Project No. 247-34-2011

Development of Natural Flow Forecasting Models for the Upper Snake River

Preliminary Work in Progress

Prepared for Twin Falls Canal Company

March 27, 2013

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Executive Summary

In this study, hydrologic indicators were used to predict future natural flow conditions in the Snake River at Milner. The specific objective was to develop methods by which the diversion of both natural flow and storage by the Twin Falls Canal Company could be predicted for an upcoming season based on hydrologic conditions in April, May, and June. These predictions are important to the company for planning purposes, and could be utilized to assist with determination of mitigation requirements.

It was hypothesized that natural flow should be related to both surface water and groundwater indicators, since the total natural flow at Milner is a combination of both residual runoff after upstream water users are satisfied, and groundwater inflow from Blackfoot to Milner, known as reach gain.

Numerous indicators were evaluated and linear regression and data transformation techniques were employed to select optimal models, using data from 1990 through 2010, reserving 2011 and 2012 as verification years. Separate models were developed based on hydrologic conditions as of April 15, May 15, and June 15. It was found that the natural flow and storage (deficit) diversions could be predicted with reasonable accuracy. Natural flow was found to be a function of both surface water and groundwater indicators, as expected. Models were also developed to predict the date of first storage draw, which was found to be a function primarily of surface water indicators. Independent models were developed to predict diversion deficit, or required storage draw. This variable was found to be a function of both surface water and groundwater indicators, as expected.

The performance of the model was assessed using data for 2011 and 2012, years which were not included in the model calibration period. The results are shown in Table A.1.

The findings of this study indicate that reasonably-accurate forecasts can be made of natural flow, both in general and specifically for the Twin Falls Canal Company. This effort is a work in progress, and will continue to be refined as additional data becomes available.

Table A.1. Comparison of observed and predicted values for 2011 and 2012.

	Observed	April Model	May Model	June Model
2011				
Storage Date	**August 13**	July 27	August 12	August 19
Demand after storage date (kaf)	**308**	289	289	289
Natural Flow Diversion (kaf)	**233**	149	186	189
Deficit (kaf)	**74**	69	75	40
2012				
Storage Date	**June 17**	July 5	June 19	July 15
Demand after storage date (kaf)	**646**	656	656	656
Natural Flow Diversion (kaf)	**472**	348	393	335
Deficit (kaf)	**174**	238	212	235

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1. Overview and Purpose of Study

Natural flow in the Snake River in the Blackfoot to Neeley reach is the primary source of irrigation water for approximately 600,000 acres of irrigated land. Natural flow is calculated daily by Water District 1 and utilized in the allocation of natural flow and storage water rights. The primary objective of this study was to develop a forecasting tool that would allow managers of the Twin Falls Canal Company or other canal companies to predict natural flow availability in the Snake River for an upcoming irrigation season or for the remainder of a season and thereby plan accordingly to secure the necessary supplemental storage.

Using hydrologic indicator variables in the Upper Snake basin above Milner, models were developed to:

1. Predict natural flow availability to Twin Falls Canal Company (TFCC) for the period after the company begins drawing on storage in the Upper Snake reservoirs. After this time, flow in the river is primarily groundwater inflow, i.e. "reach gain," but also has a component of "remaining natural flow" passing Blackfoot after upstream senior users are satisfied. Both components may go to fill the natural flow rights held by users in the lower reaches.

2. Predict the date of the first storage draw by TFCC. The first storage draw occurs when the natural flow in the river declines below the required diversion of the canal company. This date can range from early May to early August.

3. Predict the natural flow deficit, or the supplemental storage requirement, after the date of the first storage draw.

4. Account for uncertainty in the predictions by estimating confidence limits for the storage requirement to allow company managers to plan accordingly with a known level of risk.

1. Snake River Hydrology Overview

The Snake River in Southern Idaho serves as the drainage area for the bulk of the southern half of the State. With its headwaters in Yellowstone National Park in western Wyoming, the Snake River courses through some 500 miles of semi-arid land to the border of Oregon and Idaho. Major tributaries contribute to the flow, which amounts to 15,000 to 35,000 cfs on an annual basis at Hells Canyon Dam.

The drainage basin for the Snake River has generally been divided into two major reaches: namely the Upper Snake, defined as the area from King Hill upstream to Jackson Lake, and the Lower Snake, essentially from King Hill downstream. A major hydrologic divide in the Upper Snake reach is Milner Dam where all of the flow of the river is typically diverted for irrigation during the summer months. Therefore, the river above this point is often referred to by water managers as the Upper Snake.

Irrigation development, utilizing diversions from the Snake River began in the late 1800s with irrigation canals constructed to serve lands that were reachable by canals, generally within 10 miles of the river. Natural flow for irrigation was not ample in the late season and storage dams were constructed to enhance the late season flows. Flood control and hydropower operations were integrated in the reservoir system. Ten major storage and run-of-the-river impoundments now regulate the flow for irrigation, power, and flood control purposes and other dams on major tributaries serve the same purpose.

The Snake River flows from east to west through the Eastern Snake River Plain. This area is underlain by massive permeable basalt flows which constitute the Eastern Snake Plain Aquifer (ESPA). Extensive groundwater development from the ESPA for irrigation began in the 1950s and now about 1.1 million acres are irrigated with groundwater.

The Upper Snake River and the underlying aquifer (ESPA) are hydraulically interconnected along most of the river’s length. In most reaches the Snake River gains flow from the aquifer which constitutes some of the natural flow of the river. About 2 million acre feet enter the Snake River from the ESPA in the reach just upstream from American Falls Reservoir and some 4 million acre feet emerge from the aquifer at springs in the Kimberly to King Hill reach.

Water rights and the priority system for appropriation for irrigation from the Snake River govern the management and distribution of natural flow and storage in the system.

The complex hydrology of the ESPA/Snake River system and the large, diverse drainage area make forecasting of expected flow in the Snake River difficult. However, accurate forecasts of natural flow availability are mandatory for efficient water supply planning and management for the irrigation entities through-out both the Eastern and Western Snake Plain areas.

a. Runoff

Runoff from contributing areas of the Snake River drainage is primarily from snowmelt and sometimes rain-on-snow events. Fourteen snow courses in the Upper Snake basin are managed by the Natural Resources Conservation Service (NRCS) to assist in estimating runoff for water supply and flood forecasting. Other snow courses on major tributary watersheds are also managed by the NRCS.

The USGS streamflow gage on the Snake River at Heise has been utilized as a major indicator of water supply. This gage is the earliest on the Snake River in Idaho and the historical unregulated flow at Heise has been utilized for water resources planning, drought history evaluations, and forecasting of irrigation water supplies. A hydrograph of the unregulated flow of the Snake River at Heise for various years is shown on Figure 1. Unregulated flow is the natural flow as adjusted for upstream changes in storage in the reservoirs.

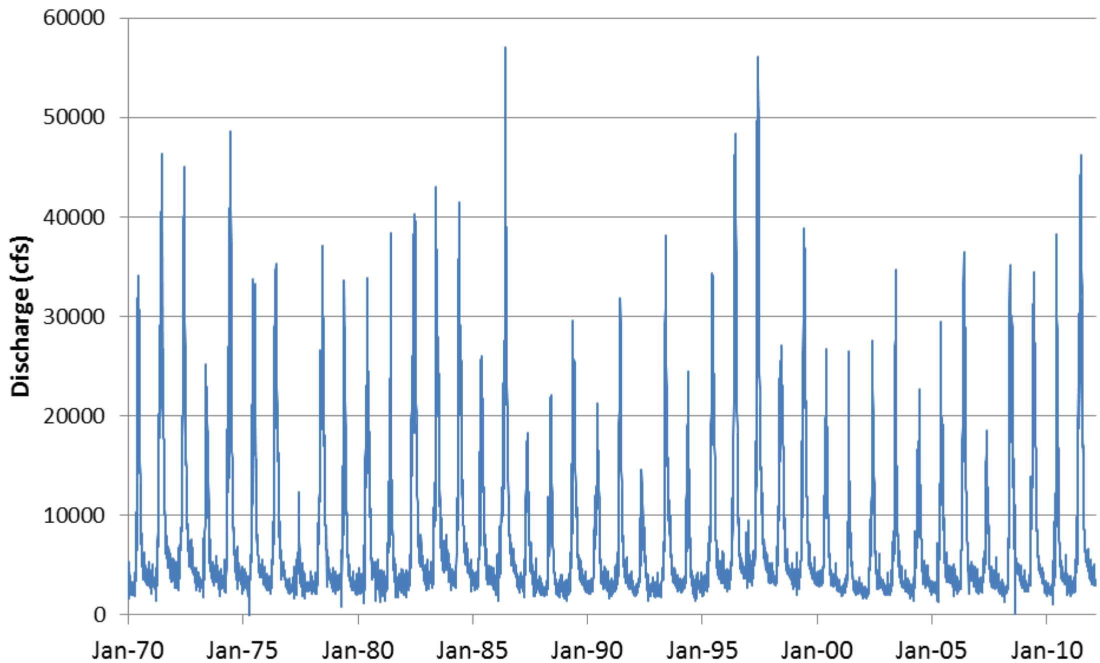


Figure 1. Unregulated flow in the Snake River at Heise, 1970-2011.

Generally, the minimum flow occurs in March, just prior to runoff commencement, and the peak flow occurs sometime in late May or early June. The April through July period is an often-used forecasting period to represent the runoff duration. Note the variability of both the peak flows and minimum flows.

b. Regulation by Upper Snake Storage Reservoirs

The reservoirs on the Snake River are indispensible for water management for irrigation and flood control. Jackson Lake Dam, the first major dam constructed on the river in 1907 was subsequently raised and improved in 1916 to store 847,000 acre-feet. Palisades Dam is also an integral component of the U.S. Bureau of Reclamation Minidoka and Palisades Projects and has an active storage of 1,200,000 acre feet. Other, smaller, storage dams such as Grassy Lake, Henrys Lake, Island Park Reservoir, and Ririe Dam provide smaller amounts of irrigation and flood control. Efficient reservoir management depends on accurate runoff forecasting, and the reservoirs are operating according to “rule curves” which balance the need to maximize storage with the need to release water for flood control or other operations.

Regulation of the reservoirs alters the shape of the hydrograph significantly, as illustrated in Figure 2. The unregulated hydrograph exhibits a sharp increase in April, a peak in June, and a sharp recession limb. In contrast, the regulated hydrograph results in lower off-season flows as the reservoirs store water, a higher peak flow (on average) due to irrigation releases, and an extended recession limb as the releases are made for irrigation supply later in the season.

