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Evapo-transpiration Losses Produced by Irrigation in the Snake River Basin, Idaho

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Abstract

An estimated 8 MAF (million acre-feet) of water is diverted annually from the Snake River in Idaho, a tributary of the Columbia River, for irrigation of about 3.5 million acres of cropland. However, a recently developed water balance model for the Snake basin indicates that approximately 9 MAF (31 inches averaged over the irrigated areas) is lost from the system by evapotranspiration (ET), suggesting that not all diverted water is measured. Reconstructed inflows at Lower Granite Dam on the Snake River do not account for diversions for irrigation or for ET losses, therefore are 20-25 % less than natural flow. The ET model presented in this report simulates daily water losses using observed temperature and precipitation, and is based on the premise that the difference in the timing and quantity of Snake River inflows compared with nearby river basins is caused by large and unusual water losses in the Snake River basin. Addition of simulated ET to the reconstructed inflows produces a more realistic natural flow estimate and significantly improves the accuracy of seasonal streamflow forecasts at Lower Granite Dam.

Knowledge of the volume and timing of water that is lost by ET is an important factor in the hydrology of the Snake River basin because:

1. It increases the error of Snake River seasonal runoff forecasts at Lower Granite Dam.
2. It demonstrates the need to improve irrigation distribution efficiency to minimize water losses.
3. It is a essential factor for water conservation and land use planning
4. It provides the missing link for Snake River water balance models

A water balance model has been developed to produce daily ET losses for the Snake River basin above Lower Granite Dam for the 1969-2007 period. The model is based on the premise that the difference in runoff patterns (timing and quantity) of reconstructed Snake River inflows, compared with those of the nearby Pend Oreille and Columbia River at Grand Coulee Dam, is caused by an unusual amount of water loss due to agricultural irrigation in the Snake River basin. All three basins have ET losses due to irrigation, however, diversions in the Snake River basin are an order of magnitude or more greater than in the Columbia and Pend Oreille basins.

Input to the ET model are:

1. Daily inflow of the basin above Lower Granite (reconstructed by BPA and NWS)
2. Daily precipitation (weighted average of 70 weather stations used for Lower Granite Dam streamflow forecasts)
3. Daily mean temperature (average of three weather stations in the basin)
4. Daily reconstructed inflow of the Pend Oreille basin above Albeni Falls Dam
5. Daily reconstructed inflow of Columbia River above Grand Coulee Dam

All input data are daily values for the 1969-2007 period.

The Snake River inflow record reconstructed by BPA and NWS takes into account reservoir regulation at dams above Brownlee Reservoir but does not account for diversions from the Snake River or for ET losses produced by irrigation. Therefore, reconstructed inflows are significantly lower than actual natural flow.
Linear regression of daily reconstructed inflows of the Snake versus the Pend Oreille inflows for the full period of record (14,235 days) produces an R^2 of 0.76, and regression of Columbia River daily inflows versus the Snake for the same period the R^2 is 0.63.

RS (n,i) = a1 (RP(n,i) + b1
And
RS (n,i) = a2 (RCn,i) + b2

Where RS(n,i) = Snake River inflow for year n and day i (1969-2007)
RP(n,i) = Pend Oreille inflow for year n and day i
RC(n,i) = Columbia River inflow for year n and day i
a1, b1, a2, b2 = Linear regression coefficients

The ET model is designed to calculate daily evapo-transpiration throughout the full period of record so when added to existing inflows significantly increases in the R^2 of these daily regressions. An algorithm that uses daily mean temperatures and precipitation simulates daily ET, which is then added to the reconstructed inflows. Three coefficients are optimized (two for temperature and one for precipitation) to maximize the R^2 of regressing daily inflows of the Snake versus the Pend Oreille and Columbia Rivers. The mean R^2 for the full period regression is used as the objective function to find optimum values for the three ET coefficients. When the maximum R^2 is attained for both the Snake/Pend Oreille and the Snake/Columbia regressions the final coefficients are applied to calculate daily ET losses for the 1969-2007 period.

