Lower Walker River Conveyance Protocols

Necessity of Including Both Gains and Losses in the Accounting System

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I. Introduction

The National Fish and Wildlife Foundation (NFWF) has filed Application No. 80700 with the Nevada State Engineer seeking to change acquired natural flow decree water rights into the Walker River at and below the Yerington Weir for conveyance to and including Walker Lake (Program Water). A conveyance protocol document and associated spreadsheet were developed jointly by NFWF, the Walker River Paiute Tribe (WRPT) and the Bureau of Indian Affairs (BIA) in order to properly account for and track Program Water as it flows downstream in the Lower Walker River through the Walker River Indian Reservation and ultimately to Walker Lake. These "Accounting Protocols" were designed to provide for the accurate and transparent management and administration of NFWF's Program Water in the Lower Walker River (i.e. from the USGS Gage at Wabuska down to Little Dam) and to provide a transparent set of tracking equations so that the WRPT, BIA, NFWF and the United States Board of Water Commissioners (USBWC or Federal Watermaster) may cooperatively and collaboratively manage and accurately track the instream flow of Program Water in the Lower Walker River.

The Protocols require as input the following data on a daily basis:

- Measured surface water flow in Walker River at the Wabuska Gage
- Amount of Program water that is administered in priority at the Wabuska Gage
- Measured surface water flow in Walker River below Weber Reservoir
- Measured surface water flow in Canal No. 1 below Little Dam near Schurz
- Measured surface water flow in Canal No. 2 above Little Dam near Schurz
- Measured surface water flow in Walker River above Little Dam near Schurz
- Weber Reservoir stage and storage
- Maximum temperature and precipitation at Wabuska (or future station at Weber Res.)

Downstream of the Wabuska Gage, the Accounting Protocols provide the measurements and equations necessary to account for gains and losses of Program Water through to Little Dam, just below the final point(s) of diversion at Canals 1 and 2. It is important to note that Program Water gains and losses are only tracked below the Wabuska Gage within this accounting tool.

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As a consultant to NFWF, I am aware that there may be some concerns with the Accounting Protocols' treatment of measured gains to surface water flow in the Lower Walker River. However, it is necessary that the equations track *both gains and losses of measured surface water flow* in order to prevent the introduction of bias into the long-term flow accounting (but importantly, where gains can occur as a result of surface precipitation at Weber Reservoir, those gains are calculated and excluded from the Program Water flow tracking equations). Long-term bias in the tracking of Program Water would be introduced if only losses were accounted for due to three separate and widely understood hydrological factors: 1) gage error, 2) bank storage effects, and 3) surface water travel time. This assessment investigates the first two of these issues through the use of simple accounting examples, and clearly explains the logic for third, all with the goal of demonstrating the necessity of including gains, as well as losses, in the Conveyance Accounting Protocols

II. Gage Error Assessment

All gage flow measurements of surface water flow are assumed to contain some degree of unavoidable error, but it is generally assumed that gages do not have a systematic bias. In other words, gage flow measurements may be higher than actual water flow on some days, and lower than actual water flow on others, but over the long-term the high and low errors tend to cancel each other out to render an accurate long-term average flow measurement. This is a widely-understood and accepted part of surface water hydrology and surface flow measurements.

The purpose of this hypothetical accounting exercise is to illustrate the long-term bias that would be introduced into the tracking and accounting of Program Water in the Lower Walker River because of known and accepted gage error if gains in surface water flow are not accounted for with losses in flow in the Accounting Protocol. Put simply, if the Accounting Protocol subtracts from Program Water to account for naturally-occurring losses in surface flow, but does not credit Program Water to account for naturally-occurring gains in surface flow, the resulting final measurement of Program Water at Little Dam would not be an accurate representation of the actual Program Water flow at Little Dam.

This case study was developed using Draft 1A of the Lower Walker River Conveyance Protocol Accounting Tool (Excel Spreadsheet). The spreadsheet was modified to easily calculate the total surface water flow measurements of an entire irrigation season while maintaining all of the underlying accounting equations as outlined in the Conveyance Protocol document (September 28, 2013 version). The time period represents a hypothetical irrigation season from March 1 – October 31. Actual temperatures and precipitation data were collected from the Wabuska meteorological station over the same period in 2010. To simplify the exercise, Weber Reservoir stage and storage was kept constant at 4187 ft above mean sea level and 1000 acre-feet (ft), respectively.

