Appendix E
Stream Gain/Loss Estimates

1.0 Purpose

The purpose of this appendix is to present the stream gain/loss estimates developed as part of the development of the South Platte Decision Support System (SPDSS) Alluvial Groundwater Model. In the SPDSS there was a specific task, Task 46.2 Stream Gain/Loss Estimates to develop stream gain/loss estimates for the main stem of the South Platte River and its tributaries within the study area. The objective of this task is as follows:

> *To develop estimates of stream gains and losses from groundwater in the main stem of the South Platte River and its tributaries within the study area to be used to help calibrate the alluvial groundwater model being developed under Task 48.*

The stream gain/loss data collected through this effort were used to assist in the calibration of the SPDSS Alluvial Groundwater Model.

A copy of this technical memorandum is included in this Appendix E.

Task 46.2 Stream Gain/Loss Estimates Technical Memorandum

SPDSS Phase 4 Task 46.2
Stream Gain/Loss Estimates Technical Memorandum
FINAL

To: Ray Alvarado
From: Camp Dresser and McKee Inc.
Jessica Gilliam, Jordan Dimick, and Gordon McCurry
Subject: SPDSS Groundwater Component Phase 4 Task 46.2 Final Stream Gain/Loss Estimates Technical Memorandum
Date: April 10, 2008

Introduction

The groundwater component of the South Platte Decision Support System (SPDSS) focuses on compiling and evaluating available relevant data to support the Decision Support System (DSS) for the South Platte River watershed and to add the data to HydroBase, the State of Colorado's hydrological database. The SPDSS study area is presented in Figure 1. For the purposes of the SPDSS, the groundwater study area is divided into two hydrologic regions. The Denver Basin Region includes the bedrock aquifers of the Denver Basin. The South Platte Alluvium Region consists of the unconsolidated deposits of the South Platte River mainstem, extending downstream from just below Chatfield Reservoir to the Nebraska state line at Julesburg. The South Platte Alluvium Region also includes the alluvium overlying the Denver Basin bedrock aquifers in Water Divisions 1 and 2.

This task was undertaken for the Colorado Water Conservation Board (CWCB) and Division of Water Resources (DWR), under Task 46 of Phase 4 of the SPDSS by Camp Dresser & McKee (CDM). Task 46 of the SPDSS includes the collection and analysis of existing data on stream inflows and outflows in the main stem of the South Platte River and selected tributaries to characterize stream gains and losses in each reach. The objectives of this task are as follows:

> *To develop estimates of stream gains and losses from groundwater in the main stem of the South Platte River and its tributaries within the study area to be used to help calibrate the alluvial groundwater model being developed under Task 48.*

This Technical Memorandum (TM) summarizes the compilation and analysis of data for the computation of monthly gains and losses for the main stem of the South Platte River and selected tributaries for the study period of 1950-2005.

Approach

Gains and losses to the key rivers and streams in the study area were estimated using a process developed by the State for the Rio Grande and Republican Rivers. This process involves compiling surface water data on the daily inflows and outflows for specified river or stream reaches, and then applying a set of steps to convert the daily flows into estimates of monthly gains or losses between the surface water system and the hydrologically-connected aquifer system. The gain/loss results, referred to as baseflow, are an important part of the water balance of the South Platte River system. The baseflow results will be used in helping calibration the alluvial groundwater flow model being developed under Task 48.

The following table summarizes the sections contained in this TM.

Section	**Description**
1.0	Investigation Area and Data Collection
1.1	Areas of Investigation
1.2	Data Collection
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2.1	Mass Balance Determination
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A	Mass Balance Components
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C	Monthly Mass Balance Approach
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1.0 Investigation Area and Data Collection

Stream gain or loss is defined in this TM as the recharge from or discharge to the alluvial aquifer that is in hydrologic communication with the overlying stream system, respectively. The flow in a stream that is due to groundwater discharge is commonly referred to as baseflow.

This task was initiated to complement similar work performed recently (and not yet published) by the United States Geological Survey (USGS) on a limited portion of the main stem of the South Platte River from Denver to the Kersey gage near Greeley. The results of this task will be used to help calibrate the alluvial groundwater model being developed under Task 48 by comparing the estimated gain/loss from this Task and the model-simulated gain/loss in a given reach and time period. In addition, the results of this task will provide a useful addition to the understanding of the South Platte River surface water – groundwater system.

1.1 Areas of Investigation

Stream gain/loss estimates were determined for seven reaches along the South Platte River and two tributaries located within the study area. The reaches were defined using stream gages located along the South Platte River, the Cache la Poudre River and Cherry Creek, as shown in Table 1.

Table 1 - Reaches Included in Gain/Loss Evaluation

Reach Name	Upstream Gage Name	Downstream Gage Name
South Platte 1 - Waterton to Denver[1]	SOUTH PLATTE RIVER AT WATERTON (670800) and PLUM CREEK NEAR LOUVIERS (6709500)	SOUTH PLATTE RIVER AT DENVER (6714000)
South Platte 2 - Denver to Henderson	SOUTH PLATTE RIVER AT DENVER (6714000)	SOUTH PLATTE RIVER AT HENDERSON (6720500)
South Platte 3 - Henderson to Fort Lupton	SOUTH PLATTE RIVER AT HENDERSON (6720500)	SOUTH PLATTE RIVER AT FORT LUPTON (6721000)
South Platte 4 - Fort Lupton to Kersey	SOUTH PLATTE RIVER AT FORT LUPTON (6721000)	SOUTH PLATTE RIVER NEAR KERSEY (6754000)
South Platte 5 - Kersey to Weldona	SOUTH PLATTE RIVER NEAR KERSEY (6754000)	SOUTH PLATTE RIVER NEAR WELDONA (6758500)
South Platte 6 - Weldona to Balzac	SOUTH PLATTE RIVER NEAR WELDONA (6758500)	SOUTH PLATTE RIVER AT COOPER BRIDGE NEAR BALZAC AND SOUTH PLATTE RIVER AT BALZAC,CO (6759910)[2]
South Platte 7 - Balzac to Julesburg	SOUTH PLATTE RIVER AT COOPER BRIDGE NEAR BALZAC AND SOUTH PLATTE RIVER AT BALZAC,CO (6759910)	SOUTH PLATTE RIVER AT JULESBURG (COMBINED) (6764000)
Cache la Poudre - Ft Collins to Greeley	CACHE LA POUDRE AT CANYON MOUTH NEAR FORT COLLINS (6752000)	CACHE LA POUDRE NEAR GREELEY (6752500)
Cherry Creek – Franktown to Denver	CHERRY CREEK NEAR FRANKTOWN, CO (6712000)	CHERRY CREEK AT DENVER, CO (6713500)

[1] Flow at this upstream boundary was defined by gaged flow from both the South Platte River at Waterton gage and the Plum Creek near Louviers gage

[2] Segment Boundary was defined by two separate combined gages because daily streamflow records for South Platte at Balzac were available from 1950 through 1980 and South Platte at Cooper Bridge daily streamflow records were available after 1980.

These reaches were selected because the streamflow gages that define the reaches had the daily flow data for the study period that was needed for the analysis. The stream reaches and gages used are displayed in Figure 1.

1.2 Data collection

A spreadsheet-based approach was used to estimate monthly baseflow values for each reach evaluated for the study period, which extends from 1950 to 2005. In order to estimate the monthly baseflow values, daily baseflow values were calculated for the study period. To develop the daily baseflow estimates all significant measured and quantifiable daily surface water inflows and outflows within a river reach were collected. These flows were summed to produce what is referred to in this TM as a daily mass balance. Details on the mass balance and subsequent data processing are described in Section 2.

Inflows included the streamflow into the reach defined by the upstream flow gage, streamflows from tributaries, industrial and municipal discharges, and reservoir releases. Outflows included 85 key diversions and 10 aggregate points as defined in SPDSS Task 3 Memorandum (LRE, 2007a) and stream outflow defined by the downstream flow gage. Diversions defined as key diversion structures were identified as diversion structures representing the approximately upper 85 percent of net absolute decreed water rights within each water district in the SPDSS study area. Diversions defined as aggregate points are groupings of diversions which were not identified as key diversions (LRE, 2007a). The inflows and outflows used in this analysis are listed from upstream to downstream separately for each reach in Appendix A. Straight-line diagrams displaying the surface water inflows and outflows within the SPDSS study area have been developed by Colorado Division of Water Resources (CDSS, 2007) and show their locations schematically. The data collection, filling of missing data and final analysis of inflow and outflow daily records are described below.

1.2.1 Streamflow Data

Daily streamflow data recorded for each gage utilized was obtained from HydroBase using TSTools. The TSTool command files used to obtain these data are included in Appendix B. An evaluation of the data obtained indicated that several stream gage records were incomplete. Since a daily record is required for each component of the mass balance, various filling techniques described below were implemented to fill the missing data. Table 2 depicts the percentage of daily records missing for each gage which defined the reaches used in the analysis based on stream gage locations.

Table 2 – Missing Streamflow Data for Gages that Defined the Reaches

Station ID	Station Abbreviation	Station Name	Percentage of Missing Data (1950-2005)
6708000	PLAWATCO	SOUTH PLATTE RIVER AT WATERTON	0%
6709500	PLULOUCO	PLUM CREEK NEAR LOUVIERS	27%
6714000	PLADENCO	SOUTH PLATTE RIVER AT DENVER	0%
6720500	PLAHENCO	SOUTH PLATTE RIVER AT HENDERSON	0%
6721000	PLALUPCO	SOUTH PLATTE RIVER AT FORT LUPTON	14%
6754000	PLAKERCO	SOUTH PLATTE RIVER NEAR KERSEY	0%
6758500	PLAWELCO	SOUTH PLATTE RIVER NEAR WELDONA	5%
6759910	PLABALCO	SOUTH PLATTE RIVER AT COOPER BRIDGE NEAR BALZAC AND SOUTH PLATTE RIVER AT BALZAC,CO (COMBINED)	0%
6764000	PLAJUCCO	SOUTH PLATTE RIVER AT JULESBURG (COMBINED)	0%
6752000	CLAFTCCO	CACHE LA POUDRE AT CANYON MOUTH NEAR FORT COLLINS	0%
6752500	CLAGRECO	CACHE LA POUDRE NEAR GREELEY	0%
6713500	CHEDENCO	CHERRY CREEK AT DENVER, CO.	23%
6712000	CHENEFCO	CHERRY CREEK NEAR FRANKTOWN, CO.	0%

The two reaches that included data from the South Platte River near Balzac gage were defined by two separate gages, the South Platte near Balzac gage and the South Platte at Cooper Bridge gage. The South Platte near Balzac gage had a record of available daily streamflow data from 1/1/1950 through 9/30/1980 and South Platte at Cooper Bridge has daily streamflow data available after 9/30/1980. To fill the entire period of record a command file was implemented in TSTools that combined the records of both gages to estimate daily flow in the South Platte River near Balzac for the entire study period. The data after 9/30/1980 was adjusted to account for the intermediate diversions that exist between the two gage locations.

The streamflow data for the South Platte at Waterton location was computed from the combined inflows of Plum Creek near Louviers and the South Platte at Waterton (Table 1). The inflow was represented by these two gages because the confluence of Plum Creek and the South Platte River is immediately downstream of the Waterton stream gage.

Missing data records for the following stream gages which defined the stream reaches had been previously estimated on a monthly time step as described in the SPDSS Task 2 Technical Memorandum (LRE, 2006): Plum Creek near Louviers, South Platte River near Weldona and South Platte River at Balzac. To fill the missing records from these gages on a daily interval, a command file was developed for use in TStools similar to the technique applied to fill data on a monthly time step. The command files for these gages fill missing data by utilizing streamflow data from a nearby gage or with historical flows from the same gage. An additional command file was developed to fill the missing data for the South Platte River at Fort Lupton gage which had not been previously filled on a monthly time step using similar filling techniques. Appendix B contains the command files used to fill the missing stream flow records.

Missing data from the Cherry Creek at Denver, CO gage was filled using interpolation when only isolated daily flow records were missing. When there was missing data for several consecutive months or years, the missing records were estimated by computing an average flow from historic flow records for the day in question using the available daily flow data for that gage in HydroBase. It was determined that utilizing linear interpolation as a filling method did not accurately estimate the seasonal variation in flow when there were large periods of missing data. Therefore, filling missing records based on average daily flow patterns was determined to be the most appropriate over interpolation to fill the missing daily values because it utilized the pattern established on the historical daily basis.

Missing data records for the Big Thompson River at Mouth near La Salle which was included as an inflow into one South Platte reach had been previously estimated on a monthly time step as described in the SPDSS Task 2 Technical Memorandum (LRE, 2006). Appendix B contains the command files used to fill the missing records. Data was filled similar to the method utilized to fill missing data for the Cherry Creek at Denver, CO gage described above.

Table 3 depicts the percentage of daily records missing for each stream flow gage included in the estimated baseflow as inflows into a reach.

Table 3– Missing Streamflow Data from Inflows into the Reaches

Station ID	Station Abbreviation	Station Name	Percentage of Missing Data (1950-2005)
06711500	BCRSHECO	BEAR CREEK AT SHERIDAN	0%
394839104570300	SANCOMCO	SAND CREEK AT MOUTH NR COMMERCE CITY,CO	75%[1]
06720990	BIGDAFCO	BIG DRY CREEK AT MOUTH NEAR FORT LUPTON	75%[2]
06720000	CLEDERCO	CLEAR CREEK AT DERBY	0%
06731000	SVCPLACO	SAINT VRAIN CREEK AT MOUTH NEAR PLATTEVILLE, CO	0%
06744000	BIGLASCO	BIG THOMPSON RIVER AT MOUTH NEAR LA SALLE	
06753990	LONGRECO	LONETREE CREEK NEAR GREELEY, CO.	89%[3]
06756500	CROBARCO	CROW CREEK NEAR BARNSVILLE, CO.	89%[4]
06758300	KIOBENCO	KIOWA CREEK AT BENNETT, CO	92%[5]
06759100	BIJMORCO	BIJOU CREEK NEAR FT. MORGAN, CO.	81%[6]
6763500	N/A	LODGEPOLE CREEK AT RALTON, NEBR.	50%

[1] Streamflow data only available after 1/31/1992
[2] Streamflow data only available after 10/1/1991
[3] Streamflow data only intermittently available after 3/17/93
[4] Streamflow data only available between 7/25/51 and 9/30/57
[5] Streamflow data only intermittently available after 3/1/60 to 9/30/64
[6] Streamflow data only available between 12/01/76 to 9/30/86

Stream inflows from ungaged tributaries were estimated to be zero and were not added to the gain/loss flow calculations. As described in Section 2.0, the pilot point method for estimating baseflow tends to eliminate any sporadic ungaged tributary inflow.

1.2.2 Diversion Data

Key diversions that transport water directly from the South Platte River, Cherry Creek, or the Poudre River were included as part of the mass balance for each defined reach. The key diversions were previously identified under Task 3 of the SPDSS (LRE, 2007a).

Daily data for each key diversion was obtained from HydroBase using TSTools for the study period. A small portion of the daily diversion records was missing. The missing data were filled using diversion patterns identified during previous years of record and from the estimated monthly diversion volumes previously estimated under Task 3 (LRE, 2007a). Many of the missing diversion data occurred during the non-growing season; standard DWR daily diversion data estimates non-growing season diversions to be zero as long as there were observations in the previous year. In other cases the missing diversion data occurred during months with no reported surface water diversion and therefore a value of zero was assigned. Key Diversions used for the mass balance calculation and their locations are listed in Appendix A.

In addition, Task 3 (LRE, 2007a) identified thirteen aggregate diversion points located within the reaches used in this analysis. An aggregate point diversion is a sum of diversions not defined in Task 3 as key diversions that are in the same general location and whose sum volume is comparable in magnitude to a key diversion. Aggregate diversion data is not recorded or available on a daily time step in HydroBase; therefore filled monthly aggregate data values under Task 3 (LRE, 2007a) were used. A daily average of each aggregate monthly diversion was calculated and used for the daily gain/loss analysis. The aggregate diversion points and their locations are listed in Appendix A.

1.2.4 Reservoir Release Data

Reservoir releases were also included in the gain/loss analysis. Jackson Lake and Prewitt Reservoir outlets both release directly into the South Platte River. Reservoir releases are not recorded on a regular basis and daily data was unavailable, therefore reservoir releases previously identified under Task 5 of the SPDSS (LRE, 2006) were utilized in the gain/loss calculations. Reservoir release data was previously estimated on a monthly basis by the SPDSS Water Balance contractor. For this level of analysis, the monthly release data was used to estimate the daily reservoir releases by dividing the monthly data by the number of days in the particular month. This process was determined to be adequate and consistent with the SPDSS Water Balance contractor.

1.2.5 Municipal Discharge Data

Three industrial and 14 municipal entities directly discharge into the South Platte River, Cherry Creek, or the Cache la Poudre River reaches included in this evaluation and are listed in Table 4. These entities are included in this analysis because they are classified as major dischargers by the Environmental Protection Agency (EPA). The major discharges are defined by the EPA based on a scoring of several categories including: Toxic Pollutant Potential, Flow/Stream Volume, Conventional Pollutants, Public Health Impact, Water Quality Factors and Proximity to Coastal Waters. Additional minor dischargers were also identified but were not included in the gain/loss calculations due to the small amount of permitted discharge flow. Dischargers and discharge point locations are identified for each reach define in Table 1 in Appendix A.

Table 4 – Major Dischargers Within the Gain/Loss Study Area

Brighton
Brush
Littleton-Englewood
Commerce City
Fort Lupton
Fort Morgan
Greeley
Sterling
Fort Collins
Evans
Windsor
Glendale
Stonegate
Public Service Company of Colorado Arapahoe Station
Public Service Company of Colorado Cherokee Station
Eastman Kodak Company
Metro Wastewater Reclamation District

Daily discharge data from the identified dischargers was not historically recorded for the desired period of record and therefore could not be directly obtained, with the exception of intermittent daily records obtained from the Denver Metro Wastewater District. In order to include daily discharge data for all of the major industrial and municipal dischargers in the mass balance calculations, daily values were estimated.

Industrial and municipal daily data was estimated using two separate procedures. Industrial discharge was estimated using historical monthly discharge flow from approximately 2002 through 2007 obtained from the EPA. To calculate daily values, average monthly values were calculated and then divided by the number of days in the month. This method was determined to be adequate for the purposes of this evaluation.

Municipal discharge was based on population data and an Indoor Return Rates calculated for each municipality by county included in the SPDSS study area. The population data set was developed using available population data from HydroBase and a linear interpolation method to fill missing data consistent with Task 66.2 (LRE, 2007b). Indoor Return Rates for each key municipality within a county were based on engineering estimates provided by the SPDSS Consumptive Use contractor. The reported rates were utilized to estimate gallons per capita per day (gpcd) of wastewater flow directly discharged into the South Platte River, Cherry Creek or the Cache la Poudre River. The yearly population value was multiplied by the gpcd to obtain an average discharge value for each municipality. The resultant yearly discharge values were varied on a monthly basis to account for seasonal variations in water use. The basis for the monthly variations was developed from wastewater discharge obtained from the Metro Wastewater Reclamation District.

2.0 Methodology

A spreadsheet-based approach called the Pilot Point method was used to estimate monthly baseflow values for each reach evaluated for the study period, which was from 1950 to 2005. The Pilot Point method determines a daily water balance by summing the measured daily surface water inflows and outflows for each reach. This is defined for the purposes of this TM as the mass balance. The Pilot Point method then applies constraints to limit extreme flow values, and then applies a long-term average to produce a smoothed result of net gain or loss which is defined as the estimated baseflow.

Prior to implementing the Pilot Point method to estimate baseflow, the use of a traditional mass balance estimation method was evaluated. The mass balance method is better suited to estimating baseflow in watersheds that are not influenced by human activities. Flows in the South Platte River are highly influenced by agricultural diversions and other human activities so the mass balance method could not accurately estimate baseflow. A comparison of the mass balance approach and the Pilot Point method is discussed on Appendix C.

The Pilot Point method was initially implemented to estimate stream gains and losses for groundwater modeling in the Republican River Basin and was later adapted to estimating baseflow in Rio Grande River Basin in Colorado. The original method used on the Republican was a spreadsheet-graphical method that utilized control or "pilot" points with an accompanying curve superimposed on the computed mass balance for the reach. The pilot points were manually manipulated using professional judgment to produce a curve that best approximated baseflows in the reach. During the development of the Rio Grande Decision Support System groundwater model, the original Pilot Point method was enhanced. In an attempt to reduce the effects of subjectivity involved in this approach, an automated spreadsheet version was created for the Rio Grande and applied to the South Platte herein that mimicked the results from the manual method of manipulating the data yet makes the results of baseflow analysis more reproducible.

The Pilot Point method as applied in this task estimates monthly baseflow values using the following process for each reach:

1. daily inflows and outflows are used to compute a daily mass balance
2. a short-term moving average is applied to the daily mass balance to account for stream lagging,
3. the lagged daily values are constrained to reflect the maximum gains and losses expected for the reach, and
4. a longer-term moving average is applied to the constrained and lagged values to estimate monthly baseflows.

The mass balance discussed in the first two steps refers to the difference in daily inflows and outflows described in Section 1. The baseflow, described in the final step, differs from the mass balance due to the processing steps that comprise the Pilot Point method. Details regarding the various processes involved with the Pilot Point method are discussed in the remainder of this section.

2.1 Daily Mass Balance Determination

All inflow and outflow data described in Section 1.2 was added to a spreadsheet and applied in a mass balance equation to estimate baseflow for each day within the period 1950 to 2005. The mass balance was developed by subtracting all of the inflows and adding all of the outflows to the flow values from the downstream gage for each reach. The sources of these flow data are described in Section 1.2.

Inflows used in the mass balance calculation include the following:

- the flow of the upstream gage defining the reach,
- streamflows from tributaries,
- industrial and municipal discharges, and
- reservoir releases.

Outflows used in the mass balance calculation include the following:

- key diversions
- aggregate diversions
- the flow of the gage at the downstream end of the reach

2.2 Short-Term Averaging

The graphed results of the daily mass balance calculated for each reach displayed large swings in values, from high positive to negative values and back. These wide daily variations are partly a result of the travel time (lag) of streamflow from the upstream end of the reach to the downstream end, partly a result of irrigation runoff, and partly a result of inflows from ungaged locations.

