SPDSS Memorandum
Final

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Subject: SPDSS Task 84 – Laramie River Basin Water Budget Procedures and Results Memo

Date: April 15, 2009

Introduction

This memorandum summarizes the results of Task 84 of the Consumptive Use and Water Budget portion of the South Platte Decision Support System (SPDSS) effort. The objective of this task is as follows:

> *Update the initial average annual basin-wide water budget reports with information developed during Phase 3. Develop annual and monthly water budgets for the two basins in the SPDSS Study Area – South Platte and Laramie – and the areas represented by the South Platte Alluvium ground water model.*

StateWB is a generic water budget model that allows the user to develop a water budget for a wide variety of conditions and available data. For SPDSS, three water budgets and sets of input files were developed; The South Platte River Basin, The Laramie River Basin, and the South Platte Alluvial Ground Water Area. This memorandum discusses the approach and results of the Laramie River Basin water budget, as shown in **Figure 1**.

Results

A monthly water budget analysis of the Laramie River Basin over the 1950 to 2006 time period was performed using StateWB. A description of each of the analyses components is included below the Results section. The StateWB analyses solved for the unknown components of the water budget based on the mass balance equation of *Inflows – Outflows = Change in Storage*. These unknown components include the native vegetation consumptive use and winter sublimation (both outflow components). The average annual results of the water budget analyses are presented below in **Table 1**.

Table 1
Laramie River Basin
Average Annual Water Budget Results
(1950 – 2006)
All values in acre-feet

Water Budget Components		Laramie River Basin
Inflows	Imports	-
	Precipitation	446,918
	Gaged Surface Water Inflow	-
	Ungaged Surface Water Inflow	-
	Ground Water Inflow	-
	Inflow Total	**446,918**
Change in Storage	SW Change in Storage	-
	GW Change in Storage	-
Outflows	Agricultural CU	7,131
	M/I CU	1,070
	Livestock CU	148
	Reservoir Evap.	1,025
	Surface Water Outflow	120,113
	Exports	19,067
	Ground Water Outflow	-
	Outflow Total	**148,554**
Unknown 'Residual' Components	Native Veg. CU Winter Sublimation	298,364

The 'residual' component includes native vegetation consumption of precipitation and the outflow of winter precipitation due to sublimation. As a general check of the residual, it was estimated that winter sublimation for the Laramie River basin was 59 percent of winter precipitation (November through March) for the lower valley area and 40 percent for the upper forested area. Approximately one-third of the Laramie River basin area is in the upper forested area, and the remaining two-thirds is the lower plains area. This amounts to an average of 60,193 acre-feet per year of winter sublimation for the 1950 through 2006 study period. The remaining native vegetation consumptive use was then calculated to be 238,171 acre-feet per year for the study period. Native vegetation is estimated to cover approximately 75 percent of the total basin area, therefore the native vegetation average consumptive use rate is calculated as 1.2 acre-foot/acre. This is a reasonable consumptive use rate estimate for a mix of forested and grassland area.

Figure 2 graphically depicts the results of the average annual water budget analysis for the Laramie River Basin.