To investigate the impact of unavoidable but expected gage error on the accounting system bias, random error (normally distributed) was introduced to all of the input flow measurements on a daily basis. All flow measurements were assumed to be accurate to $\pm$ 10 percent of the mean flow rate which is typical of a standard U.S. Geological Survey gage. Table 1 shows the flow values used for the hypothetical example. Total flow at the Wabuska gage ranged between 28 – 36 cubic feet per second (cfs) in increments of two cfs. In one case, the river loss of measured surface flow ($Loss_{riv}$) was allowed to become positive (loss) and negative (gain) as is described in the Conveyance Protocol document. In a second case, the loss term was only allowed to be positive to determine the effect of removing all surface water flow gains from the accounting calculations. In both cases, the cumulative flow (acre-feet) at Little Dam was calculated.

Table 1. Hypothetical flow rates used in the accounting exercise that illustrates the effect of gage error.

Gage	Mean Flow (cfs)
Wabuska (total)	28-36
Wabuska (program water)	10
Weber	28
Little Dam	23
Canal 1	0.1
Canal 2	0.9

The cumulative flow of Program Water at Little Dam for various flow rates at the Wabuska gage is shown in Figure 1. In both cases the cumulative flow of Program Water decreases as surface water flow rate at the Wabuska Gage increases because the loss rates are higher. Recall that the river loss rates are determined as the difference in measured surface water flow rates between the successive gages. In this hypothetical example the downstream flow rates are fixed but the Wabuska gage are adjusted between 28 and 36 cfs. As the measured flow rates at Wabuska increase so does the river loss. More importantly, the Program Water accounting error introduced by excluding gains from the accounting calculations increases with smaller flow rates at Wabuska. As the surface water flow rates at Wabuska decrease, there are more instances in time where the river as a whole is gaining measured surface water flow, thereby increasing the error in measurement and bias in Program Water accounting in the hypothetical case that excludes surface water gains from the calculations.

The results of the hypothetical example suggest that the accounting system will produce errors of nearly 20 percent when only losses are included. This error is caused by gage errors even when there is no systematic bias in the measurements (i.e. over the long term gage error can be greater or less than the actual measurements). Therefore, both gains and losses need to be included in the accounting equations to ensure that bias is not introduced in the long-term flow accounting of Program Water.

III. Bank Storage Assessment

A rapid rise in river flow (and stage) can cause river surface water to quickly percolate into an adjacent groundwater aquifer. This effect is many times referred to as the "bank storage effect" because the surface water is essentially soaking into the river banks, and it then slowly returns to the river after the river flow subsides and the surface water and adjacent groundwater gradually return to an equilibrium state. Prior to the change in flow, the river and aquifer are likely to be in a state of equilibrium. The sudden rise in water level causes a hydraulic head (water level) gradient from the river to the aquifer which is the driving force for flow from the river to the aquifer (Figure 2). The hydraulic gradient will reverse after the surface flow in the river decreases causing the flow direction to change from the aquifer to the river.