To account for streamflow travel time within each reach, and to help smooth the results, a one- to two-day averaging was applied to the mass balance data for each reach. The lag applied to each reach is listed Table 5.

Table 5 -Short-Term Lagging Applied to Gain/Loss Study Reaches

Study Reach	Short-Term Lagging (days)
South Platte 1 - Waterton to Denver	1
South Platte 2 - Denver to Henderson	1
South Platte 3 - Henderson to Fort Lupton	1
South Platte 4 - Fort Lupton to Kersey	1
South Platte 5 - Kersey to Weldona	1
South Platte 6 - Weldona to Balzac	1
South Platte 7 - Balzac to Julesburg	2
Cache la Poudre - Ft Collins to Greeley	1
Cherry Creek – Franktown to Denver	1

The number of days used for the short-term averaging was determined by analyzing the number of days between the peak flows at the upstream and downstream gages for each reach during high flow events. The number of days differed for each reach and was generally dependent on the length of the reach. Figure 2 shows an example of the daily mass balance for a reach (South Platte 4 - Fort Lupton to Kersey) for a single year (1977) and the effect of applying the short-term average. As shown in this figure, the short-term averaging reduces the more extreme peak daily mass balance flow values.

2.3 Constraint Determination

A small portion of very large positive (stream gain) or negative (stream loss) daily mass balance values remained in the data set after the short-term averaging was applied. Due to the relatively slow movement of groundwater, these large values are not expected to be caused by stream gains or losses. Instead, the extreme values are likely a result of inflows or outflows that are not included in the daily mass balance calculations, such as inflow from farm runoff, ungaged tributaries, storm precipitation runoff, surface water return flows or ungaged diversions. The computed monthly gain/loss values would be biased by including these outlier flows in the calculations. To avoid biasing the monthly gain/loss results, the short-term averaged daily flow data was constrained using estimates of the maximum possible gain or loss ground water flow for each reach.

Flow constraints were estimated using Darcy's law and the Glover equation for the maximum gain and the maximum loss, respectively. Two different methods were required to determine the maximum gain and maximum loss constraints because different hydrologic processes occur during gaining and losing conditions and these are better represented by the different approaches.

The flow constraints were calculated to represent the highest possible flow value for a given day for each reach, not to represent an average flow value typically observed. Average flow results could overly constrain the daily flow data. The flow constraints were calculated to represent flow into and out of the alluvial aquifer from both sides of the river. Representative values for aquifer properties and hydraulic gradients were obtained from published available sources. Values of hydraulic conductivity, average saturated thickness values and alluvial length were obtained from data presented in the SPDSS Phase 3 Task 43.3 TM (CDM, 2006). Hydraulic gradient values along the study reaches were estimated from maps presented in Hurr and Schneider (1972a-f) and the CDM Task 44.3 TM (CDM, 2006).

Maximum Gain Constraint

Darcy's law was used to estimate the maximum groundwater gain expected for each river reach. Darcy's law assumes constant flow conditions and uniform aquifer properties. It was utilized to estimate the maximum flow constraint because, in general, the largest gains to the river are observed during the irrigation season when the aquifer hydraulic gradient has been elevated by irrigation-based recharge and shallow groundwater flow is towards the river. Darcy's law is defined as:

$$Q=KA\ (dh/dl)$$

Where:

Q = Flow through a cross sectional area (cubic feet per second [cfs])

K = Hydraulic conductivity (ft/day) [multiplied by a constant to convert to ft/sec]
A = Cross-sectional area (ft^2) (River Reach Length*Average Saturated Thickness)
dh/dl = Hydraulic gradient

For purposes of this analysis, dh/dl was calculated as the gradient from a point 0.5 mile from the stream to the stream edge parallel to the average direction of groundwater flow using water table maps from Hurr and Schneider (1972a-f) and CDM (2006). The values used in the Darcy's Law calculations for each reach are presented in Appendix D Table D**1**.

Constraints for the maximum gain are presented in Table 6. Results for the reaches along the South Platte River varied between 182 cfs and 574 cfs. An exception is the maximum gain of 1041 cfs for the South Platte 7 -Balzac to Julesburg reach. This reach is almost twice as long as the other mainstem reaches. When converted to gain per river mile the maximum constraints range from 11 to 13 cfs/mile for the mainstem reaches (Table 6). The lower gain per river mile values are in the three upstream reaches, from Waterton to Fort Lupton, and also downstream of the Balzac gage. The higher values, in the middle reaches of the mainstem, correlate to areas where the floodplain of the South Platte River is wider and more irrigation activity occurs. It is also possible that the increased gain could be in part due to greater contribution from the Denver Basin bedrock aquifers. The maximum gain constraints for the Cache la Poudre River and Cherry Creek reaches were 522 cfs and 303 cfs, respectively, equating to gains of 9 and 8 cfs/mile, respectively (Table 6).

Table 6 - Maximum Gain Constraints

Reach Name	Total Q (cfs)	Q (cfs) per River Mile
South Platte 1 - Waterton to Denver	192	11
South Platte 2 - Denver to Henderson	182	11
South Platte 3 - Henderson to Fort Lupton	195	11
South Platte 4 - Fort Lupton to Kersey	499	13
South Platte 5 - Kersey to Weldona	574	13
South Platte 6 - Weldona to Balzac	315	13
South Platte 7 - Balzac to Julesburg	1,041	11
Cache la Poudre - Ft Collins to Greeley	522	9
Cherry Creek – Franktown to Denver	303	8

Maximum Loss Constraint

To quantify the maximum loss that might occur in each reach, the analytical Glover equation (Glover 1974) was applied by treating the stream as a parallel drain. The Glover parallel drain solution quantifies the flow to or from a river based on the difference between stream stage and groundwater levels, the duration of the difference, the area over which the stage-groundwater levels occur, and on aquifer properties. The Glover equation can be defined as:

$$\mathbf{Q = iL\ (1\text{-}P)X}$$

Where:

Q = Stream loss within the reach (cubic feet per second [cfs])
i = Calculated stage height multiplied by alluvial aquifer porosity of 0.2
L = Alluvial aquifer width (ft)
P = Ratio of aquifer volume to be drained (a function of $\alpha t/L^2$)
where α = aquifer constant (transmissivity /specific yield)
t = Time since one day of infiltration (day)
X = Reach length (ft)

The values used for the Glover calculations for each reach are presented in Appendix D Table D2.

Stream losses from the South Platte River and its tributaries typically occur during peak flow events when the stream stage is significantly higher then average. Peak flows are typically observed during snowmelt periods prior to the start of the growing season and during localized rainfall events. The stage height parameter (i) was estimated as the difference in stage between peak and average runoff conditions. The timing parameter (t) is the duration of high flow events when stream stage was elevated. It was determined by examining the stage data from each of the nine reaches during historical high flow events. On average, within the mainstem reaches, the high flow events lasted seven days so this duration was used in estimating the maximum loss constraint.

Maximum loss constraints for the flow data are presented in Table 7. Results for the reaches along the South Platte River varied between 81 cfs and 442 cfs, with the exception of a value of 1031 cfs for the South Platte 7 -Balzac to Julesburg reach. As discussed above, some of the differences in flow are due to differing lengths of each reach. When converted to a loss per river mile, the maximum loss constraints range from 5 to 11 cfs/mile for the mainstem reaches (Table 7). The lower calculated loss rates in the mainstem are upstream of the Fort Lupton gage. In general, it appears that the maximum loss constraint increases downstream. This may be because there is of more pumping in the downstream reaches which would induce more stream loss. Additionally, the alluvial aquifer widens downstream which increases the flow and transmissivity values used in the Glover calculations. Maximum loss constraints for the Cherry Creek reach and the Cache la Poudre River reach were 314 cfs and 232 cfs, respectively, equating to losses of 6 cfs/mile in for both reaches (Table 7).

Table 7 –Maximum Loss Constraints

Reach Name	Total Q (cfs)	Q (cfs) per River Mile
South Platte 1 - Waterton to Denver	81	5
South Platte 2 - Denver to Henderson	83	5
South Platte 3 - Henderson to Fort Lupton	110	6
South Platte 4 - Fort Lupton to Kersey	442	11
South Platte 5 - Kersey to Weldona	413	9
South Platte 6 - Weldona to Balzac	192	8
South Platte 7 - Balzac to Julesburg	1031	10
Cache la Poudre - Ft Collins to Greeley	314	6
Cherry Creek – Franktown to Denver	232	6

The maximum loss constraints (Table 7) are smaller than the maximum gain constraints (Table 6). This is mainly due to the different methods of calculation for the two constraints, which reflect the different flow situations when maximum gains and losses might occur. For the maximum loss constraint the shorter duration of high flow, high stage events would likely result in stream losses of lower magnitude than the maximum gains, which occur for a more sustained period of time.

2.4 Long-Term Averaging

Due to the relatively slow rates of groundwater movement, it is expected that patterns of stream gains and losses should be gradual when considered on a reach by reach basis. To better represent the more gradual movement of groundwater and to produce a gain-loss curve that is more smooth and gradual a long term averaging period was applied. The long-term averaging consists of a 31-day moving average. This averaging period was selected because it produced a reasonably smooth result that, based on engineering judgment, produced suitable results. By comparison, the Pilot Point method applied in the RGDSS arrived at a 61-day long-term average based on a trial and error approach that produced suitable results for that basin. The stream gains and losses resulting from the long-term averaging are called the estimated baseflow values. These are discussed in Section 3.

3.0 Results

The estimated monthly gain/loss values for each reach are summarized below and are displayed graphically in a series of hydrographs. Average annual baseflow and associated mass balance values for the study period (1950 to 2005) are shown for each reach in Figures 3 through 11. Average monthly baseflow and mass balance values for 1991 through 1994 for each reach in Figures 12 through 20. This is the steady-state calibration period that will be used in the alluvial groundwater flow model being developed under Task 48. The average monthly values are also presented as gain/loss per river mile in Figures 21 through 30. The time series of monthly baseflow results corresponding to the transient model calibration period (1999 through 2005) are presented for each reach in Figures 31 through 39. Each set of graphs (average annual, average monthly 1991-1994, average monthly 1991-1994 per river mile, and average monthly 1999-2005) include the same range on the axes to facilitate comparison between reaches. Positive flows shown on all graphs represent gaining stream conditions and negative flows represent losing stream conditions. Flow values may not transition smoothly between adjacent reaches since the values represent the average baseflow over the entire reach. The baseflow values show much smoother trends than the mass balance values due to the data processing steps associated with the Pilot Point method. The difference between the baseflow and mass balance curves represent other flows that are not quantified.

Data files developed to estimate stream gain/loss have been provided to the State with the Final TM, under separate cover. The monthly average baseflow data presented in Figures 12 through 20 and Figures 31-39 will be used to help qualitatively calibrate the steady state and transient alluvial groundwater models, respectively, by comparing the computed to simulated groundwater gain/loss in a given reach and time period. In addition, the results of this task will provide a useful addition to the understanding of the South Platte River surface water – groundwater system.

The average annual baseflow results are generally positive for the seven South Platte reaches and the two tributary reaches, indicating that an annual basis these rivers are gaining flow from the alluvial aquifer. Table 8 summarizes the average mass balance and estimated baseflow from each reach for the full period of record. The column labeled Other Gain-Loss represents the difference between the mass balance and estimated baseflow values. The high values for the South Platte 7 – Balzac to Julesburg reach (Table 8) is likely due to the relatively long length of this reach (98 miles) compared to the other reaches. The South Platte 4 – Fort Lupton to Kersey reach also shows high values but is not long at 39 miles. The higher baseflow values in this reach may be related to a relatively large amount of surface water-based irrigation in this area that would provide return flow water as baseflow. The negative mass balance value for the South Platte 5 – Kersey to Weldona reach (Table 8) demonstrates the effect of a few very low annual values that are dampened out in the associated baseflow value for this reach.

Table 8 Gain/Loss Summary, 1950 - 2005

Reach	Mass Balance (cfs)	Estimated Baseflow (cfs)	Other Gain-Loss (cfs)
South Platte 1 - Waterton to Denver	93.1	75.9	17.1
South Platte 2 - Denver to Henderson	51.5	45.3	6.1
South Platte 3 - Henderson to Fort Lupton	47.3	37.7	9.5
South Platte 4 - Fort Lupton to Kersey	263.2	219.1	44.1
South Platte 5 - Kersey to Weldona	-16.2	42.7	-58.9
South Platte 6 - Weldona to Balzac	84.4	80.6	3.8
South Platte 7 - Balzac to Julesburg	252.6	255.9	-3.3
Cache la Poudre - Ft Collins to Greeley	161.6	144.2	17.4
Cherry Creek – Franktown to Denver	16.4	16.5	-0.1

During the 1991 to 1994 period all monthly averages remained positive for all reaches (Figures 11-20). With the exception of the South Platte 2 - Denver to Henderson reach (Figure 13), the reaches had the highest baseflow values (representing flow from groundwater to streams) during the summer months and the lowest baseflow values during the winter. This trend likely corresponds to the general pattern of lower summer flows and application of surface water for irrigation and suggests that much of the return flow occurs within a few months following irrigation. The South Platte 2 - Denver to Henderson reach has a wide alluvial aquifer relative to other reaches, which may result in lagging of irrigation return flows for this reach and the opposite pattern of baseflow. Figures 21 to 30 present the average monthly baseflow and mass balance values for the 1991 to 1994 period on a per river mile basis. Figure 21 shows the baseflow hydrographs posted on the map of the study area so one can evaluate spatial as well as temporal aspects of the average monthly baseflow. The baseflow values in the South Platte River reach generally range from 2 to 8 cfs/mile with the exception of higher values in the South Platte 4 – Fort Lupton to Kersey reach, whose range is 4 to 10 cfs/mile (Figure 25). The average baseflow for the period is presented for each reach in Table 9. Also shown in this table are the average baseflow values per river mile.

Table 9 Estimated Baseflow, 1991 – 1994

Reach	Estimated Baseflow (cfs)	Estimated Baseflow Per River Mile (cfs)
South Platte 1 - Waterton to Denver	94.1	5.4
South Platte 2 - Denver to Henderson	87.7	5.5
South Platte 3 - Henderson to Fort Lupton	62.8	3.7
South Platte 4 - Fort Lupton to Kersey	245.3	6.3
South Platte 5 - Kersey to Weldona	173.3	4.0
South Platte 6 - Weldona to Balzac	132.3	5.3
South Platte 7 - Balzac to Julesburg	293.1	3.0
Cache la Poudre - Ft Collins to Greeley	172.0	3.1
Cherry Creek – Franktown to Denver	18.0	0.5

The monthly average baseflow values for the 1999 through 2005 period are displayed graphically in Figures 30 through 39. The baseflow values depict similar trends as discussed above.

4.0 Summary and Conclusions

This task developed monthly estimates of stream gains and losses due to groundwater, or baseflow, for seven reaches in the main stem of the South Platte River and two tributaries, the Cache la Poudre River and Cherry Creek, within the SPDSS study area for the period 1950 to 2005. A spreadsheet-based water balance method termed the Pilot Point method was employed in this analysis. This method uses daily data that are constrained and smoothed to estimate baseflow. It was compared to a mass balance method involving average monthly flows without smoothing and found to produce more realistic results due to the additional data processing involved.

These baseflow results will be used to help qualitatively calibrate the alluvial groundwater model being developed under Task 48, by comparing the trends in computed to simulated baseflow over time and also by comparing individual baseflow values in a given reach and time period.

This task also provides information on the general trends of the stream-groundwater system of the reaches analyzed. In general, baseflow is larger in the South Platte River downstream of the Fort Lupton gage but there are no consistent trends amongst the reaches. Seasonal trends, however, were generally depicted in all reaches.

The monthly baseflow values ranged from reach to reach based on the daily inflows and outflows included in the analysis for each reach. The largest monthly baseflow gains of the reaches typically occurred in July, August and September and indicate a gaining stream condition. During this time a groundwater gradient is towards the river which would be expected due to an increase in groundwater levels typically observed during an irrigation season in the alluvial aquifer of the South Platte River. The timing of the largest baseflow during the latter portion of the growing season suggests that much of the irrigation-based recharge infiltrates into the alluvial aquifer and returns to the stream quickly, within a few months. This pattern was not observed in the South Platte 2 - Denver to Henderson reach. Possible reasons for this difference are due to differences in inflows and outflows within each reach, to the amount and location of irrigation occurring within the reach, to the timing of return flows and to well depletions as a result of pumping.

5.0 Recommendations

Below are recommendations from the activities performed under Task 46:

- Alluvial aquifer parameters used in the constraints of maximum gain or loss are representative values for an entire reach of river and should not be applied as localized values within the river reaches.

- The monthly baseflow averages developed for each reach are appropriate characterizing stream gain and losses over time within each reach and should be used to assist in the model calibration being conducted under Task 48 of the SPDSS.
- Several steps could be taken to improve the accuracy of the baseflow estimates if necessary for localized analyses. These could include additional gaging to better quantify the currently ungaged inflows and outflows (such as small municipal dischargers and farm runoff), and including smaller-volume inflows and outflows. This detailed information was not necessary for the purposes of this regional analysis.

6.0 References

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________. 1972d. Hydrogeologic Characteristics of the Valley Fill Aquifer in the Brush Reach of the South Platte River Valley, Colorado, USGS Open File Report 73-123.

________. 1972e. Hydrogeologic Characteristics of the Valley Fill Aquifer in the Sterling Reach of the South Platte River Valley, Colorado, USGS Open File Report 73-126.

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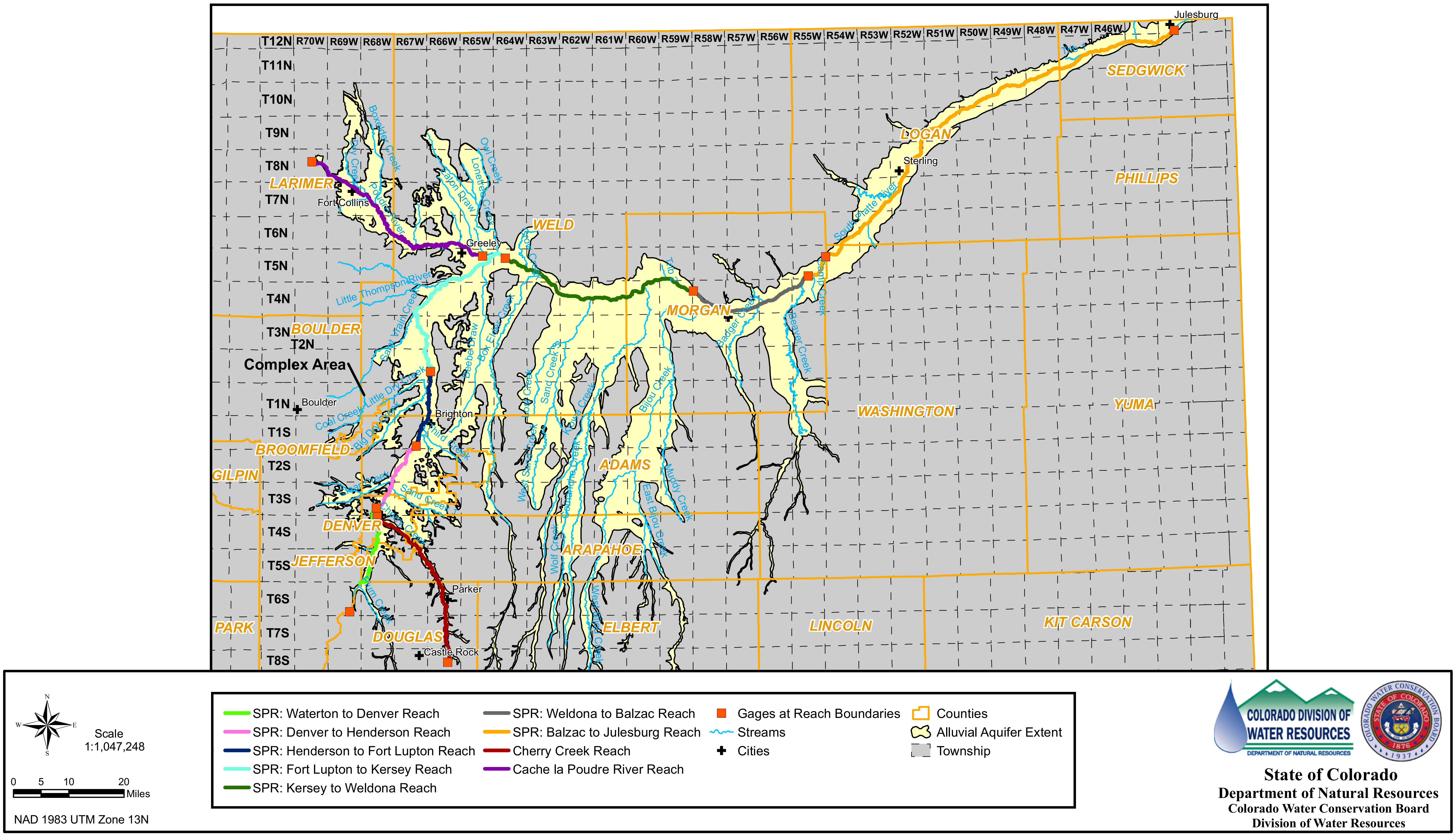
Figure 1: Stream Reaches and Gages Used in Gain/Loss Estimation



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

Prepared by: CDM

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Figure 2: South Platte - Fort Lupton to Kersey Reach
Mass Balance and Short Term Average Comparison (1977)

Figure 3: South Platte 1 - Waterton to Denver Reach Average Annual Mass Balance and Baseflow Results