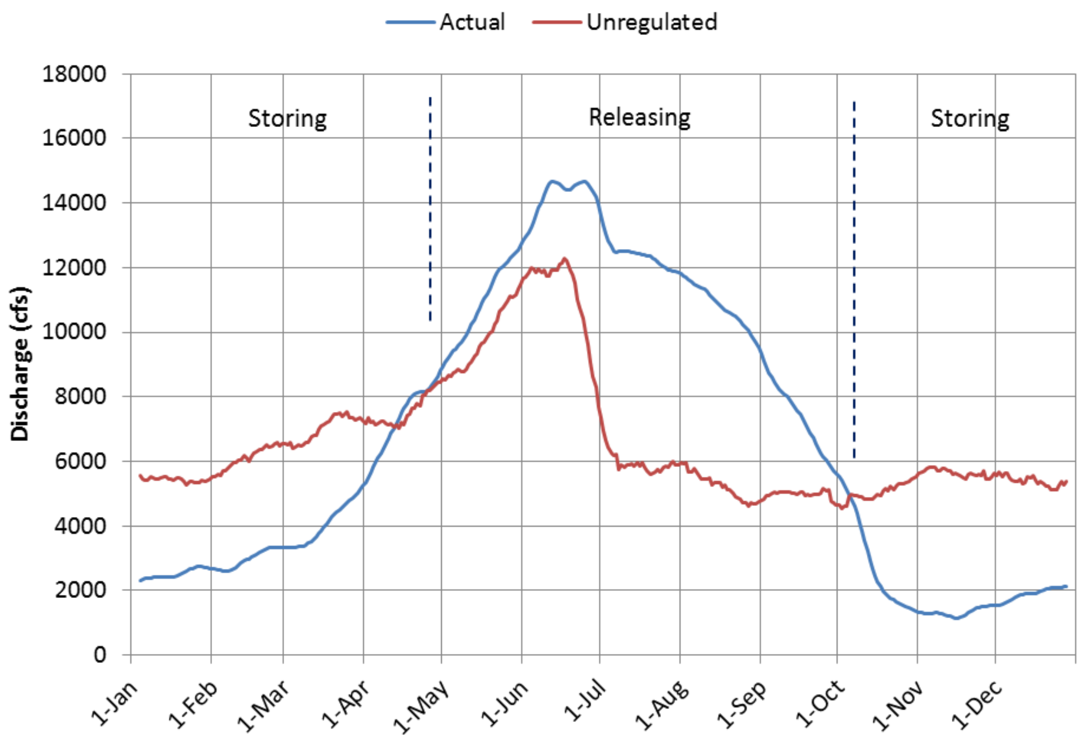


Figure 2. Average weekly discharge in the Snake River at Neeley, actual and unregulated (period of record 1990-2011).

c. Inflow from Groundwater (Reach Gain)

Natural flow within any reach of the river is an accumulation of main river inflow, surface runoff from minor streams and irrigation return flow, and groundwater inflow distributed throughout the length of the reach, called reach gain. Since proper water rights administration requires an accounting at each diversion location of both natural flow and storage water released from upstream reservoirs, it is imperative that procedures for calculating natural flow be available. Since the natural flow is fully appropriated, it is necessary for IDWR and canal companies to develop an appropriate method of estimating the temporal availability of natural flow at strategic sites on the river. Reach gains or losses and their relative magnitudes are qualitatively depicted in Table 1.

Table 1. Expected reach gain in Snake River from Heise to King Hill.

Snake River Reach	Reach gain (loss)	Relative magnitude
Heise to Shelly	Gain	+
Shelly to near Blackfoot	Loss	-
Near Blackfoot to Neeley	Gain	++++
Neely to Minidoka	Near zero	
Minidoka to Milner	Gain	+
Milner to Kimberly	Gain	+
Kimberly to Buhl	Gain-springs	+++
Buhl to Upper Salmon	Gain-springs	++++
Upper Salmon to Bliss	Gain-springs	++++
Bliss to King Hill	Gain-springs	+

Early season natural flow is generally fully appropriated upstream of the near Blackfoot gage. From the near Blackfoot gage downstream to Milner, the reach gain provides the primary natural flow supply for irrigation diversions serving nearly 600,000 acres, chiefly the Twin Falls Canal Company and the Northside Canal Company. Between Milner Dam and Bliss, major springs, collectively flowing in excess of 5500 cfs, issue from the north wall of the canyon and have been developed primarily for aquaculture purposes.

Losses or gains within a river reach are distributed throughout the length of the reach and the magnitude varies throughout the season. The calculated gain is usually lowest around mid-July and reaches a high point in October. The seasonal pattern is influenced by both natural recharge, irrigation recharge, and seasonal groundwater pumping on the ESPA.

The temporal pattern of reach gain available to the lower reaches of the Snake River from July 15 through September 30 is shown on Figure 3. The magnitude varies from year to year within a wide range. The shape of the hydrograph is influenced by the amount of flow that is attributed to storage releases. Later in the season, the measured flow at the near Blackfoot gage is comprised almost entirely of storage releases; however, there may be natural flow remaining at Blackfoot that is allocated to the lower reaches.

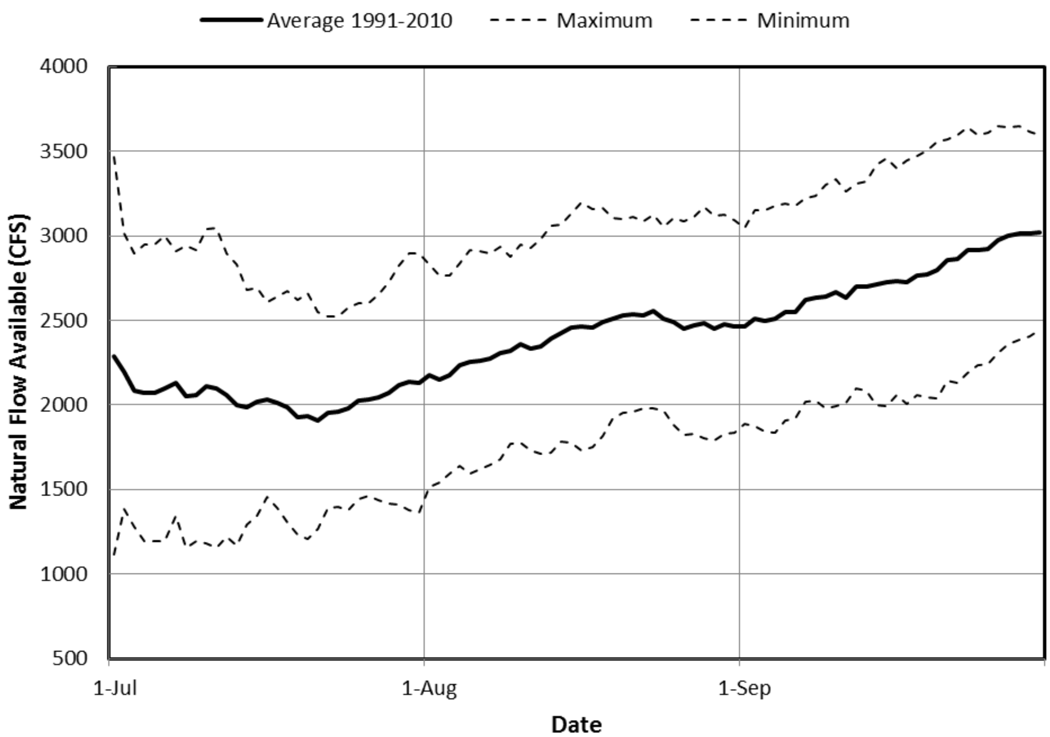


Figure 3. Variation of natural flow from reach gain over a season, near Blackfoot to Milner, July 21 – September 30, calculated by Water District 1.

The seasonal total (July 1 – September 30) reach gain appears to have been trending downward since the early 1990s. The reduced reach gains are likely the result of increased groundwater pumping in the Eastern Snake Plain Aquifer, drought, reduced surface water recharge due to changes in irrigation practices, and potentially other factors (Figure 4). The slope of a least-squares regression line through the data is 2,430 ac-ft per year.

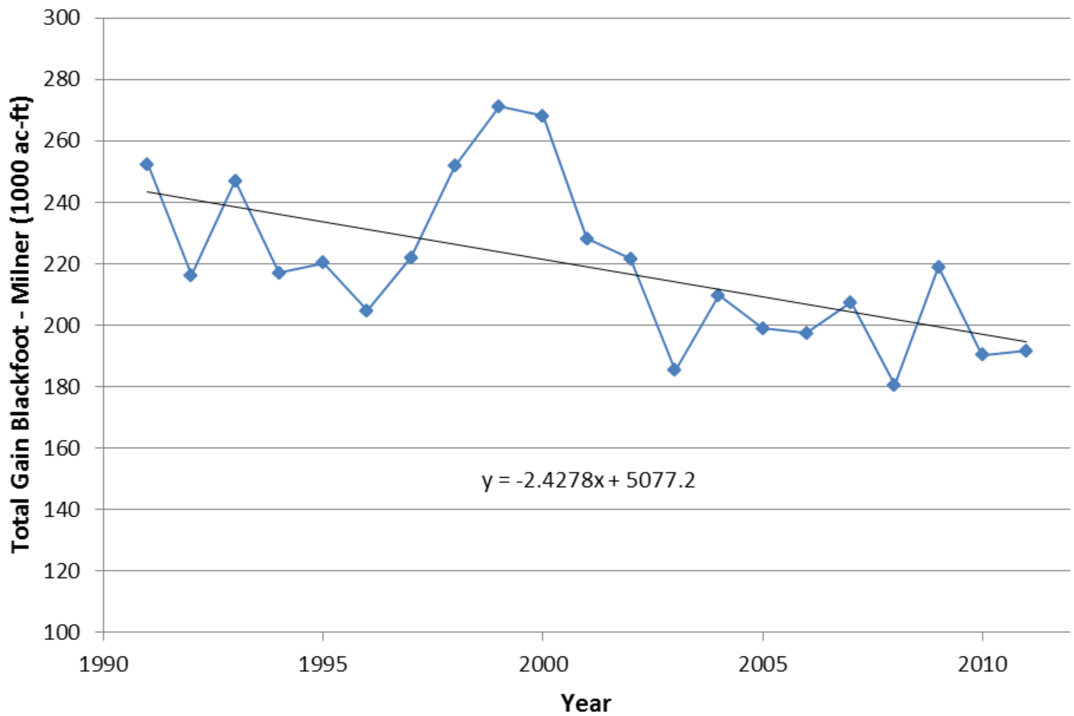


Figure 4. Seasonal total natural flow, July 1-September 30, from near Blackfoot to Milner, calculated by Water District 1.

2. Importance of Natural Flow Forecasts

Accurate forecasts of natural flow prior to the irrigation season or for any time during the season are indispensible for management of irrigation water supplies. For example; major irrigation companies with water rights downstream of Neeley have both natural flow rights and finite amounts of storage under contract.