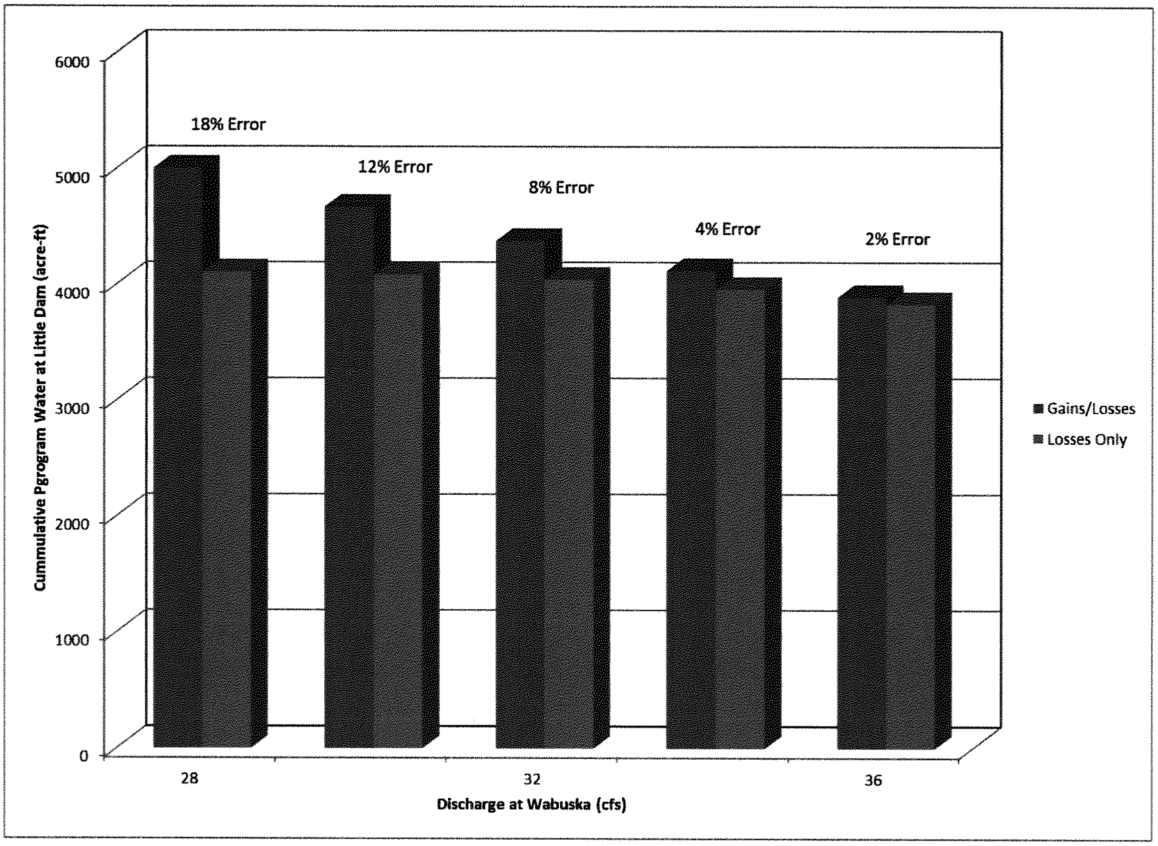

Figure 1. Estimated cumulative flow of Program Water at Little Dam Gage for various hypothetical flows rates at the Wabuska Gage.

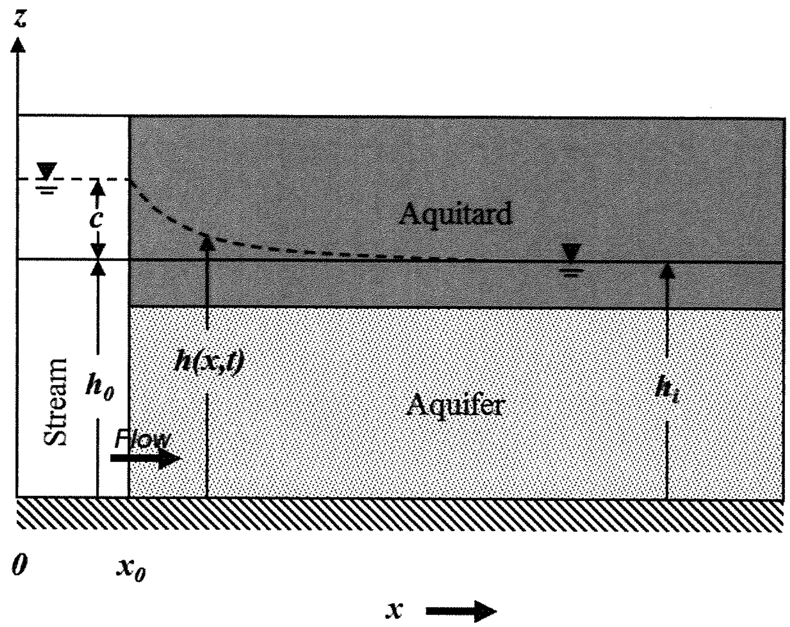

Figure 2. Conceptual diagram of the impact of rapidly rising flow causing bank storage effects.