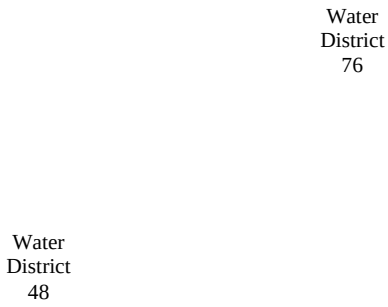
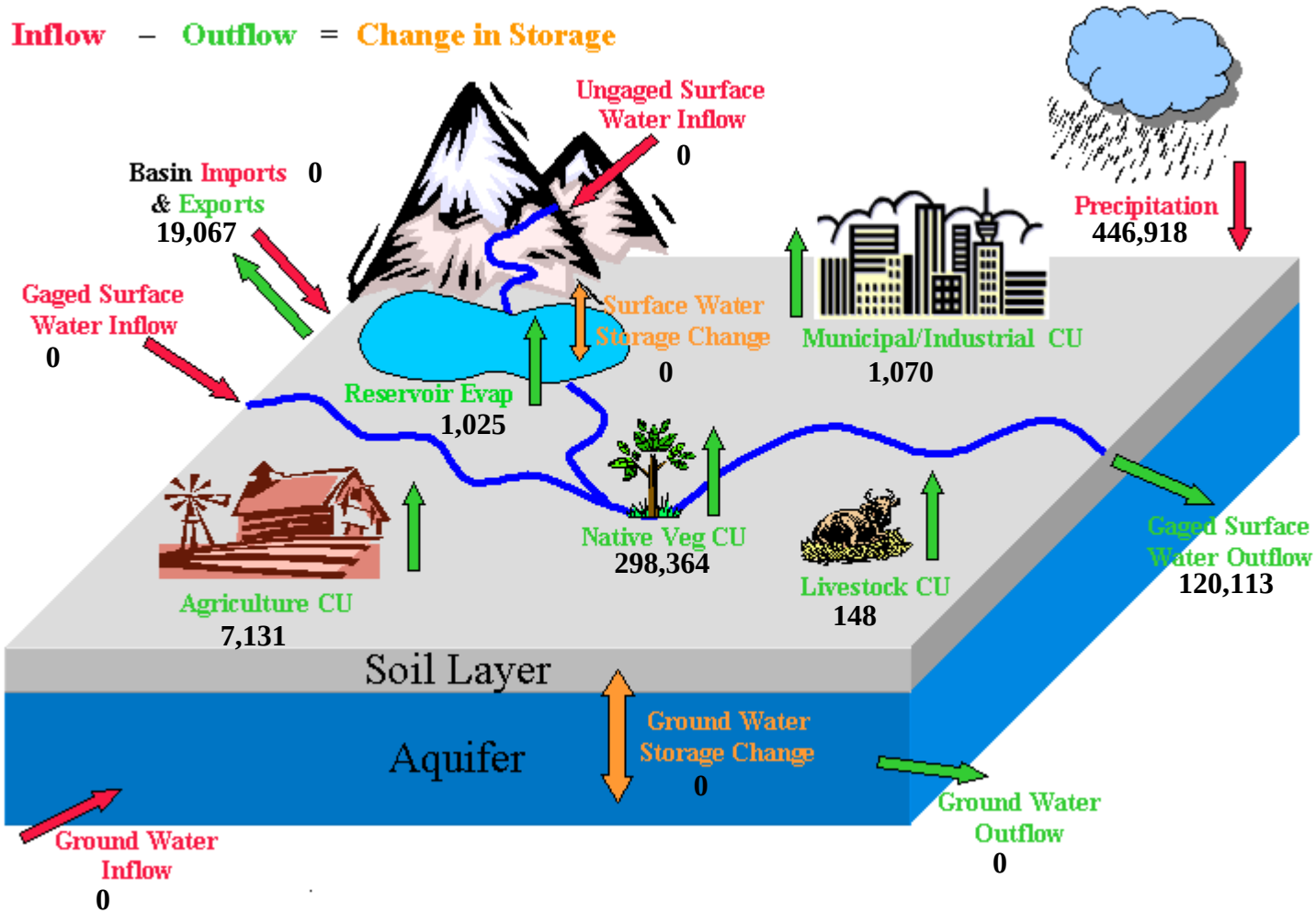


Figure 1 – Laramie River Basin Boundary



Note: (*) Indicates input data was not provided and estimate is included in the Native Veg CU Residual.

Figure 2 - Laramie River Basin Average Annual Water Budget Analysis
1950 – 2006 (Values Shown in Acre-Feet)

Background

The overall Water Budget calculation maintains mass balance by assuring that inflows less outflows equal change in storage. The following list summarizes the inflow, outflow, and change in storage components of the water budget model.

