Water Supply Forecasting Models for Libby, MT
2014 Revision

US Army Corps of Engineers
Seattle District

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Executive Summary

Seattle District, U.S. Army Corps of Engineers completed a review and update of the Libby seasonal volume runoff forecast in the summer of 2014 to address the following:

1. Develop forecast equations that improve month-to-month consistency but also physically represent the Kootenai Basin hydrology.

2. Eliminate the Quasi Biannual Oscillation (QBO) from the forecast equations.

3. Consider only those climatic indices with a fully-explained connection to the Kootenai Basin hydrology, show a relatively strong correlation with the Apr-Aug inflow volume, and do not misinform the forecast equations.

4. Eliminate the November first-of-month forecast. No seasonal volume forecast uses it.

5. Reduce and minimize forecast and regression errors from the previous set of forecast equations.

6. Improve geographic coverage of the snow stations.

New statistical equations were developed to forecast the April-August inflow volume to Libby Dam, Montana. These forecast equations make use of three classes of hydro-meteorological predictor variables: climate index through the 1-January forecast, precipitation sums from October-to-date, and snow water equivalent (SWE). These predictor variables and the forecast statistics are summarized Principal Components Regression Results Section.

All of the objectives of the forecast review and update were met. The new forecast equations provide improved forecasts with both smaller forecast cross validation standard error (CVSE) and better month-to-month forecast consistency. The forecast consistency is achieved through stability in the variable sets used from one month to the next. This forecast update also emphasizes using physical measurements (snowpack and precipitation) over the use of climatic indices after the January forecast. Finally, several climate indices were evaluated, and the QBO was replaced by the Southern Oscillation Index (SOI). Furthermore, the SOI is not a predictor variable after the January forecast, thereby emphasizing physical measurements (snowpack and precipitation) and eliminating the prior tendency of the QBO to randomly misinform the forecast.

While the current and proposed forecast models do not completely eliminate error due to extreme precipitation as seen in water year 2012, the proposed forecast model does reduce the error of the forecast from the current model. These types of forecast models assume average future precipitation and are subject to errors in extremely dry and wetter springs in the Kootenai Basin.

Contents

Table of Figures

Table of Tables

Introduction

Water supply forecasts in the western United States provide information critical to both local and regional interests. Accurate and timely prediction of the spring and summer streamflow allows reservoir operators additional flexibility in planning effective strategies for the storage and release of the anticipated runoff. These strategies strive to provide maximum benefits to a wide assortment of purposes and water users, while meeting all statutory and regulatory constraints.

Libby Dam was brought into service by the US Army Corps of Engineers (Corps) in 1973 as the sole U.S. project under the Columbia River Treaty. Libby is operated by the Corps as a multi-purpose project for hydropower, flood risk management, and recreation. Project operations also incorporate water quality and quantity targets in support of fisheries and environmental objectives. The dam is located on the Kootenai River in northwestern Montana, about 40 miles south of the US-Canadian border. The drainage basin above Libby Dam covers 8985 square miles, with a topography ranging from 2000 feet to 12,000 feet elevation. Lake Koocanusa, the reservoir behind Libby Dam, contains approximately 5.0 million acre-feet (MAF) of active storage that can be utilized to fulfill the often competing authorized purposes and environmental objectives. Annual reservoir operations consist of drafting the reservoir during the winter months to provide space to store water for either local or system flood risk management, with reservoir refill occurring during the spring and summer months to provide water later for other purposes including hydropower, environmental and recreation objectives. The water supply forecast (WSF) models provide advanced insight into the expected reservoir volume inflows during the spring-through-summer runoff season. These runoff forecasts, issued monthly from December through June, are used to set targets that guide the draft and refill operations of the reservoir, set minimum spring and summer flow for bull trout, and determine the volume to be provided for sturgeon pulse, up to 1.6 MAF each spring.

Libby Dam Operational Runoff Volume Forecast History

The initial Libby Dam Water Supply Forecasting (WSF) procedure was developed prior to project completion in 1972 and the initial filling of the reservoir in 1973. The initial WSF procedure, known as the "split-basin" model, subdivided the basin into a northern region ("above Fort Steele") and a southern region ("Libby local") and developed a set of regression equations for each region. Each regional model contained four variables: Fall Runoff (FRO), Winter Precipitation (WP), Snow Water Equivalent (SWE) and Spring Precipitation (SP), with each variable representing a weighted combination of observed values for several stations and/or several months. The calculated values from the equations for the two regional models were added together to determine the total basin runoff. Reviews and updates to this initial procedure were performed by Tom Perkins (USACE, 1977), which was followed by the "Wortman-Morrow" forecast update (Wortman, 1986). Additional details of these earlier forecast models are provided in the 2004 forecast update discussed below.

The 2004 Libby water supply forecast update (Wortman, 2004) developed new Libby water supply forecasting equations based on forecasting the entire basin, rather than separate northern and southern basins. Significant features of the 2004 revision (2004PCReg) included:

1) Consideration of the maximum available record for the snow and precipitation data stations.

2) Utilizing principal components regression techniques to develop the monthly forecast equations.

3) Consideration of climate indices in the pool of predictor variables (i.e. SOI/ENSO).

4) Utilizing the cross-validation standard error as a performance statistic in evaluating and comparing forecast models.

The forecast model was revised in 2010 (2010PCReg) after six years of new data and the loss of two snow courses to avalanche and fire. The forecast model was revised once again in 2011 (2011PCReg) after NOAA changed the calibration for the climatic indices. The 2011PCReg extends the dataset through water year 2010 and updates the dataset of climate indices. The following factors and issues are related to the forecast equations developed for the 2011PCReg and can be reviewed in more detail in that report:

1) The historic inflow series to Libby Dam displays two distinct shifts in the record (an upward shift in the mid-1940's and a downward shift in the mid-1970's). The streamflow series is not statistically stationary. The streamflow from 1975 to 2010 (36 years) was identified as stationary and was selected for use in the statistical forecast model.

2) A single climate index (SOI) used in the previous model has been enhanced with the addition of two other climate indices (QBO and PNA).
3) Eight Alberta pillows near the Kootenai basin were brought online between 1984 and 1991. These pillows are all located on the western edge of the Province of Alberta, Canada, along the Continental Divide, just outside the boundary of the East Kootenai basin. Data for six of the eight sites (all but Lost Creek South and Mount Odlum) could be extended back to 1985. This review is the first time these Alberta snow pillows had been considered in the Libby forecast.
4) The use of the Alberta snow pillow sites limited the data calibration dataset to 23 years (1988 to 2010) for the winter season forecast equations and 27 years (1985 to 2010) for the spring season forecast equations, rather than the 36 years that met the streamflow stationarity conditions. The 1-Nov and 1-Dec forecast equations were all calibrated on the full 36 years since these issue dates do not include any snow data. The 1-January to 1-June forecast equations, which all utilize snow data, are calibrated on the available 23 or 27 years of data.

The following sections will discuss the development of the proposed 2014 update to the Libby Dam forecast, and compare it against the 2011PCReg forecast equations.

2014 PCR Forecast Procedure

A Principal Components Regression forecast model (2014PCReg) was developed to forecast the 1-April to 31-Aug runoff volume into Libby Dam Reservoir. First-of-month forecasts are generated during the operations season starting 1-December and continuing through 1-June. This update of the Libby Dam forecast will not include a November forecast since it does not impact the operation of the Dam. The 1-May and 1-June are a Date-to-31-August forecast. The 2014PCReg forecast was developed primarily to maximize the statistical fit to the historic record, measured by the cross-validation standard error (CVSE). The other main goal was to have month-to-month consistency. One of the primary goals of this forecast update is to develop monthly equations that reflect the physical parameters within the basin (SWE and precipitation) versus climatic indices. While climatic indices can inform future precipitation, they also can misinform the monthly forecasts as described in Appendix C. Maximizing geographic coverage and maintaining station consistency throughout the forecast period were secondary considerations in the development of the forecast equations. During development of each month's forecast the equations were reviewed to ensure proper geographic coverage. The watershed above Libby Dam covers 8985 square miles and it is important, given its size, that there is enough spatial coverage to ensure that one part of the basin is not being overly represented. The 2014PCReg forecast equations were developed using SWE data, precipitation data, and climate index data from 1984-2013 for the 1-December through 1-June forecast dates. The selection of the 1984-2013 period of record will be applied across all the months that the forecast is issued and is meant to minimize month-to-month variations.