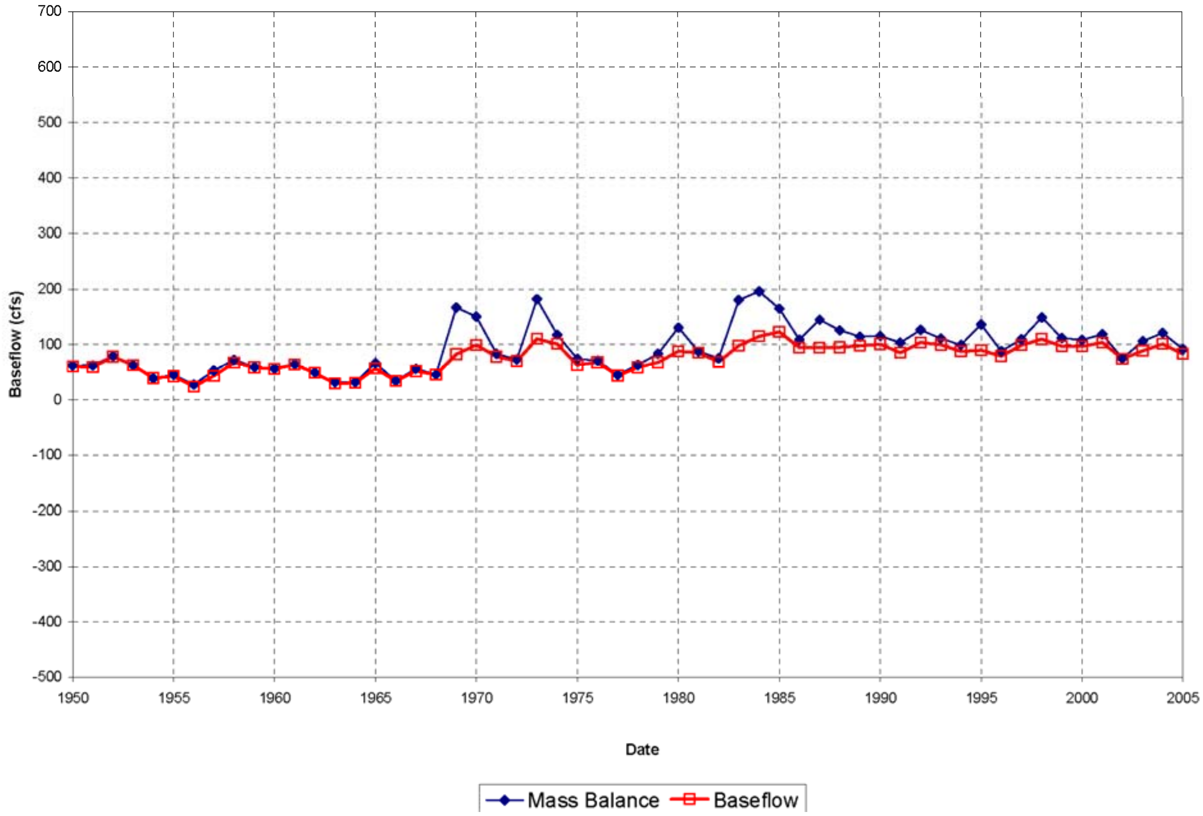


Figure 4: South Platte 2 - Denver to Henderson Reach Average Annual Mass Balance and Baseflow Results

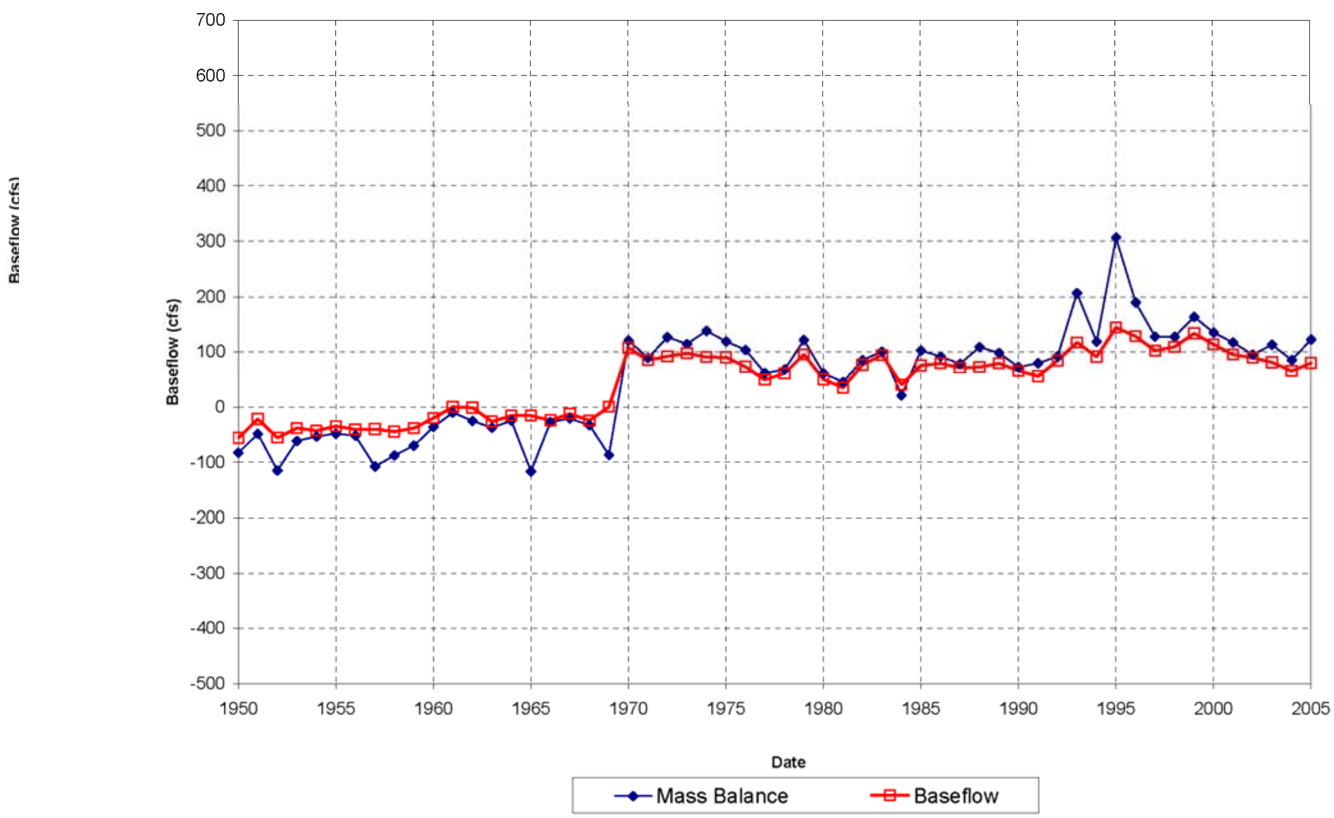


Figure 5: South Platte 3 - Henderson to Fort Lupton Reach
Average Annual Mass Balance and Baseflow Results

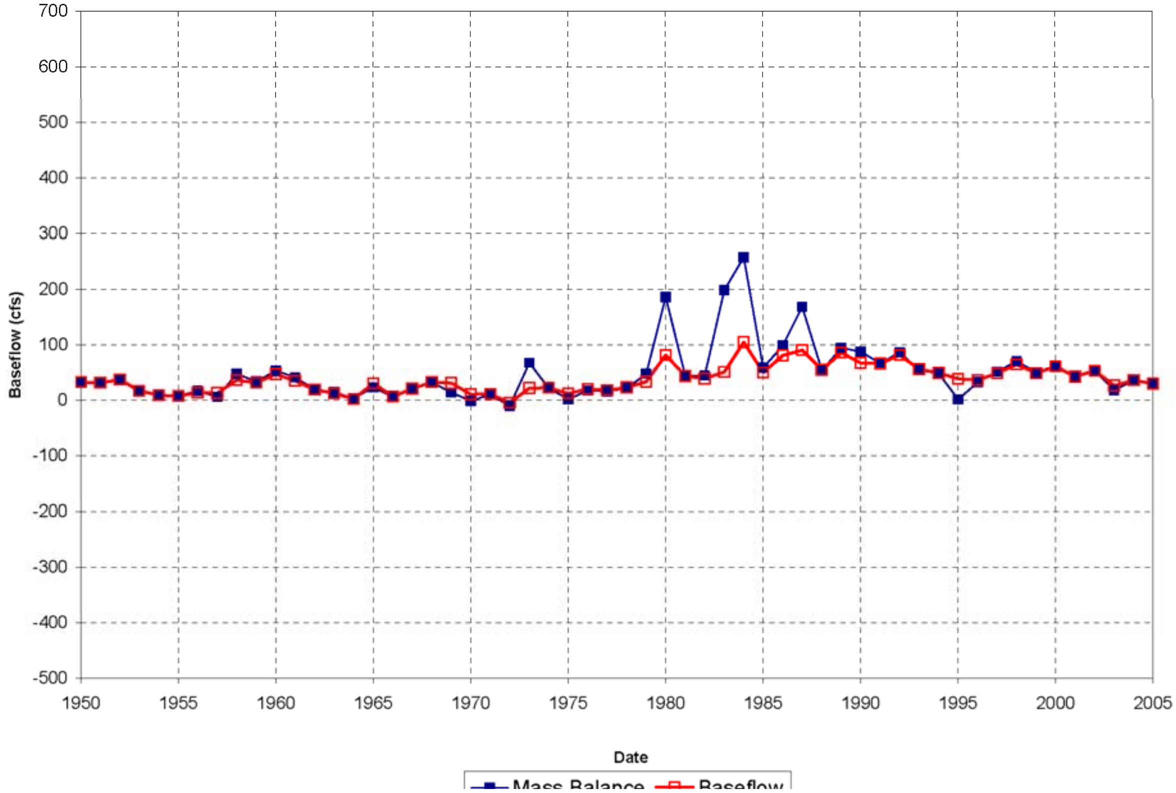


Figure 6: South Platte 4 - Fort Lupton to Kersey Reach
Average Annual Mass Balance and Baseflow Results

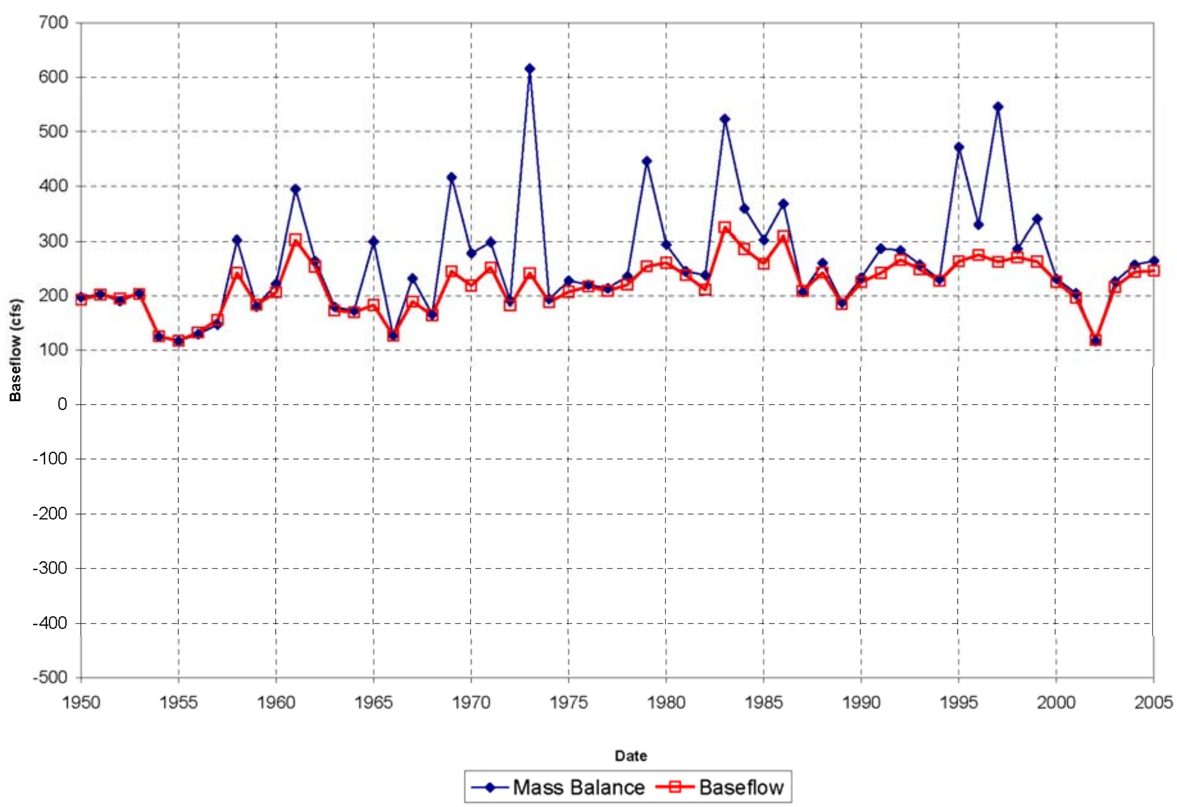


Figure 7: South Platte 5 - Kersey to Weldona Reach
Average Annual Mass Balance and Baseflow Results

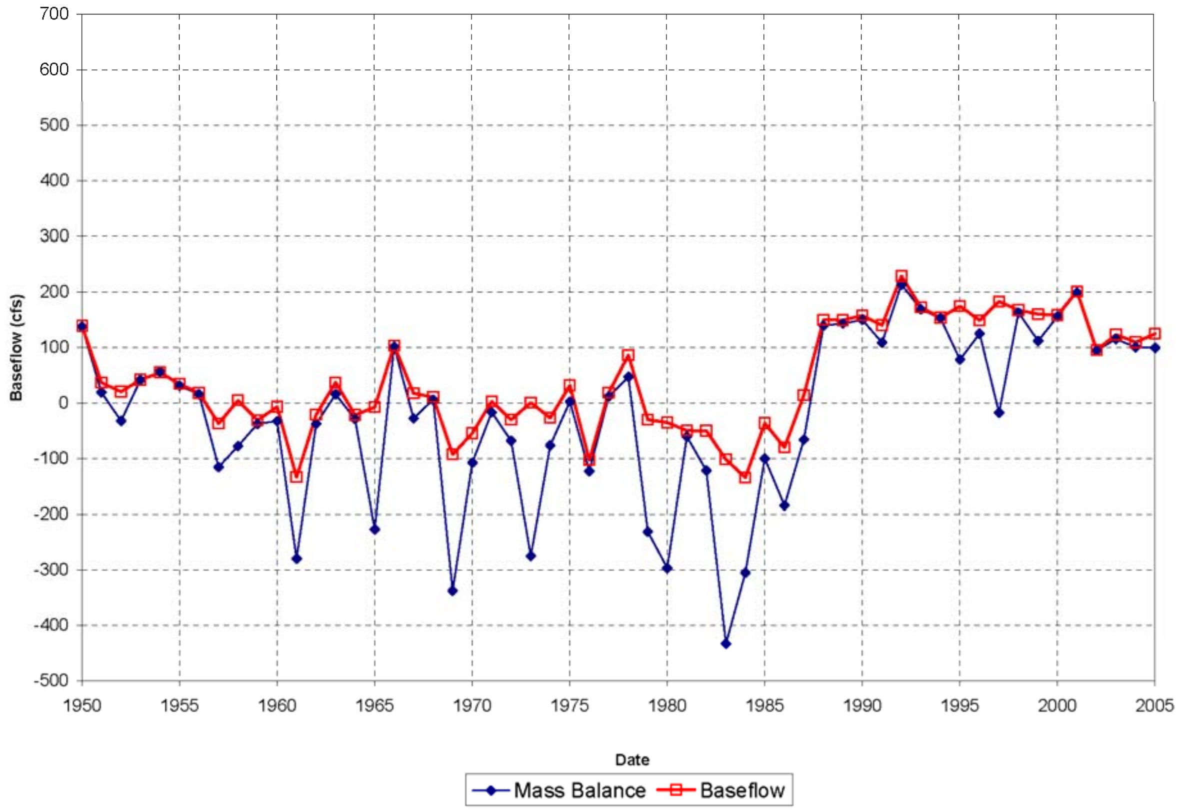


Figure 8: South Platte 6 - Weldona to Balzac Reach
Average Annual Mass Balance and Baseflow Results

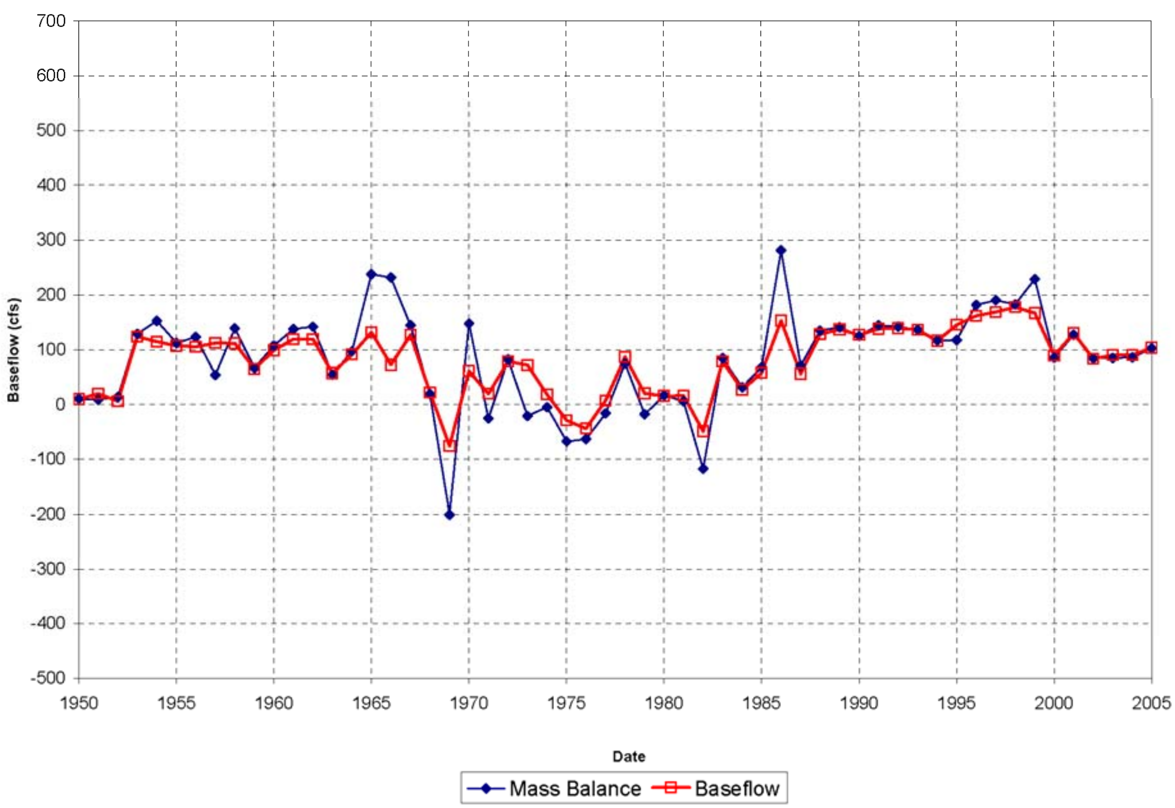


Figure 9: South Platte 7 - Balzac to Julesburg Reach
Average Annual Mass Balance and Baseflow Results

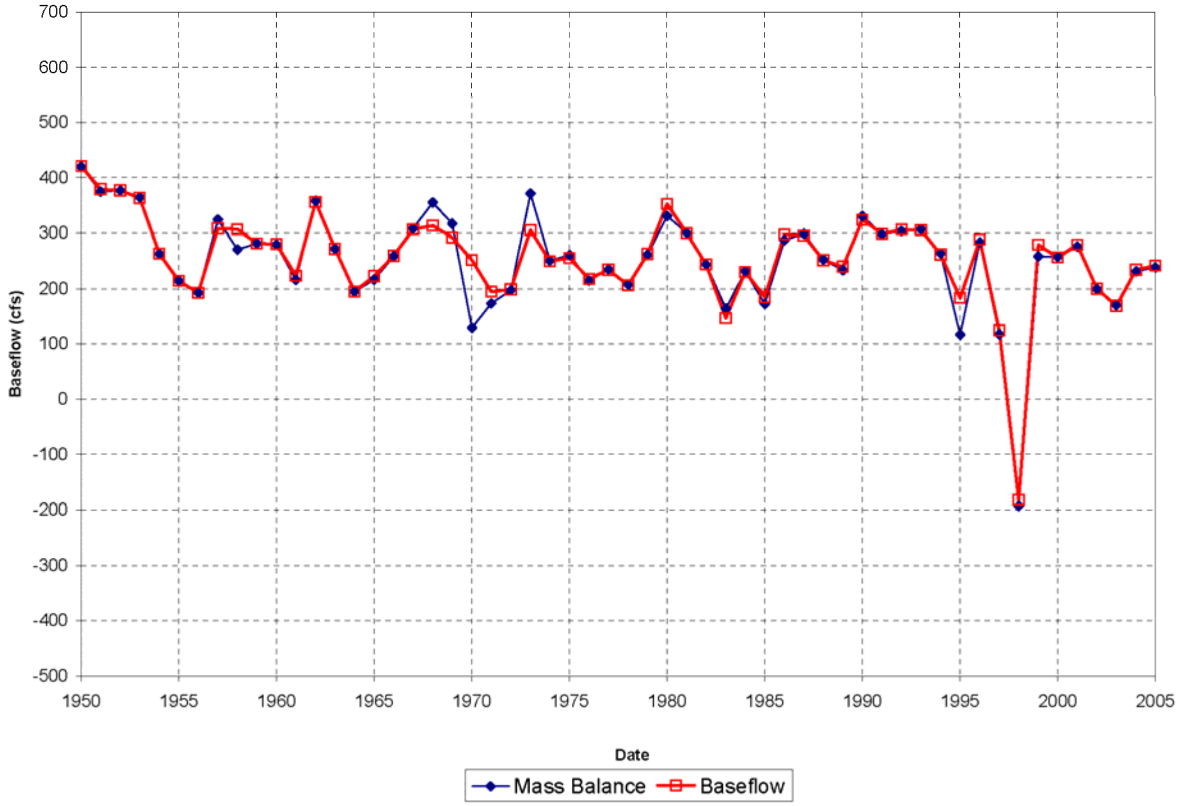


Figure 10: Cache la Poudre - Fort Collins to Greeley Reach
Average Annual Mass Balance and Baseflow Results