Managers of canal companies which rely on natural flow must make a prediction each year of the likely deficit in natural flow availability relative to company's diversion requirements. The deficit must be supplied by storage in the Upper Snake reservoirs, either from the company's own inventory or from the rental pool. Alternatively, cuts in irrigation deliveries must be made. The amount of storage to secure or the likely amount of the cut must be decided prior to or close to the start of the irrigation season. Historically, various indicators have been considered by company managers when making this decision. The traditional indicator has been the flow in Spring Creek near Sheepskin Road, which is a spring-fed creek that is assumed to be a proxy for reach gain conditions. Another indicator has been the general water-supply status of the Upper

Snake basin, including snowpack levels and forecasts of runoff made by the Natural Resources Conservation Service. Frequently, managers have tried to find an analogous year based on qualitative and perhaps some quantitative data, and acquire the same storage that was needed in that year. A variation of this approach is used by the Director of IDWR in determining mitigation for water calls by canal companies.

Decisions have normally been made based on a qualitative evaluation of these indicators and the general inclinations of the company's board members. The risk is that incorrect forecasts of natural flow can result in maintenance of normal irrigation deliveries with resulting shortages at the end of the season, or reductions in deliveries when the supply is, in fact, adequate. It is also possible that an irrigation entity may incur the expense of purchasing additional storage as a result of an inaccurate predicted shortfall in natural flow and not have to use the storage at the end of the season. In short, the accurate prediction of natural flow availability for irrigators is a necessity in managing storage accounts and assuring that adequate irrigation water is available. Efficient management of storage allows optimum use of reservoir storage capacity and can result in enhancement of carry over volumes for irrigation entities.

A tool which could provide quantitative guidance for these decisions by forecasting the natural flow in the Snake River after July 15 would be of significant benefit.

3. Reach Gain Calculation by Water District 1

Because of its importance in allocation of water rights in the Snake River, natural flow due to reach gain in the Snake River is calculated on a daily basis in real time through each irrigation season by Water District 1 (WD1). Some background on the methodology used in this calculation is instructive for understanding the models developed in this study. The information in this section was derived from verbal and written discussions with WD1 staff and is believed to be accurate.

The methodology amounts to a simple water balance, with corrections made for the water travel time in the river through a particular reach, changes in storage made in the intervening reservoirs, and evaporation and seepage losses from the reservoirs. To make this calculation, WD1 utilizes the IDWR water right accounting program. This program was first developed in the late 1970s, and has been updated periodically. Significant changes in the accounting program were made in approximately 1990, such that calculations made in earlier periods are not directly comparable to those made after that time.

Natural flow is computed daily to determine the amount of water physically available for diversion to the holders of natural flow water rights. For the lower reaches of the Snake River (below Blackfoot) the calculation is made for three river reaches and one external tributary reach:

- Near Blackfoot to Neeley
- Neeley to Minidoka
- Minidoka to Milner
- Portneuf River (external reach)

These reaches are used because streamflow gauging stations are situated at the endpoints of the reaches, providing both the inflow and outflow discharges for each reach.

As described in Section 2, natural flow in the river may be a combination of surface runoff and groundwater inflows. However, after approximately July 15 in most years, the natural runoff hydrograph has essentially receded to the base flow level. Therefore, natural flow in one of the above reaches from this time forward is equal to the increase in measured flow from one gauge to the next, termed the “reach gain.”

Natural flow or reach gain (RG) for a 24-hour period is calculated as follows:

RG = Inflow – Outflow + Diversions + Evaporation +/- Change in Reservoir Storage

Calculation procedures for each of the components of the reach gain equation are described below.

a. Stream gauging procedure

Inflow and outflow values for the natural flow calculation come from gauging stations maintained by the U. S. Geological Survey. At each station, flow is measured using the “rated section” approach, in which the discharge is assumed to be related to the gauge height, or water level in the river, and this relationship is derived empirically by multiple measurements of streamflow made using a current meter. A curve fitted through these multiple measurements becomes the base rating curve for the station. Because the stage-discharge relationship can change due to build-up of sediment or vegetation, or other morphologic changes in the river channel, frequent measurements are made to check the curve, and a gauge shift may be applied if the measured value falls too far “off the curve.” For the Snake River stations, measurements are made every two months through the irrigation season. The USGS applies certain protocols to determine when shifts are made, but scientific judgment is also used to determine whether a shift is truly warranted. If a gauge shift is applied, it typically remains in force until the next measurement, at which time a potentially different shift, or no shift, may be applied.

The USGS publishes real-time preliminary data on a daily basis based on the above procedure. This data is utilized in the reach gain calculation by WD1.

The preliminary data collected throughout the season is evaluated after the end of the year by USGS technical staff. At this time, apparent anomalies in the data are examined and may be corrected or discarded if deemed erroneous. Gauge shifting is also reevaluated at this time, and the daily data may be recalculated by applying, for example, linear interpolations of shifts between measurements.

b. Diversions

All significant surface water diversions within WD1 are required to have measuring devices approved by the district, and to implement a means of reporting daily diversion volumes. These devices are typically weirs or flumes within the main diversion canal operated by a canal company. The devices are periodically checked by WD1 staff to assure their continued accuracy.

c. Reservoir Evaporation

American Falls reservoir evaporation is calculated based on Agrimet data for reference evapotranspiration at the Aberdeen Experiment Station, applying coefficient to estimate open water evaporation. Lake Walcott and Milner evaporation is not factored in the reach gain calculation.

d. Change in Reservoir Storage

Even if all inflows and outflows to a reach are accounted for, the computed gain is not a true measure of the gain if there is a change of storage within the reach. Three reservoirs are located within the reaches of interest: American Falls Reservoir, Lake Walcott (Minidoka), and Milner Reservoir. Changes in reservoir storage can be dictated by the operating criteria of the facility, i.e. the “rule curve,” or by demands on the storage in the reservoir. Storage may be increasing if, for example, natural flow is being stored early in the season for later release. The storage may be decreasing if draws are being made for irrigation releases.

For the natural flow calculation, changes in storage are determined for each 24-hour period by changes in the reported gauge heights and the currently effective storage capacity curve for the facility.

The primary difficulty in accounting for storage changes in this manner is the sensitivity of storage volume to gauge height. For example, a 0.5-inch change on the American Falls gauge over 24 hours equals approximately 2000 acre-feet in that period or an average flow of 1000 cfs. Gauge readings can be significantly affected by the friction of wind blowing across the reservoir surface. High winds on the reservoir can easily cause gauge runup of a few inches, resulting in a major apparent change in storage, when the actual change may be minimal. WD1 attempts to adjust for any obvious errors of this nature when making the final accounting.

e. Travel Time Adjustment

Even if all inflows, outflows, evaporation losses, and storage changes were known with perfect accuracy, the calculation described above would still not reflect the true reach gain because of the time required for changes in inflow to propagate downstream to the corresponding outflow gauge. Therefore, WD1 adjusts the data in an attempt to account for the water travel times by simply lagging the daily data by increments of 1 day, as follows:

- Near Blackfoot to Neeley – 1 day
- Neeley to Minidoka – 0 days
- Minidoka to Milner – 1 day

Although having the benefit of simplicity, the lagging approach does not reflect physical conditions because 1) travel times are not perfect multiples of 1 day, 2) travel times are not constant but are a function of discharge, and 2) the travel time from Neeley to Minidoka is not zero. One reason for using this approach is because the time step of the accounting model is 24 hours, and therefore changes which occur at lesser intervals cannot be accounted for.

f. Post-Processing and Finalization

Throughout the irrigation season, real-time calculation of 24-hour natural flow is made and published by WD1. This data is not reviewed in detail by WD1 and is prone to the error sources described above. After the end of the season, the raw data is examined and manually processed to result in a final, published data set of daily natural flow. This processing includes incorporation of the final approved streamflow data from the USGS. Obvious anomalies which appear to be artifacts of the calculation procedure may be corrected. In order to smooth out any remaining fluctuations that do not represent the true reach gain, a moving average filter is applied. The approved dataset is generally published in February or March of the following year.

g. Criticisms

Clearly, valid criticisms could be made of the water balance methodology and the fairly crude adjustment procedures used by WD1. Alternatives to the current approach which incorporate physically-based modeling of the river should be explored. However, for the present study involving prediction of natural flow using hydrologic indicators, the final, published daily values of reach gain were assumed to be correct. This choice was a pragmatic one: whether correct or not, it is that data which is used by WD1 to determine water right allocations to the surface water users, and to evaluate past patterns and trends. It is more valuable to be able to predict a parameter which has meaning for actual diversions rather than a theoretical value which may have more physical justification but is not adopted by the State for allocations purposes.

4. Total Natural Flow and Water Right Accounting

In allocating natural flow to diversions in the Near-Blackfoot to Milner reach, both the reach gain (RG), calculated as described above, and any additional natural flow entering the lower section of the river must be accounted for. Natural flow occurring above Blackfoot is calculated by WD1 and allocated to upper-river water users by priority. Any natural flow remaining at the Near-Blackfoot gauge is available for allocation to the lower diversions. This flow is termed remaining natural flow, or RNF. In dry years, there may be minimal RNF or it may decrease to zero very early in the season. In wet years, RNF may be considerable and it may extend even into September. Furthermore, it is possible that RNF may go to zero early in the season, then reappear later in the season due to anomalous precipitation events which could result in runoff and/or upper-river water usage decreasing. The sum of these two components of natural flow, RG and RNF, is termed total natural flow (TNF).

The water right allocation is made daily on a near-real-time basis. A simplified exposition of the procedure utilized by WD1 is as follows:

1. Natural flow above Blackfoot is calculated, and allocated to all senior water rights above Blackfoot by priority.

2. Remaining natural flow (RNF) is calculated as the natural flow passing Blackfoot after filling all upstream senior water rights.

3. Reach gain from Blackfoot to Milner is calculated (RG).
   Caveat: If the gain in the below-Blackfoot to near-Blackfoot reach is positive, the gain is added to the gains from Neeley to Milner. If the gain is negative, it is used to reduce the natural flow supply for diversions above Blackfoot and has no effect on lower reach supply.

4. Total natural flow allocable below Blackfoot (TNF) = RNF + RG.

5. If TNF > 3,400 cfs, the October 11, 1900 water right at Milner is filled:
   - Northside Canal Company allocated 400 cfs
   - Twin Falls Canal Company allocated 3,000 cfs
   - (TNF – 3,400 allocated to Minidoka canals and Twin Falls Canal Company's later-priority rights.

   If TNF < 3,400 cfs, the October 11, 1900 water right is not filled and is allocated on a pro-rata basis:
   - Northside Canal Company allocated 11.76% of TNF
   - Twin Falls Canal Company allocated 88.24% of TNF

6. If the actual diversion by the Twin Falls Canal Company exceeds its allocated natural flow, the company's storage is released and accounted for to make up the difference.

The date that the Twin Falls Canal Company (TFCC) begins using storage is termed the "storage date," and varies widely from year to year depending on natural flow availability (see Section 8.a). For the purposes of storage use planning and prediction of natural flow, it is the natural flow occurring after the TFCC storage date that is important in calculating the anticipated deficit. Natural flow occurring prior to this date may be an indicator of conditions later in the season, but is not itself used to calculate deficit, i.e. storage requirement. Northside Canal Company has comparatively little natural flow water right authorization (for the 1900 water right supply), and relies primarily on storage releases.