Libby Dam Inflow Data

As discussed in the Water Supply Forecasting Models for Libby - 2011 Update-Report, the historic inflow (April – August volume) series to Libby Dam displays two distinct shifts in the record (an upward shift in the mid-1940's and a downward shift in the mid-1970's), see Figure 1. The streamflow series is not statistically stationary per the averages at the time of the shifts. The streamflow from 1975 to 2010 (36 years) was identified as stationary and was selected for use in the 2011 Update statistical forecast model. Since the development of the 2011PCReg equations the Apr-Aug inflow volumes from 2011 to 2013 have the largest consecutive three-year average volumes since 1975, displayed in Figure 2. One of the main motivations to rework the equations was to determine if newer equations can more reliably predict to the Apr-Aug inflow volume with the inclusion of the last three high water years. There may be 3 year averages that are higher than the 2011 to 2013 average but those inflow volumes are not part of the inflow record.

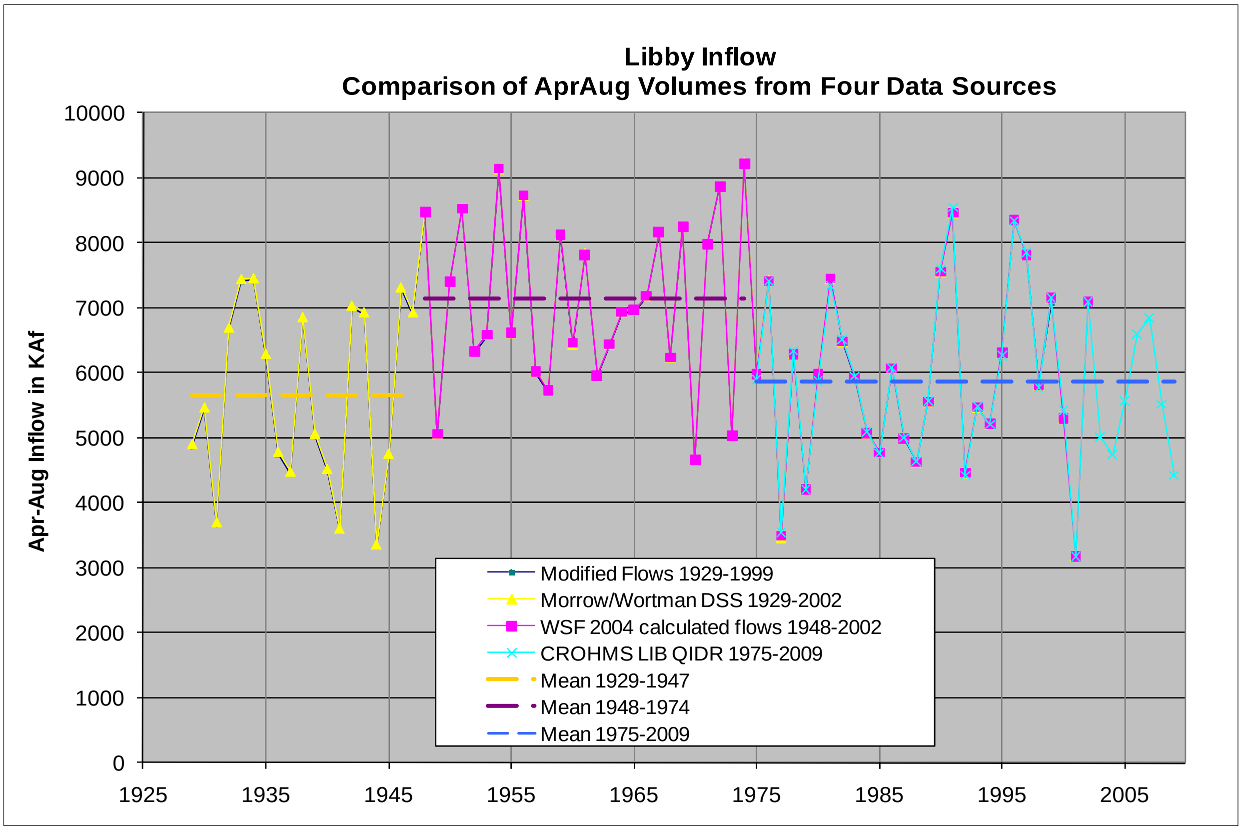


Figure 1. Historic seasonal runoff volume at Libby Dam 1929 - 2010

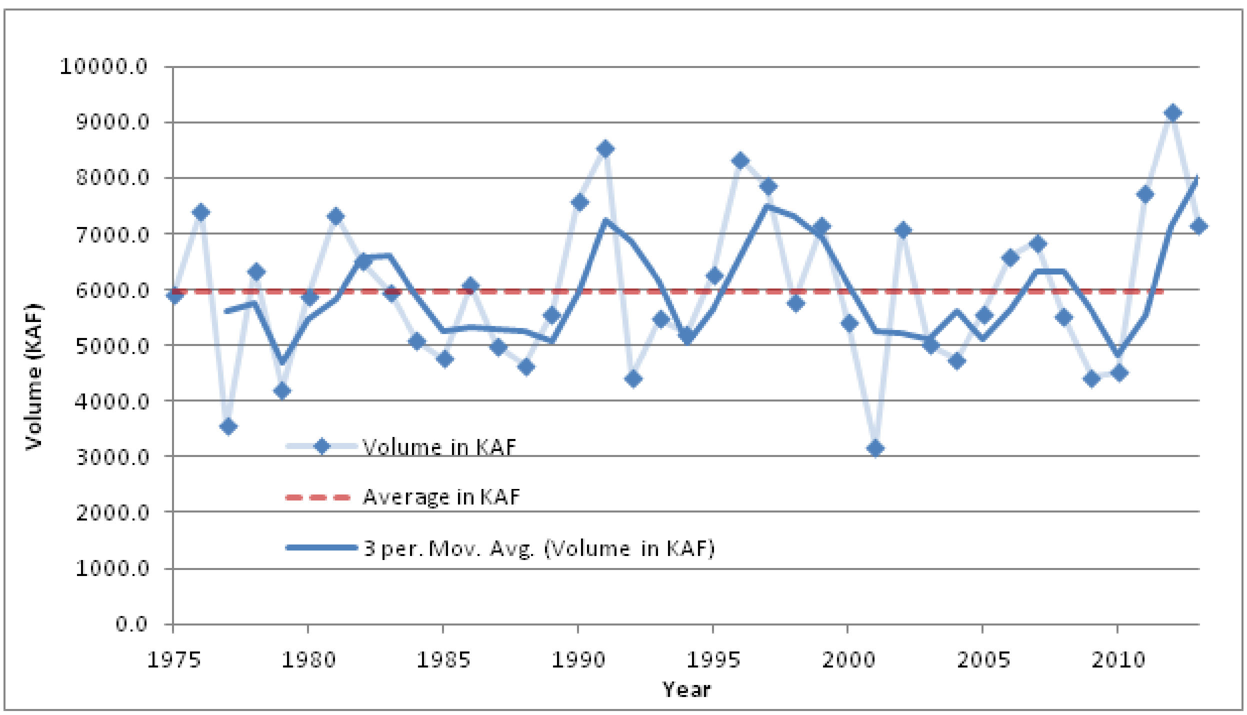


Figure 2. Libby Dam Apr-Aug inflow volumes from 1975 to 2013 with 3 year moving average.

Snow Water Equivalent (SWE) Data

Snow Water Equivalent (SWE) data are reported monthly for the first-of-month observations for snow pillow sites. Only snow pillows were considered for this update because they report in real time. Having SWE stations that report in real time allows for monthly forecast to be issued close to the beginning of the month. Real time reporting also allows for forecasts to be estimated at the end of the month for the next issued forecast in order to smooth operations from month-to-month. In addition to the SWE stations in Montana and British Columbia, eight snow pillow sites in Alberta near the eastern boundary of the Kootenai basin were included as candidate variables. The overall review and selection of snow stations is presented in Appendix A.

Twelve snow stations in and near the Kootenai Basin were prescreened (see Appendix A) for inclusion into the 2014PCReg forecast update. The correlation for each station versus the runoff volume is listed below in Table 1 for each forecast date.

Table 1. SWE stations used to develop proposed equations and their correlation to the Apr-Aug inflow volume from 1984 to 2013.