Numerous hydrologists have studied the effects of bank storage on river gains and losses. Figure 3 shows a typical response in the aquifer, river flow, and bank storage volume due to a river stage fluctuation (Ha et al., 2008). Following a rapid increase in river stage (and flow) the water level in the adjacent aquifer rises in a similar but attenuated fashion. After the initial rise in river stage, river water is moving into the aquifer. Once the river recedes, the water level in the aquifer remains elevated causing water to flow from the aquifer to the river (Figure 3 – middle graph). The amount of water being stored in the bank can also be tracked as shown in the lower graph in Figure 3.

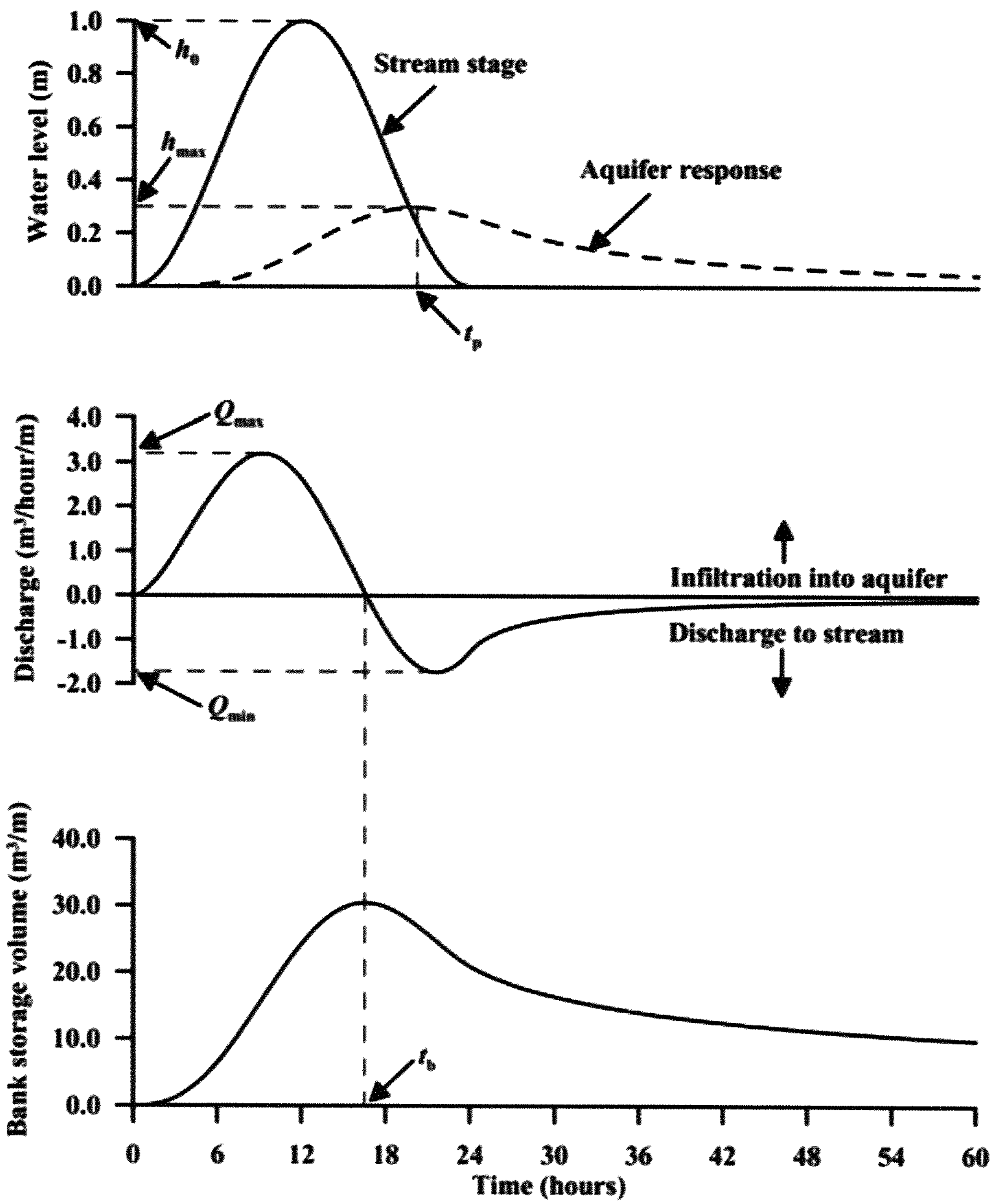

Figure 3. Aquifer response (top), flow rate into or out of aquifer from river (middle), and bank storage due to a river stage fluctuation (bottom) (adapted from Ha et al., 2008).