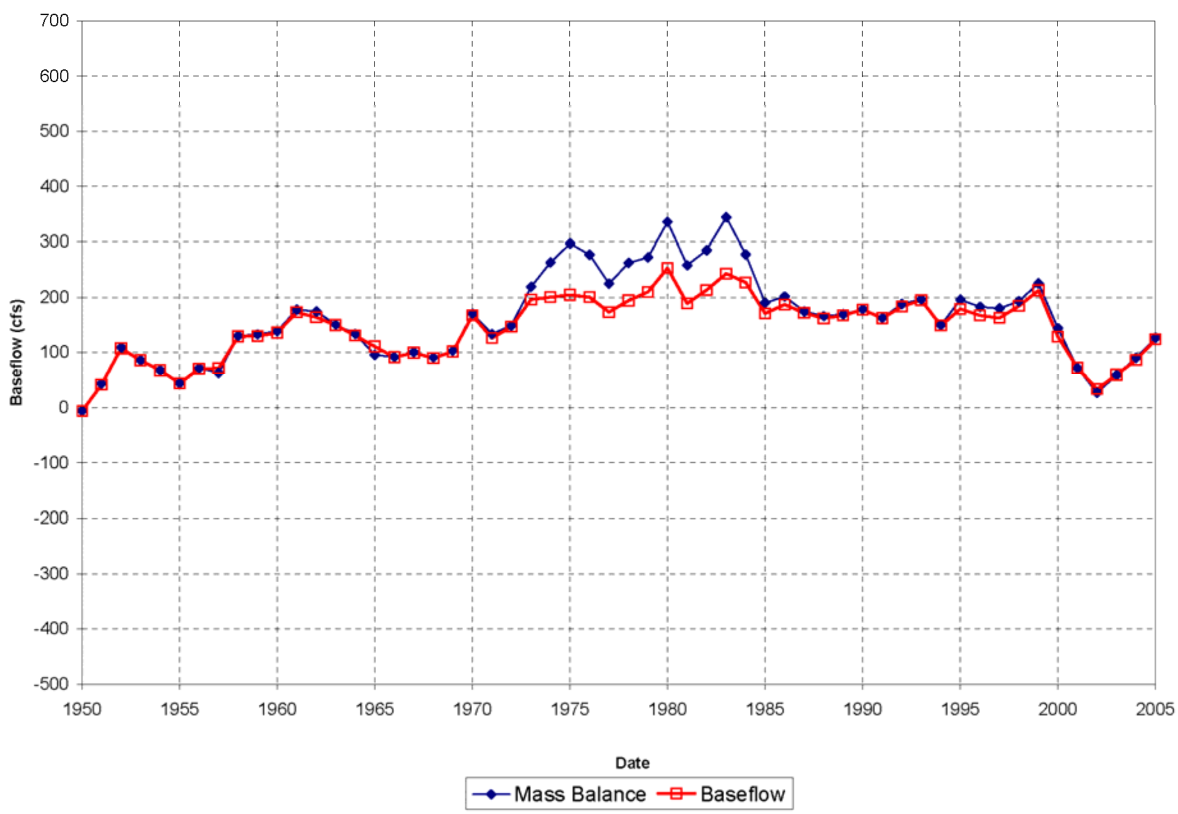


Figure 11: Cherry Creek - Franktown to Denver Reach Average Annual Mass Balance and Baseflow Results

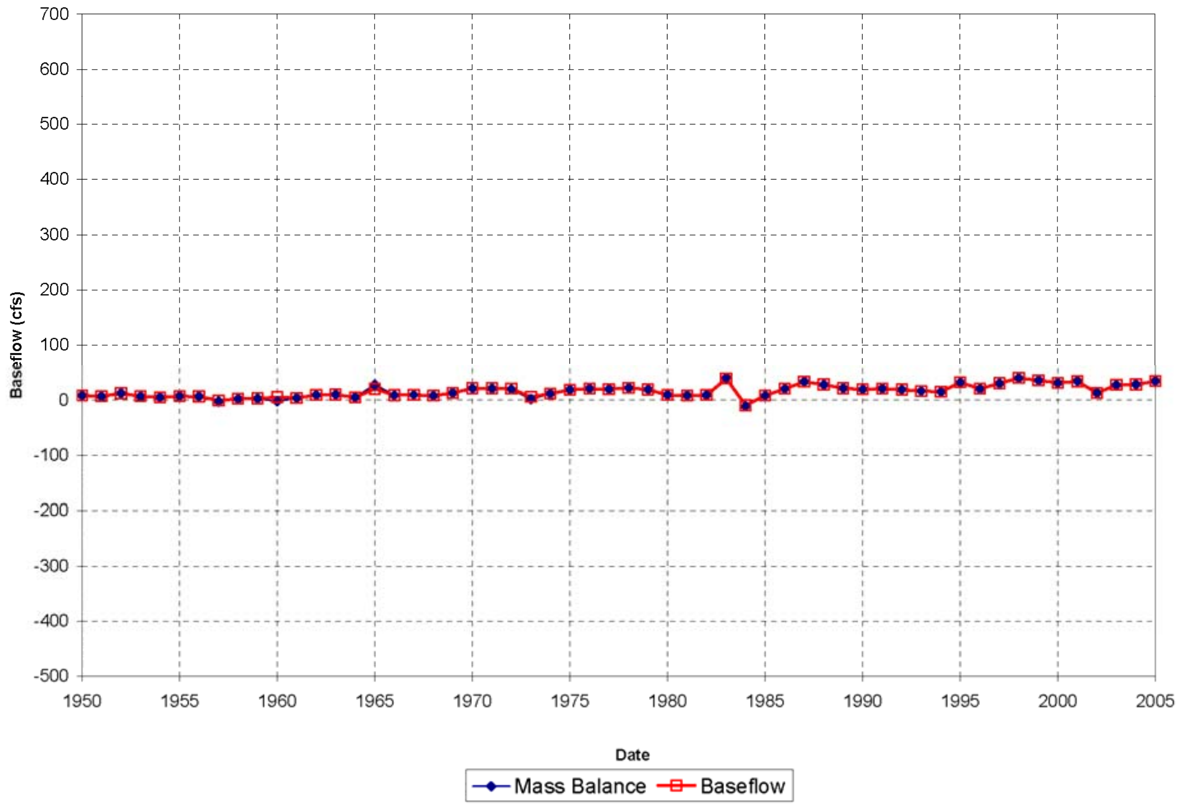


Figure 12: South Platte 1 - Waterton to Denver Reach
Average Monthly Mass Balance and Baseflow Results (1991 - 1994)

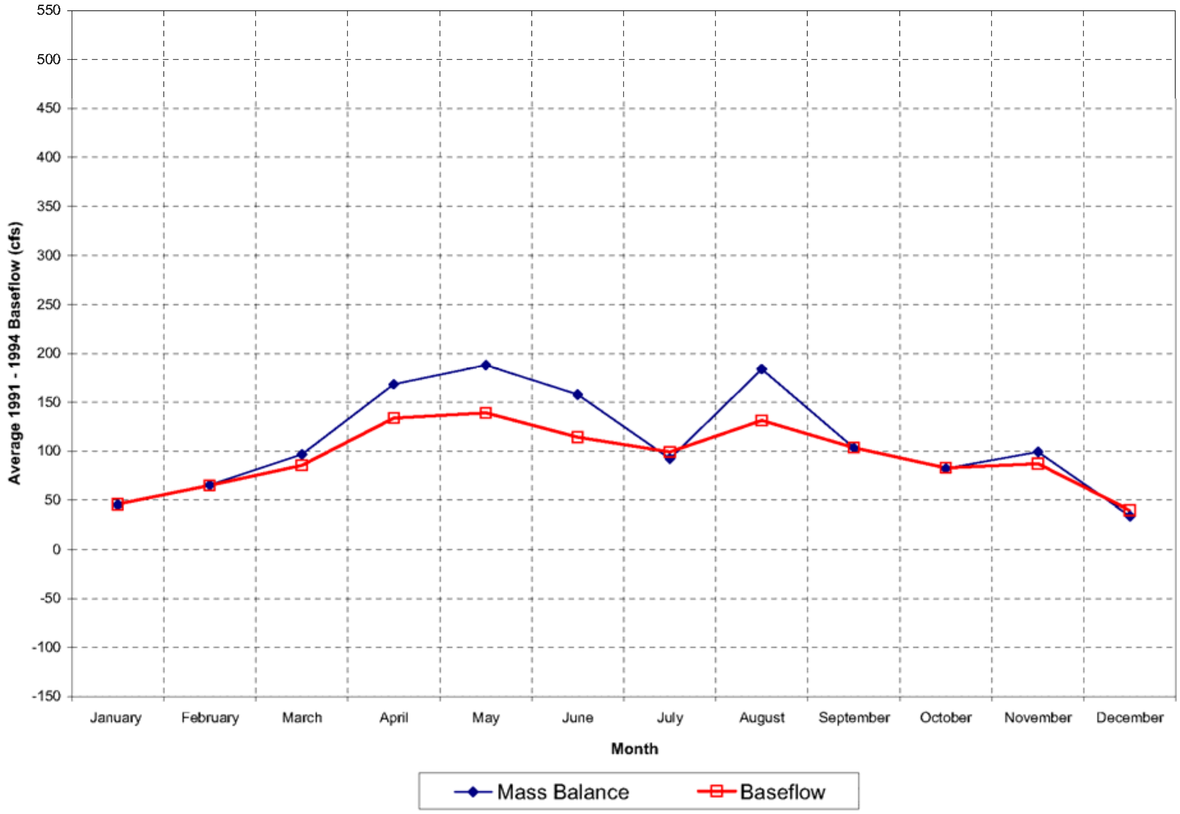


Figure 13: South Platte 2 - Denver to Henderson Reach
Average Monthly Mass Balance and Baseflow Results (1991 - 1994)

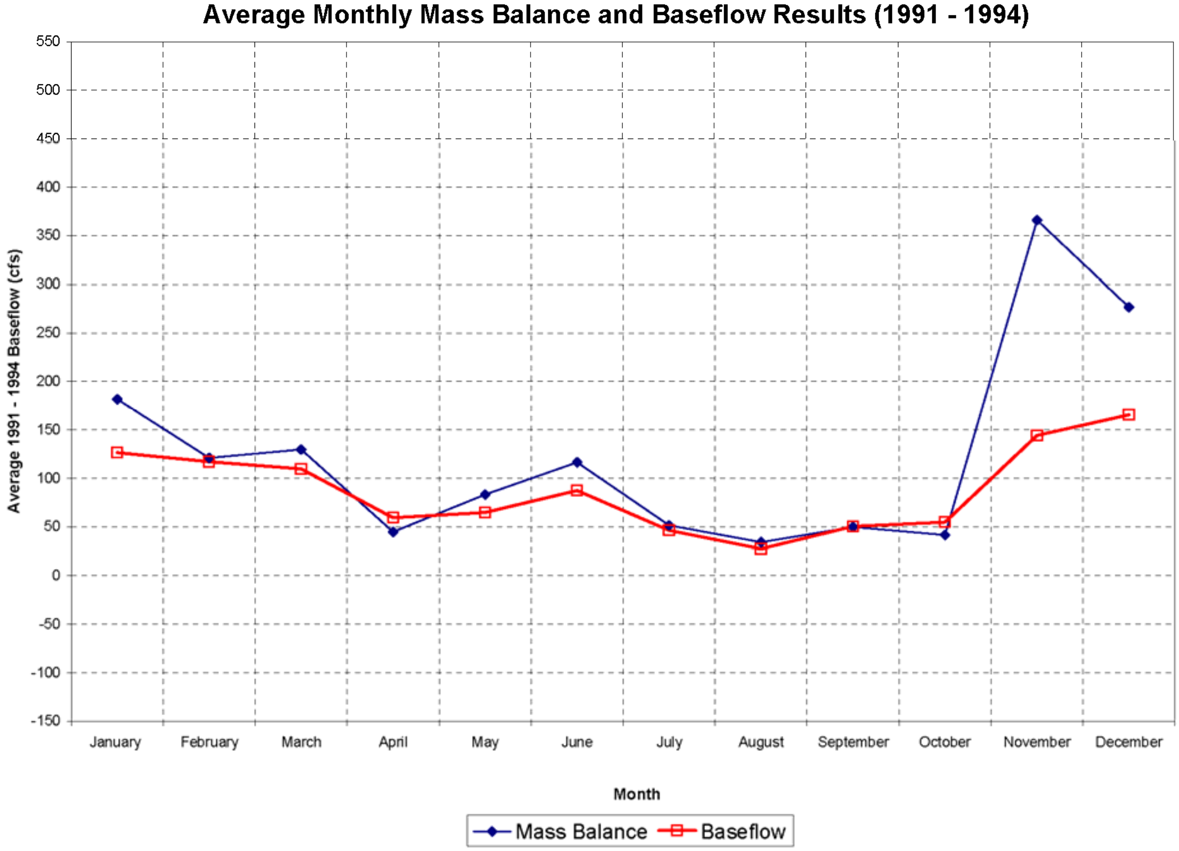
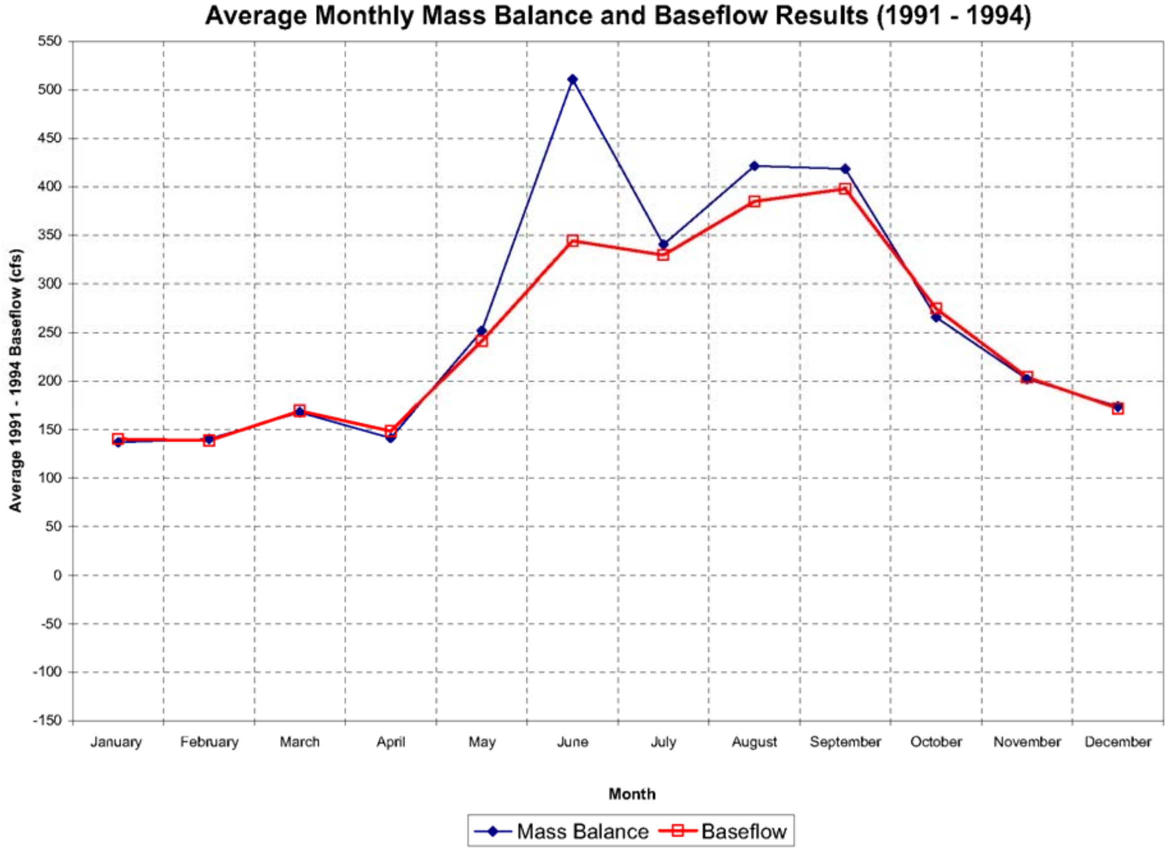


Figure 14: South Platte 3 - Henderson to Fort Lupton Reach
Average Monthly Mass Balance and Baseflow Results (1991 - 1994)

Figure 15: South Platte 4 - Fort Lupton to Kersey Reach
Average Monthly Mass Balance and Baseflow Results (1991 - 1994)



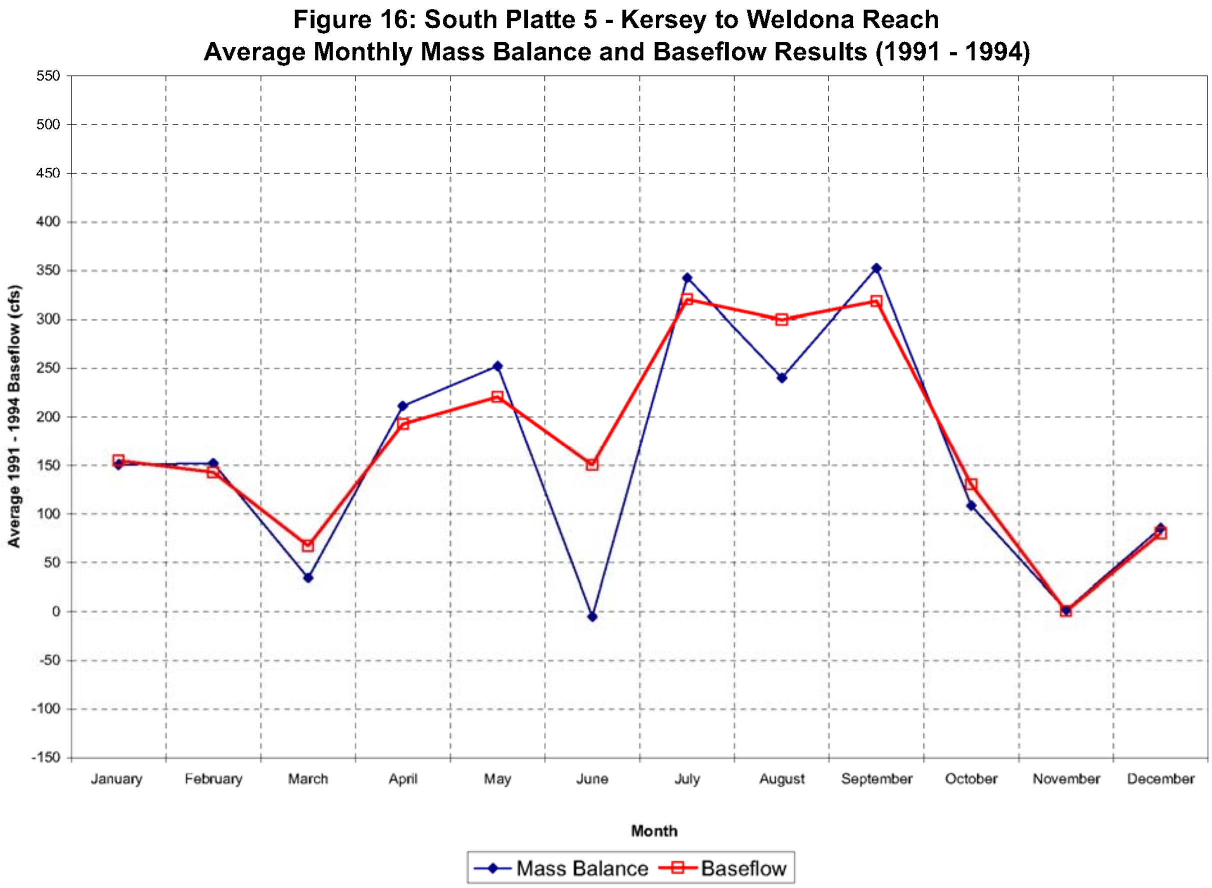


Figure 16: South Platte 5 - Kersey to Weldona Reach
Average Monthly Mass Balance and Baseflow Results (1991 - 1994)
Average 1991 - 1994 Baseflow (cfs)
550
500
450
400
350
300
250
200
150
100
50
0
-50
-100
-150
January
February
March
April
May
June
July
August
September
October
November
December
Month
Mass Balance
Baseflow

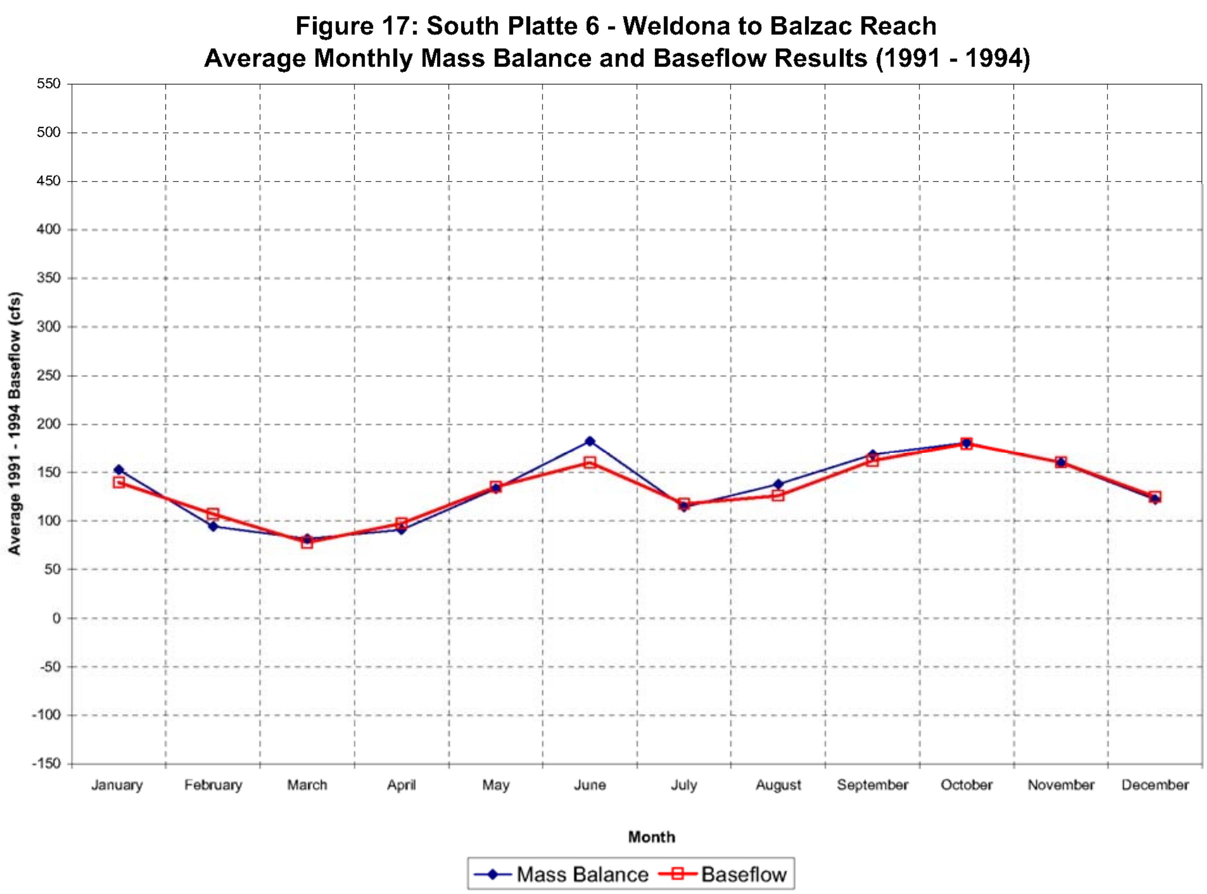


Figure 17: South Platte 6 - Weldona to Balzac Reach
Average Monthly Mass Balance and Baseflow Results (1991 - 1994)
Average 1991 - 1994 Baseflow (cfs)
550
500
450
400
350
300
250
200
150
100
50
0
-50
-100
-150
January
February
March
April
May
June
July
August
September
October
November
December
Month
Mass Balance
Baseflow