Station Name	Site ID	Elev (ft)	1-Jan	1-Feb	1-Mar	1-Apr	1-May	1-Jun
MORRISSEY RIDGE, BC	2C09Q	5906	0.413	0.633	0.695	0.787	0.784	0.563
MOYIE MOUNTAIN, BC	2C10P	6365	0.407	0.677	0.710	0.730	0.684	0.647
EAST CREEK, BC	2D08P	6660	0.450	0.695	0.672	0.777	0.698	0.578
HAWKINS LAKE, MT	HAWKM	6450	0.559	0.773	0.805	0.824	0.783	0.682
STAHL PEAK, MT	STHLM	6030	0.493	0.721	0.797	0.809	0.809	0.773
AKAMINA PASS AB	AKAMI	5932	0.493	0.689	0.671	0.610	0.543	0.352
S. RACEHORSE CREEK, AB	SRACE	6299	0.529	0.773	0.818	0.868	0.750	0.580
SUNSHINE VILLAGE, AB	SUNSH	7316	0.574	0.743	0.732	0.834	0.809	0.624
THREE ISLE LAKE, AB	TISLE	7103	0.538	0.730	0.766	0.738	0.643	0.590
GARVER CREEK, MT	GVRM8	4250	0.391	0.558	0.516	0.581	0.410	N/A*
GRAVE CREEK, MT	GRCW4	4300	0.045	0.343	0.483	0.425	0.365	0.221
HAND CREEK, MT	HANW3	5035	0.391	0.558	0.516	0.581	0.410	N/A*

* Garver and Hand Creek are melted out by June

Precipitation Data

The monthly precipitation variables were developed after a review of climate station sites that report in real time in or near the East Kootenai basin. This review resulted in consideration of monthly precipitation data from 17 climate stations. All 17 stations were selected for consideration as candidates for use in the statistical forecast model. The precipitation variables developed from these 17 sites included the observed monthly values and monthly accumulations for durations from two to six months. Appendix B contains analysis and a listing of the 17 climate stations used for monthly precipitation data for this study, including how missing data was filled. The appendix also analyzed the impact of October precipitation on each month's forecast. Table 2 shows the precipitation stations that will be considered as candidate predictor variables for the proposed water supply forecast.

Table 2. Precipitation stations considered for the Libby Dam water supply forecast.

Precipitation Station	Station ID	Location	Latitude	Longitude	Elevation	Period of Record
Cranbrook A	1152102	British Columbia, Canada	49.62 N	115.78 W	3084 ft (940 m)	1938-Present
Creston BC	1142160	British Columbia, Canada	49° 6'	116°31'	2003 ft (610 m)	1913-Present
Fernie	1152850	British Columbia, Canada	49° 30'	115°4'	3284 ft (1001 m)	1913-Present
Glacier NP	1173191	British Columbia, Canada	51° 17'	117°31'	4341 ft (1322 m)	1965-2013?
Golden A	1173210	British Columbia, Canada	51° 18'	116° 58'	2582 ft (787 m)	1914-Present
Kaslo	1143900	British Columbia, Canada	49° 55'	116°55'	1939 ft (591 m)	1914-Present
Sparwood	1157630	British Columbia, Canada	49° 44'	114°53'	3733 ft (1138 m)	1979-Present
Wasa	1158730	British Columbia, Canada	49° 49'	115°38'	3051 ft (930 m)	1924-Present
Porthill	107264	Idaho, United States	49°0'	116° 30'	1775 ft (541 m)	1917-Present
Creston MT	242104	Montana, United States	48° 11'	114° 8'	2940 ft (591 m)	1949-Present
Eureka	242827	Montana, United States	48° 54'	115° 4'	2532 ft (2104 m)	1960-Present
Fortine 1 N	243139	Montana, United States	48°47'	114° 55'	3000 ft (914 m)	1913-Present
Kalispell	244558	Montana, United States	48°19'	114° 15'	2957 ft (901 m)	1913-Present
Libby1 NE	245015	Montana, United States	48° 24'	115° 32'	2096 ft (639 m)	1913-Present
Libby32 SSE	245020	Montana, United States	48° 58'	115° 14'	3465 ft (1056 m)	1949-Present
West Glacier	248809	Montana, United States	48°30'	113° 59'	3154 ft (961 m)	1949-Present
Whitefish	248902	Montana, United States	48° 25'	114° 22'	3100 ft (945 m)	1939-Present

Climate Index Data

For this update the only variables considered are the SOI and PNA. The QBO was in the 2011PCReg update and, while at the time the variable looked to improve the CSVE, as discussed in Appendix C the QBO did cause instability in the forecasts between years 2011 and 2012 when the forecasts should have been similar. Both years had similar percent of average snowpack but the resulting February and March issuing forecasts varied quite differently in those years because of the QBO. The exclusion of the QBO will be discussed more thoroughly in the Climate Index Appendix C.

The El Nino Southern Oscillation Index SOI is included as a candidate variable as a necessary supplement for evaluation of variable drafts, both NMFS (RPA Number 36) and USFWS (RPA 8.1.i) recommend development of a revised methodology to forecast runoff volume for Libby Project based in part on climatic indices such as SOI. The conclusion in Appendix C was the SOI should be used in the December and January forecasts but the QBO and PNA should not be used to try and predict the Apr-Aug inflow volume. The SOI was included in the January forecast as a transition month when the SWE stations were introduced into the forecast equations to stabilize the equations from month-to-month. The SOI did show some ability to reduce errors for January and did not decrease the performance of that month's forecast. The June-July SOI sum from the previous year was selected as the forecast variable. The June-July sum was chosen by PCReg's optimization routine as the best period sum in relation to the Apr-Aug inflow volume. The PNA demonstrated a minor link to future precipitation, but will be considered only in the December- and January-issued forecasts and were then rejected. Appendix C has more details and analysis on the climatic indices.

Forecast Training Period and Increasing Error

In a regression model, the subset of the period of record that is employed for training/validating can have a significant effect on the skill or accuracy of the model. Three commonly used descriptors for the shape of distribution are the mean, standard deviation and skew. A higher or lower standard deviation and skew in the training period does not create a necessarily create a better forecast, any more than choosing a training period with a higher or lower mean would. What is most important is that the chosen training period has a distribution that is shaped in the same way as the expected future distribution. Absent any reason to predict a differently-shaped future distribution, using a longer training period is preferable over a shorter one because there is less likelihood of a single year exerting undue influence.

In the case of the Libby water supply forecast, the variability (sample standard deviation) ranges from about 1,300 to 1,450 KAF, depending on which years are selected for the training period The mean and station skew (distribution asymmetry) also vary depending on the training period chosen (Table 3). Similarly, if the current forecast equations are used to hindcast prior years' inflow volumes (Figure 3), the verification range selected will change the error statistics in the forecast.

The 2011PCReg forecast used different training periods for each month's forecasts and was driven mainly by availability of data from snow stations that showed skill in improving the forecast. The training period for the 1 Jan through 1 Mar equations was limited because of the inclusion Lost Creek South snow station, which had data back only to 1988. As noted in Table 3, and along the x-axis of Figure 3, the 2011PCReg training periods varied from 23 years to 36 years. The variation in training data can affect the shape, distribution and errors of the forecasts. For example when the 1988 to 2010 training period was used the standard error of the current forecasts (Figure 3) shows a smaller error than if the same equations were verified over a longer training period. As shown in Figure 3, changing the verification period from 1988-2010 to 1981-2010 would increase the standard error in the forecast by almost 100 KAF, even though the forecast equation coefficients have not changed at all. The increase in standard error does not represent decreased skill, only a more variable verification space. The errors increase once the years 2011 through 2013 are introduced into the verification period. All three years had above average late spring precipitation in the Kootenai Basin and affect the standard error. The months of January to March are extremely important to the flood risk management operations for Libby Dam prior to the freshet. Using a longer training period that includes higher runoff years would lead to a forecast that can better inform operation of Libby Dam during the drawdown period from December to April.

Given the range of shape parameters (standard deviation, mean, and skew), the shape of the future distribution of Libby inflow volume will better match the hydrologic characteristics of the longer training period. Standardizing the training period across all months will make month-to-month error comparisons more meaningful. The training period for this update to the Libby Dam forecast will use the 1984-2013 period of record. This period of record was chosen for the following reasons:

1. Utilizes the Alberta SWE sites longest period of record, back to 1984, and maximizes the inflow period of record after the shift in 1975 with the 1984 limitation.
2. Limits the amount of filled-in data gaps.
3. Is similar to the 1981 to 2010 averaging period being used currently by several agencies in the Pacific Northwest for reporting purposes and inter-basin forecast comparisons.

An important point is that because 2011-2013 are difficult years to forecast, due to high precipitation events in the late spring and early summer, the CVSE will increase from the last update. The increased error can be seen in Figure 3 where the 84-10 training period has much smaller error terms than the 84-13 training period.

