MEMORANDUM

Subject: **Bear River Basin Plan**
Task 3C. Surface Water Model Calibration

Date: **July 21, 2000**

1.0 Introduction

The Bear River Spreadsheet Model is a complex spreadsheet which incorporates multiple diversions, reservoirs, gaging stations, and other water resources within the Bear River Basin located in the extreme southwest corner of Wyoming. The purpose of the model is to provide a planning tool to the State of Wyoming for use in determining those river reaches in which flows may be available to Wyoming water users for future development. The purpose of this task is to assess the accuracy of the model to simulate river operations in the Bear River Basin and to address the adequacy of the model in analyzing future water developments.

1.1 Model Overview

Individual spreadsheet models were developed which reflect each of three hydrologic conditions: dry, normal, and wet year water supply. As discussed in the Task 3A Memorandum, Surface Water Data Collection and Study Period Selection, each model relies on historical data to estimate the hydrologic conditions. Such factors as streamflow, diversions, and irrigation returns are analyzed to determine the type of hydrologic condition. The development of the model is discussed in the Memorandum for Task 3B, Surface Water Spreadsheet Model Development.

1.2 Model Development

To mathematically represent the Bear River system, the river system was divided into twelve reaches based primarily upon the location of USGS gaging stations. Other key locations, such as reservoirs or confluences with major tributaries, were also used to determine the extent of reaches. Each reach was then sub-divided by identifying a series of individual nodes representing locations where diversions occur, basin imports are added, tributaries converge, or other significant water resources features are located. Figure 1 presents the node diagram of the model developed for the Bear River.

At each node, a water budget computation is completed to determine the amount of water available as flow downstream out of the node. Total flow into the node and diversions or other losses from the node, are calculated. At non-storage nodes, the difference between inflow, including return flows, and diversions is the amount of flow available to the next node downstream. For storage nodes, an additional loss calculation for evaporation and the flow to or from storage is algebraically added or subtracted to get the flow out the node. Also, at storage nodes, any uncontrolled spill which occurs is added to the scheduled release to get total outflow. Mass balance or water budget calculations are repeated for all nodes in a reach, with the outflow of the last node being the inflow to the top node in the next reach.

For each reach, ungaged stream gains (e.g., ungaged tributaries, groundwater inflow, and return flows from unspecified diversions) and losses (e.g. seepage, evaporation, and unspecified diversions) are computed. Stream gains are input at the top of a reach to be available for diversion throughout the reach and losses are subtracted at the bottom of each reach.

Model output includes the target and actual diversions at each of the diversion points, streamflow at each of the Bear River Basin nodes, and evaluation of water emergency conditions as defined in the Bear River Compact. By changing input data, estimates of impacts associated with future water projects can be analyzed, as decreases in available streamflow or as shortages to existing diversions. Reservoirs that alter the timing of streamflows or shortages may also be evaluated.

2.0 Model Operation and Calibration

The model was developed as detailed in Task 3B, with an objective of maintaining water balance throughout the basin. Calibration is usually performed by comparing modeled output to historic data. Often this is done at gaging stations, but in this model the gaging stations were used to calculate gains and losses; consequently, the flow at gages will be the same as the modeled results. Also, the operation of reservoirs is calibrated by setting either the release from the reservoir (output) or the end-of-month storage contents to be the same as the historic values and then checking the other variable (i.e., if set release, then check end-of-month contents, or vice versa) to see how close the modeled variable is to historic or measured conditions. In this model development, reservoir release was set by the model to be the average flow which occurred at the USGS gage downstream of both reservoirs, Sulphur Creek and Woodruff Narrows, for the average hydrologic condition.

Consequently, the end-of-month storage contents can be analyzed versus the historic levels, although it must be remembered that these are both based on average levels.