The required storage varies widely from year to year, due to the wide variation in total natural flow and date of first storage, as depicted on Figure 5. Storage requirement has ranged from 16,000 acre-feet in 1997 to 253,000 acre-feet in 2007.

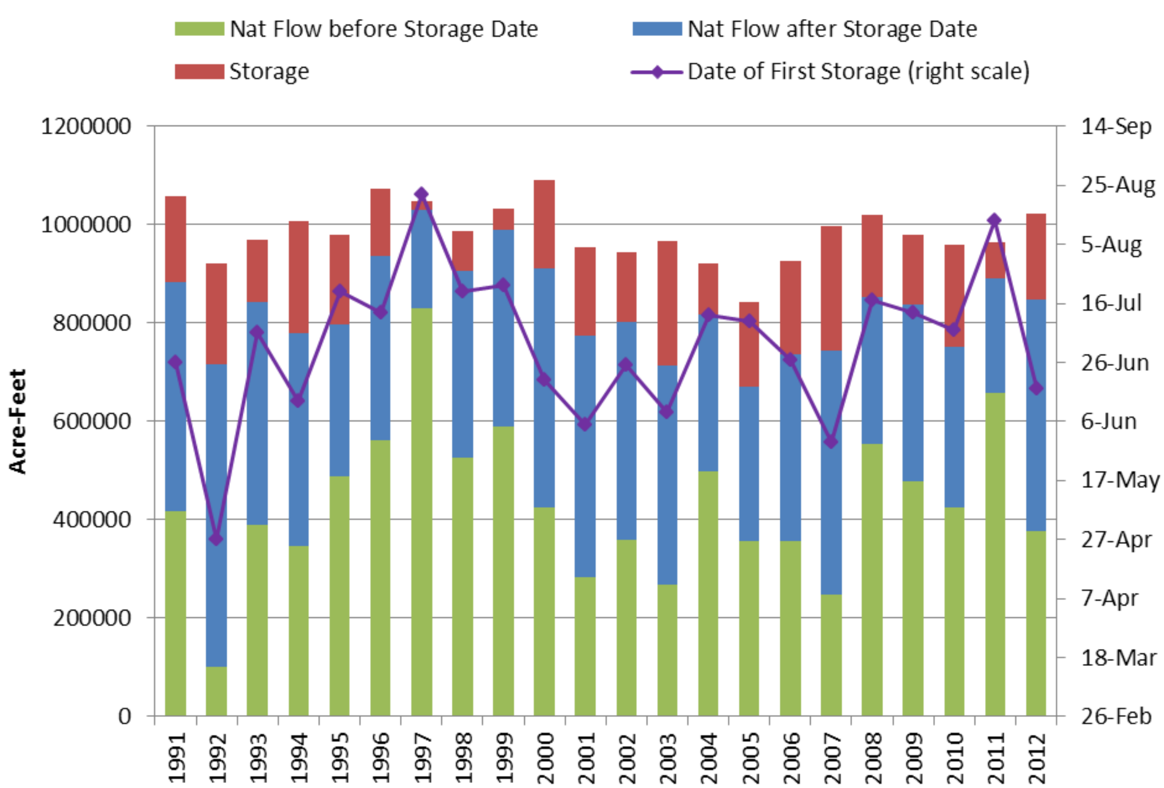


Figure 5. Twin Falls Canal Company natural flow and storage usage patterns, 1991-2012.

Historical data for RNF is not directly available in the IDWR water right accounting database. However, the relationship between the two natural flow components and TFCC diversion may be illustrated as in Figure 6.

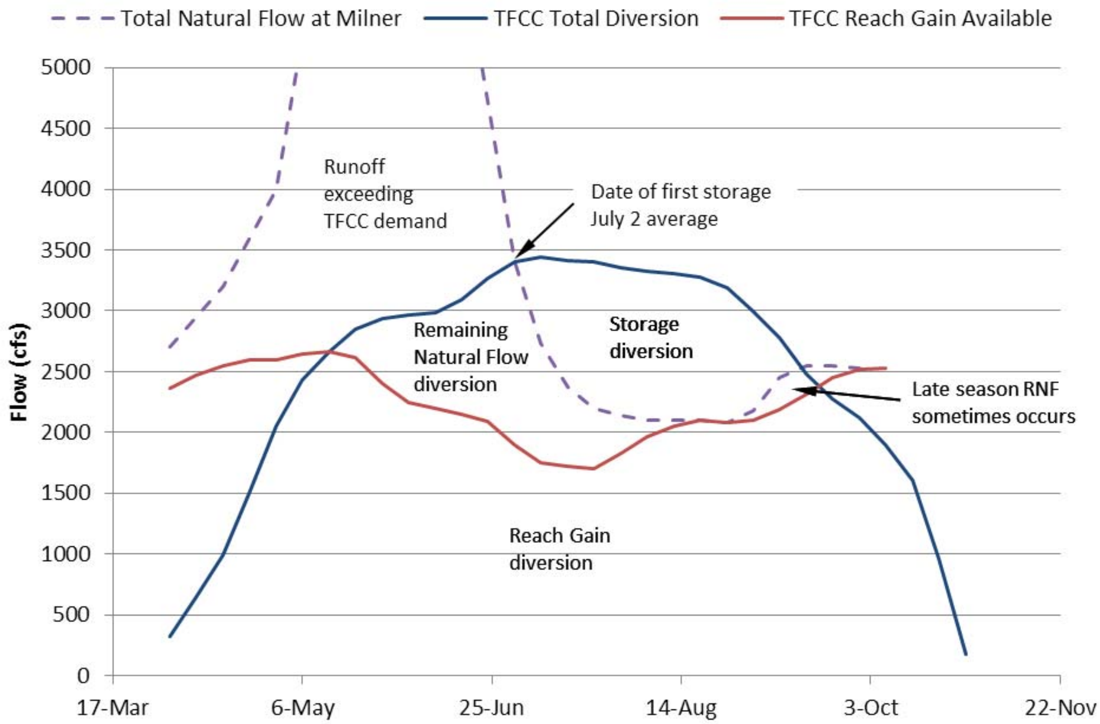


Figure 6. Relationship between total natural flow, reach gain, and diversion demand for a typical year. Curves in this figure are conceptual, but are adapted from average hydrographs for 1990-2010.

5. Natural Flow Forecasting Models

a. Model Conceptualization

Since natural flow in the Snake River is a combination of surface and groundwater inflow, the natural processes which affect these two sources should have some influence on the measured natural flow. For example, increased groundwater levels should result in greater reach gain from groundwater. A year with high precipitation will generally be a year in which the surface runoff is high and the hydrograph extend further into the season, resulting in a larger magnitude of remaining natural flow at Blackfoot. It is postulated that hydrologic indicators exist which can provide a reasonable forecast of future natural flow in the Snake River from Blackfoot to Milner. By similar rationale, it is postulated that hydrologic indicators exist which can provide reasonable forecasts of the storage date and deficit (storage requirement) for Twin Falls Canal Company.

The general form of the postulated model is

$$Y = B_o + B_1 x_1 + B_2 x_2 + \ldots + B_m x_m$$

where

Y is the one of the following:

Storage date, as determined from WD1 accounting

Natural flow diversion by TFCC from the storage date through September 30, as reported by WD1

Demand, or total diversion requirement for TFCC

Deficit, or storage requirement, by TFCC, as reported by WD1

$x_1, x_2, \ldots, x_m$ are the hydrologic indicator or predictor variables, or transformations of these variables, observed on or near a certain point in time.

$B_o, B_1 \ldots B_m$ are the model coefficients

Several models were developed using hydrologic indicator variables observed at different times. Most of the hydrologic variables examined are observed at monthly or bi-monthly intervals; therefore the models were developed for observations at April 15, May 15 and June 15, which for this study are termed the "observation dates." The purpose of this approach is to provide canal managers with both an early estimate of natural flow for the upcoming season, and more refined values as the season progresses. The assumption is that model predictive power will increase when using variables closer in time to the parameter being predicted.

Thus, for each observation date of the predictors, three models were developed to predict storage date, natural flow diversion, and deficit. Since there are three observation dates, a total of nine models were developed.

Alternative modeling approaches were extensively investigated. For example, models were developed to predict RG and RNF separately. Models were also investigated to predict the storage date, then use the storage date as a factor in predicting natural flow and demand, and find the deficit by subtracting the two. Overall, it was found that the most accurate method is to directly and independently predict the desired variables.

The steps involved in developing a model based on this concept were as follows:

Step 1: Potential predictor variables were identified for which a rational basis exists to postulate a link to reach gain in the Snake River.

Step 2: From the many hundreds of possible regression models involving all possible combinations of the predictor variables, statistical techniques were used to select a handful of “best” models containing the predictor variables which have the largest influence on reach gain.

Step 3: The models were evaluated based on predictive capacity and statistical validity and the final model selected using engineering judgment.

b. Critieria for Model Selection

Given the number of hydrologic indicator variables which could possibly enter into a model to predict natural flow, the number of possible models is literally in thousands. Some systematic means of narrowing the field of possible models is needed. General criteria which serve as the goals of the model development are discussed below, and the systematic approach to arriving at the “best” model is discussed in Section 5.

i. Minimum no. of variables (parsimony).

Development of a multiple regression model usually involves a trade-off. Entering more variables can lead to a marginally better fit to the data, but more variables can also elevate the standard error of prediction and cause instability of the model coefficients in some cases. Therefore, the principle of parsimony was employed, which states that between two models with nearly the same predictive power, the smaller model should be selected.

ii. High F-statistic

This statistic comes from the F-test and is a measure of the model’s significance, i.e. the likelihood that the relationship between the variables did not arise simply by random chance. The higher the F-statistic, the better. In this study the value is characterized in terms of the p-value, or the probability that the model does not arise from random chance.

iii. High R^2

This parameter represents the fraction of variability in the dependent variable (natural flow in this case) that is explained by the independent or predictor variables. R^2 ranges from 0 (no variability is explained) to 1 (a perfect prediction). Obviously, the higher the better, but R^2 is inflated as more variables enter the model. Therefore, the adjusted R^2 was used. This parameter is R^2 adjusted for the influence of the number of predictor variables.

iv. Low standard error

Standard error is the standard deviation of the difference between the predicted values and the true values. It is a measure of the magnitude of the model predictive error.

v. Well-behaved Residuals

The model residuals, which are the differences between the predicted values and the true values, should be as close to normally distributed as possible. Given two models with similar predictive capacities, the model with more normally-distributed residuals was selected.

vi. Coefficients should make physical sense

The sign of the coefficients on the indicator variables should agree with expectations given the physical linkage to natural flow. For example, the coefficient on surface water indicators should be positive (high values of precipitation or streamflow should be associated with high values of natural flow). The coefficient on a variable representing depth to water in a groundwater well should be negative (higher values of depth to water should be associated with lower values of natural flow). Because of high cross-correlation between the indicator variables, this is not always the case. Correlation between predictors, or collinearity, is pervasive in this model study because the hydrologic indicators are often different measures of the same process, or measures of the same process at different locations. A full discussion of the effects of collinearity on multiple regression models is beyond the scope of this report, but techniques for dealing with it are discussed in Section 9.