Table 3. Statistics for inflow volume distribution parameters over different training periods

Range	Sample Mean (KAF)	Sample Standard Deviation (KAF)	Station Skew	Applicability
1975-2010	5830	1296	0.21	Currently used in December forecast
1981-2010	5880	1288	0.33	Not currently used
1984-2010	5800	1322	0.47	Currently used in May, June forecasts
1985-2010	5830	1340	0.42	Currently used in April forecast
1988-2010	5900	1396	0.29	Currently used in January, February and March forecasts
1984-2013	6025	1449	0.40	Proposed for training updated forecast
1981-2013	6080	1401	0.32	Not currently used
1975-2013	6000	1399	0.25	Period of record since completion of dam Sparse snow data available before 1981. .

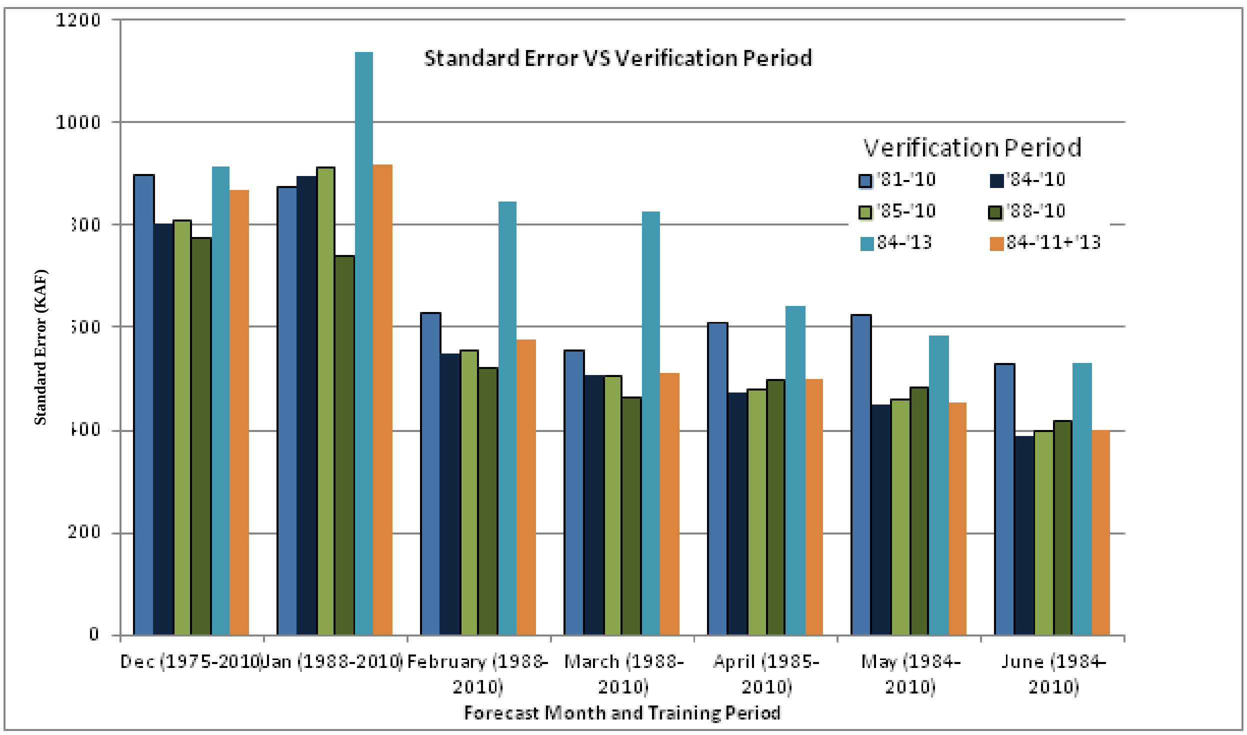


Figure 3. Standard Error, using equation coefficients from 2011PCReg procedure with different verification periods.

Principal Component Regression Results

The 2014PCReg forecast equations were developed using the NRCS PCReg model through VIPER which is a spreadsheet interface that facilitates importing data and output of the PCReg model. PCReg was chosen because of the limited training period due to the lack of stationarity in the inflow record as previously discussed, along with the desire to have a consistent training period for all forecast months. PCReg also is ideal for filtering out candidate variables that give similar predictive ability when trying to forecast the Apr-Aug inflow volume of Libby Dam. The PCReg model produces the top 30 equations for each forecast date based on the CVSE for each equation and was run several times to determine the best set of regression variables. The first run was to optimize the SWE variables with all the candidate precipitation variables forced into PCReg by VIPER. If particular variables were selected consistently for each month's forecast they were considered in the final mix of predictor SWE variables. If the resulting list of SWE variables that PCReg selected as the best 30 equations did not adequately represent snow conditions in the basin, PCReg was rerun to see if those variables with better geographic coverage would detrimentally affect the forecast's ability to predict the Apr-Aug inflow volume at Libby Dam once they were required in the training of the equations.

Once the list of SWE variables were determined that minimized both the CVSE and gave sufficient geographic coverage, these variables were used in all forecast months and were selected to use in determining the precipitation variables. The precipitation variables that consistently landed in the top 30 statistically best equations were evaluated for geographic coverage. The regression predictors for the final 2014PCReg forecast equations are listed below in Table 4. Antecedent inflow to Libby Dam was considered as a predictor variable, and was not determined to be a strong predictor variable.

Table 4. Proposed regression variables for the 2014 update to the Libby Dam water supply forecast.

Regression Variables		Forecast Issue Date						
Type	Variable Name	1-Dec	1-Jan	1-Feb	1-Mar	1-Apr	1-May	1-Jun
CLX	SOI	JunJul	JunJul					
PPT	Cranbrook AP, BC	Oct-Nov	Oct-Dec	Oct-Jan	Oct-Feb	Oct-Mar	Oct-Apr	Oct-May
	Eureka, MT	Oct-Nov	Oct-Dec	Oct-Jan	Oct-Feb	Oct-Mar	Oct-Apr	Oct-May
	Fernie, BC	Oct-Nov	Oct-Dec	Oct-Jan	Oct-Feb	Oct-Mar	Oct-Apr	Oct-May
	West Glacier, MT	Oct-Nov	Oct-Dec	Oct-Jan	Oct-Feb	Oct-Mar	Oct-Apr	Oct-May
SWE	Akamina Pass, AB			1-Feb	1-Mar	1-Apr	1-May	1-Jun
	East Creek, BC			1-Feb	1-Mar	1-Apr	1-May	1-Jun
	Hawkins Lake, MT			1-Feb	1-Mar	1-Apr	1-May	1-Jun
	Moyie Mountain, BC		1-Jan	1-Feb	1-Mar	1-Apr	1-May	1-Jun
	Stahl Peak, MT		1-Jan	1-Feb	1-Mar	1-Apr	1-May	1-Jun
	Sunshine Village, AB		1-Jan	1-Feb	1-Mar	1-Apr	1-May	1-Jun
	South Racehorse Creek, AB			1-Feb	1-Mar	1-Apr	1-May	1-Jun
Depen-dent	Libby Inflow (in KAF)	Apr-Aug	Apr-Aug	Apr-Aug	Apr-Aug	Apr-Aug	May-Aug	Jun-Aug

Table 5. Proposed Regression coefficients for the 2014 update to the Libby Dam water supply forecast. All equations trained 1984-2013. Sites in the United States assume English units (inches) and sites in Canada assume Metric units (mm)

Regression Variables		Forecast Issue Date						
Type	Variable Name	1-Dec	1-Jan	1-Feb	1-Mar	1-Apr	1-May	1-Jun
CLX	SOI	133.38	95.28					
PPT	Cranbrook AP, BC	8.79	4.58	2.84	2.73	2.99	2.80	2.03
	Eureka, MT	267.66	141.74	78.47	65.87	68.52	57.45	37.66
	Fernie, BC	1.95	1.20	0.72	0.63	0.71	0.61	0.50
	West Glacier, MT	105.96	58.42	30.95	28.51	29.47	28.04	22.46
SWE	Akamina Pass, AB			1.27	1.04	0.72	0.55	0.68
	East Creek, BC			0.75	0.65	0.73	0.57	0.43
	Hawkins Lake, MT			30.61	24.33	22.43	17.30	10.09
	Moyie Mountain, BC		1.59	1.48	1.27	1.21	0.91	0.85
	Stahl Peak, MT		34.63	22.99	19.11	19.70	16.74	10.31
	Sunshine Village, AB		2.14	1.47	1.26	1.43	1.26	0.62
	South Racehorse Creek, AB			1.53	1.40	1.35	0.83	0.64
-	Constant (in KAF)	3704	2724	1291	1142	70.54	408	977

Table 6. Percent average contribution by forecast variable.