Inflow components include:

- Precipitation
- Gaged Surface Water Inflows
- Ungaged Surface Water Inflows
- Imports
- Ground Water Inflows

Outflow components include:

- Agricultural Consumptive Use
- Municipal, Commercial, and Industrial Consumptive Use
- Livestock Consumptive Use
- Reservoir Evaporation
- Native Vegetation Consumptive Use
- Surface Water Outflows
- Exports
- Ground Water Outflows

Changes in Storage include:

- Surface Water Change in Storage
- Ground Water Change in Storage

Approach – Data Collection and Preparation

StateWB reads water budget components in standard StateMod format (*.stm). Most of the water budget components are created by extracting data directly from HydroBase and applying consumptive use factors using the CDSS DMI TSTool. The main exceptions are agricultural (crop) consumptive use and precipitation meeting crop demands (effective precipitation), which are calculated by StateCU and output in standard StateMod format for use by StateWB.

Basin-wide initial water budgets were developed in Task 83 of SPDSS Phase 2 to estimate the current and historical conditions in the SPDSS study area based on an average annual basis. The initial water budgets were expanded in this effort to include analyses carried out in subsequent SPDSS tasks. Model inputs were developed under separate individual tasks and documented in technical task memoranda, referenced herein. The approaches and summary tables from supporting SPDSS task memoranda are not repeated fully; however the task memoranda are available on the CDSS website <cdss.state.co.us>.

Note that the Sand Creek basin (Water District 76) is included in the Laramie River basin (Water District 48) water budget. There are no active diversions in the Sand Creek basin except for the transbasin inflows from the Laramie River basin that are subsequently exported, along with Sand Creek native supplies, through the Wilson Supply Ditch into the South Platte River basin. These operations are included in the exports in the Laramie River basin water budget. The only other water budget component specific to the Sand Creek basin is the surface water outflows from the basin to the state of Wyoming, which are included in the gaged surface water outflows in the Laramie River basin water budget.

Monthly estimates for the final water budget components were developed to characterize variable conditions over the hydrology of the SPDSS study period (1950-2006), as discussed below.

Where to find more information

- Additional information on the initial water budget for the South Platte Basin is presented in Task 83 – Prepare Initial Water Budgets.
- A review of published reports regarding South Platte water budget analyses is presented in Task 82 – Review Published Reports on Water Budgets.

Inflows

Precipitation

The total volume of precipitation that falls on the basin is the major inflow component. Missing climate data from key climate stations in the SPDSS study area were filled and the key climate stations were associated with upper and lower elevations (above and below 6,500 feet respectively) of water districts in SPDSS Task 53.3. The Red feather climate stations (combined) were used to represent Water District 48 and 76. Orographic adjustments were made to climate data to represent differences in elevation from Red Feather Lakes to each Water District, as shown in **Table 2** at the end of this memorandum.

Total monthly weighted precipitation was multiplied by the water district areas. The precipitation by water district was summed by basin to provide the precipitation inflow to the Laramie River basin water budget. As shown in **Table 3** at the end of this memorandum, average precipitation inflow is 446,918 acre-feet per year for the period 1950 through 2006.

Gaged Surface Water Inflows

No gaged surface water inflows occur in the Laramie River basin; therefore this water budget component is null.

Ungaged Surface Water Inflows

No ungaged surface water inflows occur in the Laramie River basin; therefore this water budget component is null.

Imports
No trans-mountain diversions terminate in the Laramie River basin; therefore the import component is null.

Ground Water Inflows
No ground water inflows occur in the Laramie River basin; therefore this water budget component is null.

Where to find more information

- Additional information regarding climate station assignment and orographic adjustments to precipitation data is presented in Task 53.3 - Assign Key Climate Information to Irrigated Acreage and Reservoirs.

Outflows

Agricultural Consumptive Use
The agricultural consumptive use component includes the crop consumptive use from surface and ground water supplies as well as the consumptive use met by precipitation (termed effective precipitation). Estimates for components of the agricultural consumptive use were estimated for the entire SPDSS study area, using data developed in several SPDSS tasks and the CDSS StateCU consumptive use model. The SPDSS Historic Crop Consumptive Use Report discusses input components and results of the consumptive use analyses. The average annual crop consumptive use from precipitation and diversions in the Laramie River basin is 7,131 acre-feet for the period 1950 through 2006.