6. Model Development

a. Selection of Hydrologic Indicators

Indicator or predictor variables were selected based on a postulated physical linkage between the variable and natural flow in the Snake River, given the prevailing knowledge of the river's hydrology. Variable generally fall into three categories: wells, surface water flows, and basin precipitation or snowpack.

In addition to the postulated physical linkage, indicator variables were required to meet several criteria:

1. The period of record must cover 1991-2010, which is the period used to develop the regression models.
2. Data points must be available on or near the observation dates.
3. Data collection must be likely to continue in the future.
4. The data must be accessible in real-time as of the observation date. This precludes data sets such as NWS co-op precipitation stations.
5. The observation must not involve complicated calculations, to ensure ease of use for canal managers. For example, basin snow index is calculated by the NRCS for the first of each month. The index could be calculated for any other date, but would involve gathering the data for all the stations involved and making the calculation manually.

The list of variables used in the model selection is shown in Table 2.

i. Wells

Groundwater levels, especially those in close proximity of the gaining river reaches, should be related to natural flow based on the fact that groundwater physically discharges to the river and makes up nearly all of the reach gain in the late season. Numerous wells are monitored regularly by the U. S. Geological Survey and the U. S. Bureau of Reclamation. The wells shown in Table 2 were selected based on the above criteria. Both wells near to the river and away from the river were included.

ii. Tributary Inflows

Spring Creek, Blackfoot River, and Portneuf River were selected as possible indicators. All three gauges are maintained by the USGS and daily values are published. However, the rating curves on Spring Creek and Blackfoot River are extremely poor, with estimated error of +/-20% or more. Therefore, rather than utilize the daily data from the rating curve, data was interpolated between the monthly current meter measurements which are made at these sites.

iii. Snake River Indicators

Snake River unregulated runoff at Heise was included since the unregulated flow is often used as an indicator of water supply conditions. The indicators included runoff from April 1, May 1, or June 1, through the assumed end of the runoff season, July 1. This corresponds to forecasts prepared by the U. S. Bureau of Reclamation in April, May, and

June of each year. To the extent this predictor enters a model, it is the forecast value which must be used. The USBR forecast is derived primarily from snowpack indices in the Upper Snake basin.

Reservoir storage in the Upper Snake system on the observation date was included, based on the assumption that higher storage generally indicates larger carryover and/or higher surface water supply, which could lead to greater natural flow in the later season.

iv. Precipitation

Precipitation is a general indicator of basin water supply and a more direct indicator of surface water runoff. A precipitation index was developed including readily-available station data in the Upper Snake basin. In addition, precipitation at the Afton, Wyoming gauge was included as a separate variable because preliminary model testing indicated that it had an unusually strong correlation with natural flow.

v. Snowpack

The basin snow conditions prior to June 1 were assumed to be related to natural flow later in the season. High snowpack generally leads to an extended runoff hydrograph, greater surface water diversions, and greater surface water infiltration which could return to the river as reach gain later in the season. Snowpack indices above American Falls and above Heise, as calculated and published by the NRCS, were used.

vi. Canal Diversions

As a more direct measure of surface water diversions, the cumulative diversions in the Upper Snake through the observation date were postulated to be an indicator of surface water infiltration and potential groundwater return flow later in the season.

vii. Miscellaneous Indicators

Other indicators with a possible linkage to natural flow were included. These include the previous-year evapotranspiration at Aberdeen, the Palmer Drought Index (PDI), and the yield from the Big Lost River basin. The PDI was included as a potential indicator of persistent drought which should lead to overall downward or upward trends in reach gain. Several lags were evaluated and it was found that the 1-year lag PDI had the highest correlation. The Big Lost yield was included as a potential indicator of input to the ESPA from tributary basins. Due to its distance from the river, several lags were evaluated and the 2-year lag was found to have the highest correlation.

viii. Other Possible Indicators Exist

The parameters listed in Table 2 are surely not the only hydrologic indicators that could possibly be evaluated. However, they are believed to be representative of all factors which could affect natural flow and for which data is readily available. Further investigations could be made using other data not included in this list.

Table 2. Hydrologic indicator variables utilized for the model selection.

Variable	Description	Units
03N37E12BDB1	USGS observation well depth to water	Feet
03N38E22BAB1	USGS observation well depth to water	Feet
02N37E02ABA1	USGS observation well depth to water	Feet
08S27E31DDA1	USGS observation well depth to water	Feet
08S26E33BCB1D	USGS observation well depth to water	Feet
08S25E36DAA1	USGS observation well depth to water	Feet
09S25E03CAC1	USGS observation well depth to water	Feet
08S24E31DAC1	USGS observation well depth to water	Feet
05S31E27ABA1	USGS observation well depth to water	Feet
Spring Creek	Discharge at the USGS gauge 13075983, Spring Creek at Sheepskin Road, actual current meter measurements interpolated to the observation date since the rating curve is very poor.	CFS
Blackfoot River	Discharge at the USGS gauge 13068500, Blackfoot River nr Blackfoot, actual current meter measurements interpolated to the observation date since rating curve is very poor.	CFS
Portneuf River	Discharge at the USGS gauge 13075500, Portneuf River nr Pocatello, published daily value since rating curve is good. 60-day average of Portneuf River flow was also investigated.	CFS
Canal Diversions	Cumulative canal diversions from Idaho Falls to American Falls from season commencement through the observation date, from USBR Hydromet system	Acre-Feet
Precipitation Index	Cumulative water year precipitation through the observation date at Upper Snake gauges Afton, Ashton, Rexburg, and Pocatello	Inches
Precipitation Afton	Cumulative precipitation at Afton gauge, both calendar year (January 1 through the observation date) and water year (October 31 through the observation date) were examined.	Inches
Snake River at Heise Unregulated	Unregulated discharge from Apr 1, May 1, or June 1, through July 1 (note: it is necessary to use the forecasted Heise unregulated discharge prepared by the U. S. Bureau of Reclamation.)	CFS
Snow Index above American Falls	NRCS snow index for Upper Snake basin above American Falls on April 1, May 1, or June 1	Inches
Snow Index above Heise	NRCS snow index for Upper Snake basin above Heise on April 1, May 1, or June 1	Inches
Reservoir Fill	Active reservoir capacity on the observation date in Upper Snake system, excluding Minidoka, Milner, Henry's Fork, and Little Wood, from USBR Hydromet system	Percent
ET Previous Year	Previous-year total ET at Aberdeen station for crop Alfalfa-mean, from USBR Agrimet system	Inches
PDI Lag 1	Palmer Drought Index, average monthly from May through April, lagged by 1 year. From NOAA North American Drought Monitor, Climate Division 1009 (Upper Snake River Plains)	Unitless
Natural Flow Lag 1	Natural flow from Blackfoot to Neeley, July 15 through end of season, lagged by 1 year, from Water District 1.	Acre-feet
Big Lost yield	Total annual discharge passing the stream gauge near Arco, USGS gauge 13132500, lagged by 2 years	Acre-feet

b. Model Selection Process

A number of techniques exist and have been utilized to select the "best" model from among the thousands of potential models involving all possible combinations of the predictor variables. The techniques generally fall into two categories:

1. Stepwise techniques, in which variables are systematically entered or removed from the model and statistical tests performed to determine whether the entered or removed variable adds or removes significant information.

2. All-best-subsets techniques, in which every possible model is examined and a statistical measure of model fit is calculated for each. Typically, the number of variables entering the model is limited to some number smaller than the total number of predictor variables.

Stepwise approaches have been shown to have certain limitations that can result in selection of sub-optimal models. The primary methodology for selecting the model is the all-best-subsets approach, using the statistical parameters Mallow's C_p and adjusted R-squared. Preference was given to smaller models, preferably with no more than four predictor variables. Stepwise approaches were used in some cases where the all-best-subsets approach were ineffective in narrowing the number of models.

It must be noted that there is not one unique, "best" model. A number of models usually exist that are nearly equivalent in terms of quantitative measures of adjusted R-squared and standard error. Judgment was employed to select the optimal model based on ease of use, residual normality, and parsimony. Often two competing models will be statistically similar, but one model will be a better fit to data on the extremes, which is important for this study.

7. Models

The selected models resulting from application of the above approach are discussed below, along with pertinent statistics regarding the goodness-of-fit of each model. A description of each predictor variable used is provided in Table 3.

Table 3. Key to predictor variables selected and used in the models.

HeiseQU4	Heise unregulated flow joint forecast, April through July	Million acre-feet
HeiseQU5	Heise unregulated flow joint forecast, May through July	Million acre-feet
HeiseQU6	Heise unregulated flow joint forecast, June through July	Million acre-feet
Wells: 02N37E02ABA1 08S24E31DAC1 09S25E03CAC1 08S25E36DAA1	Depth to water in well as published by USGS for the month of the prediction date. The measurement is typically made from the 15th through the 20th. Some wells are measured by the USGS, and some are measured by the USBR.	Feet
P_AftonCY5	Cumulative precipitation at Afton WY station from January 1 through May 15, from USBR Agrimet	Inches
P_AftonCY6	Cumulative precipitation at Afton WY station from January 1 through June 15, from USBR Agrimet	Inches
SpringCr4	Spring Creek discharge on April 15, interpolated from field measurements made by USGS (not the daily value from the rating curve)	Cubic feet per second
SpringCr5	Spring Creek discharge on May 15, interpolated from field measurements made by USGS (not the daily value from the rating curve)	Cubic feet per second
SnowAF4	Snow index above American Falls on April 1, published by NRCS	Inches
SnowAF6	Snow index above American Falls on June 1, published by NRCS	Inches
Portneuf60	Average flow in Portneuf river for 60 days prior to the prediction date, based on USGS daily values.	Cubic feet per second
ResFill5	Reservoir fill percentage in upper snake on May 15, equal to the sum of storage in American Falls, Grassy Lake, Island Park, Jackson Lake, Palisades, and Ririe, divided by 3.9501 million acre-feet	Percentage (range 0 to 100)
ResFill6	Reservoir fill percentage in upper snake on June 15, equal to the sum of storage in American Falls, Grassy Lake, Island Park, Jackson Lake, Palisades, and Ririe, divided by 3.9501 million acre-feet	Percentage (range 0 to 100)

a. Storage date

It is desirable to know the date that the canal company first begins to utilize storage to a significant degree. This point in usually referred to as "going on storage." The SCD is normally not determined by the canal company but is a function of the water rights allocation model used by WD1. The canal company calls for a certain diversion rate, and WD1 determines whether adequate natural flow exists to supply this rate, based on the natural flow calculation algorithm described in Section 3. If not, the difference is made up by a draw on storage.

The date that TFCC begins the storage draw each year was obtained from WD1 records. Judgment was required to select a date, since in some years a very small amount of storage might be allocated by WD1, followed by a long period of no storage use, leading to a point where storage use clearly begins. This may be an artifact of the accounting methodology. Thus, this variable is more properly called the “date of first significant storage commencement.” For example, usage patterns of storage are illustrated on Figure 7 for the years 2001 through 2010. The point where the storage begins is clearly evident in most years.