Predictor Variable		Forecast Issue Date						
		01-Dec	01-Jan	01-Feb	01-Mar	01-Apr	01-May	01-Jun
	Constant	61%	45%	21%	19%	1%	7%	25%
CLX	SOI	0%	0%					
PPT	Cranbrook AP, BC	9%	7%	5%	6%	8%	9%	12%
	Eureka, MT	11%	8%	6%	5%	7%	7%	8%
	Fernie, BC	9%	7%	6%	6%	8%	8%	11%
	West Glacier, MT	11%	9%	6%	7%	8%	9%	12%
SWE	Akamina Pass, AB			7%	7%	6%	3%	1%
	East Creek, BC			8%	8%	10%	10%	8%
	Hawkins Lake, MT			8%	8%	9%	8%	3%
	Moyie Mountain, BC		5%	7%	7%	9%	6%	2%
	Stahl Peak, MT		9%	9%	9%	11%	11%	8%
	Sunshine Village, AB		10%	9%	10%	13%	14%	8%
	South Racehorse Creek, AB			7%	8%	10%	6%	2%

Table 7. Forecast Model Statistics for proposed 2014PCReg equations.

Forecast Model Statistics	Forecast Issue Date						
Proposed Equations, Trained over 1984-2013	1-Dec	1-Jan	1-Feb	1-Mar	1-Apr	1-May	1-Jun
Number of Training Years	29	29	29	29	29	29	29
Number of Components	1	1	1	1	1	1	1
Standard Error of Regression (over 1984-2013)	1025	1040	832	792	575	572	575
Cross Validated Standard Error (over 1984-2013)	1076	1087	875	836	620	611	618
R^2 (Over 1984-2013)	0.518	0.503	0.682	0.712	0.848	0.829	0.769
Skew of Forecast Residuals (over 1984-2013)	-0.37	-0.86	-1.05	-1.35	-0.54	-0.80	-1.82

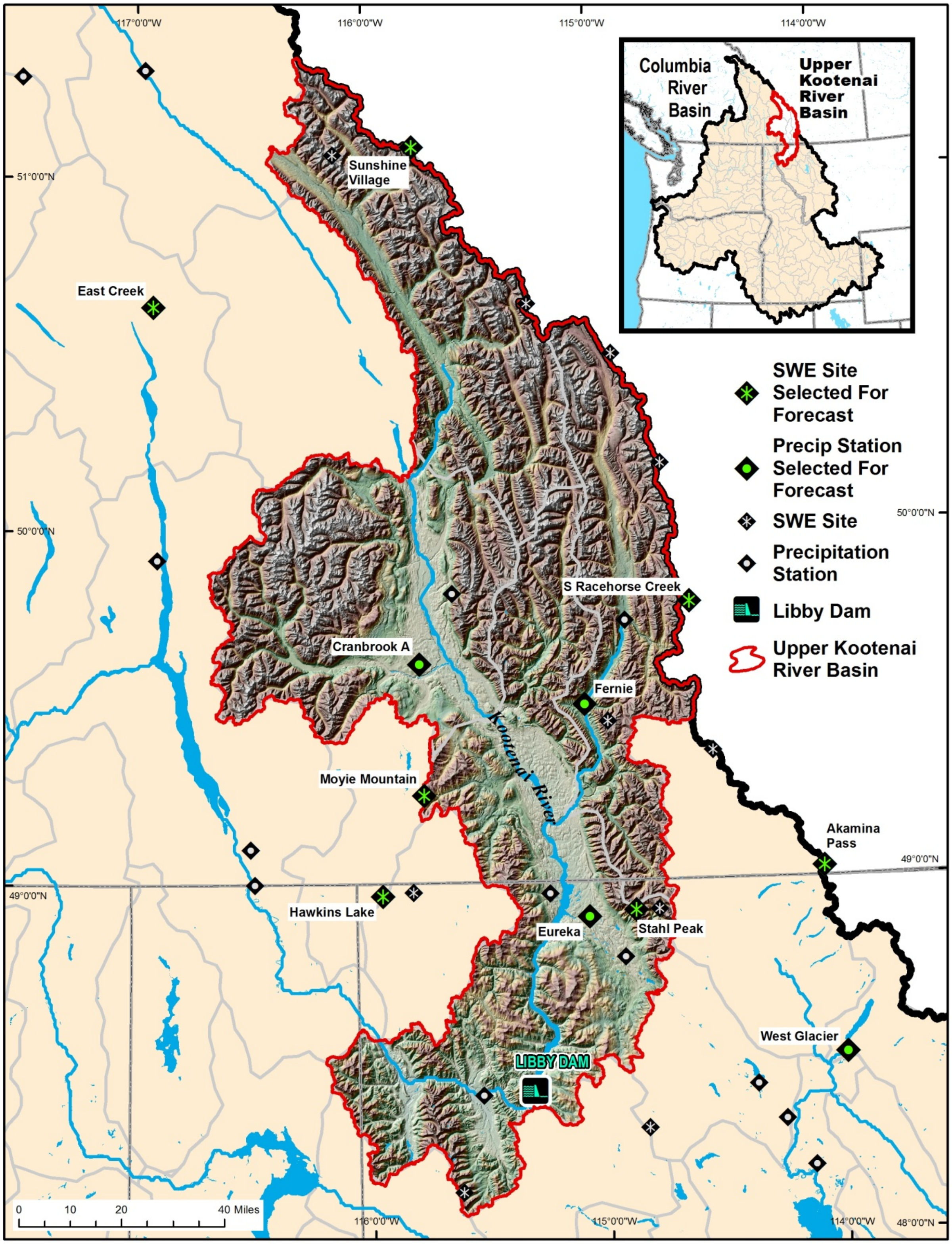


Figure 4. Map of Upper Kootenai Basin highlighting selected SWE and precipitation station for the 2014PCReg equations

Comparison of Forecast Procedures

This section will compare the performance of the current 2011PCReg equations if they were retrained to include the 2011 - 2013 Apr-Aug volumes and the proposed 2014PCReg equations. The current equations were retrained with the inclusion of the larger inflow volumes in to Libby Dam since 2010 in order to compare the CVSE statistic with the same training periods. Table 8 shows the error differences between the 2011PCReg equations (retrained) and the proposed 2014PCReg equations. The 2014PCReg equations improved the error relative to the 2011PCReg in all metrics except for the month of June which showed a slight increase in the CVSE. The year 2012 shows the highest error in the verification period due to unprecedented precipitation in the month of June and can be seen in the maximum error rows at the bottom of Table 8. The maximum error is the largest one year difference between the forecasted and observed Apr-Aug volumes in the training period. The maximum errors displayed at the bottom of Table 8 are decreased with the 2014PCReg forecast, the April and May equations have a 1 MAF and 1.5 MAF decrease from the 2011PCReg forecasts respectively. Residuals for each month's equation as well as hindcasts for each year for the current and proposed equations are presented in Appendix D and Appendix E.

Table 8. Statistical comparison of retrained 2011PCReg forecast, and proposed 2014PCReg forecast from 1984 to 2013.

Statistic	Forecast	1-Dec	1-Jan	1-Feb	1-Mar	1-Apr	1-May	1-Jun
CVSE	2011PCReg	1091	1239	922	899	671	633	586
	2014PCReg	1077	1087	875	836	620	611	618
Std Error	2011PCReg	1044	1168	886	859	634	596	527
	2014PCReg	1025	1040	832	792	575	572	575
R^2	2011PCReg	0.499	0.373	0.640	0.661	0.815	0.814	0.812
	2014PCReg	0.518	0.503	0.682	0.712	0.848	0.829	0.769
Maximum Error	2011PCReg	3326	3386	3050	3069	2043	1971	2130
	2014PCReg	2747	3216	2642	2676	1272	1415	2020

Review and Conclusion

The 2014PCReg equations meet the intended goals listed at the beginning of this report in the executive summary:

1. Show consistency from month-to-month.
    a. Selected predictor variables are left in through June once they enter the equations with the exception of the SOI. The SOI is used as an indication of potential rainfall precipitation throughout the snowfall and freshet but is dropped out after January as the forecasts switch over to more physical based hydrological indicators SWE and precipitation stations.
    b. The forecasts in 2011 and 2012 show more consistency with the percent of average snowpack, Appendix E, than the current equations.
2. The QBO was eliminated on the basis of being a low skill predictor and the potential to misinform the forecast, Appendix D. The forecast performance will be improved with the elimination of the QBO, good geographic coverage of the basin, and reduced errors.
3. The SOI will be the only climatic index retained as it shows a consistent trend with the Apr-Aug inflow volume and had the best skill in predicting the inflow volume, Appendix D.
4. A November forecast was not developed for this update since there are no operational implications from a forecast in this month.
5. The CVSE for the 2014PCReg equations showed reductions in all forecasting months save June. The 2014PCReg also minimizes the maximum error in a given year.
6. The mix of precipitation stations and SWE stations give good geographic coverage with all three SWE sites on the west side of the basin included in the forecast and four SWE stations on the east side. The precipitation stations in BC that were selected Fernie and Cranbrook should further enhance the SWE sited selected by giving indication of the middle extent of the Kootenai River Basin above Libby Dam.