Municipal, Commercial, and Industrial Consumptive Use
Municipal, commercial and industrial (M&I) consumptive use was estimated in Task 66 based on historical population data for municipalities and counties, per capita demand rates, indoor and outdoor usage percentages, and indoor and outdoor consumptive use rates. No industrial consumptive use was estimated for the Laramie River basin water budget. M&I consumptive use was aggregated by water district to aid in summarizing the consumptive use for each basin model. The average annual M&I use in the Laramie River basin is 1,070 acre-feet for the period 1950 through 2006.

Livestock Consumptive Use
Livestock consumptive use was estimated based on historical county agricultural statistics, and per head consumptive use rates of 10, 3, and 2 gallons per head per day for cattle, hogs, and sheep, respectively. Agricultural statistical inventory data for counties in Colorado is developed by the National Agricultural Statistical Service and is stored in HydroBase. The inventory data was accessed via TSTool, and missing data was filled using linear interpolation. The complete inventory data was then multiplied by the consumptive use rates and pro-rated based on the portion of the county in the Laramie basin boundary. The Laramie basin represents 16 percent of Larimer County and the average annual livestock consumptive use for the Laramie model is 148 acre-feet for the period 1950 through 2006.

Reservoir Evaporation

Gross evaporation estimates based on free water surface area were developed for the key reservoirs in Task 5 and smaller reservoirs and stock ponds in Task 69. Gross evaporation represents the total annual amount lost to evaporation from the reservoir free water surface, compared to net evaporation which is gross evaporation less precipitation on the reservoir surface area. Note that gross evaporation is used in this analysis because the total amount of evaporation is considered an 'outflow', and the total precipitation that falls on the reservoir is considered an 'inflow'. The annual difference between these inflow and outflow components is the net reservoir evaporation. For key reservoirs, surface area was estimated based on monthly end-of-month contents and area-capacity curves. Monthly surface area data was then multiplied by gross evaporation rates, developed in Task 53.3, to produce monthly evaporation estimates. Smaller reservoirs and stock ponds were aggregated and applied an evaporation rate based on 75 percent of the full surface area, as outlined in the Task 69 memo. The reservoirs and stock ponds were then aggregated by water district to aid in summarizing the evaporative consumptive use for each basin model. Note that no key reservoirs are located in the Laramie River basin water budget boundary. The average annual evaporative consumptive use in the Laramie River basin is 1,025 acre-feet for the period 1950 through 2006.

Native Vegetation Consumptive Use

The native vegetation consumptive use component is one of the unknown variables solved for in the water budget models. Therefore, no estimate of this component is input to the water budgets. It is the primary 'residual', in that all unknowns are combined and reported under the native vegetation consumptive use category.

Surface Water Outflows

Task 2 identified the appropriate surface water outflow gages for the water budget models. Surface water outflow from the Laramie River basin water budget is provided by the sum of the Laramie River near Jelm, WY and Sand Creek at CO-WY streamflow gages. Monthly surface water flow records are available in HydroBase for the Sand Creek gage. Streamflow data for the Laramie River gage in Wyoming was obtained from the USGS website and formatted for use in TSTool. Any missing streamflow gage data was filled using techniques outlined in Task 2 through TSTool. The locations of these outflow streamflow gages are shown on **Figure 1**. The average annual surface water outflow for the Laramie Basin is 120,113 acre-feet for the period 1950 through 2006.

Exports

Average annual transmountain diversions out of the Laramie River basin were identified in SPDSS Task 4. **Table 4** shows the average annual volume of exports out of the Laramie Basin, totaling 19,067 acre-feet for the period 1950 through 2006

Ground Water Outflows

No ground water outflow is estimated to occur in the Laramie River basin; therefore this water budget component is null.