Since the three spreadsheet models incorporated average hydrologic conditions as the main input, a direct comparison to historic monthly and/or yearly stream gage values cannot be made on a year by year basis. The calculation of reach gain and/or loss is the major variable in the model to maintain the water budget; therefore, an analysis of the reasonableness of these calculations is the main calibration point. Although good records of diversions exist throughout the basin, the quantity of irrigated lands and the irrigation methods vary annually; consequently, the efficiencies and returns calculated on an average basis vary accordingly and contribute to the volume of gains and/or losses. Similarly, the aggregation of diversion data complicates the efficiencies and return flows where downstream ditches tend to rely on upstream ditch return flows. Calibration was done by adjusting diversion efficiencies, return flow patterns, and return flow points in attempting to minimize the volumes and fluctuations in reach gain and/or loss; while maintaining the engineering work done in the consumptive use analysis.

Most river systems, the Bear River Basin included, have a significant interaction with the groundwater system, particularly in the return flows from agricultural use. Since this model does not incorporate a groundwater component, the reach gain and loss calculations include this interaction. This is particularly true in the lower reaches through Utah.

2.1 Model Calibration Data

The model was developed around node points which were predominantly USGS gage locations. The major inputs to the model were the historic gaged streamflow at USGS sites above any of man=s activities and the historic diversion data. USGS gaging stations on the mainstem or on tributaries below the initial gaging point were used to calculate reach gains and losses. These, consequently, bring the river system back to average historic flow for each hydrologic condition at every gaging point. Put another way, at each intervening gage point, the average river flow is maintained by adding or subtracting reach gains or losses to match the historic conditions at these points. The reach gains and losses are, therefore, the principal measure of the accuracy of the model. Or, more directly, the reach gains and losses must be reasonably explained by water resources which have not been explicitly modeled; such as ungaged tributaries, the interaction of the groundwater system, more detailed reservoir operations or similar explanations.

2.1.1 Gage Data and Hydrologic Analysis

A 1971 through 1998 study period was selected based largely upon review of the available data, the objectives of the model, and the historical development of the basin. Monthly stream gage data were obtained from the USGS for each of the stream gages used in the model. Several of the gages contained incomplete records or missing data. Linear regression techniques were used to estimate missing values. A detailed discussion of this process is provided in the Task 3A Memorandum, Surface Water Data Collection and Study Period Selection.

2.1.2 Diversion Data and Return Flow Analysis

Estimates of monthly diversions at each of 36 key diversions were computed for each of the three hydrologic conditions. Key diversions were defined as those locations where greater than 10 cubic feet per second are diverted from the river. Eight aggregated diversions for all other diversions in Wyoming were added to complete the water balance for the basin. Diversions within Utah and Idaho were aggregated and modeled at single nodes. All diversions that are specified in the Bear River Compact are included, either explicitly in the model or in the Results Worksheets as data inputs.

Slight adjustments were made to efficiencies based on reach gain or loss calculations. Efficiencies were decreased for those diversions where reaches with large gains were calculated and could not be explained by other water resource features. These lower efficiencies would return additional flow to the stream and decrease the unexplained gain calculated to maintain the water budget. Similarly, higher efficiencies were used for those instances where losses were reported and could not be explained. Return flow patterns were reviewed, as were return flow locations and adjusted as needed. Return flow locations were especially important in balancing out the reach gains and losses from upstream to downstream reaches and were used to check the consumptive use analysis, which was primarily based on mapping of irrigated lands. Some diversions which return flow through the alluvial aquifer take six months or more to reach the surface stream system and could not be adjusted due to the single year limitation of the model. Consequently, there are reaches where a baseflow of gains or losses are reported which are largely contributions from these long-term groundwater returns from irrigation.

2.1.3 Reach Gain/Loss Calculations

The Bear River Basin, although of limited geographic size and well-documented by data sources, could not be completely modeled explicitly. Not all water features, such as small tributaries, are included in the computer representation of the physical system. Therefore, many features are aggregated and modeled, while many others are lumped together between measured flow points in the river by a modeling procedure called ungaged reach gains and losses. These ungaged gains and losses account for all water in the budget that is not explicitly named.