While the current and proposed forecast models do not completely eliminate error due to extreme precipitation as seen in water year 2012, the proposed forecast model does reduce the error of the forecast from the current model. These types of forecast models assume average future precipitation and are subject to errors in extremely dry and wetter springs in the Kootenai Basin.

Appendix A. Snow Water Equivalent Data

The report for the 2011 Update Libby Water Supply forecast (*Appendix C. Prescreening of Snow Water Equivalent Data*) describes the elimination of 134 snow stations in and near the Kootenai Basin from consideration for use in the forecast. Utilizing this previous effort and only considering SWE sites that report in real time, this update focused on using the 17 SWE stations in Figure 5 and Table 9. For this update, the focus was to select SWE sites that have sufficient correlations to Libby Dam's inflow, nearly complete records from 1984-2013, reliable reporting histories, and combine those to represent good geographic coverage in the basin. Where there are two gages near each other and at the same relative elevation, the gage that is more frequently chosen by the PCReg optimization would be selected. This would allow a nearby gage to be used to correlate and fill in missing data if the gage selected for the forecast is missing data.

In order to have consistent period of records, it was necessary to fill in missing values for the British Columbia and Alberta sites. The periods of record for the Alberta sites vary from 1984 to 1990 (Table 9). The following criteria and methods were met for extending and filling data:

- If a snow pillow contained a valid daily value within one week of the first day of the month, the closest available daily value was used as the estimate.
- If the data was missing and no values were within the first week, values were filled in through either single or multiple linear regression. The tables at the end of this appendix show the R^2 values for each of the monthly regressions and the predictor stations used for filling in the data. The following criteria were used when filling in data using regression equations:
  - When multiple years were missing for a gage, Moyie Mountain being one, and for months other than June or a single value, regressions were required to have a minimum R^2 of 0.8. This was the criteria set by NRCS (Garen, 2003) for the 2003 effort to fill in missing data at snow pillow stations for the 2004PCReg development.
  - For a single month (typically June) regressions with an R^2 greater than 0.6 were sought. A lower R^2 for June was allowed because snowpack at the beginning of June has more variability, melting out entirely in certain years, which makes it more difficult to get a strong correlation between gages.

The minimum R^2 of 0.8 ensured that the correlations would be highly correlated with the predictand SWE sites and minimized errors in the correlations. The lower minimum R^2 values of 0.6, which was desired, were also used at times to fill in a single month within a data set so that the rest of the data set could be used within PCReg. This was necessary so that each month's forecast would have consistent predictor variables from month to month. It was also occasionally desirable to use gages missing no more than 10 percent of the 198 monthly values from 1984 to 2013 to decrease the amount of covariance that is input to PCReg during the development of the monthly forecast equations. The 10 percent threshold was chosen to allow for all gages with good correlations in Table 10 to be used in the PCReg process.

Given the criteria above, 5 additional snow stations from the original 17 snow stations were eliminated as candidate predictor variables for the forecast development. The remaining snow stations are highlighted in yellow as can be seen in Table 9. Notably, the Moyie Mountain snow station, highlighted in gray, was retained because it is one of the few stations on the west side of the Kootenai Basin above Libby Dam. Floe Lake was eliminated from the list of candidate predictors due to its proximity to Sunshine Village, which reports more reliably and Sunshine Village generally has a better correlation to the April to August inflow volume, Table 10.

Table 9. SWE sites considered for the Libby Dam water supply forecast (sites highlighted in yellow are considered candidate sites after being through the screening process mentioned above, gray means that even though the site did not pass the screening test it was considered for it geographic location)

Predictand Site	Station Type	Station ID	State/Province	Country	Latitude	Longitude	Elevation	Percent of Data Filled	Period of Record
Akamina Pass	SWE	AKAQ1	Alberta	Canada	49.0272 N	114.0528 W	5932 ft (1808 m)	1	1984-Present
Gardiner Creek	SWE	GCKQ1	Alberta	Canada	49.361 N	114.5158 W	6463 ft (1970 m)	12	1987-Present
Lost Creek	SWE	LCKQ1	Alberta	Canada	50.1739 N	114.71 W	6988 ft (2130 m)	14	1988-Present
Mount Odlum	SWE	MTOQ1	Alberta	Canada	50.48592 N	114.91308 W	6759 ft (2060 m)	20	1990-Present
Sunshine Village	SWE	SUNQ1	Alberta	Canada	51.0786 N	115.78 W	7316 ft (2230 m)	1	1984-Present
Three Isle Lake	SWE	TILQ1	Alberta	Canada	50.6314 N	115.2794 W	7103 ft (2165 m)	3	1985-Present
S Racehorse Creek	SWE	SRCQ1	Alberta	Canada	49.783 N	114.6 W	6299 ft (1920 m)	9	1985-Present
East Creek	SWE	2D08P	British Columbia	Canada	50°38'	116°56'	6660 ft (2030 m)	3	1980-Present
Floe Lake	SWE	2C14P	British Columbia	Canada	51°03'	116°08'	6847 ft (2087 m)	10	1969-Present
Morrissey Ridge	SWE	2C09Q	British Columbia	Canada	49°27'	114°58'	5906 ft (1800 m)	0.5	1979-Present
Moyie Mountain	SWE	2C10P	British Columbia	Canada	49.25 N	115.7667 W	6365 ft (1940 m)	26	1971-1990, 1997-Present
Garver Creek	SWE	GVRM8	Montana	United States	48.9752 N	115.8192 W	4250 ft (1295 m)	0	1984-Present
Grave Creek	SWE	GRCW4	Montana	United States	48° 55' N	114° 46' W	4300 ft (1311 m)	0	1978-Present
Hawkins Lake	SWE	HAWM8	Montana	United States	48° 58' N	115° 57' W	6450 ft (1966 m)	0	1984-Present
Hand Creek	SWE	HANW3	Montana	United States	48° 18' N	114° 50' W	5035 ft (1535 m)	0	1978-Present
Poorman Creek	SWE	PMNM8	Montana	United States	48.1267 N	115.6233 W	5075 ft (1547 m)	37	1969-1998, 1999-Present
Stahl Peak	SWE	STCP1	Montana	United States	48° 55' N	114° 52' W	6030 ft (1838 m)	0	1978-Present

Table 10 – Active Snow Stations - Correlations of monthly SWE with Apr-Aug runoff

	Training Period from 1984 to 2013					
SWE Site	Jan	Feb	Mar	Apr	May	Jun
Akamina Pass	0.510	0.684	0.623	0.567	0.525	0.355
Gardiner Creek	0.374	0.626	0.698	0.668	0.515	0.583
Lost Creek	0.520	0.523	0.755	0.772	0.560	0.771
Mount Odlum	0.242	0.596	0.773	0.781	0.835	0.755
Sunshine Village	0.587	0.716	0.709	0.804	0.694	0.608
Three Isle Lake	0.549	0.552	0.718	0.752	0.721	0.628
S. Racehorse Creek	0.522	0.770	0.815	0.868	0.755	0.579
East Creek	0.472	0.692	0.666	0.753	0.514	0.531
Floe Lake	0.459	0.478	0.650	0.659	0.737	0.783
Morrissey Ridge	0.432	0.591	0.668	0.751	0.759	0.531
Moyie Mountain	0.383	0.621	0.664	0.675	0.644	0.603
Garver Creek	0.391	0.558	0.516	0.581	0.410	N/A*
Grave Creek	0.045	0.343	0.483	0.425	0.365	0.221
Hawkins Lake	0.557	0.731	0.774	0.788	0.757	0.668
Hand Creek	0.302	0.458	0.440	0.430	0.249	-0.066
Poorman Creek	0.347	0.582	0.630	0.568	0.567	0.608
Stahl Peak	0.477	0.669	0.759	0.766	0.780	0.732
*** Garver Creek melted out by 1-June each year from 1984 to 2013**						