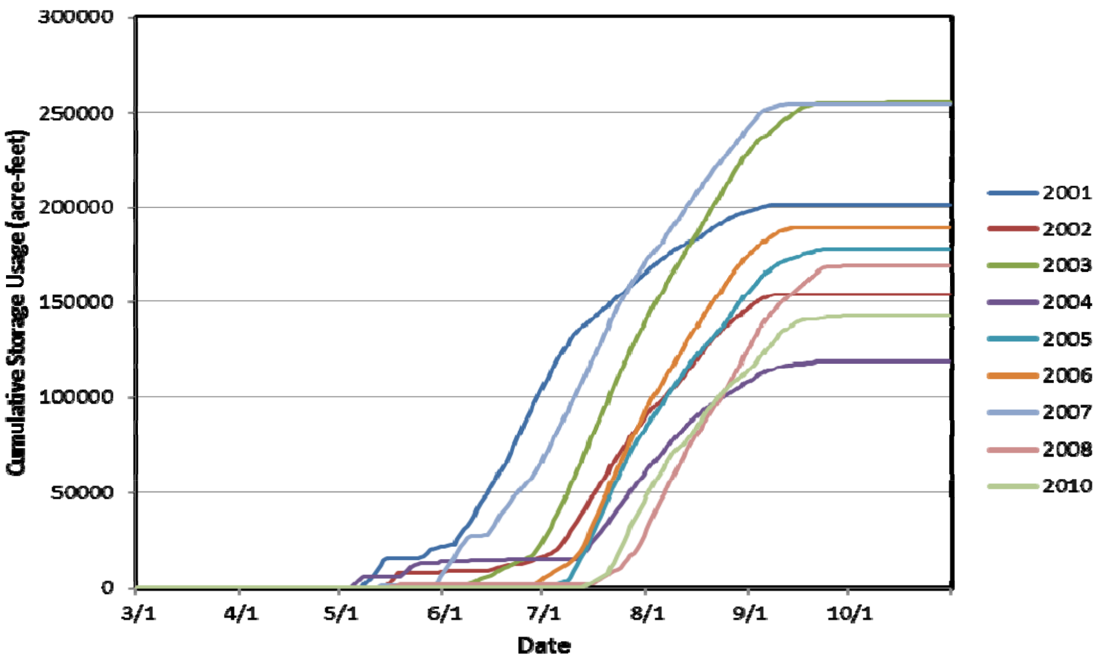


Figure 7. Cumulative storage draws by the Twin Falls Canal Company.

As would be expected, the SCD is determined almost exclusively by surface water indicators; higher runoff leads to a longer period before storage is needed. The Heise unregulated flow and the snow index above American Falls have the strongest effects. A third-order fit to Heise unregulated flow is needed to capture the extremes seen in the data, as shown in Figure 8. For the May and June models, groundwater indicators in addition to surface water were statistically significant. The selected models are shown in Table 4.

Generally, model performance is good, with r-squared above 0.8 and adjusted r-square ranging from 0.76 to 0.80, with the models able to capture even extreme years such as 1992 and 2007. Standard error of estimation is 11 or 12 days. A time series of observed and predicted data is shown in Figure 9.

Table 4. Storage date prediction models.

Prediction Date	Model	R^2_{adj}	p	SE
April 15	$SCD = -154.93 + 187.4\ HeiseQU4 - 45.87\ HeiseQU4^2 + 3.794\ HeiseQU4^3$	0.76	<0.001	12.2
May 15	$SCD = -606.56 + 3.417\ 02N37E02ABA1 + 0.1712\ SpringCr5 + 17.83\ HeiseQU5$	0.80	<0.001	11.2
June 15	$SCD = -491.0 + 4.927\ 08S24E31DAC1 - 5.553\ 09S25E03CAC1 + 2.942\ P\_AftonCY6 + 1.732\ (\ln HeiseQU5)^2$	0.78	<0.001	11.6

NOTES:
SCD is number of days after April 1
R2 = adjusted r-squared
p = probability value from the F-test
SE = standard error of estimation, in 1000 acre-feet

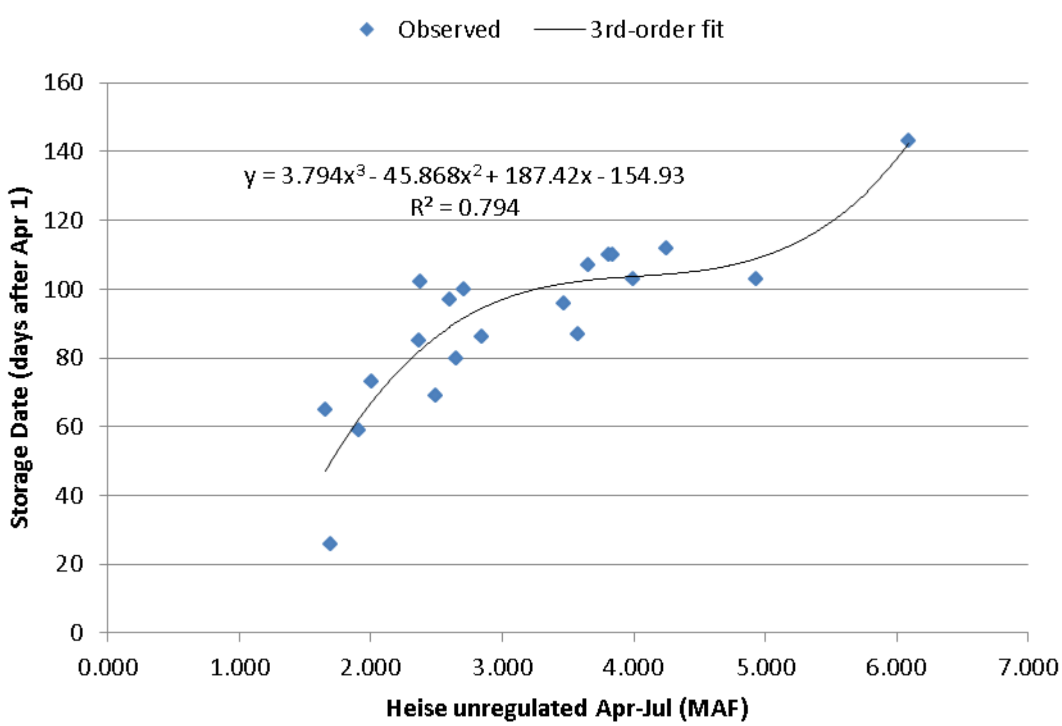


Figure 8. Example of third-order fit to Heise unregulated flow data (April model). A higher order is needed to adequately model the curvature of the data.

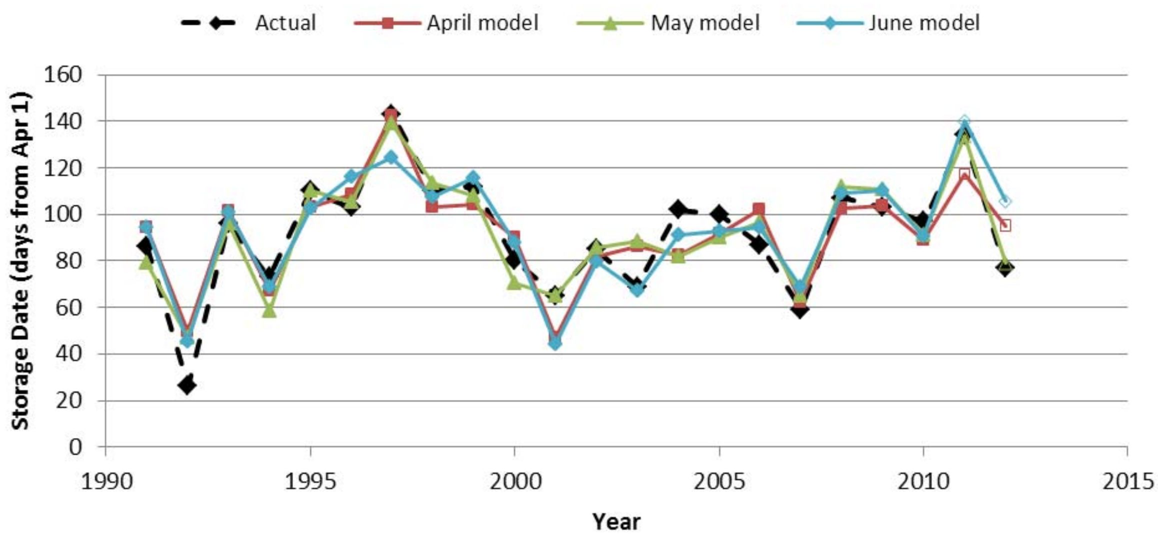


Figure 9. Comparison of observed and predicted storage date. Open symbols indicate verification years 2011 and 2012.

b. Natural Flow

Total natural flow diversion by TFCC after the storage date was obtained from WD1 records. As noted above, natural flow after the storage date is chiefly reach gain, but a significant portion may also be remaining natural flow passing Blackfoot, depending on the year. Hence, both surface water and groundwater indicators are important. Selected models are shown in Table 5 and a time series of observed and predicted data is shown in Figure 10.

Table 5. Selected models for natural flow diversion prediction (in kaf).