Ungaged gains to the model include sources such as inflow from un-modeled tributaries, return flows from some small non-irrigation diversions, and groundwater inflow. Ungaged losses include factors such as minor diversions, seepage, and evaporation from the river. These factors are computed on a reach-by-reach basis using a water budget approach:

Ungaged Gains/Losses = Difference between downstream and upstream gages +
Total diversions within the Reach -
Total irrigation return flows to the Reach +/-
Reservoir change in storage

The volume of ungaged gains and losses is a good measure of the calibration of the model and the accuracy of the modeled features. If the volumes are high in comparison to the flow in the river or to diversions, then some major water features have not been modeled or have not been modeled correctly. Table 1 presents the final set of ungaged gains and losses for the normal year model run. A reach by reach assessment of the gains and losses follows:

Reach 1, 2, & 3: A baseflow of gains is reported for the winter months. This can be attributed to several small tributaries that contribute flow to the river, such as Mill Creek. These flows resemble a hydrograph with an April-May peak, which are reflective of a snowmelt runoff contribution.

Reach 4 & 5: A baseflow of gains is reported for most months. This can be attributed to several small tributaries that contribute flow to the river, such as Yellow Creek. These flows resemble a hydrograph with a May-June peak.

Reach 6: No gains or losses are reported because the model was constructed so that the outflow from Woodruff Narrows Reservoir in this reach would match the downstream gage. In this reach, the calibration point is the review of end-of-month storage at Woodruff Narrows Reservoir.

Reach 7: A baseflow of gains is reported for all months, except August. This can be attributed to several tributaries in Utah, which were not modeled, and which contribute flow to the river. These flows resemble a hydrograph with a May-June peak. Significant interaction with the groundwater system in this reach occurs and was not modeled. Also, diversions and return flow patterns in Utah were not studied as closely as in Wyoming.

Reach 8: A baseflow of losses is reported for all months, except June and July. Diversions and return flow patterns in Utah were not studied as closely as in Wyoming and consequently, the large swing noted for reaches 7 and 8 occurs. Much of the aggregated Utah diversion which is diverted in reach 7 is returned in reach 8 in the model, however, in reality, returns from upstream diversions meet part of the downstream diversion=s demands within reach 7.

Reach 9 & 10: A baseflow of gains is reported for all months. This can be attributed to several tributaries that contribute flow to the river both on Smiths Fork and the mainstem. These flows resemble a hydrograph with an April-June peak.

Reach 11 & 12: The gains and losses are balanced fairly well in these reaches - the net gains in reach 11 are 4,000 acre-feet, while the net losses in reach 12 are 17,000 acre-feet, both in normal years. The magnitude of flow and diversions is large in these reaches in comparison to the gains and losses (the flow at the Border gage separating the two reaches in a normal year is almost 430,000 acre-feet and the diversions in reach 12 alone are over 430,000 acre-feet in normal years). Similar to the Utah diversions, the diversions in Reach 12 are aggregated Idaho diversions, which were not studied or modeled as accurately as Wyoming diversions.

The final set of ungaged gains and losses is within the range of gains and losses expected for the level of development in this model. All gains and losses can be explained from an understanding of the basin and what features were not explicitly modeled, particularly ungaged tributaries and aggregated diversions with associated return flows.

2.1.4 Reservoir Operations

Reservoir releases were set equal to the average flow which occurred at the USGS gage downstream of both reservoirs, Sulphur Creek and Woodruff Narrows, for each hydrologic condition. The modeled end-of-month storage contents for Woodruff Narrows Reservoir versus the historic levels for the normal year hydrologic condition are shown on Figure 2. The typical fill and drawdown curve is observed in both instances. The modeled end-of-month contents for the peak fill month of May are about 4,000 acre-feet less than the measured or historic contents. Since reach gains or losses were not calculated for this reach, no ungaged tributaries were accounted for in this reach and local runoff into the reservoir during the spring period could easily account for these differences.