Two main factors determine ET, temperature and the amount of moisture available. An average of three weather station's daily temperature observations (maximum and minimum) in or near the Snake River basin are used to represent basin temperature. A water storage index based on observed daily precipitation (an average of 70 stations) minus simulated ET represents available moisture. Precipitation is cumulated from the previous December 15, thus a ET year begins and ends in mid-winter. Precipitation influences the ET of diverted inflows because the amount of diversion is dependent on precipitation (i.e. more water is diverted during a year of deficient precipitation and vice versa).

Daily ET loss in kcfs is determined by:

$ET = (CF1)\ (PET)\ (ST)$

Where: PET = Potential evapotranspiration index = $1 - e^{-CF2\,(dT)}$
(PET varies from 0 to 1.0)
ST = Basin water storage index = $\Sigma\,(P) - ET$
dT = Mean daily temperature factor = $T - CF3$
T = Average basin temperature
CF1, CF2, CF3 = coefficients determined by maximizing R^2
when the following linear regressions are run for each iteration

The coefficient CF3 is a threshold temperature equal to 42° F. ET occurs only when the basin mean daily temperature exceeds this threshold. The revised Snake River inflow, after ET has been added, is regressed again with Pend Oreille and Columbia River inflows:

$RS\ (n,i) + ET(n,i) = a3\ (RP(n,i) + b3$
and
$RS\ (n,i) + ET(n,i) = a4\ (RCn,i) + b4$
Where ET(n,i) = Evapotranspiration due to irrigation for year n and day i..

The dependency of the average R^2 (derived from linear regressions of Pend Oreille versus Snake daily inflows and Columbia versus Snake inflows) on coefficient CF1 is shown in Figure 1. Although the Pend Oreille/Snake regression produces higher R^2 values, the Columbia/Snake regressions appear to have greater coefficient sensitivity, likely due to the Pend Oreille having greater irrigation ET losses than the Columbia River above Grand Coulee.

FIGURE 1

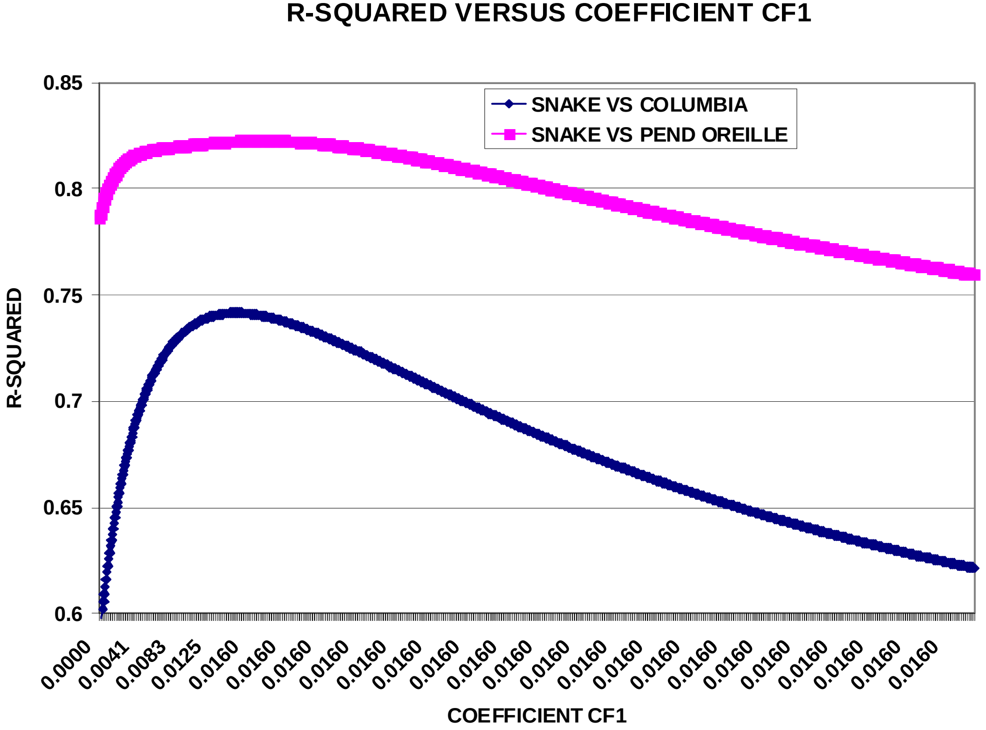

Figure 1. The R^2 for regressions of daily inflows of the Snake River versus the Pend Oreille and the Snake versus the Columbia River for the 1969-2007 period, as a function of coefficient CF1. When CF1 = 0.0, ET = 0.0 and the reconstructed inflow is unadjusted. The maximum R^2 for both regressions occurs at CF1 = 0.0150.