Prediction Date	Model	R^2_{adj}	p	SE
April 15	*NFDiv* = 5420 -16.94 *03N37E12BDB1* – 35.67 *08S25E36DAA1* +29.62 *09S25E03CAC1* – 10.10 $HeiseQU4^2$	0.71	<0.001	50.18
May 15	*NFDiv* = 3873 – 16.10 *02N37E02ABA1* – 6.760 *09S25E03CAC1* – 720.2 *SpringCr5* – 1637 $HeiseQU5^3$	0.75	<0.001	46.85
June 15	*NFDiv* = 1631 – 9.192 *08S25E36DAA1* + 0.8502 *SnowAF6* – 1.688 (ln $SnowAF6)^3$ – 5.808 $HeiseQU6^3$	0.69	<0.001	52.02

NOTES:
NFDiv is Twin Falls Canal Company natural flow diversion from the date of storage (SCD) through September 30, in 1000 acre-feet.
R2 = adjusted r-squared
p = probability value from the F-test
SE = standard error of estimation, in 1000 acre-feet

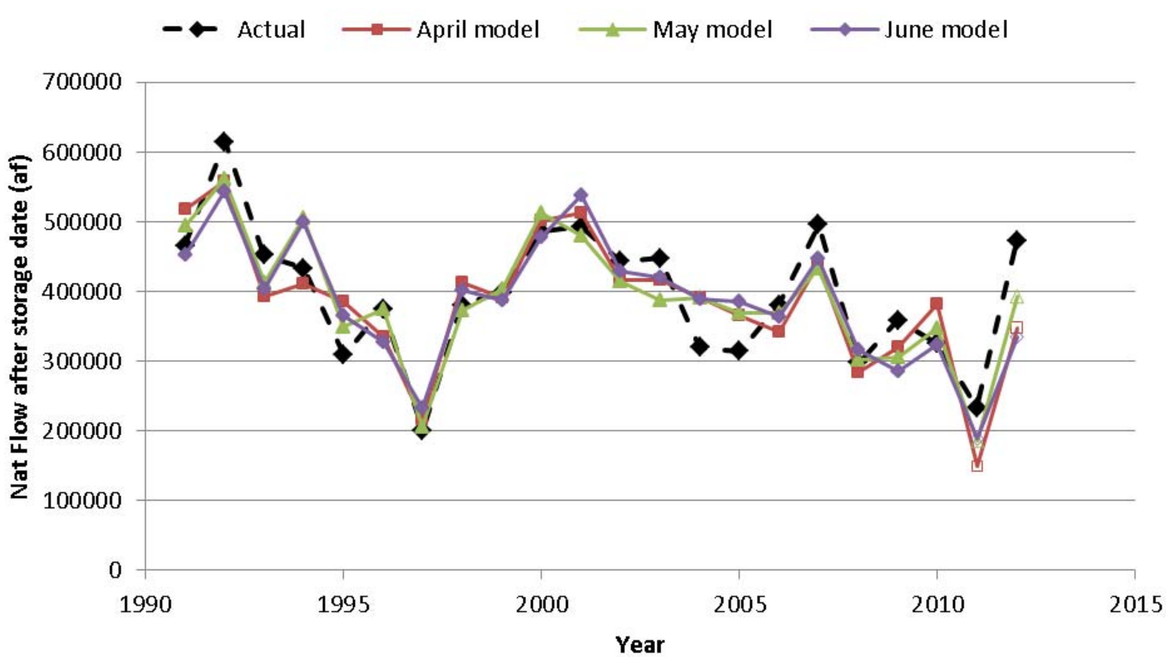


Figure 10. Comparison of observed and predicted natural flow after storage date. Open symbols indicate verification years 2011 and 2012.

c. Diversion Demand

The TFCC diversion demand after the storage date was found to be a strong function of the storage date alone, with no hydrologic indicator playing an appreciable role. The total demand varies little from year to year and each year the seasonal pattern of demand is nearly the same. Only about a 10% maximum variation is observed in demand from year to year. Thus, knowing the storage date alone, the demand after that date can be predicted with high accuracy and there is no need for any other models involving hydrologic indicators.

This approach might be suspect if the demand were nonstationary, i.e. if the probability distribution were changing over time. However, demand is at best a weak function of hydrologic variables which may be nonstationary, and irrigation practices on the tract are well established and changing slowly, if at all. Therefore, it appears to be a reasonable assumption that the time series of demand is stationary.

The diversion volume to be predicted is really the "potential demand," i.e. the demand that would exist if water supply were not limiting. Years in which the water supply was limiting to the company's diversion (1992, 1994, and 2001) were therefore omitted from the analysis.

Demand as a function of the storage date is shown in Figure 11. The omitted years shown, all lying clearly below the potential demand curve. A second-order polynomial curve is an excellent fit to the data.

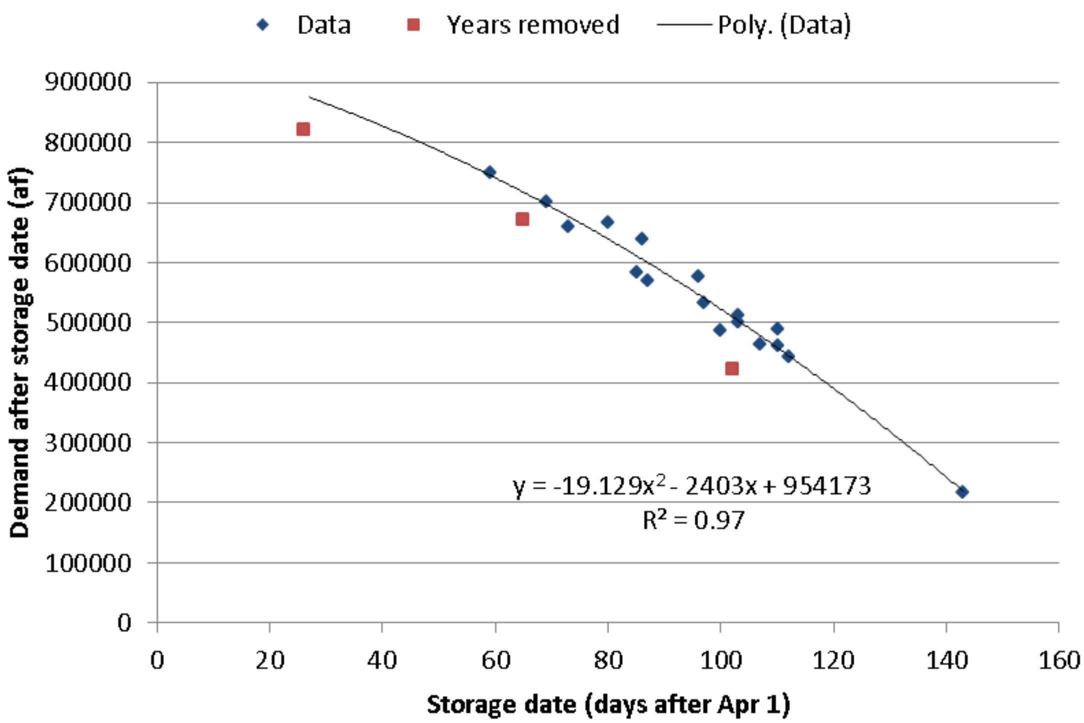


Figure 11. Regression model for TFCC demand after the storage date.

d. Storage Requirement

The storage requirement or natural flow deficit for TFCC was predicted independently of natural flow or storage date, as described above. Because of this, the predicted storage requirement is not exactly equal to the difference between the predicted demand and predicted natural flow. As in the case of natural flow, the deficit is expected to be a function of both surface water and groundwater conditions. The models indicate that this is true, with both groundwater well levels and surface water indicators found to be statistically significant predictors.

Generally the models perform well with the exception of years 2003 and 2004. The April and May models significantly underpredicted the deficit in 2003 and overpredicted the deficit in 2004. Selected models are shown in Table 6 and a time series of observed and predicted data is shown in Figure 12.

Table 6. Selected models for storage requirement (deficit) prediction.

Prediction Date	Model	R^2_{adj}	p	SE
April	*Deficit* = 2810 – 17.97 *02N37E02ABA1* + 13.29 *09S25E03CAC1* – 0.7910 SpringCr*4* + 0.3615 *SnowAF4* – 98.97 *HeiseQU4*	0.72	<0.001	33.54
May	*Deficit* = 1701 + 13.72 *09S25E03CAC1* – 13.72 *08S24E31DAC1 – 0.5845 SpringCr5* – 14.36 *P_AftonCY5* + 3.398 *ResFill5*	0.72	<0.001	33.03
June	*Deficit* = -434.52 + 3.347 *02N37E02ABA1* – 0.1796 *Portneuf60* – 16.387 *P_AftonCY6* + 3.072 *ResFill6*	0.74	<0.001	32.32

NOTES:
Deficit is in 1000 acre-feet.
R2 = adjusted r-squared
p = probability value from the F-test
SE = standard error of estimation, in 1000 acre-feet

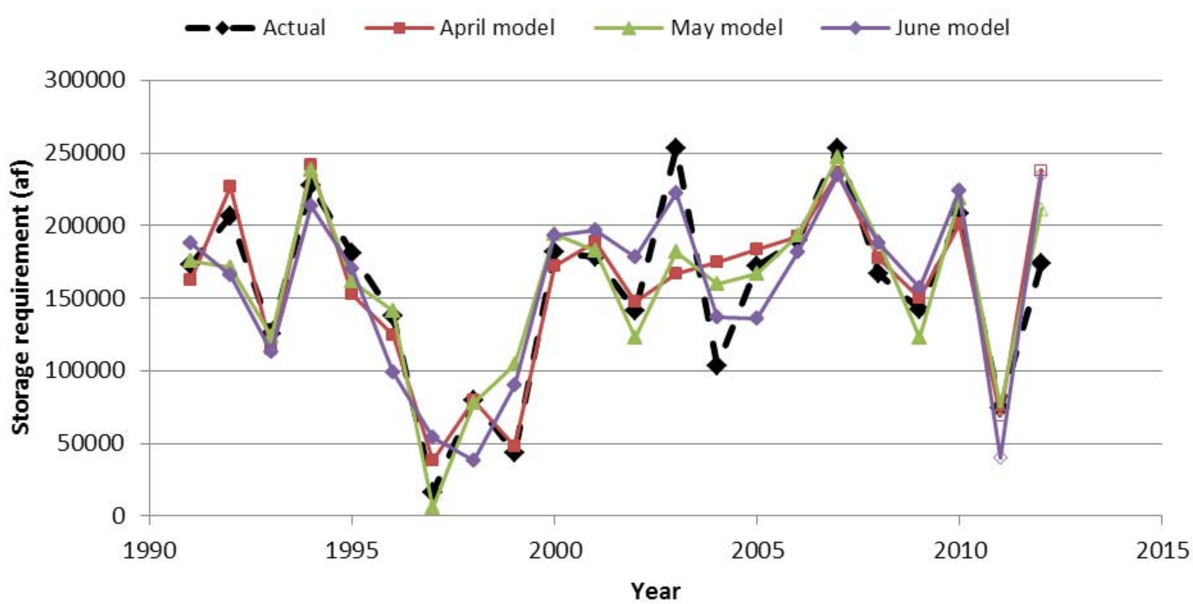


Figure 12. Comparison of observed and predicted storage requirement. Open symbols indicate verification years 2011 and 2012.

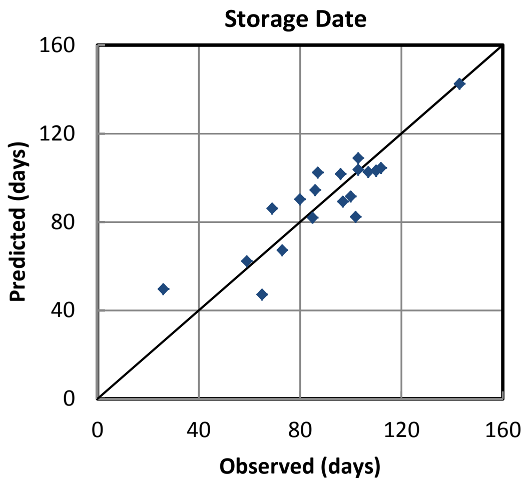
e. Prediction Error

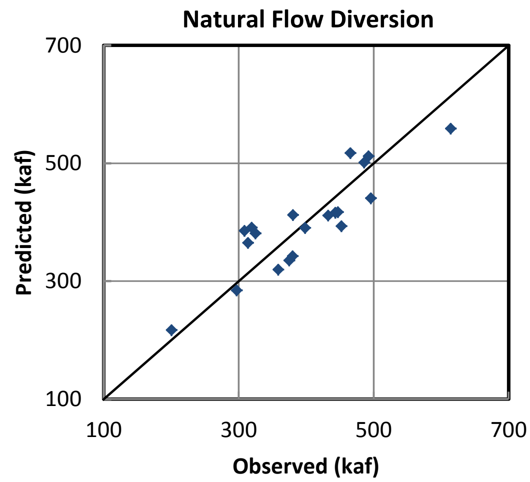
Relative to correlations typically found between natural hydrologic variables, the fit of the models is generally very good. Development of models using July 15 predictor variables was also attempted. However, all models were significantly poorer than those developed using the June 15 predictors. Therefore, there is no benefit to the use of later-season indicators.