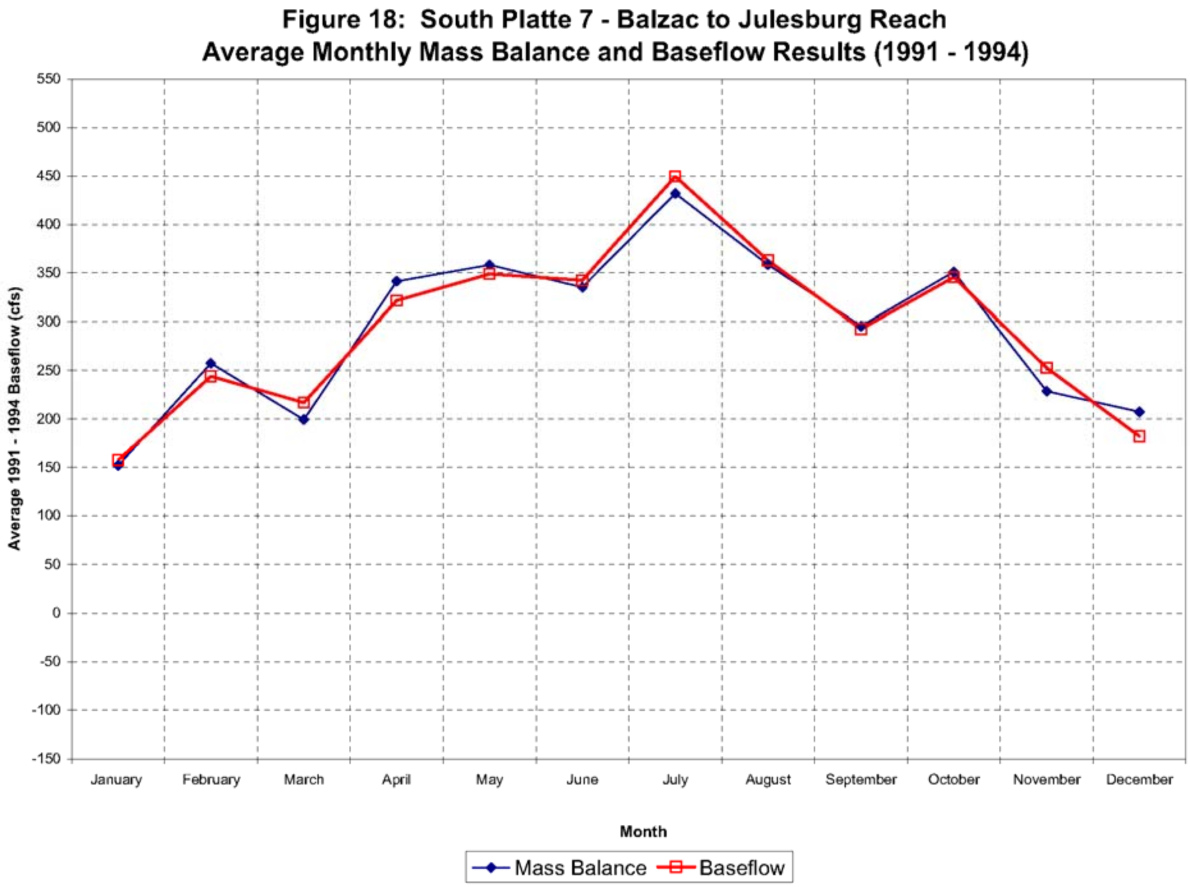


Figure 18: South Platte 7 - Balzac to Julesburg Reach
Average Monthly Mass Balance and Baseflow Results (1991 - 1994)
Average 1991 - 1994 Baseflow (cfs)
550
500
450
400
350
300
250
200
150
100
50
0
-50
-100
-150
January
February
March
April
May
June
July
August
September
October
November
December
Month
Mass Balance
Baseflow

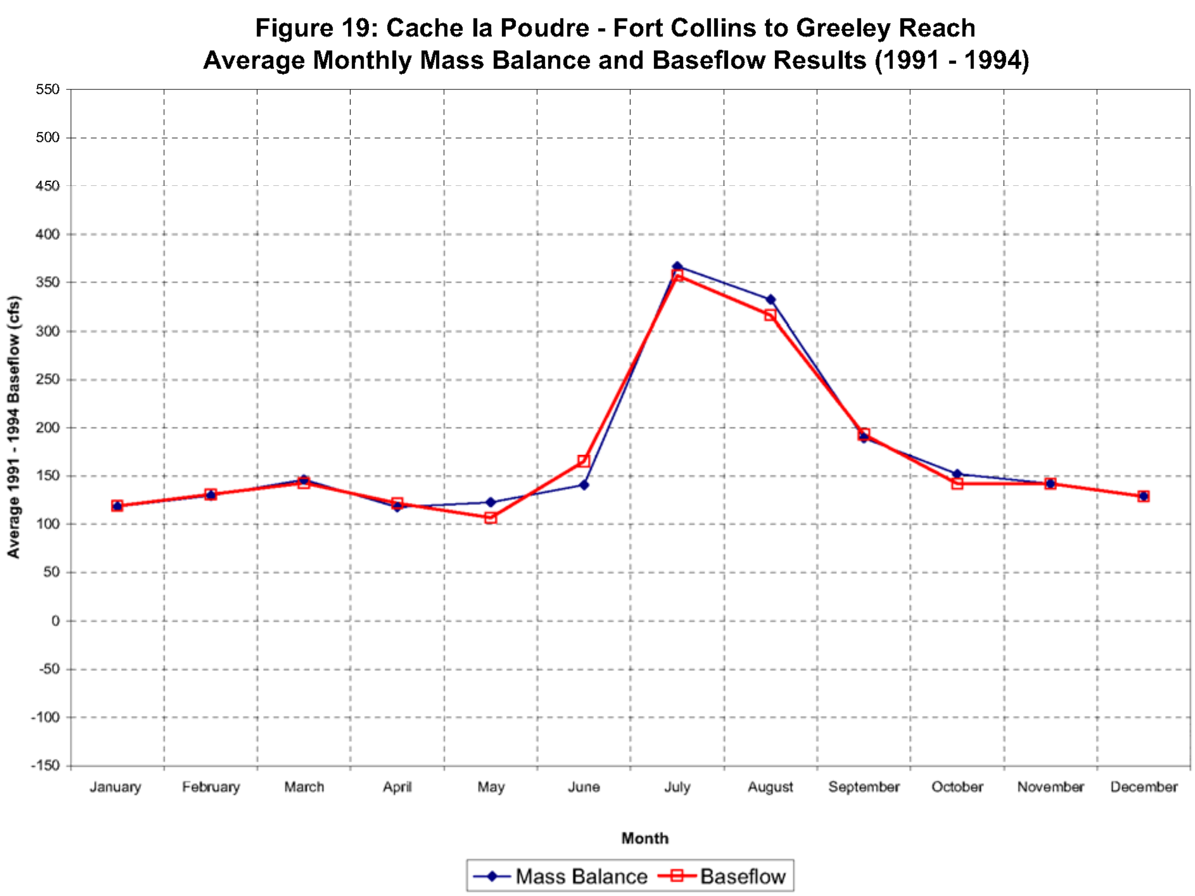


Figure 19: Cache la Poudre - Fort Collins to Greeley Reach
Average Monthly Mass Balance and Baseflow Results (1991 - 1994)
Average 1991 - 1994 Baseflow (cfs)
550
500
450
400
350
300
250
200
150
100
50
0
-50
-100
-150
January
February
March
April
May
June
July
August
September
October
November
December
Month
Mass Balance
Baseflow

Figure 20: Cherry Creek - Franktown to Denver Reach
Average Monthly Mass Balance and Baseflow Results (1991 - 1994)

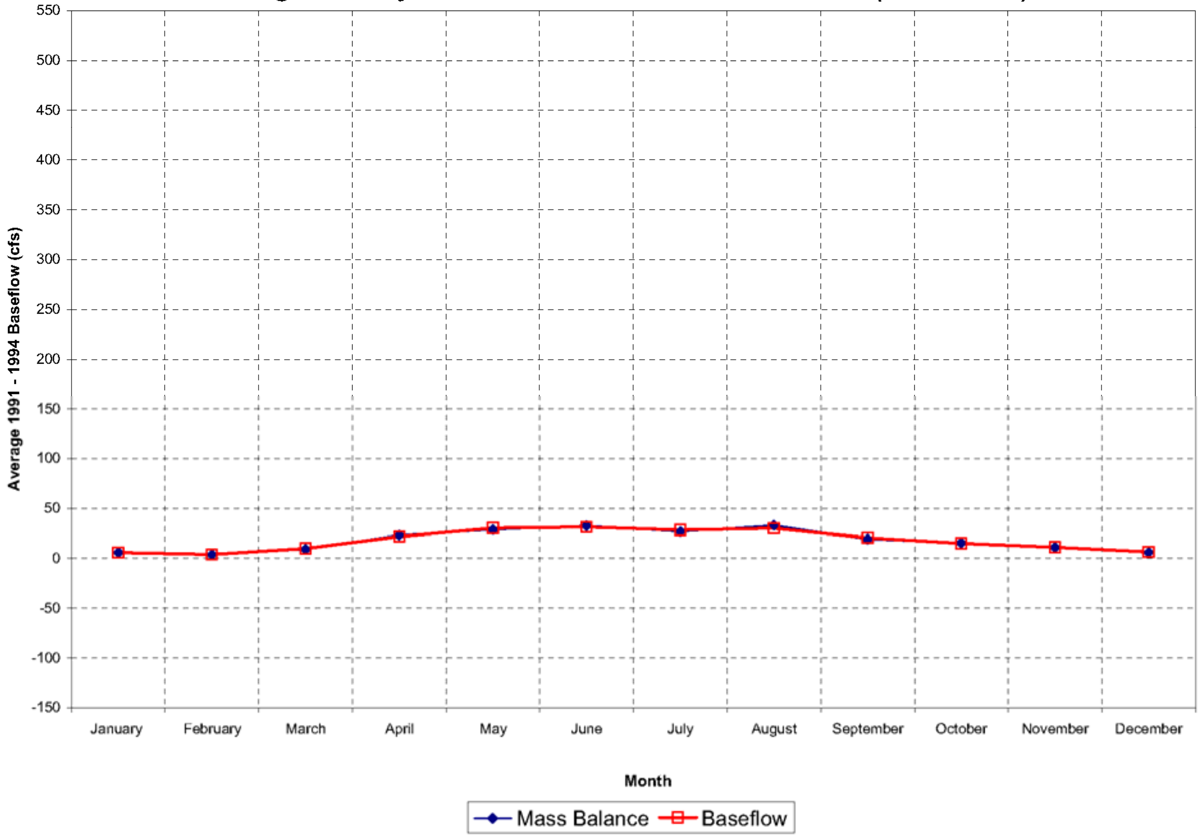


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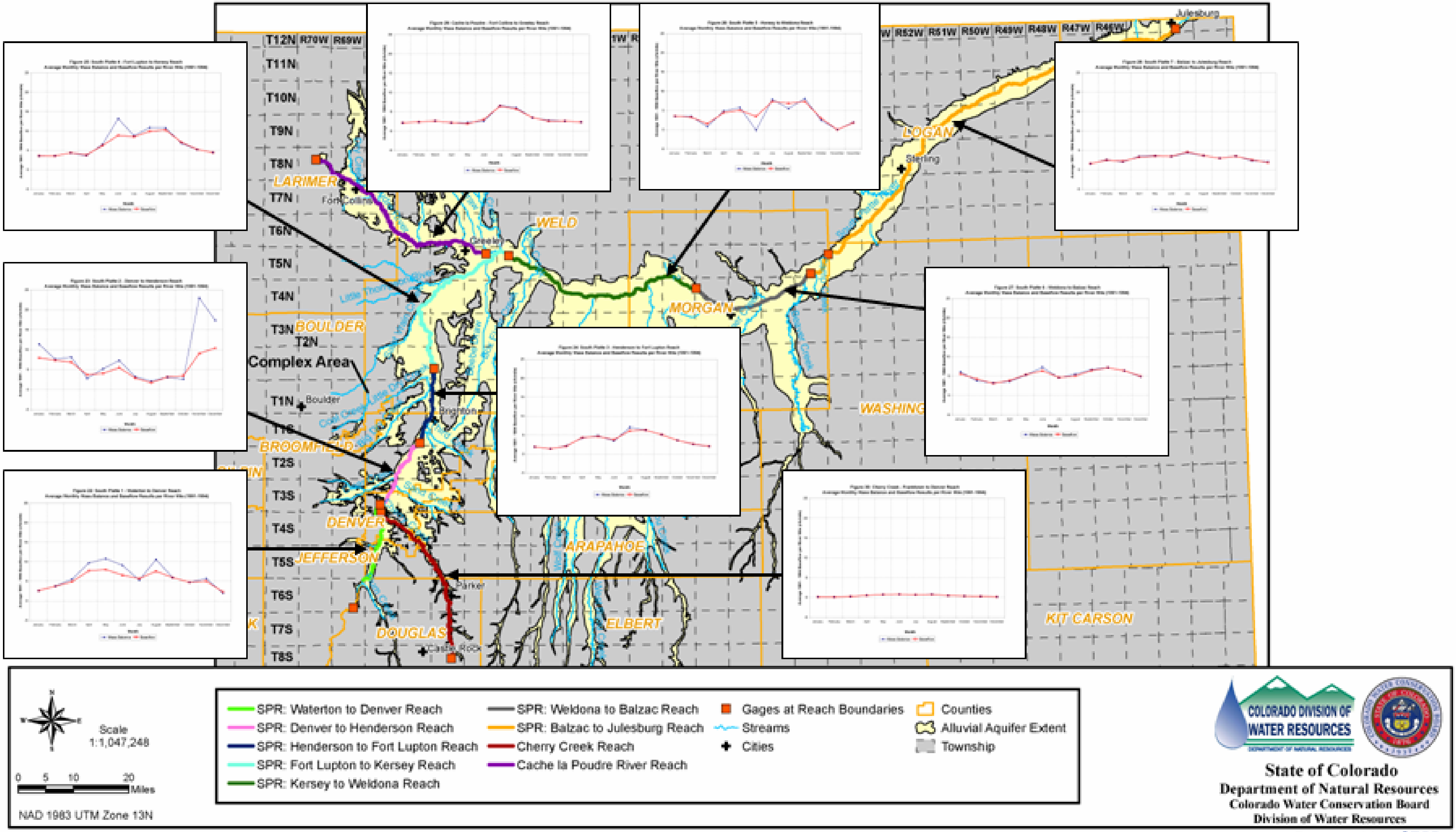
Figure 21: Average Monthly Mass Balance and Baseflow Results per River Mile (1991 - 1994)



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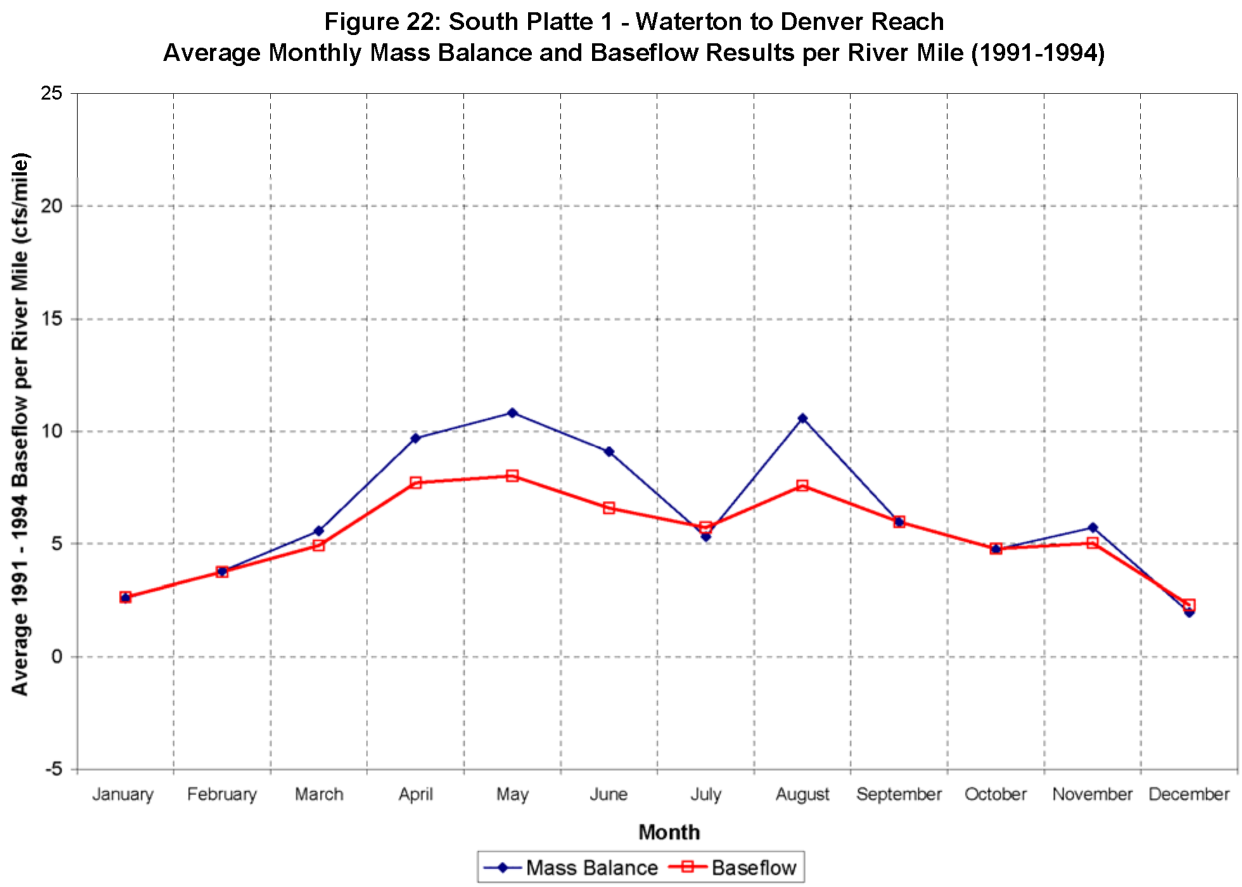


Figure 22: South Platte 1 - Waterton to Denver Reach
Average Monthly Mass Balance and Baseflow Results per River Mile (1991-1994)
Average 1991 - 1994 Baseflow per River Mile (cfs/mile)
25
20
15
10
5
0
-5
January
February
March
April
May
June
July
August
September
October
November
December
Month
Mass Balance
Baseflow

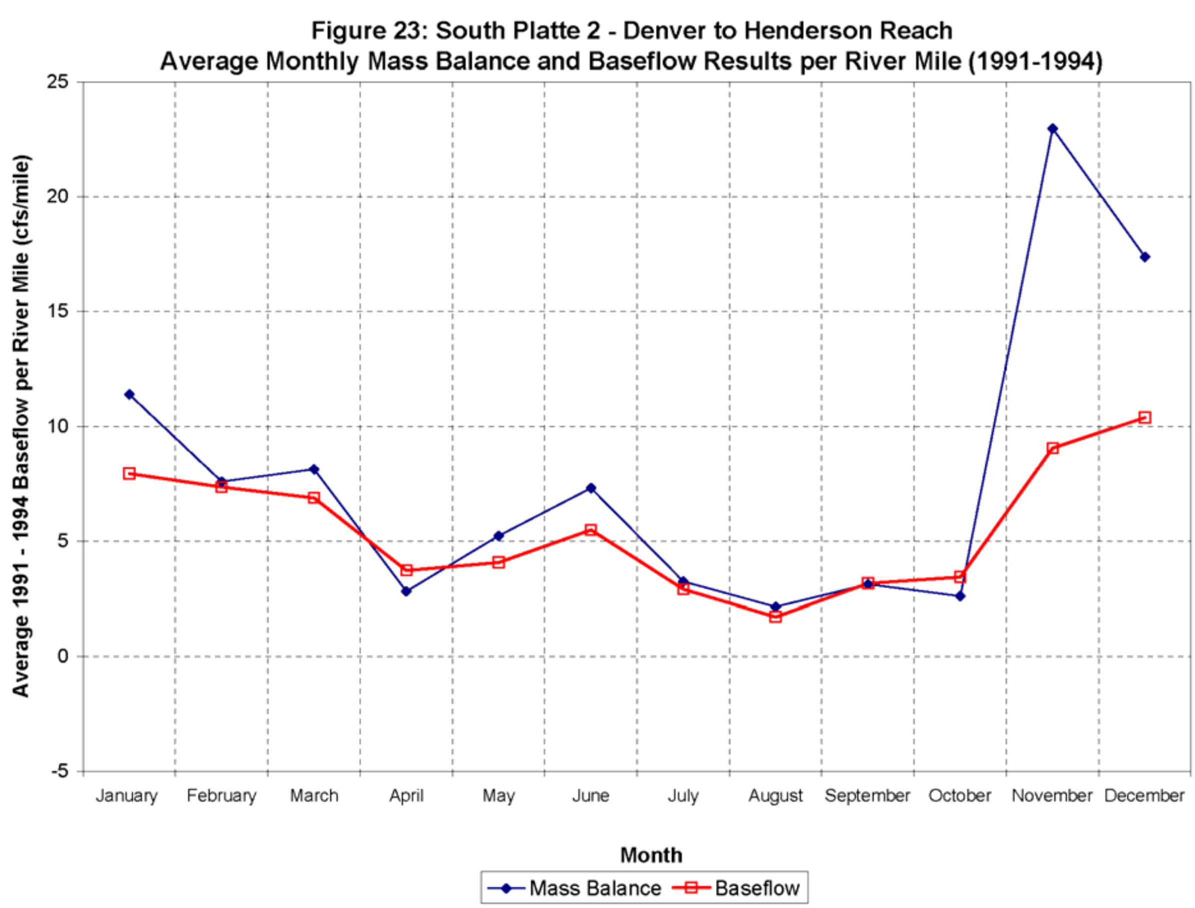


Figure 23: South Platte 2 - Denver to Henderson Reach
Average Monthly Mass Balance and Baseflow Results per River Mile (1991-1994)
Average 1991 - 1994 Baseflow per River Mile (cfs/mile)
25
20
15
10
5
0
-5
January
February
March
April
May
June
July
August
September
October
November
December
Month
Mass Balance
Baseflow