The major enlargement for Sulphur Creek Reservoir was completed in 1988 and nominal operations at Sulphur Creek Reservoir since filling in the early 1990s do not fluctuate the storage content as much as at Woodruff Narrows. Reservoir contents in the model are maintained close to full storage which is similar to the pattern of historic levels at Sulphur Creek.

2.2 Calibration Results

The analysis of the reach gain and loss calculations and a review of the end-of-month storage at Woodruff Narrows Reservoir indicate that the model is calibrated very well to historic conditions. The net reach gain/loss is about 220,000 acre-feet per year, which is primarily attributable to tributary inflow and is about the magnitude of the un-modeled tributaries in the Bear River Basin, e.g., Yellow Creek, Mill Creek, all tributaries on Sulphur Creek below the upstream gage, Pleasant Valley Creek, all Utah tributaries, Twin Creek, Sublette Creek, Birch Creek, and all tributaries on Smiths Fork below the upstream gage. The end-of-month storage at Woodruff Narrows Reservoir shows a close correlation to historic levels.

The model accurately predicts the river system and the impacts of diversions, and will, therefore, produce meaningful results to determine available water supply. It will be especially effective in assessing scenarios with and without a future project.

3.0 Summary

The model simulates the river hydrology and operation with very good precision. The reach gains and losses, which are the measure of the accuracy of the model, are reflective of the ungaged tributaries present in the basin. The gross diversions are modeled very accurately. The difficulties in estimating the diversion efficiencies and consequent returns is also represented in the gains and losses. The model simulates the operation of Woodruff Narrows Reservoir very well and can be used similarly to model a future reservoir node.

Based on the expected use of the model, the State of Wyoming will be able to reasonably estimate water availability in various reaches of the river, both during dry, normal or wet conditions and on a monthly basis. This analysis is detailed in the Task 3D Memorandum, Available Surface Water Determination.

FIGURES

Figure 1. **Bear River Model Node Diagram**

Figure 2. **Woodruff Narrows Reservoir End of Month Contents-Normal Year Hydrology**