Consideration of the bank storage effect is important for the Conveyance Agreement Accounting Protocols because similar to gage error effects, one needs to account for both gains and losses of surface water flow due to bank storage to prevent the introduction of bias into the long-term flow accounting. When gains are not included in the accounting calculations, the amount of surface water that is temporarily stored in the bank material is lost for accounting purposes – even though in reality the water gradually returns to the river where it is measured as a gain of surface flow. The bank storage effect is similar to the storage created by Weber Reservoir, which is explicitly calculated in the accounting equations. The bank storage effects are calculated correctly by including surface water flow measurements upstream (Wabuska Gage) and downstream (Weber and Little Dam Gages), but only if both gains and losses are included in the Accounting Protocols. In terms of the equations presented in the Lower Walker River Conveyance Protocol document, one must allow equations 4 and 6 to either be positive or negative.

A hypothetical example is helpful to illustrate the bias introduced into the conveyance accounting system if only losses, and not gains, are tracked during a condition where river flow increases rapidly then decreases. MODFLOW-2005 (Harbaugh, 2005) was used to simulate stream aquifer interactions as shown in Figure 2 using a one-dimensional model. Model parameters are shown in Table 2 and were chosen to be representative of fluvial systems. The stage fluctuation was assumed to be represented by a half-period of a cosine function over a period of 50 days followed by a constant stage (and flow) as shown in Figure 4. Flow rates used in the hypothetical case study are shown in Table 3. Flow at Wabuska

Table 2. Hydraulic parameters used in the groundwater model.

Parameter	Value	Units
Hydraulic Conductivity	1	m/day
Specific Storage	10^{-5}	(-)
Specific Yield	0.3	(-)

Table 3. Hypothetical flow rates used in the accounting exercise that illustrates the bank storage.

Gage	Flow (cfs)
Wabuska (total)	28
Wabuska (program water)	10
Weber	28 +/- reach #1 gain/loss
Little Dam	28 +/- reach #2 gain/loss
Canal 1	0.1
Canal 2	0.9