The relationship between the average R^2 determined from linear regressions of Snake/Pend Oreille daily inflows and Columbia/Snake inflows is shown in Figure 2. The optimum value of CF1 to produce the maximum R2 is 0.0155. Coefficients CF2 and CF3 were found by the same procedure.

FIGURE 2

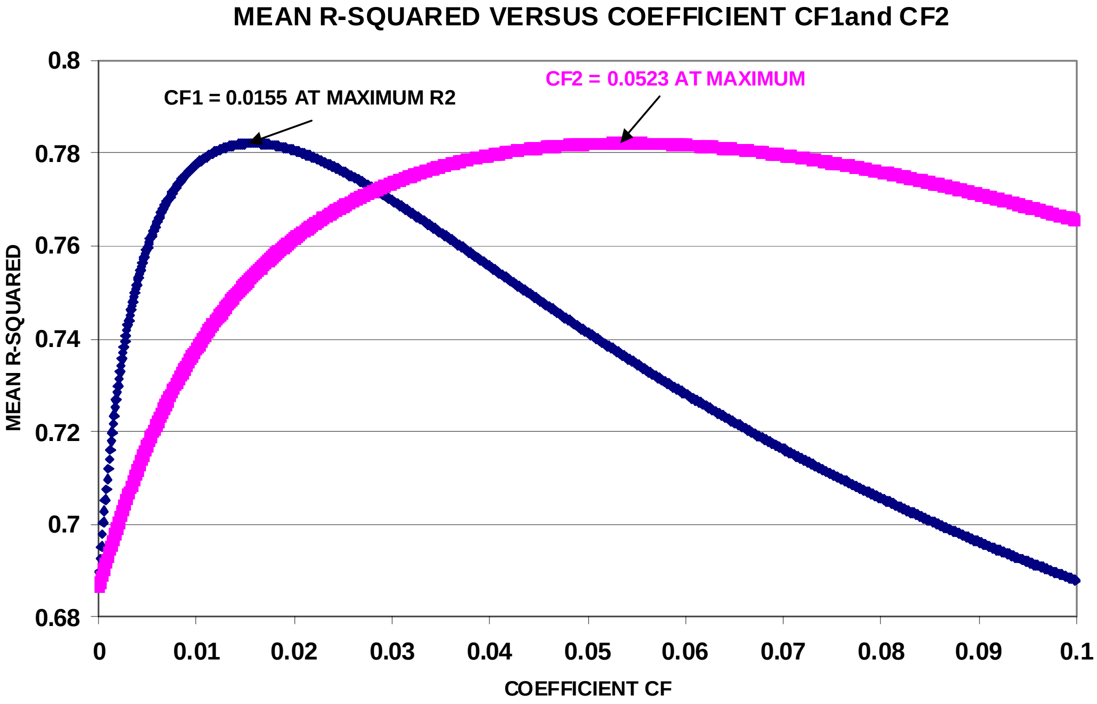

Figure 2. Mean R^2 (average of linear regressions of Pend Oreille versus Snake and Columbia versus Snake) as a function of coefficients CF1 and CF2.