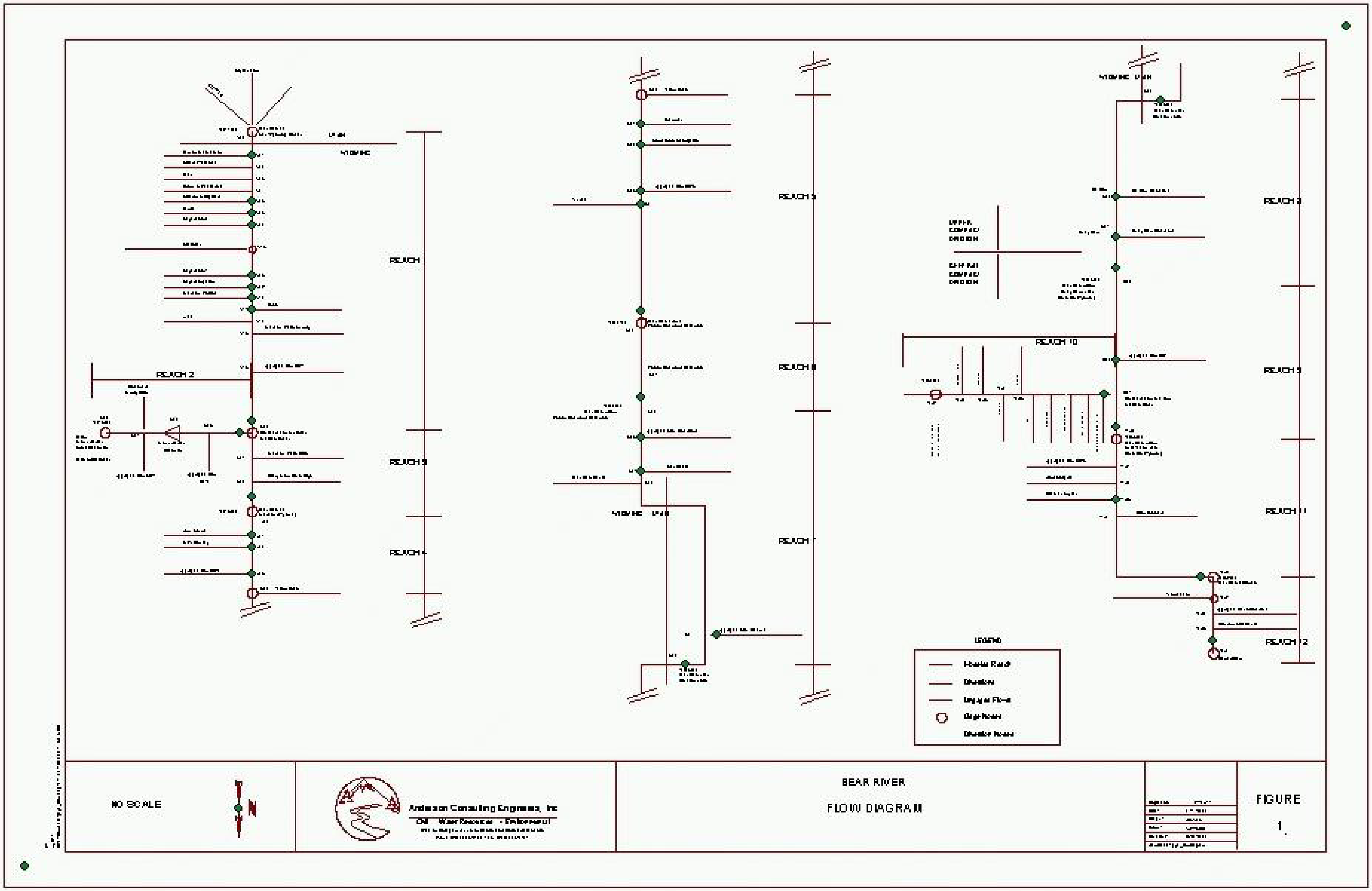
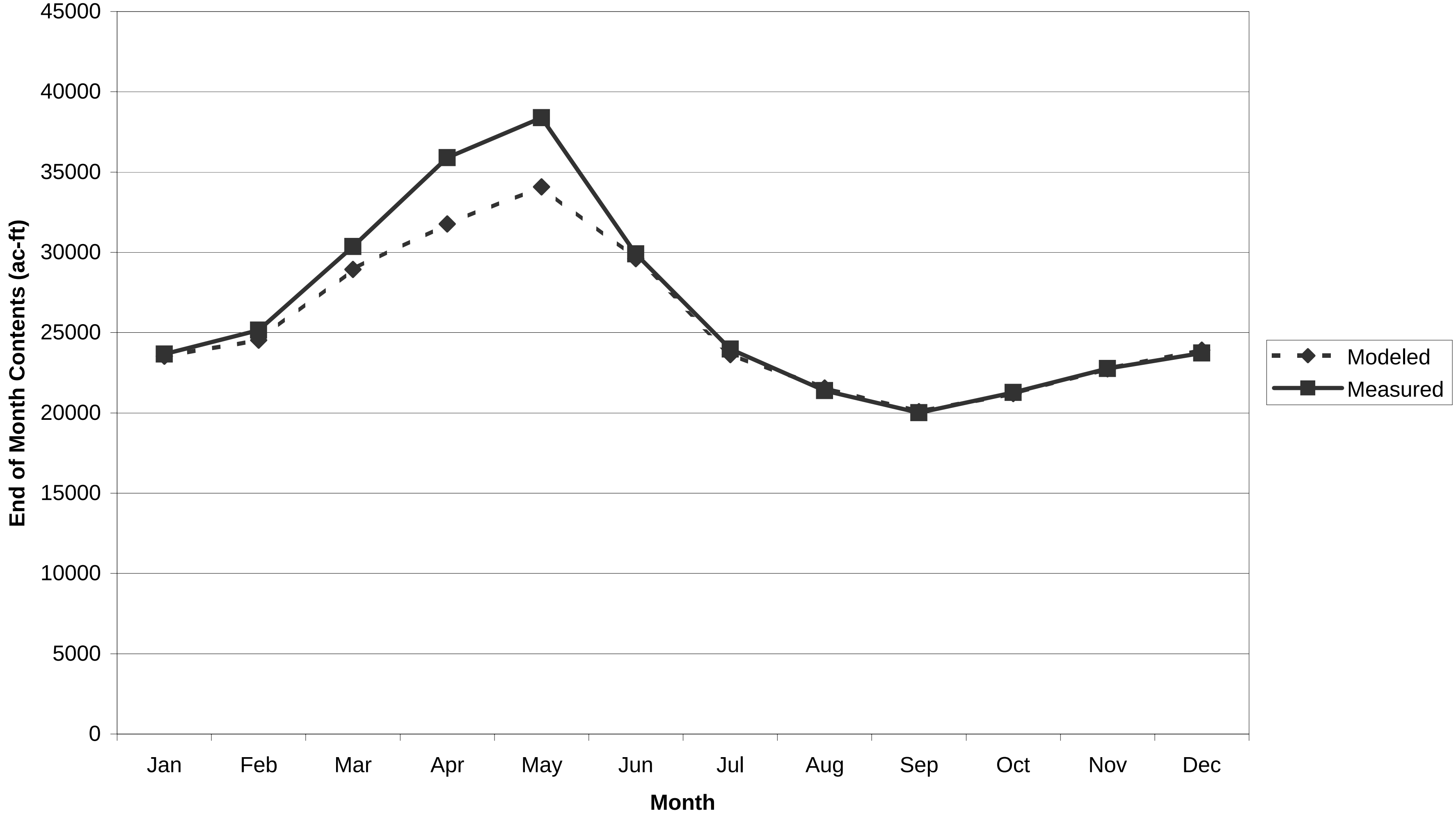