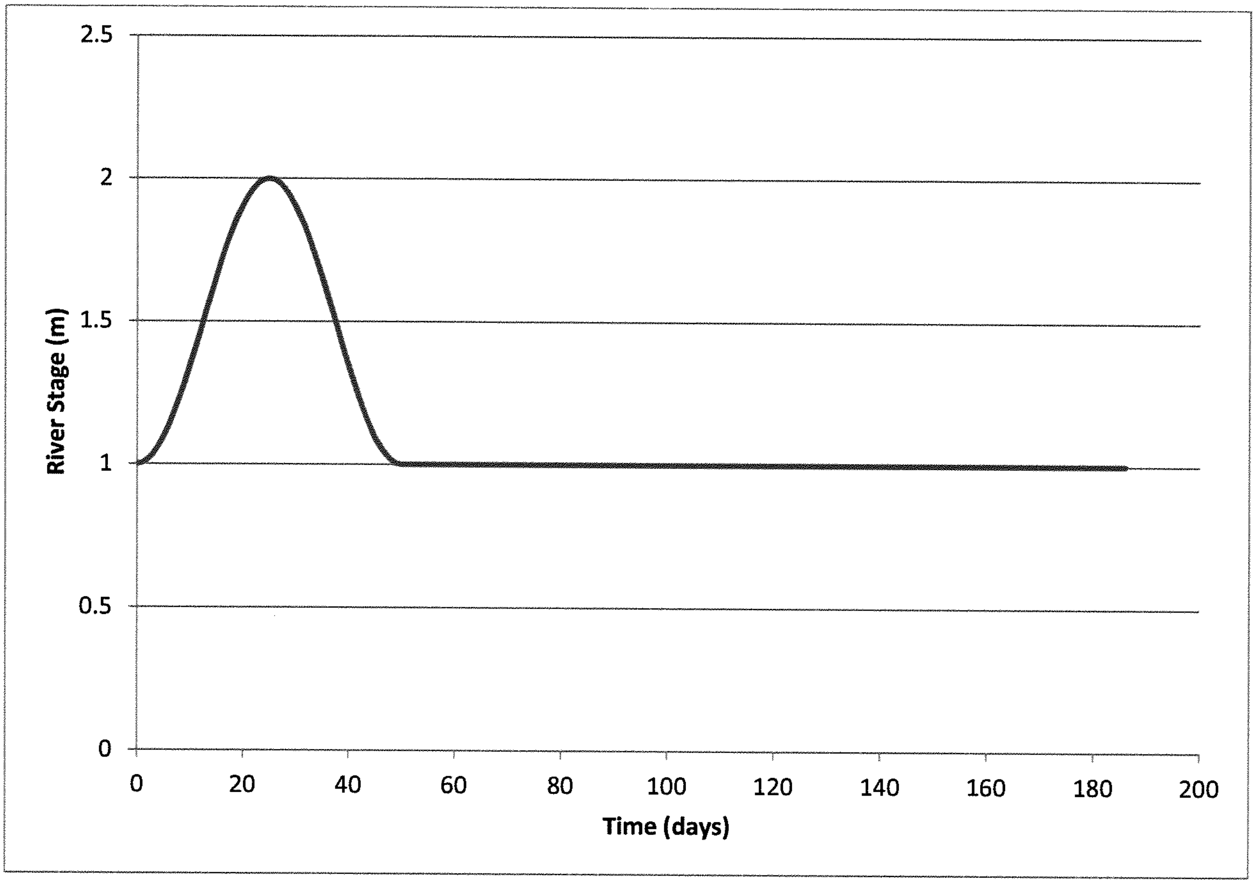

Figure 4. Hypothetical stage fluctuation.

was assumed to be constant at 28 cfs, with 10 cfs being designated as Program Water. Flows in Canal 1 and 2 were specified as 0.1 and 0.9 cfs, respectively. Flow rates below Weber Reservoir were assumed to be 28 cfs plus or minus the gains or losses calculated by the MODFLOW simulation (scaled based on the approximate river length between Wabuska and Weber Reservoir). Flow rates at Little Dam were calculated in a similar fashion, but scaled to the distance between Weber Reservoir and Little Dam.

The gains and losses as simulated by MODFLOW are shown in Figure 5. Following the increase in stage, river losses in Reach #1 (Wabuska to Weber) gradually increase to approximately 10 cfs after about 25 days. In Reach #2, losses increase to approximately 1 cfs. After 50 days, the river flow rate returns to the previous conditions of 28 cfs and the stream converts from a losing trend to a gaining trend (as the water stored in the banks gradually moves back to the river to reach equilibrium) with peak gains of approximately 3 cfs in Reach #1 and approximately 0.3 cfs in Reach #2.

The river flow rates that incorporate the MODFLOW simulated gains and losses were entered into the accounting spreadsheet to determine the impact of excluding surface water gains from the calculation while continuing to account for surface water losses. In one case, the river loss term ($Loss_{riv}$) in the accounting equations was allowed to become positive (i.e. a loss) and negative (i.e. a gain) as described