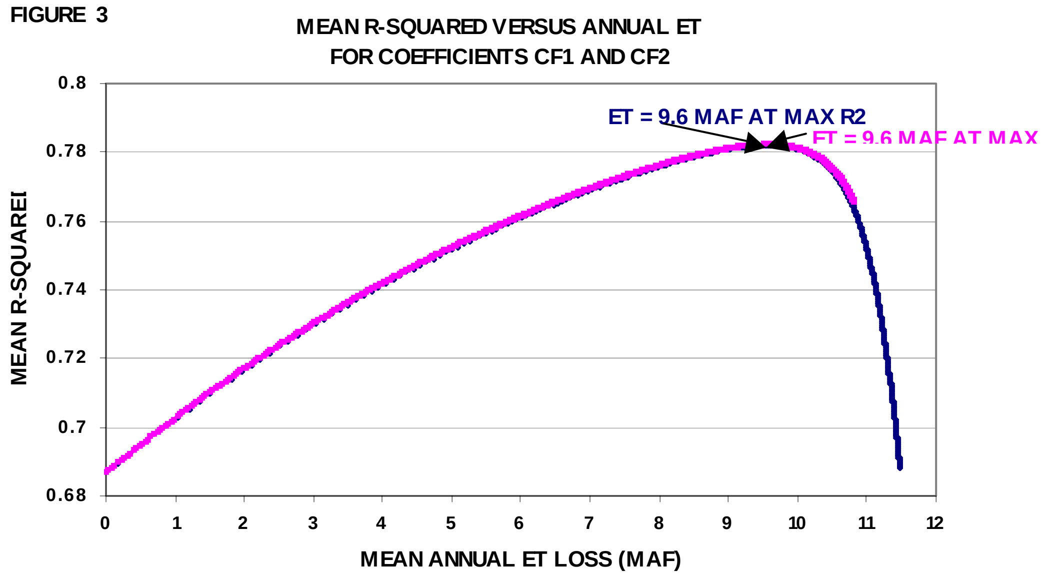

Figure 3. The relationship between the mean R^2 and annual ET water loss for coefficients CF1 and CF2. When ET equals zero, the R^2 is equal to that produced by a linear regression of unadjusted (before ET is added) Snake River inflows versus Pend Oreille and Columbia River inflows. ET at the maximum R^2 is 9.6 MAF, compared with 9.0 MAF that results when both coefficients are determined simultaneously.

FIGURE 4

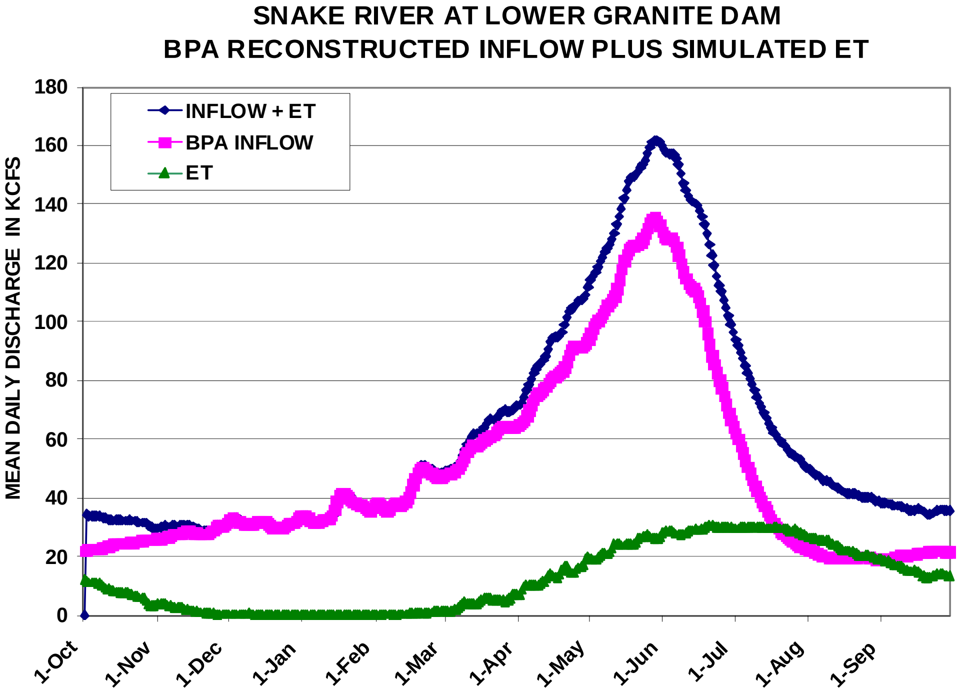

Figure 4. Hydrographs of the mean daily inflows at Lower Granite Dam reconstructed by BPA and NWS (pink line), and the resulting inflows after the simulated ET has been added (black line) to the reconstructed inflows. The mean daily ET (green line) is in kcfs for comparison with inflows.

Also shown is the mean daily ET, converted to kcfs for comparison with the inflows. The daily water loss due to irrigation ET, averaged for the 1969-2007 period, for 2001 - a low runoff year, and for 2007, an above normal year, is shown in Figure 2.