Figure 24: South Platte 3 - Henderson to Fort Lupton Reach
Average Monthly Mass Balance and Baseflow Results per River Mile (1991-1994)

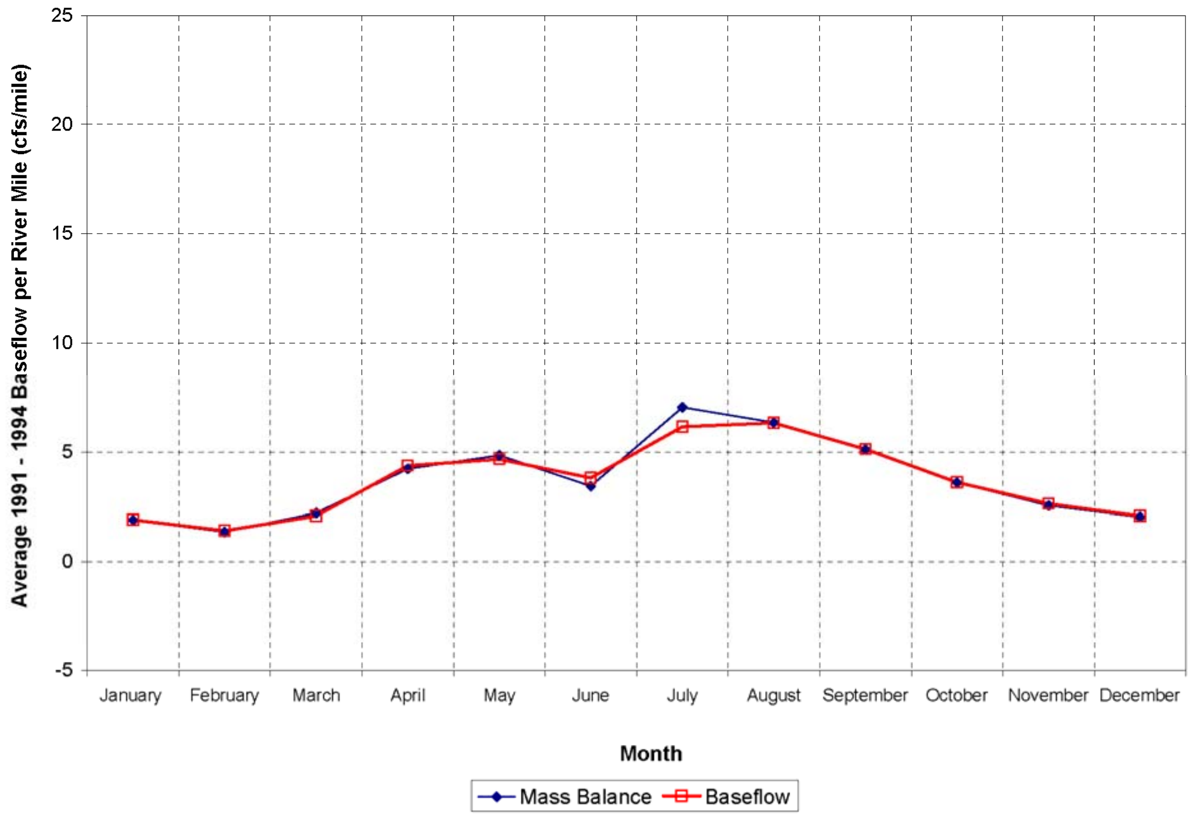


Figure 25: South Platte 4 - Fort Lupton to Kersey Reach
Average Monthly Mass Balance and Baseflow Results per River Mile (1991-1994)

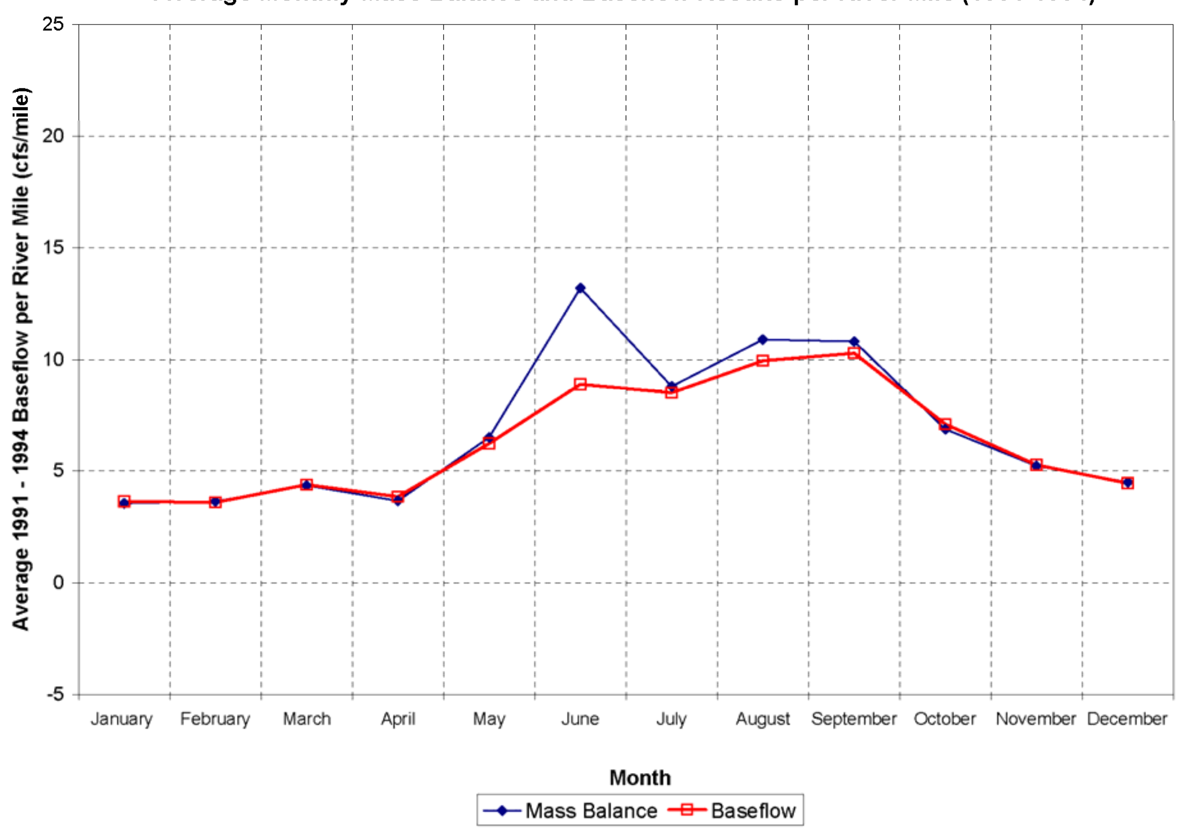


Figure 26: South Platte 5 - Kersey to Weldona Reach
Average Monthly Mass Balance and Baseflow Results per River Mile (1991-1994)

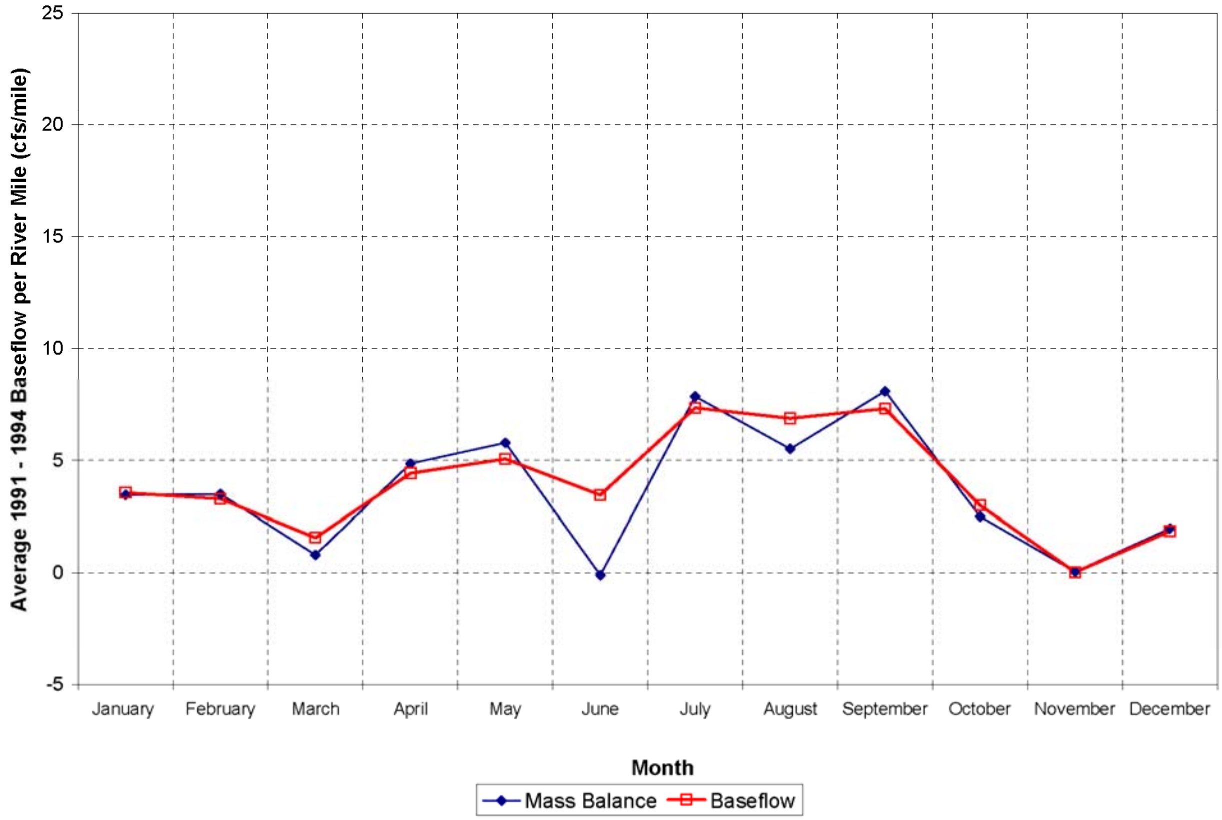


Figure 27: South Platte 6 - Weldona to Balzac Reach
Average Monthly Mass Balance and Baseflow Results per River Mile (1991-1994)

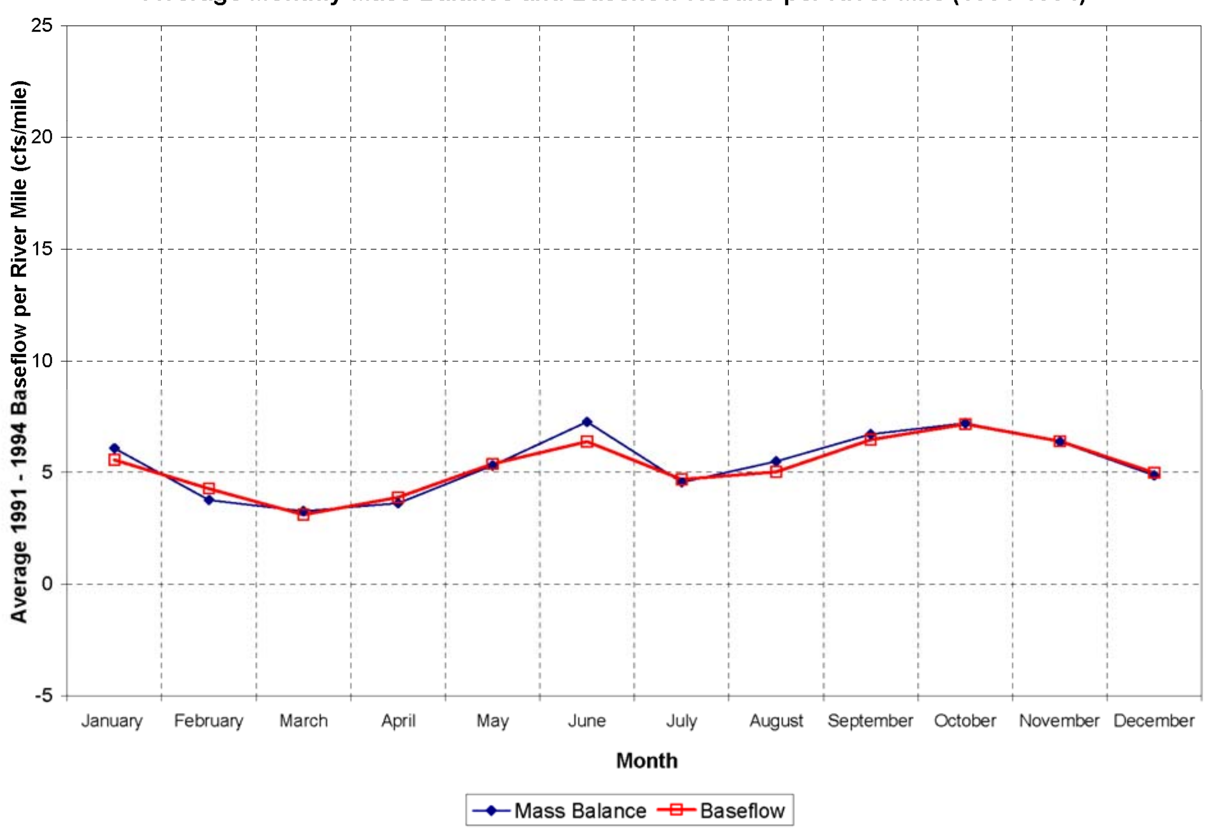


Figure 28: South Platte 7 - Balzac to Julesburg Reach
Average Monthly Mass Balance and Baseflow Results per River Mile (1991-1994)

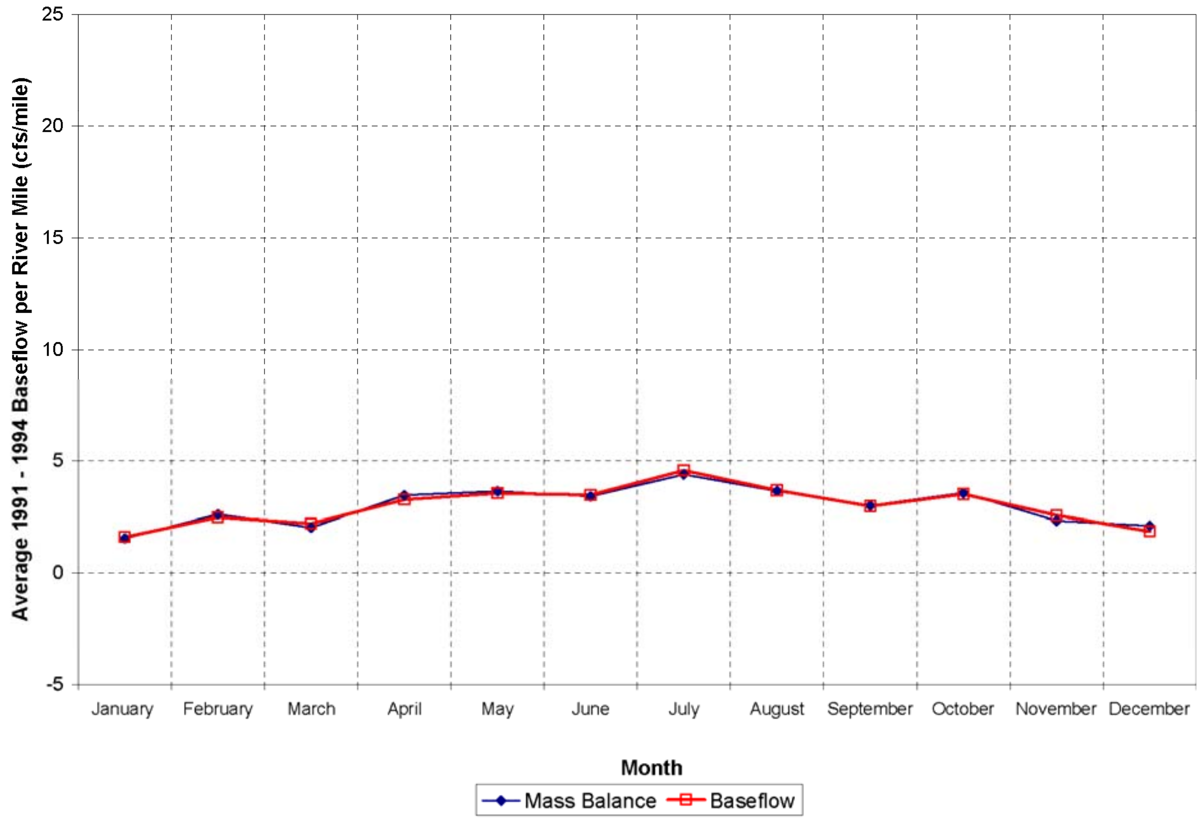
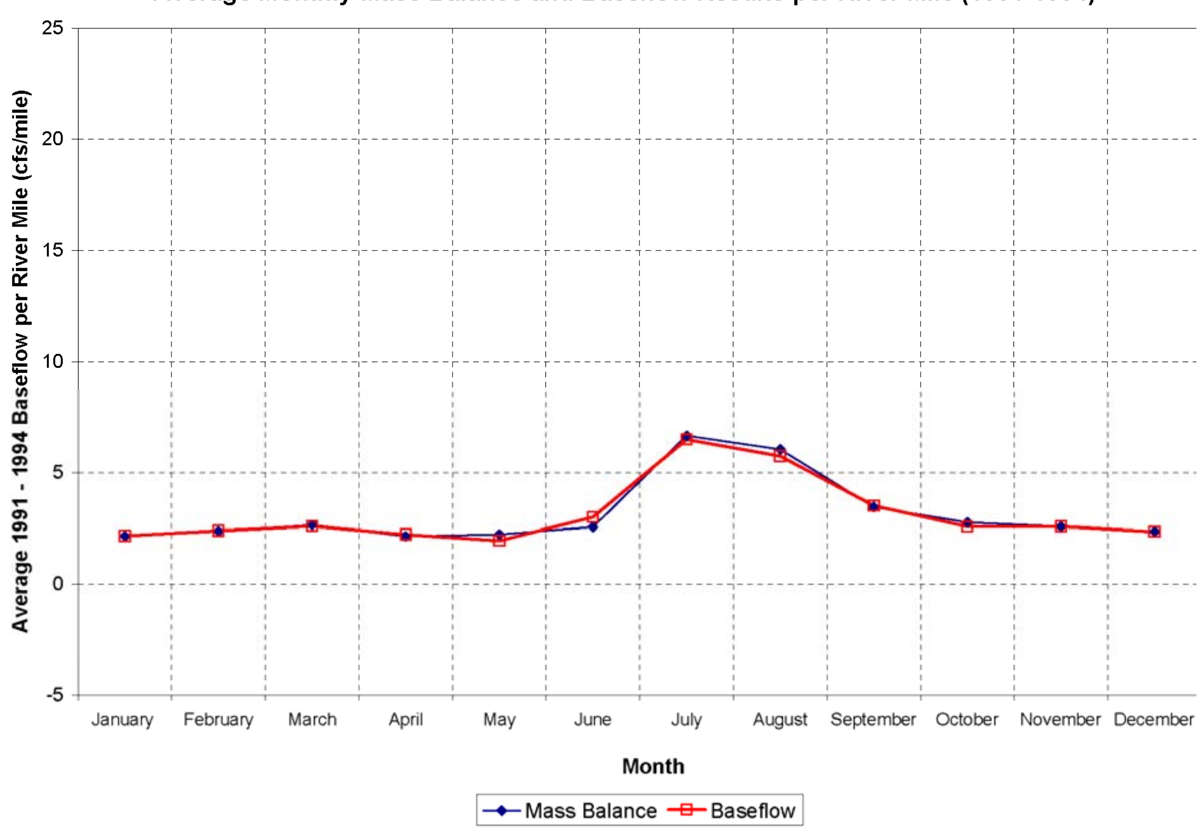


Figure 29: Cache la Poudre - Fort Collins to Greeley Reach
Average Monthly Mass Balance and Baseflow Results per River Mile (1991-1994)