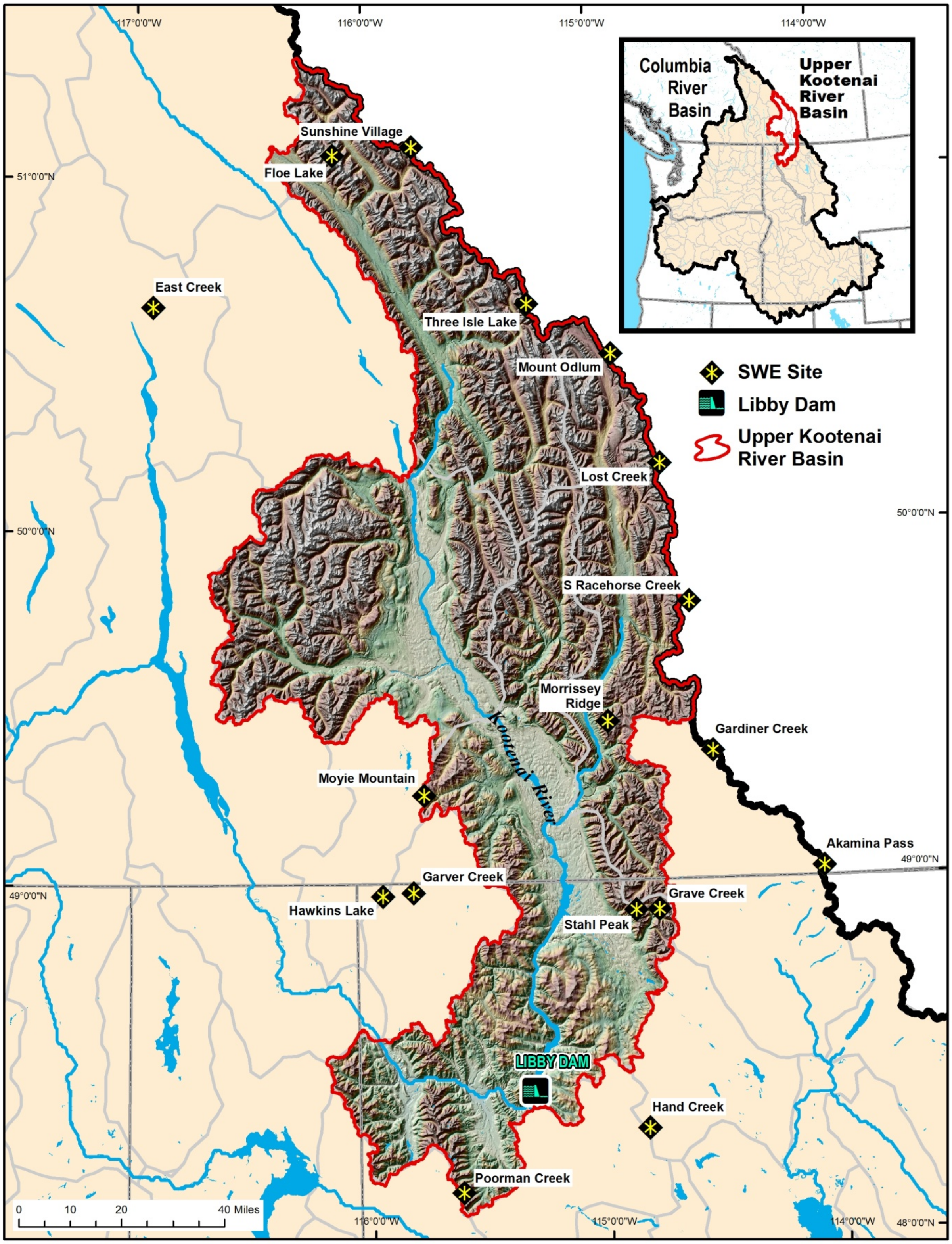


Figure 5. Candidate SWE sites in the Kootenai Basin

The following tables show the predictand sites and, by month, the missing years which sites were used as predictors the R^2 associated with the regression, and the specific predictor used in each of the missing periods.

Predictand SWE Site	Akamina Pass						
Interpolation Month	**Predictand Period Of Known Record**	**Predictand Years Missing**	**Predictor Sites**	**Predictor R^2**	**Predictor Specific Period Used to Create Interpolation**		**Reliability Comment***
January	1984-Present	None	NA	NA	NA	1984-2012	NA
February	1984-Present	None	NA	NA	NA	1986-2012	NA
March	1985-Present	1984	Poorman Creek, Hawkins Lake	0.78	Poorman/Hawkins 1984	1984-2012	Reliable
April	1984-Present	None	NA	NA	NA	1984-2012	NA
May	1984-Present	None	NA	NA	NA	1984-2012	NA
June	1984-Present	None	NA	NA	NA	1984-2012	NA

* Reliability Comment **Very Unreliable < Unreliable < Potentially Reliable < Reliable < Very Reliable**

R^2 Range 0-.64 < .65-.69 < .70-.74 < .75-.84 < .85-1

Predictand SWE Site	Gardiner Creek						
Interpolation Month	**Predictand Period Of Known Record**	**Predictand Years Missing**	**Predictor Sites**	**Predictor R^2**	**Predictor Specific Period Used to Create Interpolation**	**Predictor Specific Period Used to Create Interpolation**	**Reliability Comment***
January	1985-2003, 2005-Present	1984-1986, 2004	Stahl Peak, Akamina Pass	0.87	Stahl 1984, Stahl/Akamina 1984-1986 and 2004	1987-2012	Very Reliable
February	1985-2003, 2005-Present	1984-1986, 2004	Stahl Peak, Morrissey Ridge	0.85	Morrissey/Stahl 1984-1986 and 2004	1987-2012	Very Reliable
March	1985-2003, 2005-Present	1984-1986, 2004	Stahl Peak, Morrissey Ridge	0.86	Stahl/Morrissey 1984-1986 and 2004	1987-2012	Very Reliable
April	1984-2003, 2005-Present	1984-1986, 2004	Morrissey Ridge, Floe Lake	0.71	Morrissey/Floe 1984, 1985-1986, 2004	1987-2012	Potentially Reliable
May	1984-2003, 2005-Present	1984-1986, 2004	Stahl Peak, Poorman Creek	0.48	Stahl/Poorman 1984, 1985-1986, 2004	1987-2012	Very Unreliable
June	1984-2003, 2005-Present	1984-1986, 2004	Stahl Peak, Poorman Creek	0.86	Stahl/Poorman 1984, 1985-1986, 2004	1987-2012	Very Reliable

* Reliability Comment **Very Unreliable < Unreliable < Potentially Reliable < Reliable < Very Reliable**

R^2 Range 0-.64 < .65-.69 < .70-.74 < .75-.84 < .85-1

Predictand SWE Site	Lost Creek						
Interpolation Month	**Predictand Period Of Known Record**	**Predictand Years Missing**	**Predictor Sites**	**Predictor R^2**	**Predictor Specific Period Used to Create Interpolation**	**Predictor Specific Period Used to Create Interpolation**	**Reliability Comment***
January	1988-2011, 2013-Present	1984-1987, 2012	East Creek, Morrissey Ridge	0.90	East/Morrissey 1984, Morrissey 1984-1985, East/Morrissey 1986-1987, East/Morrissey 2012	1988-2011	Very Reliable
February	1988-Present	1984-1987	East Creek, Hawkins Lake	0.87	East/Hawkins 1984, Hawkins 1984, East/Hawkins 1985-1987	1988-2012	Very Reliable
March	1988-Present	1984-1987	East Creek, Hawkins Lake	0.88	East/Hawkins 1984, Hawkins 1984, East/Hawkins 1985-1987	1988-2012	Very Reliable
April	1988-Present	1984-1987	East Creek, Poorman Creek	0.84	East/Poorman 1984, Poorman 1984, East/Poorman 1985-1987	1988-2012	Reliable
May	1988-Present	1984-1987	Morrissey Ridge, Floe Lake	0.87	Morrissey/Floe 1984-1987	1988-2012	Very Reliable
June	1988-Present	1984-1987	Stahl Peak, Poorman Creek	0.46	Stahl/Poorman 1984-1987	1988-2012	Very Unreliable

* Reliability Comment **Very Unreliable < Unreliable < Potentially Reliable < Reliable < Very Reliable**