FIGURE 5

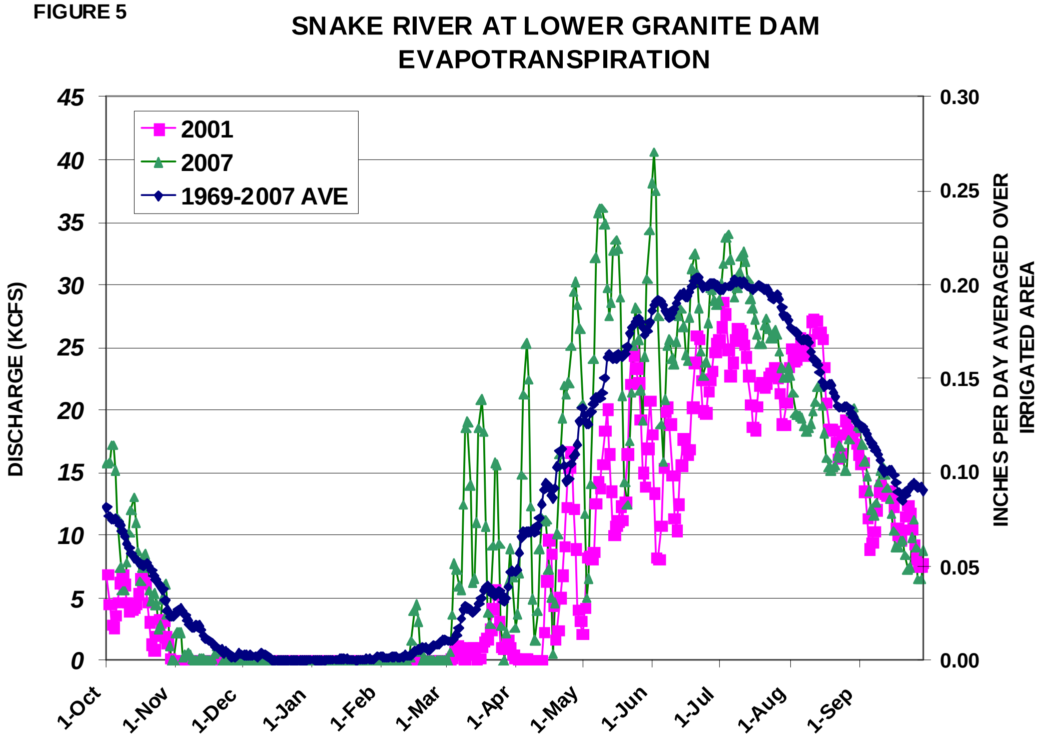

Figure 5. Mean daily ET simulated by the model in kcfs (left side) and in inches per day averaged over 3.5 million acres of irrigated area (right side): 1969-2007 average (dark blue line), 2001 (pink), 2007 (green). The high rates of ET in the spring of 2007 reduced inflows and affected seasonal forecasts at Lower Granite Dam. Average annual ET is approximately 31 inches averaged over the 3.5 million acres of irrigated area.

The average annual evapotranspiration (ET) loss for the Snake River above Lower Granite Dam derived from this model is 9 MAF, therefore average annual ET per unit area of irrigated cropland is approximately 2.6 feet (31 inches). Total annual inflow based on the BPA/NWS reconstruction is 25 MAF, thus total natural runoff including ET is approximately 34 MAF, and ET losses due to irrigation is 26% of total runoff. However total ET losses would include natural evapotranspiration and would be greater than 9 MAF. Figure 6 shows the annual irrigation ET that is lost from the Snake basin above Lower Granite Dam for the period 1969 – 2007.