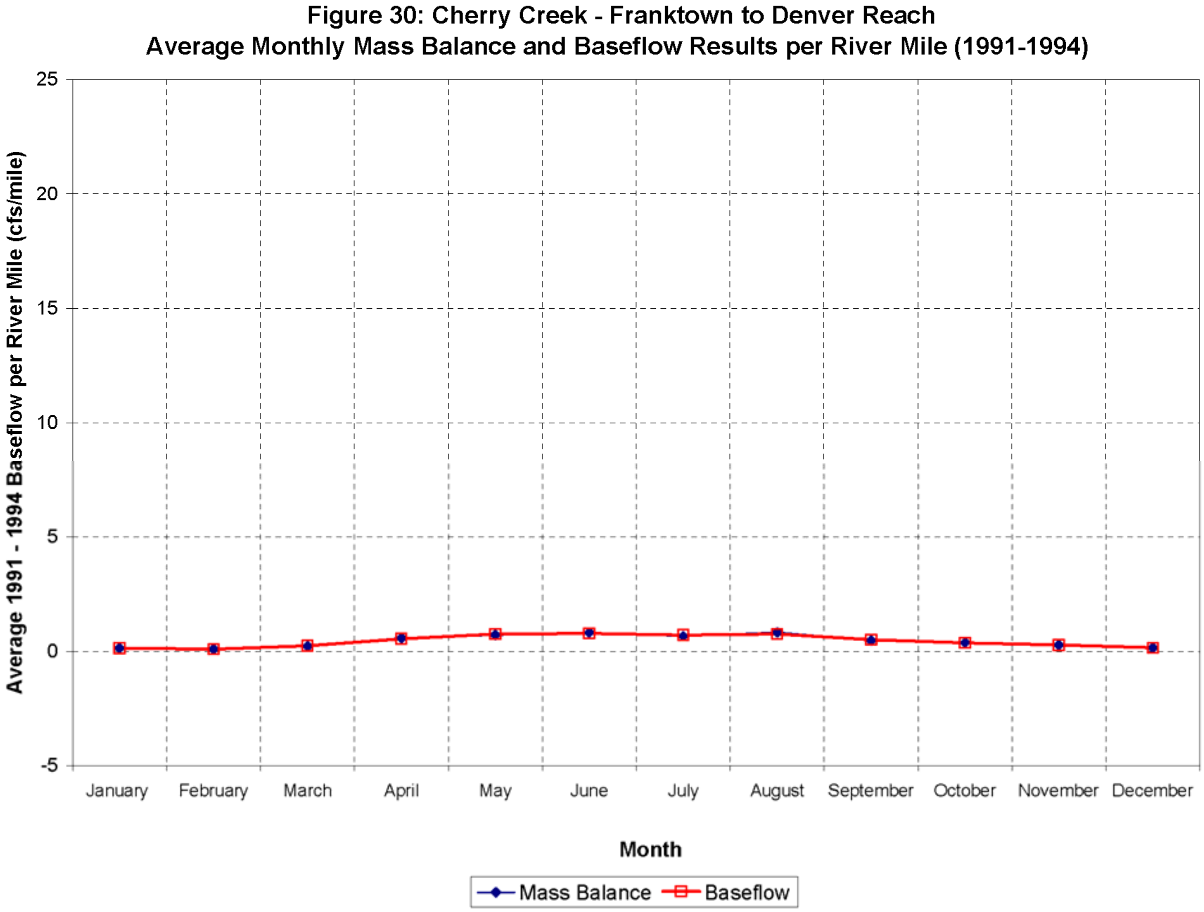


Figure 30: Cherry Creek - Franktown to Denver Reach
Average Monthly Mass Balance and Baseflow Results per River Mile (1991-1994)
Average 1991 - 1994 Baseflow per River Mile (cfs/mile)
25
20
15
10
5
0
-5
January
February
March
April
May
June
July
August
September
October
November
December
Month
Mass Balance
Baseflow

Figure 31: South Platte 1 - Waterton to Denver Reach
Average Monthly Baseflow Results (1999 - 2005)

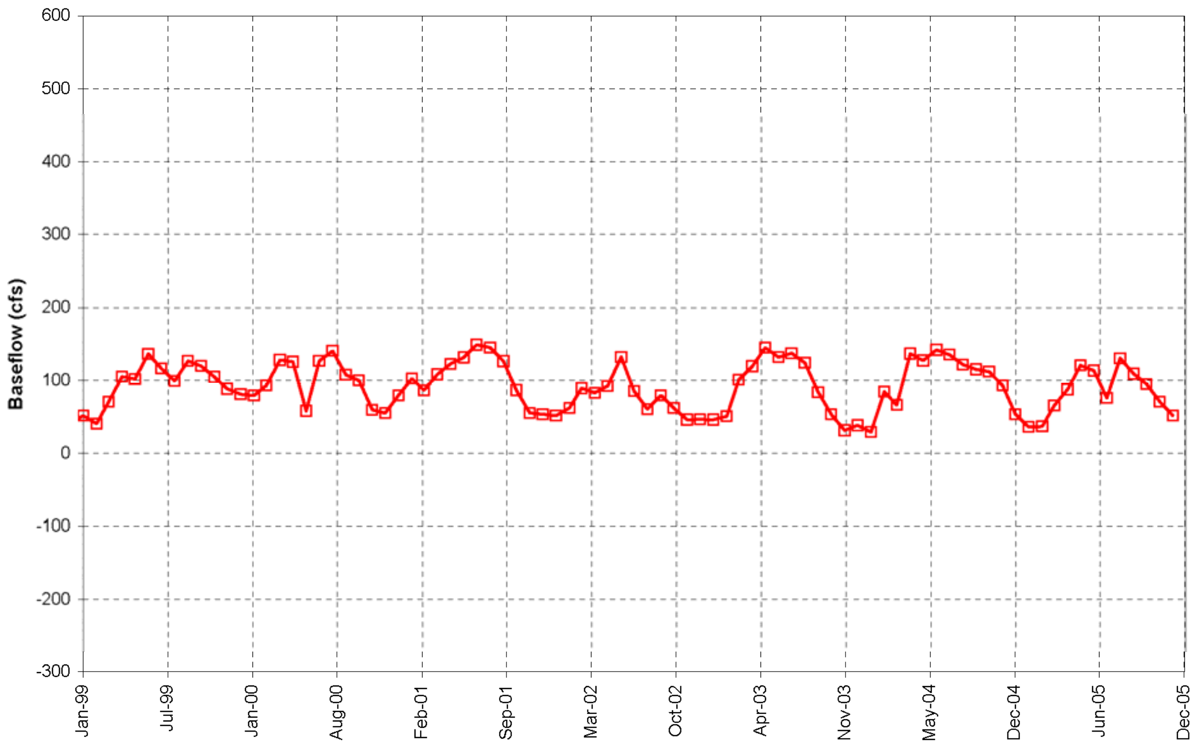


Figure 32: South Platte 2 - Denver to Henderson Reach
Average Monthly Baseflow Results (1999 - 2005)

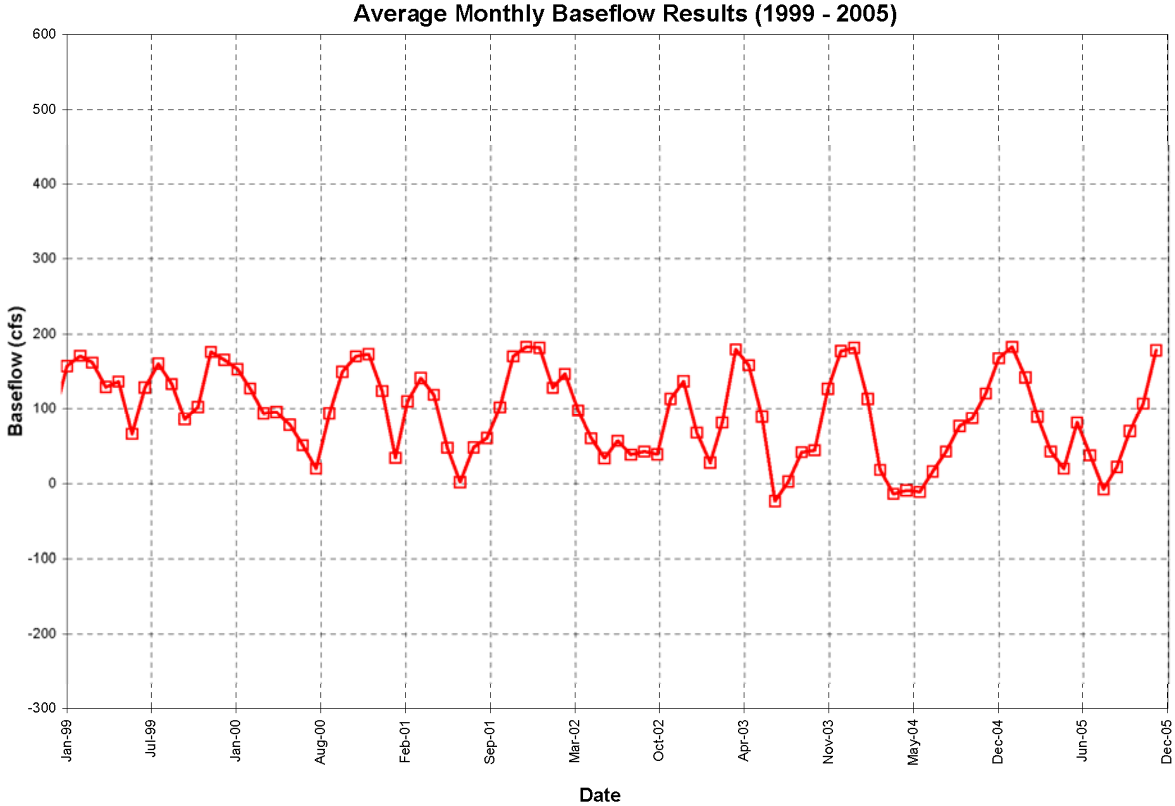


Figure 33: South Platte 3 - Henderson to Ft Lupton Reach
Average Monthly Baseflow Results (1999 - 2005)

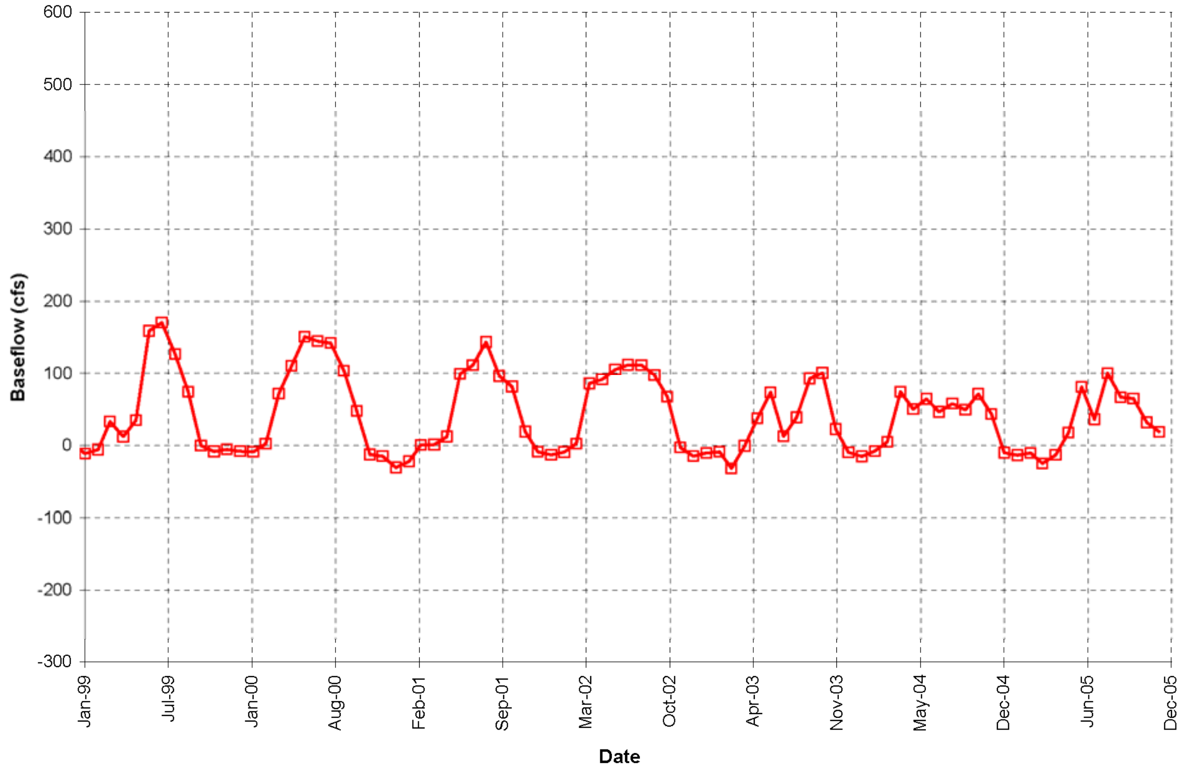


Figure 34: South Platte 4 - Ft Lupton to Kersey Reach
Average Monthly Baseflow Results (1999 - 2005)

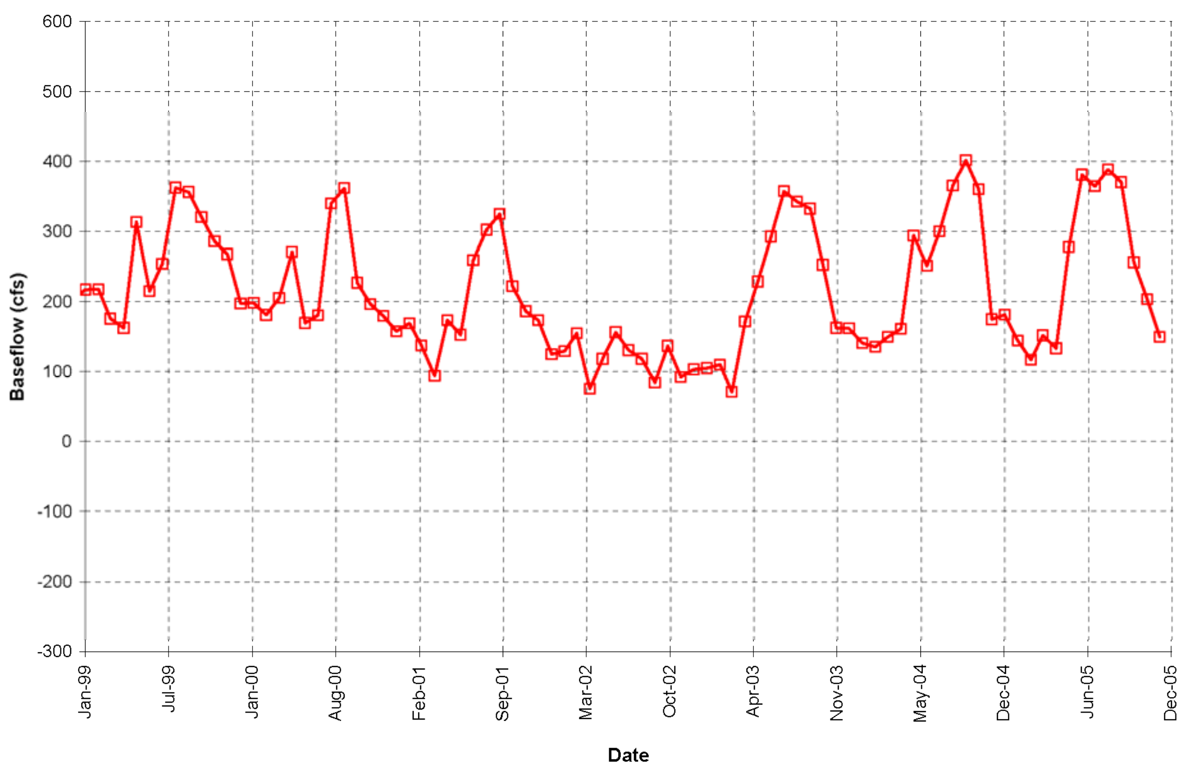


Figure 35: South Platte 5 - Kersey to Weldona Reach
Average Monthly Baseflow Results (1999 - 2005)

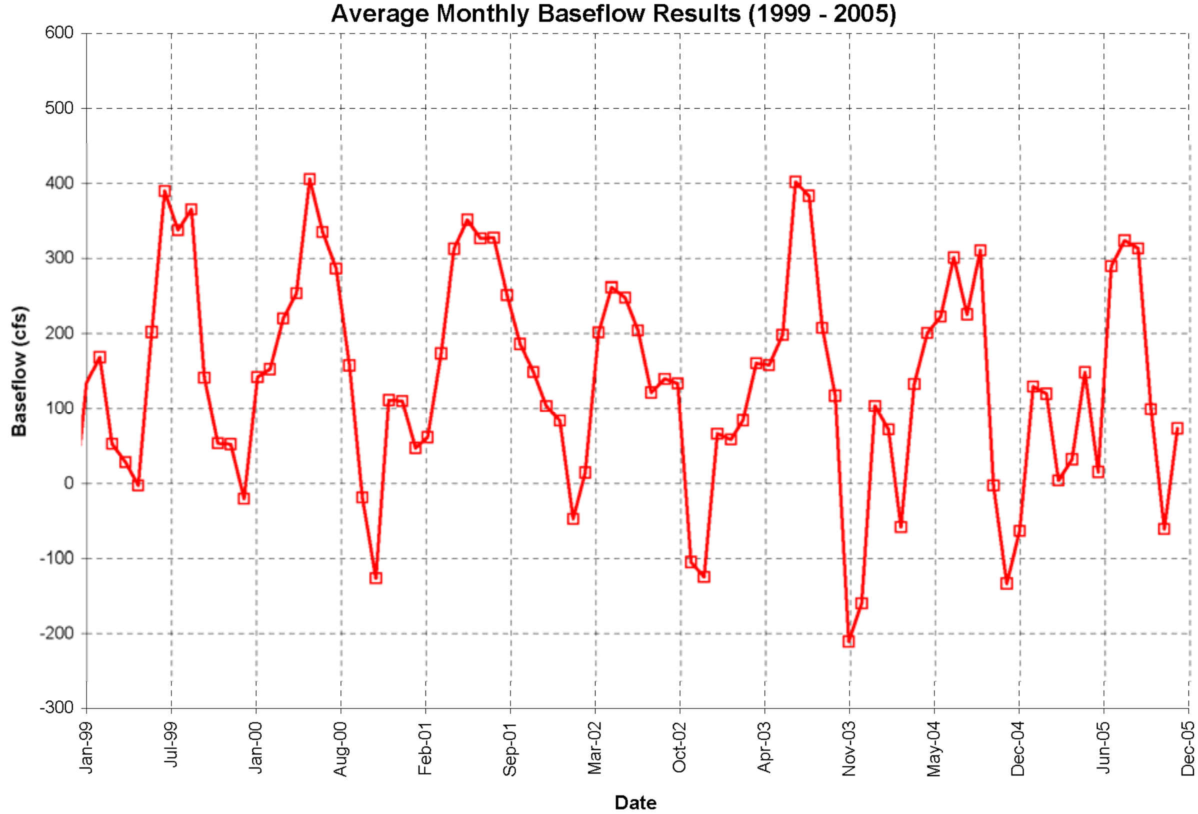


Figure 36: South Platte 6 - Weldona to Balzac Reach
Average Monthly Baseflow Results (1999 - 2005)

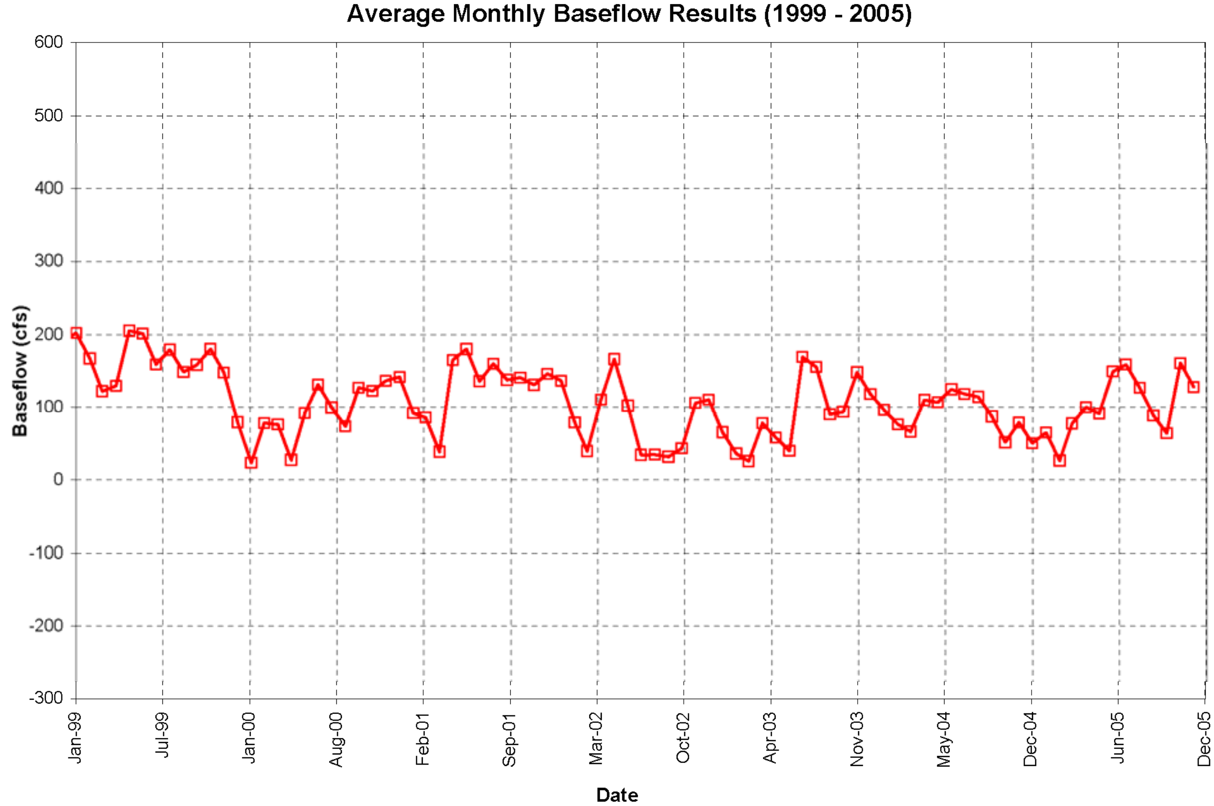


Figure 37: South Platte 7 - Balzac to Julesburg Reach
Average Monthly Baseflow Results (1999 - 2005)