Changes in Storage

Surface Water Change in Storage

End-of-month contents were developed for key reservoirs in Task 5, however there are no key reservoirs located in the Laramie River basin. Therefore the change in storage component is null. As outlined in Task 69, change in storage estimates were not developed for smaller reservoirs or stock ponds.

Ground Water Change in Storage

No change in ground water storage is estimated to occur in the Laramie River basin; therefore this water budget component is null.

Where to find more information

- Additional information regarding agricultural use and effective precipitation in the South Platte Basin, including irrigated acreage and efficiency information, is presented in the SPDSS Crop Consumptive Use Report.
- Additional information regarding the indoor/outdoor consumptive use of key and aggregated municipalities, as well as consumptive use estimates for major industrial water users, is presented in Task 66.2 - Collect and Develop Municipal and Industrial Consumptive Use Estimates.
- Information regarding evaporation estimates for aggregated reservoirs and stock ponds can be found in Task 69 – Estimate Reservoir and Stock Pond Evaporation.
- Additional information regarding the selection of key streamflow gages and streamflow data filling techniques is presented in Task 2 - Identify Key Streamflow Gages and Estimate Streamflows for Missing Records.
- General operation of each trans-mountain diversion is presented in structure-specific Task 5 memoranda. Information on trans-mountain diversion records, including filling techniques of missing data, is presented in Task 4 - Identify and Fill/Resolve Conflicting Records for Key Trans-mountain Diversion Structures.

Results

Monthly water budget components, excluding the 'residual' components, were input to the StateWB model for the Laramie River basin. The water budget analysis was performed and the balancing residual was reported under the native vegetation consumptive use category. The results of these analyses were presented in **Table 1** at the beginning of this memorandum.

Comments and Concerns

The initial water budget analyses, performed on an annual basis for the river basin models over the 1950 to 2002 study period, and the final water budget analyses presented herein both resulted in very similar estimates for the native vegetation consumptive use 'residual' component. In the Laramie Basin model, the initial water budget estimated 389,065 acre-feet annually for the 'residual' component, compared to 298,364 acre-feet annually in the final water budget. The following summarizes the components of the water budget that significantly differed between the initial and final analyses.

- The agricultural consumptive use for the final water budget is approximately twice that of the agricultural consumptive use estimated in the initial water budget. The final water budget includes the effective precipitation as seen by the irrigated acreage, which accounts for a portion of the difference. The remaining difference may be attributed to the climate data used in the consumptive use analysis. The initial water budget determined agricultural consumptive use based on the climate data from the Walden climate station, and the final water budget used climate data from the Red Feather Lakes combined station.
- The residual component for the basin water budgets is difficult to check, since there is not a comparative estimate for native vegetation consumptive use or winter sublimation in the forested areas in the upper areas of the basin.

Supporting Tables

Table 2
Laramie River Basin Water Budget
Climate Station Weights and Average Annual Precipitation
(1950 – 2006)

Water District	Climate Station ID and Name	Climate Station Weight	Orographic Adjustment	Average Annual Weighted Precip. (inches)
48	6921 Red Feather Lakes - combined	1.00	1.206	20.40
76	6921 Red Feather Lakes - combined	1.00	.972	16.45

Table 3
Laramie River Basin Water Budget
Model Areas and Average Annual Precipitation Volume
(1950 - 2006)

Water District	Laramie Basin Model	
	Area (acres)	Precipitation Volume (acre-ft)
48	223,610	380,244
76	48,648	66,674
Total	272,258	446,918

Table 4
Laramie River Basin Water Budget
Average Annual Surface Water Exports
(1950 – 2006)

Water District		Gage ID	Transbasin Diversion Name	Average Annual Flow (acre-feet)
Origin	Destination			
48	3	BOBGLNCO	Bob Creek Ditch	59
48	3	06747000	Laramie Poudre Tunnel	15,765
48	3	06750000	Columbine Ditch [1]	13
48	3	06746500	Skyline Ditch	1,273
76	3	06750500	Wilson Supply Ditch	1,958
			Total	19,067

[1] Operation of Columbine Ditch as a transmountain diversion stopped in 1956.