FIGURE 6

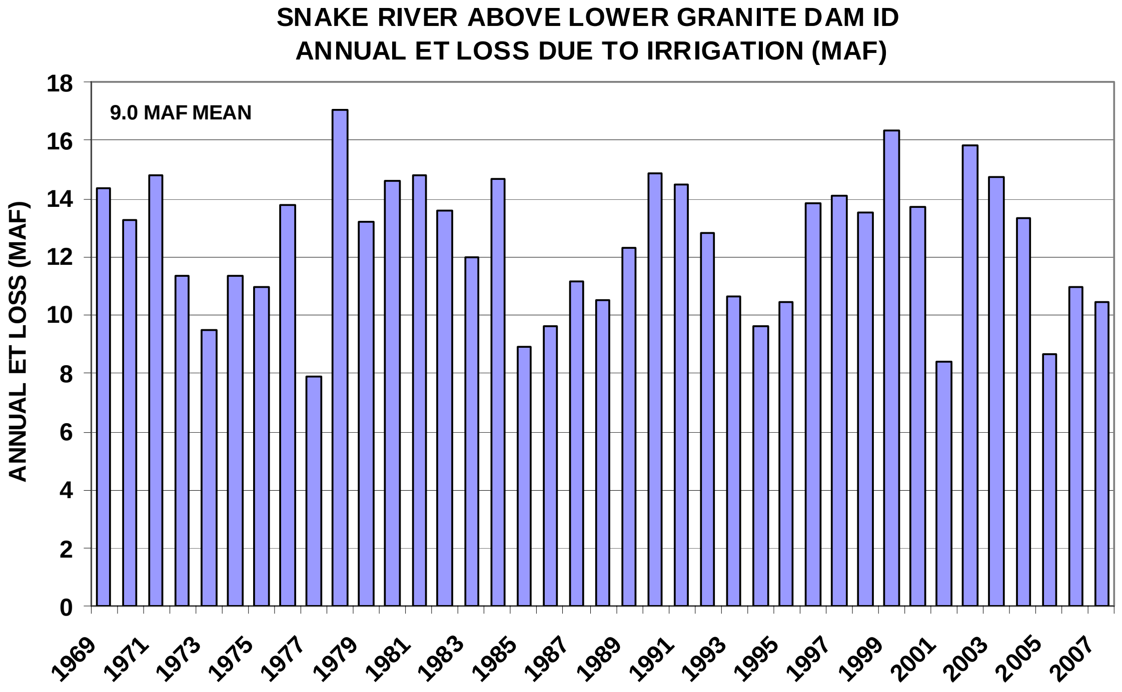

Figure 6. Annual water loss due to ET of water distributed for irrigation. The 1969-2007 average is 9 MAF, equal to 31 inches averaged over the irrigated area. A maximum of 16.4 MAF (56 inches) occurred in 1978 and a minimum of 8.0 MAF (27 inches) in 1977.

Verification of the revised Snake inflows is by independently comparing Snake River mean annual inflow (both with and without ET) with observed annual precipitation Figures 7 and 8 demonstrate the increase in R^2 resulting from the addition of simulated ET to daily reconstructed inflows. The R^2 of regressing annual reconstructed inflow versus annual precipitation is 0.76 without ET, and increases to 0.83 after ET is added to the initial inflows.

The mean annual simulated ET of 31 inches is in good agreement with evapotranspiration measurements made with a satellite-based energy balance model, which produced annual ET losses of 30 and 32 inches in 2000 and 2002, respectively (Richard G. Allen, personal communication, 2007).