REACH 1
REACH 2
REACH 3
REACH 4
REACH 5
REACH 6
REACH 7
REACH 8
REACH 9
REACH 10
REACH 11
REACH 12
LEGEND
NO SCALE
Anderson Consulting Engineers, Inc
BEAR RIVER
FLOW DIAGRAM
FIGURE
1

Figure 2. Woodruff Narrows Reservoir
End of Month Contents - Normal Year Hydrology



TABLES

Table 1. **Reach Gain and Loss Calculations for Normal Year Hydrology Scenario**

Table 1. Comparison of Average Normal Year Streamflows at USGS Gage Sites

USGS Gage	Ave Flow Breakpoint Hydrology [1] (ac-ft)	Ave Flow Mean of Study Period [2] (ac-ft)	Ave Point Flow State of Utah Study [3] (ac-ft)
10011500 Bear River near Utah-Wyoming State Line	150,264	145,129	143,000
10015700 Sulphur Creek ab Reservoir near Evanston, WY	7,458	7,148	--
10016900 Bear River at Evanston, WY	184,054	168,533	170,000
10020100 Bear River above Reservoir near Woodruff, UT	193,650	170,066	163,000
10020300 Bear River below Reservoir near Woodruff, UT	189,793	173,847	163,000
10026500 Bear River near Randolph, UT	210,204	162,548	150,000
10028500 Bear River below Pixley Dam near Cokeville, WY	175,831	135,751	177,000
10032000 Smiths Fork near Border, WY	144,609	144,748	136,000
10038000 Bear River below Smiths Fork, near Cokeville, WY	420,817	351,198	335,000
10039500 Bear River at Border, WY	426,652	351,952	343,000

Notes: 1. These are averages at gages of the Normal Year hydrology based on a breakpoint determination of dry/normal/wet water years used in this study.
2. These are the means of the streamflow at gage locations based on the 28 year study period.
3. These are flows at river points from State of Utah Point Flow Study, 1992.