No model is perfect, and these models are no exception. The predicted value will not be equal to the true value. The error, or the difference between the true and predicted values, is depicted by the scatterplots above. The error will sometimes be positive and sometimes negative, i.e. the model may predict high or low. The nature of this error is important for determining a range of likely values of storage requirement rather than one exact value.

The mean error should be zero, meaning the model is unbiased and does not consistently predict high or low. That is the case in all of the models developed in this study. The expected distribution of the prediction error can be characterized by calculated SE_{pred}, which is the standard error of prediction. It is similar to the standard error of estimation shown in Tables 3 through 5, but accounts for two factors: the imperfection of the model prediction even if all of the B coefficients were perfectly known, and the fact that the B coefficients themselves are uncertain. SE_{pred} is dependent on the value of the predictors and can be calculated once new observations become known. Then, it may be used to determine confidence limits on the predicted value assuming a normal distribution.

A visual method of interpreting model error is the scatterplot, which illustrates the correlation between predicted and observed data points. A perfect model would have all points lying on the 45-degree line. Scatterplots are shown in Figures 13 through 15 for all models.





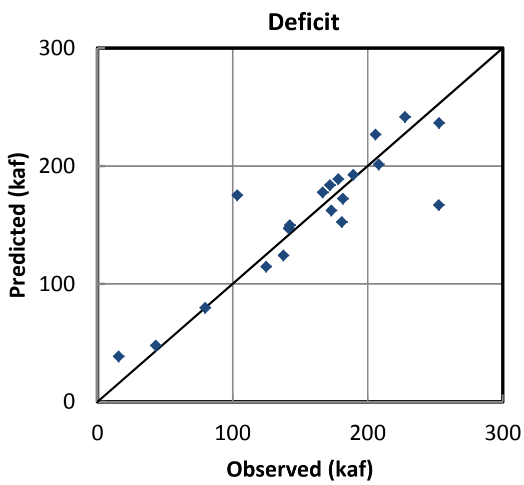


Figure 13. Scatterplots of predicted vs. observed data for models using April 15 predictor variables.

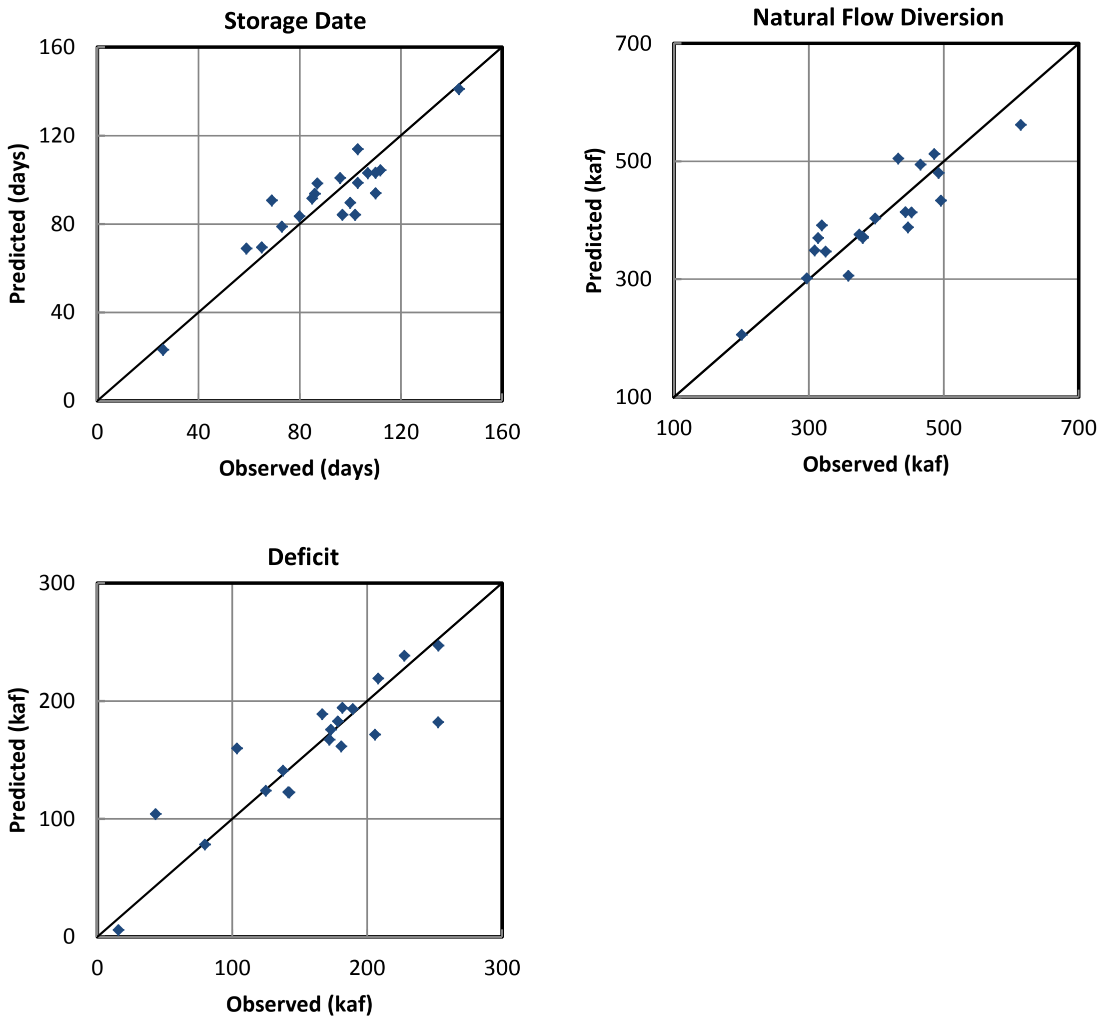


Figure 14. Scatterplots of predicted vs. observed data for models using May 15 predictor variables.

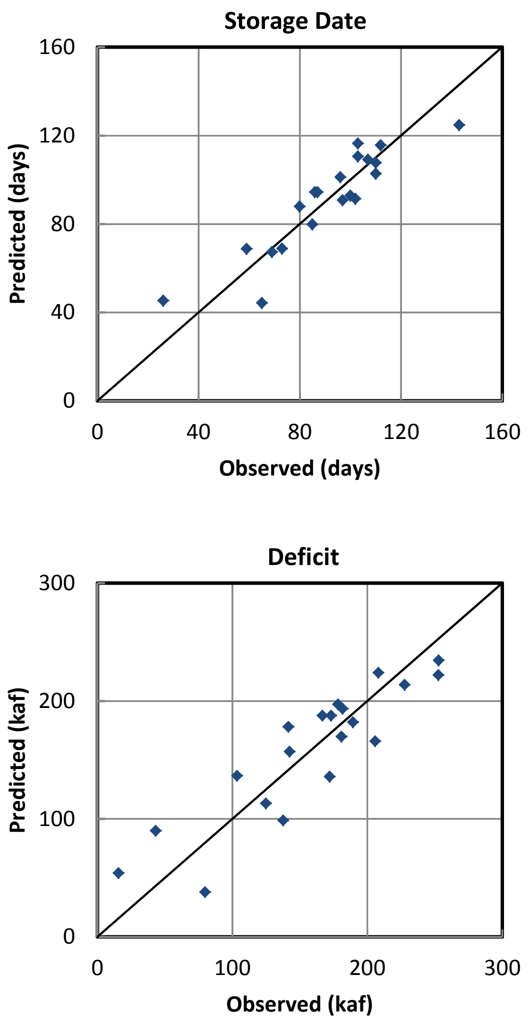


Figure 15. Scatterplots of predicted vs. observed data using June 15 predictor variables.

f. Conclusion

The conclusion of the natural flow model development is that it is feasible to utilize hydrologic indicators to forecast the storage commencement date, the natural flow diversion, and the storage requirement for the upcoming season, to an accuracy that is useful for canal company planning. The models presented are statistically defensible; however, they are not the only defensible models that could be developed. Other combinations of predictor variables are possible which would likely yield similar results. Due to the high level of correlation between variables, there may be no single "best" model in many cases.

8. Model Verification for 2011 and 2012

A rigorous approach when developing a regression model or other types of models that involve a calibration procedure to estimate model parameters involves holding out some portion of the data as a verification set. The model would be calibrated to the remaining data, and the calibrated model used to predict the values in the verification set, which were not used to calculate the model parameters. In the present study, the data set length was limited to 20 years by the fact that the Water District 1 calculation procedures changed in 1990 and 1991 was the first year with the new procedures, which are substantially different than those use in prior years. Therefore, it was decided that the value of having all of the data points to calibrate the models was greater than the value of a having a long verification period. When more data is available – 5 additional years may be adequate – the models developed in this study can be better verified and rigorous statistics calculated.

However, the years 2011 and 2012 were not used for the model calibration, so the performance of the models can at least be assessed for these two years. A comparison of observed and predicted values for storage date, natural flow, and deficit are shown in Table 7. These values are also depicted on Figures 9, 10, and 12. Recall that the deficit is predicted independently and therefore does not equal the difference between the predicted demand and natural flow.

2011 was a relatively high water year, with a low storage usage of 74 kaf. The model predicted the deficit with good accuracy, with the April and May models performing better than the June model. 2012 was a relatively dry year. The model under-predicted the natural flow diversion availability and over-predicted the deficit. An anomalous short-term appearance of remaining natural flow passing Blackfoot occurred in July 2012, after the RNF had gone to zero. Such an event is difficult to predict and likely contributed to the prediction error. In both years, all predictions were well within the typical range of error observed during the calibration period. The total diversion demand was predicted with high accuracy in both years. Based on these two years, the models appear to be performing well.

Table 7. Comparison of observed and predicted values for 2011 and 2012.

	Observed	April Model	May Model	June Model
2011				
Storage Date	**August 13**	July 27	August 12	August 19
Demand after storage date (kaf)	**308**	289	289	289
Natural Flow Diversion (kaf)	**233**	149	186	189
Deficit (kaf)	**74**	69	75	40
2012				
Storage Date	**June 17**	July 5	June 19	July 15
Demand after storage date (kaf)	**646**	656	656	656
Natural Flow Diversion (kaf)	**472**	348	393	335
Deficit (kaf)	**174**	238	212	235