FIGURE 7

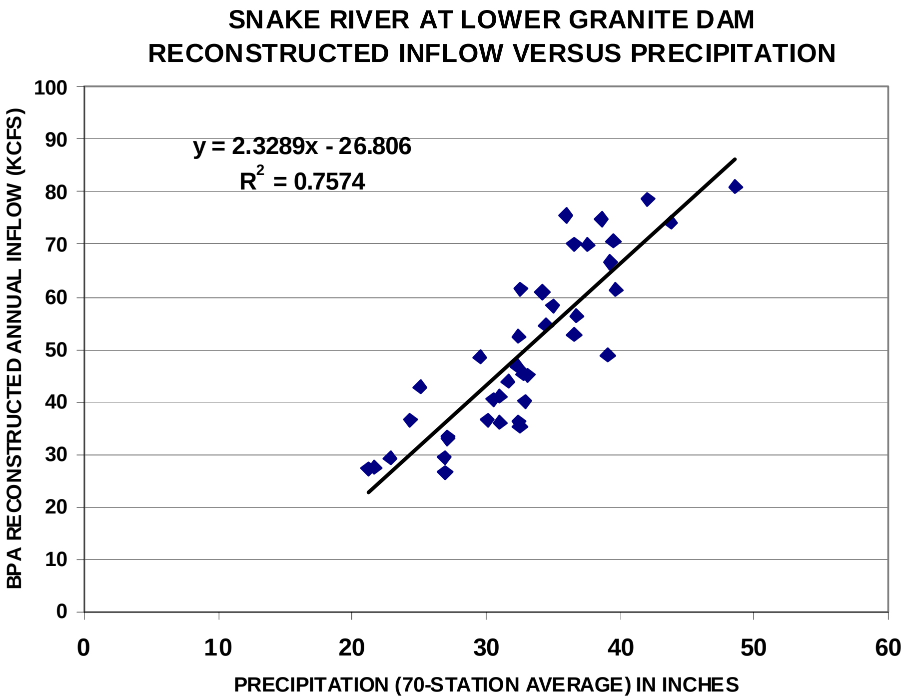

Figure 7. Annual reconstructed inflow (unadjusted for ET) of the Snake R at Lower Granite Dam versus weighted average precipitation observed at 70 stations

FIGURE 8

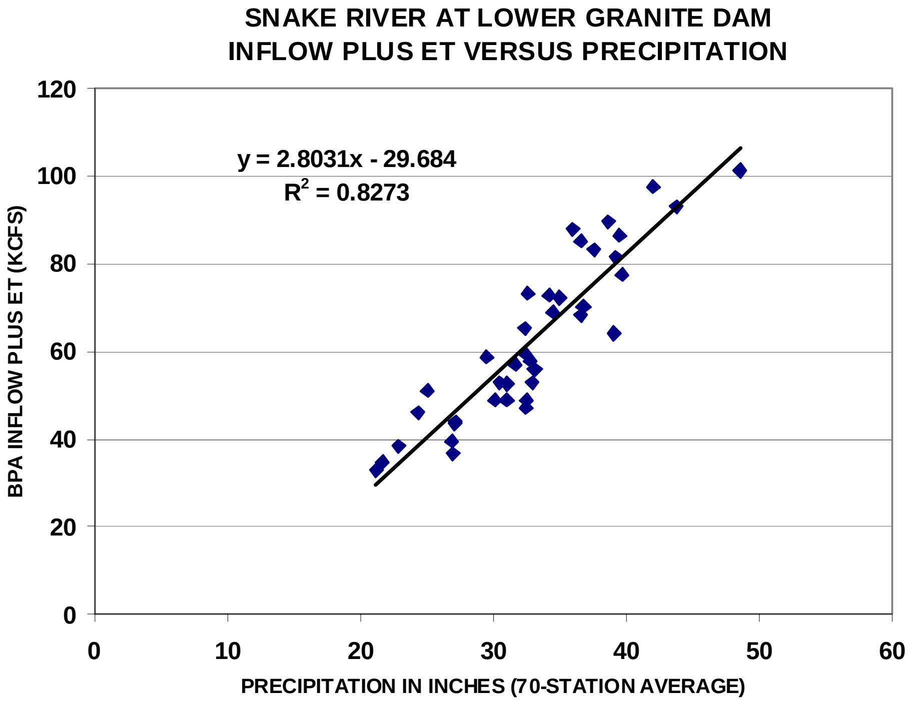

Figure 8. Annual reconstructed inflow plus simulated ET of the Snake River at Lower Granite versus weighted average precipitation at 70 stations. The addition of simulated ET increased the R^2 from 0.76 (Figure 4) to 0.83, verifying the ET simulations.

Improved accuracy in Lower Granite seasonal forecasts results when the simulated irrigation ET is added to reconstructed inflows. The procedure is to first calibrate the forecasting model using the reconstructed inflows that includes ET (natural inflow, or as close to natural flow as can be attained). A real-time forecast is then run and the mean ET during the forecast season is calculated and subtracted from the forecast.

For example, the Lower Granite forecast to September 30 on March 1, 2007 was 22 MAF and average ET from March 1 – September 30 is 4.0 MAF. Therefore, the actual forecast is revised from 22 to 18 MAF, compared with observed inflow of 18.5 MAF. The reduction in forecast error for hindcast forecasts made from January 1 to July 1 for a season ending September 30 is approximately 12%. However, the real test of incorporating simulated ET into the seasonal forecasting model will be real-time forecasts made in the future.