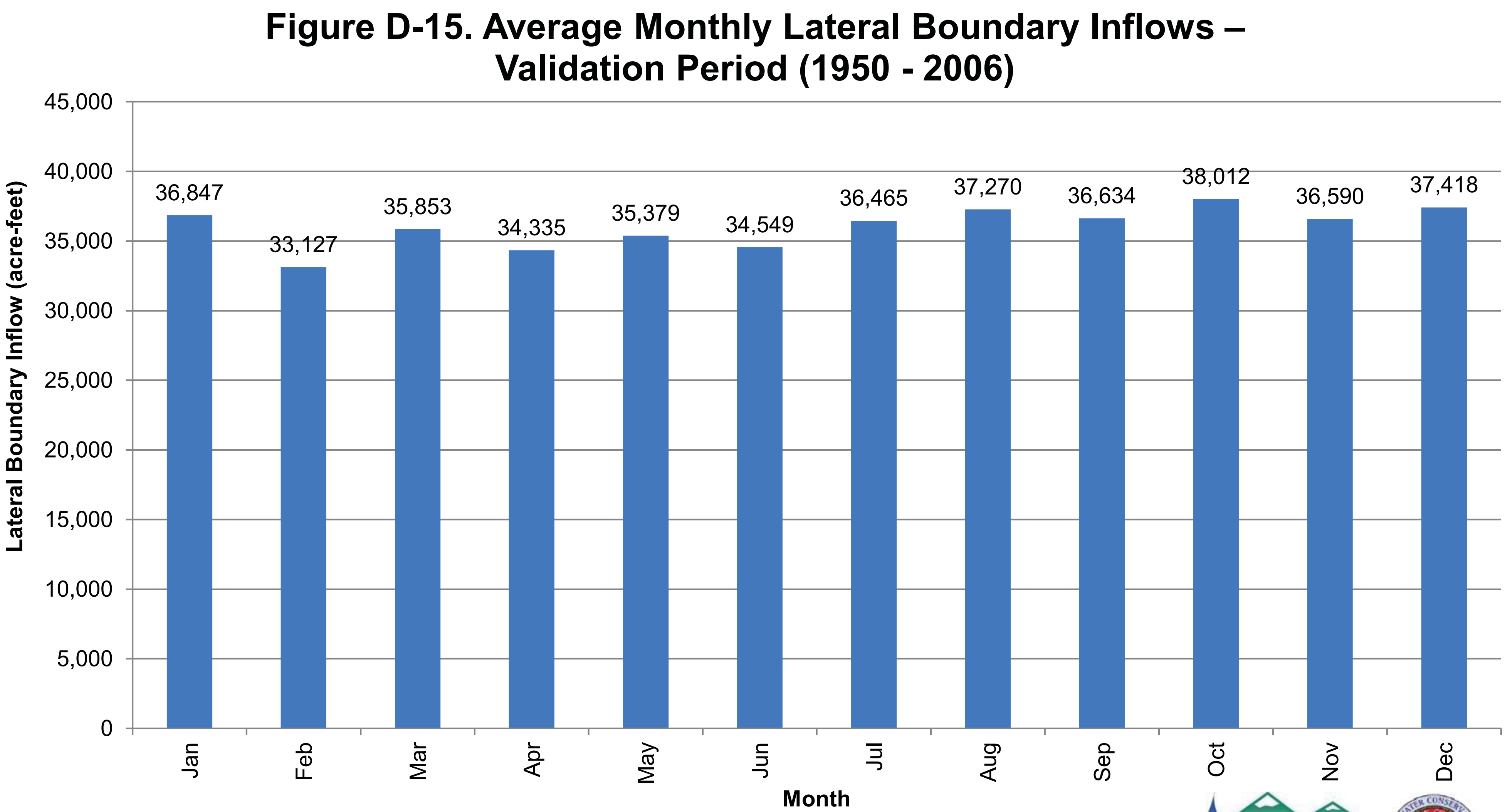

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