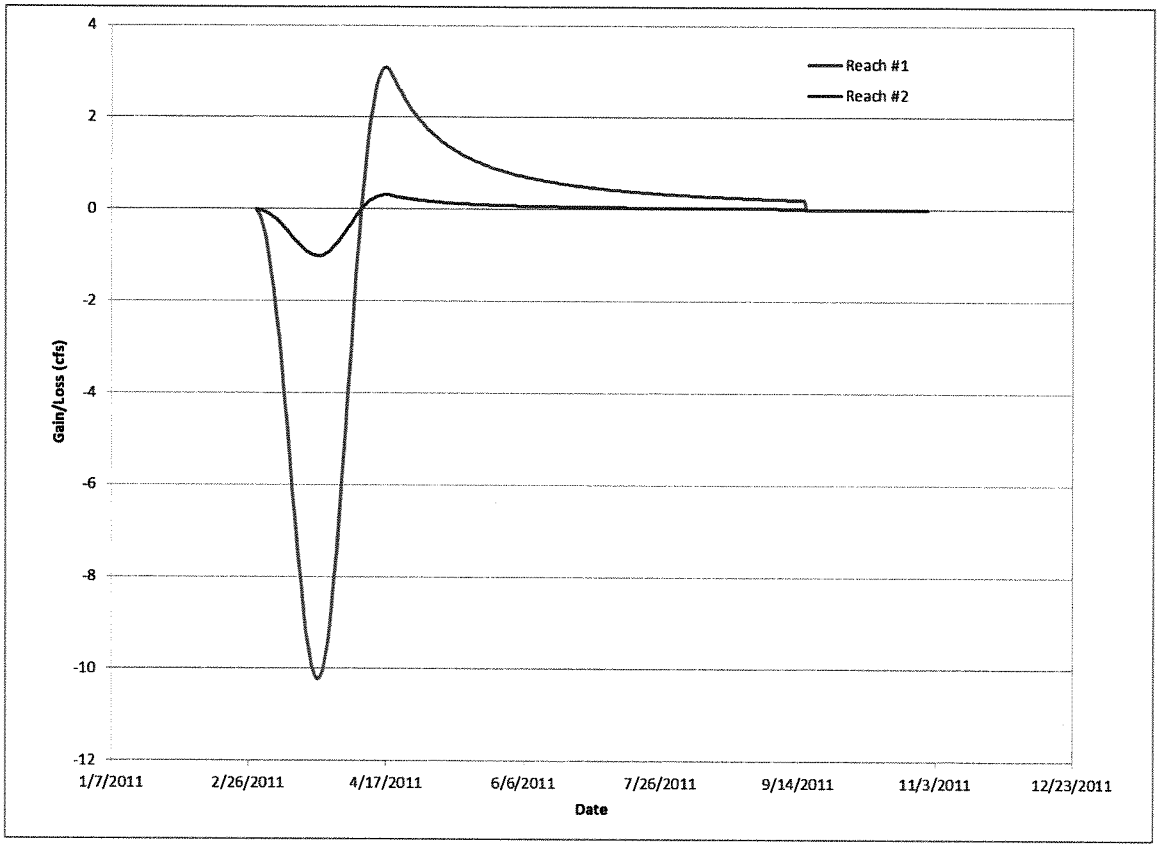

Figure 5. Simulated losses (negative) and gains (positive) for Reach #1 (Wabuska to Weber) and Reach #2 (Weber to Little Dam).

in the Conveyance Protocol document. In a second case, the loss term was only allowed to be positive to determine the effect of removing all gains from the accounting calculations. In other words, the Accounting Protocols were used to determine and compare the differences in Program Water measured at Little Dam (the final measuring point) under two different scenarios: 1) properly accounting for both gains and losses of surface water flow in the Lower Walker River, and 2) excluding surface water gains and only accounting for loss of service water in the Lower Walker River. The different conclusions of the hypothetical scenarios are described below.

The calculated cumulative flow of Program Water at Little Dam for the two conditions is shown in Figure 6. At the end of the simulation (one irrigation season), the cumulative flow at Little Dam for the case that correctly incorporates both surface water gains and losses is 5,978 af. When surface water gains are excluded from the accounting, the cumulative flow at Little Dam is only 4,863 af, which is nearly twenty percent (20%) less. Therefore, it is clear that excluding the surface water gains from the calculation caused an inaccuracy in the accounting of Program Water at Little Dam.