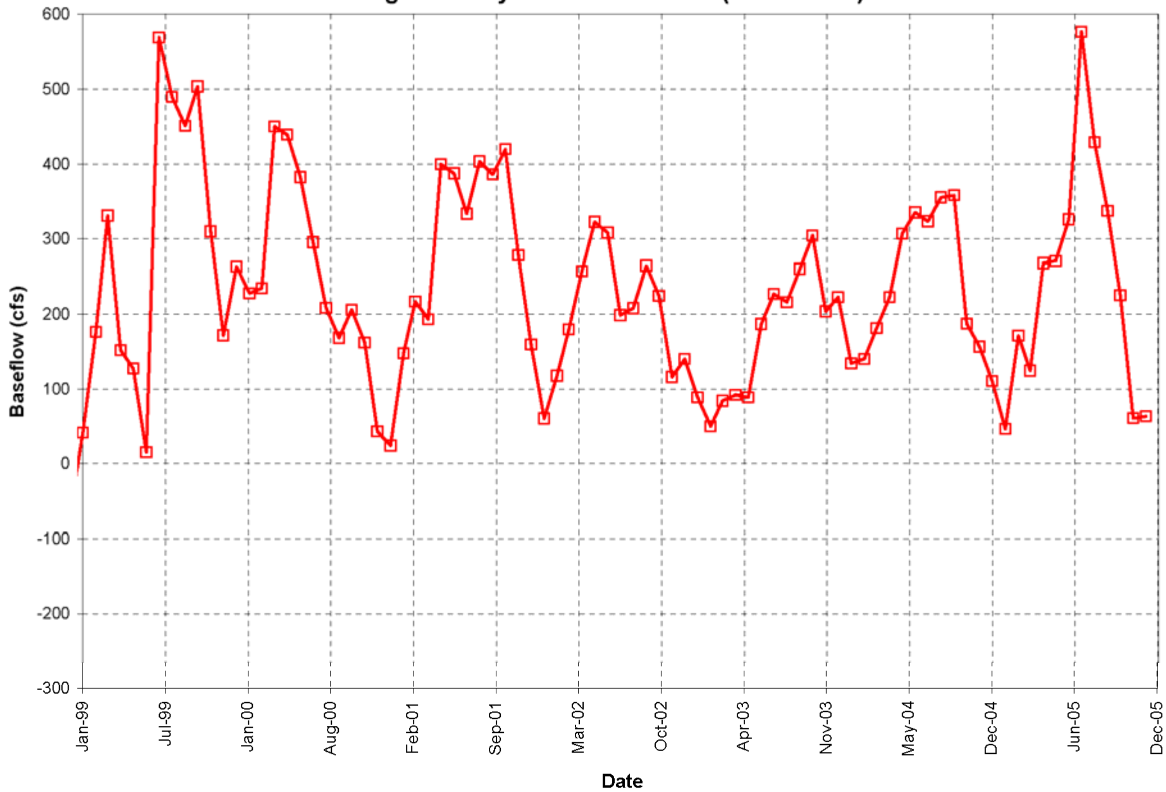


Figure 38: Cache la Poudre - Fort Collins to Greeley Reach
Average Monthly Baseflow Results (1999 - 2005)

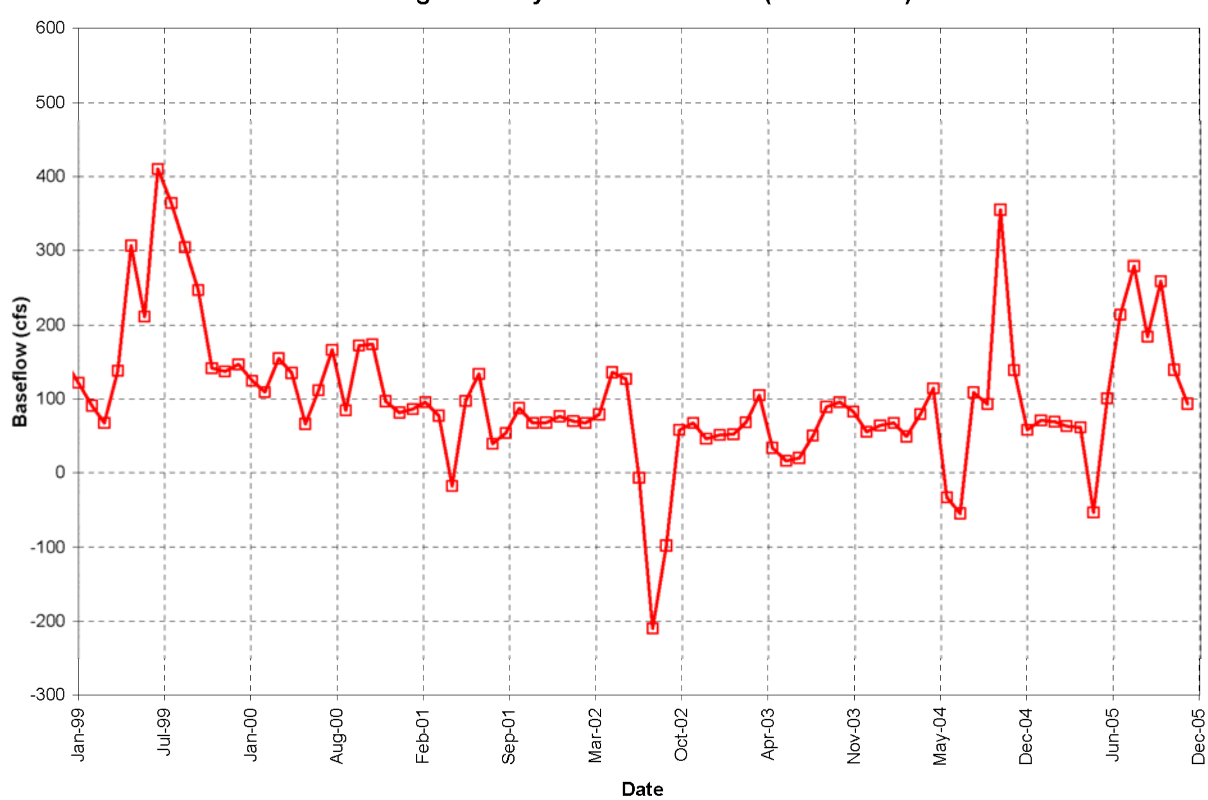
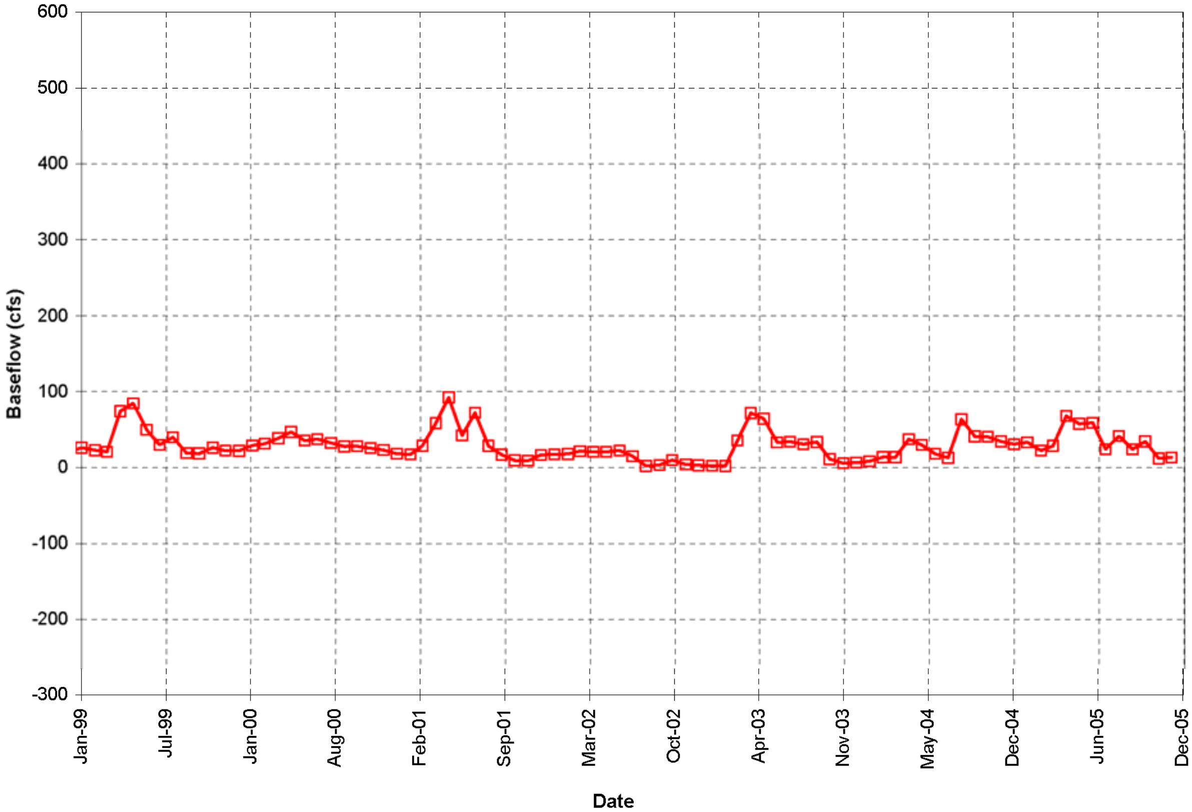


Figure 39: Cherry Creek - Franktown to Denver Reach
Average Monthly Baseflow Results (1999 - 2005)



Appendix A
Mass Balance Components

South Platte River: Waterton to Denver Reach		
Structure	**ID Number**	**Contribution**
South Platte River Gage at Waterton	06708000	Inflow
Plum Creek Gage Near Louviers	06709500	Inflow
Aggregate Point	08_AWP004	Outflow
Hayland Ditch	0801124	Outflow
Fairview Ditch	0801125	Outflow
Old Time Ditch	0801127	Outflow
Garden Ditch	0801128	Outflow
City Ditch Pl	0801008	Outflow
Nevada Ditch	0801009	Outflow
Aggregate Point	08_AWP003	Outflow
Englewood Intake	0801013	Outflow
Bear Creek Gage at Sheridan	06711500	Inflow
Littleton & Englewood WWTP	CO0032999	Inflow
Public Service Company of Colorado Arapahoe Station	CO0001091	Inflow
Epperson Ditch/Pump	0801015	Outflow
Cherry Creek Gage at Denver	06713500	Inflow
Farmers Gardners Ditch	0200800	Outflow
South Platte River Gage at Denver	06714000	Outflow

South Platte River: Denver to Henderson Reach		
Structure	**ID Number**	**Contribution**
South Platte River Gage at Denver	06714000	Inflow
Denver-Hudson Cnl	0200805	Outflow
Burlington D River HG	0200802	Outflow
Gardeners Ditch	0200806	Outflow
Public Service Company of Colorado Cherokee Station	CO0001104	Inflow
Metro Wastewater Reclamation District	CO0026638	Inflow
Sand Creek Gage at Mouth Near Commerce City	394839104570300	Inflow
Aggregate Point	08_AWP001	Outflow
Clear Creek Gage at Derby	06720000	Inflow
Aggregate Point	07_AWP001	Outflow
South Adams County Water and Sanitation District Incorperated	CO0026662	Inflow
Fulton Ditch	0200808	Outflow
Brantner Ditch	0200809	Outflow
South Plate River Gage at Henderson	06720500	Outflow

South Platte River: Henderson to Ft. Lupton Reach		
Structure	**ID Number**	**Contribution**
South Plate River Gage at Henderson	06720500	Inflow
Brighton Ditch	0200810	Outflow
City of Brighton WWTP	CO0021547	Inflow
Lupton Bottom Ditch	0200812	Outflow
Big Dry Creek Gage at Mouth Near Fort Lupton	06720990	Inflow
Fort Lupton Waste and Water Laboratory	CO0021440	Inflow
Platteville Ditch	0200813	Outflow
South Platte River Gage at Fort Lupton	06721000	Outflow

South Platte River: Ft. Lupton to Kersey Reach		
Structure	**ID Number**	**Contribution**
South Platte River Gage at Fort Lupton	06721000	Inflow
Meadow Island 1 Ditch	0200821	Outflow
Evans No 2 Ditch	0200817	Outflow
Meadow Island Ditch	0200822	Outflow
Farmers Independent Ditch	0200824	Outflow
Hewes Cook Ditch	0200825	Outflow
Jay Thomas Ditch	0200826	Outflow
Saint Vrain Creek Gage at Mouth Near Platteville	06731000	Inflow
Union Ditch	0200828	Outflow
Section No 3 Ditch	200830	Outflow
Big Thompson River Gage at Mouth Near La Salle	06744000	Inflow
Lower Latham Ditch	0200834	Outflow
Aggregate Point	02_AWP003	Outflow
City of Evans	CO0020508	Inflow
Patterson Ditch	0200836	Outflow
Highland Ditch	0200837	Outflow
Cache La Poudre Gage Near Greeley	06752500	Inflow
Lonetree Creek Gage Near Greeley	06753990	Inflow
South Platte River Near Kersey	06754000	Inflow

South Platte River: Kersey to Weldona Reach		
Structure	**ID Number**	**Contribution**
South Platte River Near Kersey	06754000	Inflow
Crow Creek Gage Near Barnsville	06756500	Inflow
Empire Ditch	0100501	Outflow
Riverside Canal	0100503	Outflow
Bijou Canal	0100507	Outflow
Jackson Lake Inlet Ditch	0100513	Inflow
Weldon Valley Ditch	0100511	Outflow
Kiowa Creek Gage at Bennett	06758300	Inflow
Ft Morgan Canal	0100514	Outflow
South Platte River Gage Near Weldona	06758500	Inflow

South Platte River: Weldona to Balzac Reach		
Structure	**ID Number**	**Contribution**
South Platte River Gage Near Weldona	06758500	Inflow
Bijou Creek Gage Near Fort Morgan	06759100	Inflow
Deuel Snyder Canal	0100517	Outflow
Upper Platte Beaver Canal	0100515	Outflow
City of Fort Morgan	CO0044849	Inflow
Lower Platte Beaver D	0100518	Outflow
Tremont Ditch	0100519	Outflow
City of Brush	CO0021245	Inflow
Union Ditch	0100688	Outflow
North Sterling Canal	0100687	Outflow
Johnson and Edwards Ditch	0100526	Outflow
Prewitt Inlet Canal	0100829	Inflow
Tetsel Ditch	0100525	Outflow
South Platte River at Balzac	06760000	Outflow

South Platte River: Balzac to Julesburg Reach		
Structure	**ID Number**	**Contribution**
South Platte River at Balzac	6400533	Inflow
Davis Bros Ditch	6400532	Outflow
Schneider Ditch	6400531	Outflow
Springdale Ditch	6400530	Outflow
Sterling Irr Co Ditch 1	6400528	Outflow
Sterling Irr Co Ditch 2	6400526	Outflow
Lowline Ditch	6400524	Outflow
Henderson Smith Ditch	6400525	Outflow
Aggregate Point	64_AWP014	Outflow
City of Sterling	CO0026247	Inflow
Bravo Ditch	6400522	Outflow
Iliff Platte Valley D	6400520	Outflow
Jud Brush Ditch	6400519	Outflow
Lone Tree Ditch	6400518	Outflow
Powell Blair Ditch	6400516	Outflow
Ramsey Ditch	6400514	Outflow
Chambers Ditch	6400513	Outflow
Aggregate Point	64_AWP008	Outflow
Harmony Ditch 1	6400511	Outflow
Settlers Ditch	6400508	Outflow
Red Lion Supply Ditch	6400506	Outflow
Peterson Ditch	6400504	Outflow
South Reservation Ditch	6400503	Outflow
Liddle Ditch	6400502	Outflow
Carlson Ditch	6400501	Outflow
Lodgepole Creek Gage at Ralton, Nebraska	06763500	Inflow
South Platte River at Julesburg (Combined)	06764000	Outflow

Cherry Creek Reach: Franktown to Denver		
Structure	**ID Number**	**Contribution**
Cherry Creek Gage Near Franktown	06712000	Inflow
John Jones Ditch	0801362	Outflow
Stonegate Village Metro District	CO0040291	Inflow
Aggregate Point	08_AWP002	Outflow
City of Glendale	CO0020095	Inflow
Cherry Creek Gage at Denver	06713500	Outflow

Cache la Poudre River Reach: Fort Collins to Greeley		
Structure	**ID Number**	**Contribution**
Cache La Poudre Gage at Canyon Mouth Near Fort Collins	06752000	Inflow
Greely Fltrs Pl	0300908	Outflow
Hansen Supply Canal	0300909	Inflow
Pleasant Valley Lake Cnl	0300910	Outflow
Larimer County Ditch	0300911	Outflow
Dry Creek Ditch	0300912	Outflow
Cache La Poudre Ditch	0300915	Outflow
Larimer Weld Irr Canal	0300919	Outflow
Josh Ames Ditch	0300921	Outflow
Lake Canal Ditch	0300922	Outflow
Aggregate Point	03_AWP002	Outflow
City of Fort Collins Water Reclamation	CO0026425	Inflow
Cache La Podr Res in CNL	0303775	Outflow
Chaffee Ditch	0300925	Outflow
Boxelder Ditch	0300926	Outflow
Platte R PWR PMPG DVR	0301203	Outflow
New Cache La Poudre Co D	0300929	Outflow
Whitney Irr Ditch	0300930	Outflow
B H Eaton Ditch	0300931	Outflow
Town of Windsor	CO0020320	Inflow
Eastman Kodak Company	CO0032158	Inflow
William R Jones Ditch	0300932	Outflow
Canal 3 Ditch	0300934	Outflow
Boyd Freeman Ditch	0300935	Outflow
Water Pollution Control Facility	CO0040258	Inflow
Ogilvy Ditch	0300937	Outflow
Aggregate Point	03_AWP001	Outflow
Cache La Poudre Gage Near Greeley	06752500	Outflow

Appendix B
Command Files

TSTool Command Files

Gage Command File

```
#Task2Input_RevFeb2007.TSTool
#SPDSS Task 2 - Key streamflow gages
#created using TSTool version 6.18.00 (2006-05-02) and HydroBase version
08/16/2006
#
#**********************************************
#
setOutputYearType(Calendar)
setOutputPeriod(01/1950,12/2005)
#
# Big Thompson River at mouth near La Salle filled with Big Thompson River at
Loveland
06744000.DWR.Streamflow.Day~HydroBase
06741510.USGS.Streamflow.Day~HydroBase
fillRegression(TSID="06744000.DWR.Streamflow.Day",IndependentTSID="06741510.USGS
.Streamflow.Day")
#
# South Platte River at Ft. Lupton filled with South Platte River at Henderson
06721000.USGS.Streamflow.Month~HydroBase
06720500.DWR.Streamflow.Month~HydroBase
fillRegression(TSID="06721000.USGS.Streamflow.day",IndependentTSID="06720500.DWR
.Streamflow.day")
#
# South Platte River near Weldona filled with South Platte River at Balzac
06758500.DWR.Streamflow.Month~HydroBase
06760000.USGS.Streamflow.Month~HydroBase
fillRegression(TSID="06758500.DWR.Streamflow.Day",IndependentTSID="06760000.USGS
.Streamflow.Day")

#Plum Creek near Louviers filled with Plum Creek at Titan Rd near Louviers
06709530 - PLUM CREEK AT TITAN RD NR LOUVIERS, CO
06709500 - PLUM CREEK NEAR LOUVIERS
06709500.USGS.Streamflow.Day~HydroBase
fillRegression(TSID="06709530.USGS.Streamflow.Day",IndependentTSID="06709500.USG
S.Streamflow.Day")
```

Appendix C
Monthly Mass Balance Approach and Comparison with the Pilot Point Method

The Pilot Point method was selected to develop the monthly baseflow averages, because it has been found by the State to give good estimates for the gain or loss from a river strongly influenced by man where natural stream baseflow separation methods are not applicable. As suggested by the previous discussion, however, this method is computationally intensive. For the purposes of this TM, the results obtained from this method were compared to an alternative method, termed the Monthly Mass Balance method. The Monthly Mass Balance method consisted of calculating a monthly mass balance for a reach using the average monthly inflow and outflow data without imposing smoothing or constraints and was applied to data in the Fort Lupton to Kersey reach. This reach was primarily because this reach includes relatively few inflows and outflows.

The baseflow results from both methods were analyzed and compared for the period of record. For most years, during months of low surface water flow, and non-growing season months, the computed difference in baseflows between methods was less than approximately 5 percent. However, during the irrigation season months, the percent difference of the monthly averages was visually evaluated and appeared to range from zero to over 200 percent.

The difference in baseflow between the two methods appears to be due primarily the large differences (either high or low) in daily stream flow values present in the upstream and downstream gages that define each stream reach. Even though these differences are suppressed by being part of monthly averages, they were not constrained in the Monthly Mass Balance method as they were in the Pilot Point method. The extreme values are inflows or outflows contributing to flow within a reach that were not quantified explicitly, such as precipitation runoff, surface water returns, ungaged inflows or ungaged diversions. Taking simple monthly averages of these daily inflows or outflows without the use of constraints caused the Monthly Mass Balance method baseflow values to be much higher or much lower than the corresponding baseflows in the Pilot Point method. This comparison of methods provided insight into the advantages of imposing constraints on daily inflow and outflow values in this type of gain/loss analysis, and provided support to use of the Pilot Point method as being an appropriate tool to estimate the baseflow of the South Platte River and its tributaries.

Appendix D
Constraint Values

Table D1-Maximum Gain Constraint Inputs

Reach	Hydraulic Conductivity (K) (ft/d)	Average Sat Thick (ft)	Stream Segment Length(ft)	Gradient (i)	Q (cfs) (DARCY)	Q (cfs) both sides (DARCY)	cfs/River Mile (DARCY)
South Platte - Waterton to Denver	667.6	19.0	91722	0.007	96	192	11
South Platte - Denver to Henderson	628.7	25.0	84082	0.006	91	182	11
South Platte - Henderson to Fort Lupton	642.9	31.2	90099	0.005	97	195	11
South Platte - Fort Lupton to Kersey	396.8	76.7	204202	0.003	250	499	13
South Platte - Kersey to Weldona	290.6	76.0	230090	0.005	287	574	13
South Platte - Weldona to Balzac	216.0	92.8	132566	0.005	158	315	13
South Platte - Balzac to Julesburg	404.8	124.6	519805	0.002	521	1041	11
Cache la Poudre - Ft Collins to Greeley	460.5	22.0	290860	0.010	261	522	9
Cherry Creek – Franktown to Denver	396.3	19.1	209653	0.008	151	303	8

Table D2-Maximum Loss Constraint Inputs

Reach	Hydraulic Conductivity (K) (ft/d)	Average Sat Thick (ft)	Stream Segment Length(ft)	Gradient (i)	Specific Yield	Calculated stage height (ft)	Q (cfs) both sides (GLOVER)	cfs/River Mile (GLOVER)
South Platte - Waterton to Denver	667.6	19.0	91722	0.007	0.2	3	81	5
South Platte - Denver to Henderson	628.7	25.0	84082	0.006	0.2	3	83	5
South Platte - Henderson to Fort Lupton	642.9	31.2	90099	0.005	0.2	3	110	6
South Platte - Fort Lupton to Kersey	396.8	76.7	204202	0.003	0.2	5	442	11
South Platte - Kersey to Weldona	290.6	76.0	230090	0.005	0.2	5	413	9
South Platte - Weldona to Balzac	216.0	92.8	132566	0.005	0.2	4	192	8
South Platte - Balzac to Julesburg	404.8	124.6	519805	0.002	0.2	4	1031	10
Cache la Poudre - Ft Collins to Greeley	460.5	22.0	290860	0.010	0.2	3	314	6
Cherry Creek – Franktown to Denver	396.3	19.1	209653	0.008	0.2	5	232	6