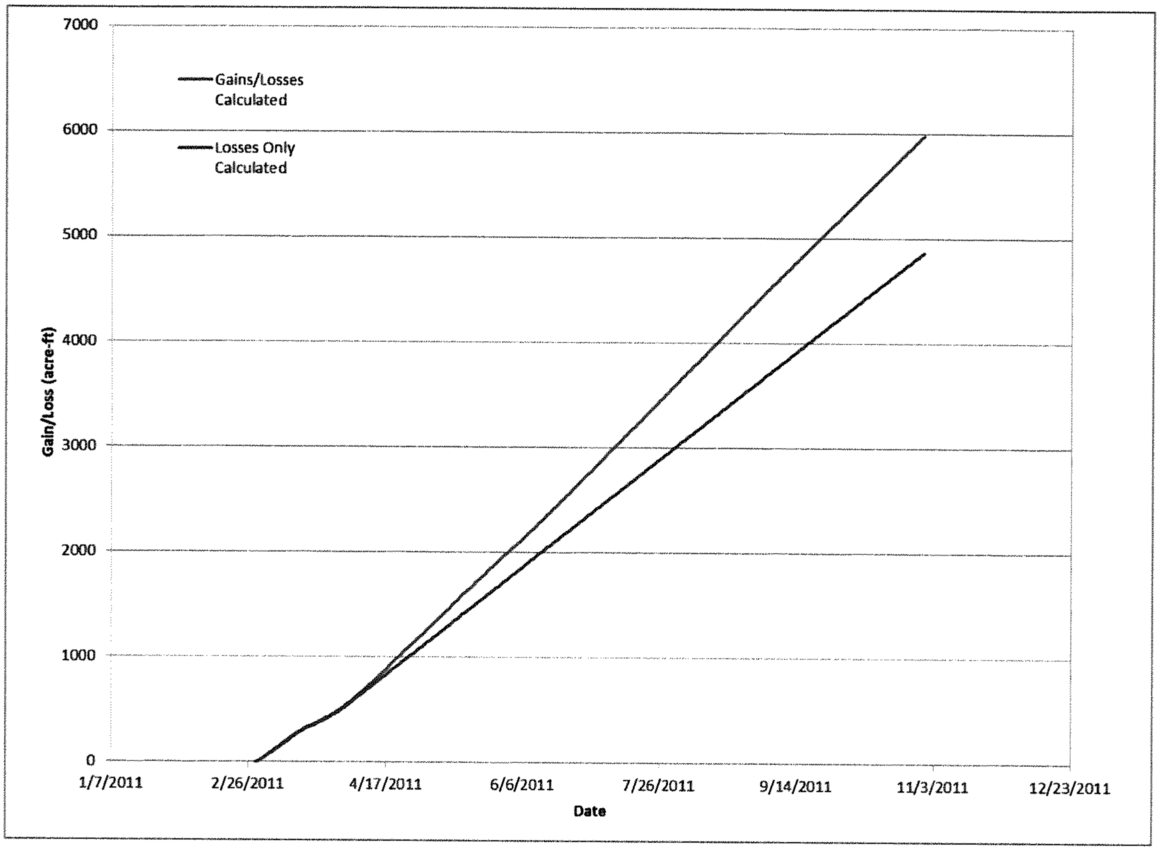

Figure 6. Cumulative flow of Program Water calculated at Little Dam.

IV. Surface Water Travel Time

There is sufficient river distance between the Wabuska gage and Little Dam that surface water travel time may affect the accounting for Program Water negatively if measured gains are not included in the Accounting Protocols. Because of the surface water travel time, measured flow for the same day at the Wabuska gage and at Little Dam (i.e. Little Dam and Canals 1 and 2), is not actually measuring the same physical water because it takes several hours for the surface water to travel between the two locations.

As a hypothetical example: on Day 1 there is measured surface flow of 30 cfs at the Wabuska gage, and measured flow of 10 cfs at Little Dam (ignoring Weber Reservoir for purposes of simplicity), which would indicate a 20 cfs loss of surface water between those points. On Day 2 there is 10 cfs of measured surface flow at the Wabuska gage and 25 cfs of measured surface flow at Little Dam, which would indicate a 15 cfs gain between those points. In reality, the high flow at Wabuska on Day 1 was not recorded at Little Dam until the next day due to the surface water travel time. This effect would be totally ignored if the Accounting Protocols only counted the loss on Day 1 but not the gain on Day 2, and the error would be to the considerable disadvantage of Program Water, i.e. in this hypothetical it would calculate to a net loss of 20 cfs instead of the proper 5 cfs.

V. Conclusions

- The Lower Walker River Conveyance Protocols must include both surface water gains and losses into the accounting equations to ensure that a long-term bias is not introduced to the detriment of Program Water.
- A hypothetical example examining the impacts of excluding surface water gains from the accounting equations indicates that errors of at least 18 percent could be produced.
- A hypothetical example examining the impacts of bank storage effects suggests that errors of nearly 20 percent can result if gains are excluded.
- A simple hypothetical examining the impacts of surface water travel time suggests that Program Water would be considerably disadvantaged if gains are excluded.

References

Ha, K. D. Koh, B. Yum, and K. Lee, 2008. Estimation of river stage effect on groundwater level, discharge, and bank storage and its field application.

Harbaugh, A.W., 2005. MODFLOW-2005, the U.S. Geological Survey modular ground-water model - the Ground-Water Flow Process: U.S. Geological Survey Techniques and Methods 6-A16, variously p.