R^2 Range 0-.64 < .65-.69 < .70-.74 < .75-.84 < .85-1

Predictand SWE Site	Mount Odlum						
Interpolation Month	**Predictand Period Of Known Record**	**Predictand Years Missing**	**Predictor Sites**	**Predictor R^2**	**Predictor Specific Period Used to Create Interpolation**	**Predictor Specific Period Used to Create Interpolation**	**Reliability Comment***
January	1990-Present	1984-1989	East Creek, Morrissey Ridge	0.89	East/Morrissey 1984, Morrissey 1984-1985, East/Morrissey 1985-1989	1990-2012	Very Reliable
February	1990-Present	1984-1989	East Creek, Hawkins Lake	0.87	East/Hawkins 1984, Hawkins 1984, East/Hawkins 1985-1989	1990-2012	Very Reliable
March	1990-Present	1984-1989	Floe Lake, Hawkins Lake	0.87	Floe/Hawkins 1984-1989	1990-2012	Very Reliable
April	1990-Present	1984-1989	Morrissey Ridge, Floe Lake	0.76	Morrissey/Floe 1984-1989	1990-2012	Reliable
May	1990-Present	1984-1989	Morrissey Ridge, Floe Lake	0.69	Morrissey/Floe 1984-1989	1992-2012	Unreliable
June	1990-Present	1984-1989	Stahl Peak, Morrissey Ridge	0.68	Stahl/Morrissey 1984, Stahl 1984, Stahl/Morrissey 1985-1989	1996-2012	Unreliable

* Reliability Comment **Very Unreliable < Unreliable < Potentially Reliable < Reliable < Very Reliable**
R^2 Range 0-.64 < .65-.69 < .70-.74 < .75-.84 < .85-1

Predictand SWE Site	Sunshine Village						
Interpolation Month	**Predictand Period Of Known Record**	**Predictand Years Missing**	**Predictor Sites**	**Predictor R^2**	**Predictor Specific Period Used to Create Interpolation**	**Predictor Period Used to Create Interpolation Regression**	**Reliability Comment***
January	1985-Present	1984	East Creek, Morrissey Ridge	0.86	East/Morrissey 1984-2983, Morrissey 1984	1986-2012	Very Reliable
February	1985-Present	1984	Floe Lake, Hawkins Lake	0.84	Floe/Hawkins 1984	1985-2012	Reliable
March	1984-Present	None	NA	NA	NA	None	NA
April	1984-Present	None	NA	NA	NA	None	NA
May	1984-Present	None	NA	NA	NA	None	NA
June	1984-Present	None	NA	NA	NA	None	NA

* Reliability Comment **Very Unreliable < Unreliable < Potentially Reliable < Reliable < Very Reliable**

R^2 Range 0-.64 < .65-.69 < .70-.74 < .75-.84 < .85-1

Predictand SWE Site	Three Isle Lake						
Interpolation Month	**Predictand Period Of Known Record**	**Predictand Years Missing**	**Predictor Sites**	**Predictor R^2**	**Predictor Specific Period Used to Create Interpolation**	**Predictor Specific Period Used to Create Interpolation**	**Reliability Comment***
January	1985-Present	1984	East Creek, Morrissey Ridge	0.79	East/Morrissey 1984, Morrissey 1984	1985-2012	Reliable
February	1985-Present	1984	East Creek, Morrissey Ridge	0.74	East/Morrissey 1984, Morrissey 1984	1985-2012	Potentially Reliable
March	1985-Present	1984	East Creek, Morrissey Ridge	0.71	East/Morrissey 1984, Morrissey 1984	1985-2012	Potentially Reliable
April	1985-Present	1984	East Creek, Morrissey Ridge	0.59	East/Morrissey 1984, Morrissey 1984	1985-2012	Very Unreliable
May	1985-Present	1984	Stahl Peak, Floe Lake	0.42	Stahl/Flow 1985-2012	1985-2012	Very Unreliable
June	1985-1988, 1990-Present	1984, 1989	Stahl Peak, East Creek	0.45	Stahl/East 1984, Stahl 1984, Stahl/East 1989	1985-2012	Very Unreliable

* Reliability Comment **Very Unreliable < Unreliable < Potentially Reliable < Reliable < Very Reliable**

R^2 Range 0-.64 < .65-.69 < .70-.74 < .75-.84 < .85-1

Predictand SWE Site	South Racehorse Creek						
Interpolation Month	**Predictand Period Of Known Record**	**Predictand Years Missing**	**Predictor Sites**	**Predictor R^2**	**Predictor Specific Period Used to Create Interpolation**	**Predictor Specific Period Used to Create Interpolation**	**Reliability Comment***
January	1985-Present	1984	East Creek, Morrissey Ridge	0.79	East/Morrissey 1984, Morrissey 1984	1985-2012	Reliable
February	1985-Present	1984	East Creek, Morrissey Ridge	0.74	East/Morrissey 1984, Morrissey 1984	1985-2012	Potentially Reliable
March	1985-Present	1984	East Creek, Morrissey Ridge	0.71	East/Morrissey 1984, Morrissey 1984	1985-2012	Potentially Reliable
April	1985-Present	1984	East Creek, Morrissey Ridge	0.59	East/Morrissey 1984, Morrissey 1984	1985-2012	Very Unreliable
May	1990-Present	1984-1989	Stahl Peak, Floe Lake	0.42	Stahl/Flow 1985-2012	1985-2012	Very Unreliable
June	1990-Present	1984-1989	Stahl Peak, East Creek	0.45	Stahl/East 1984, Stahl 1984, Stahl/East 1989	1985-2012	Very Unreliable

* Reliability Comment **Very Unreliable < Unreliable < Potentially Reliable < Reliable < Very Reliable**

R^2 Range 0-.64 < .65-.69 < .70-.74 < .75-.84 < .85-1

Predictand SWE Site	East Creek						
Interpolation Month	**Predictand Period Of Known Record**	**Predictand Years Missing**	**Predictor Sites**	**Predictor R^2**	**Predictor Specific Period Used to Create Interpolation**	**Predictor Specific Period Used to Create Interpolation**	**Reliability Comment***
January	1977, 1979, 1986-1989, 1991-Present	1984-1985, 1990	Morrissey Ridge, Moyie Mountain	0.66	Morrissey/Moyie 1984-1985, 1990	1979-2012	Unreliable
February	1969, 1985-1989, 1991-2006, 2008-Present	1984, 1990, 2007	Floe Lake, Stahl Peak	0.81	Floe/Stahl 1984, 1990, 2007	1978-2012	Reliable
March	1969, 1985-2006, 2008-Present	1984, 2007	Floe Lake, Morrissey Ridge	0.80	Floe/Morrissey 1984, 2007	1978-2012	Reliable
April	1969, 1985-2001, 2003-Present	1984, 2002	Sunshine Village, Floe Lake	0.76	Sunshine/Floe 1984, 2002	1978-2012	Reliable
May	1969, 1985-Present	1984	Stahl Peak, Sunshine Village	0.70	Stahl/Sunshine 1984	1984-2012	Potentially Reliable
June	1969, 1985-Present	1984	Stahl Peak, Sunshine Village	0.86	Sunshine/Stahl 1984	1985-2012	Very Reliable

* Reliability Comment **Very Unreliable < Unreliable < Potentially Reliable < Reliable < Very Reliable**

R^2 Range 0-.64 < .65-.69 < .70-.74 < .75-.84 < .85-1

Predictand SWE Site	Floe Lake						
Interpolation Month	**Predictand Period Of Known Record**	**Predictand Years Missing**	**Predictor Sites**	**Predictor R^2**	**Predictor Specific Period Used to Create Interpolation**		**Reliability Comment***
January	1993-Present	1984-1992	East Creek, Morrissey Ridge	0.84	East/Morrissey 1984, Morrissey 1984-1985, East/Morrissey 1986-1989, Morrissey 1990, East/Morrissey 1991-1992	1993-2012	Reliable
February	1969-Present	None	NA	NA	NA	1993-2012	NA
March	1969-Present	None	NA	NA	NA	1993-2012	NA
April	1969-Present	None	NA	NA	NA	1993-2012	NA
May	1969-Present	None	NA	NA	NA	1993-2012	NA
June	1993-Present	1984-1992	Hawkins Lake, Sunshine Village	0.87	Hawkins Lake 1984, Hawkins/Sunshine 1984-1992	1993-2012	Very Reliable

* Reliability Comment **Very Unreliable < Unreliable < Potentially Reliable < Reliable < Very Reliable**

R^2 Range 0-.64 < .65-.69 < .70-.74 < .75-.84 < .85-1

Predictand SWE Site	Morrissey Ridge						
Interpolation Month	**Predictand Period Of Known Record**	**Predictand Years Missing**	**Predictor Sites**	**Predictor R^2**	**Predictor Specific Period Used to Create Interpolation**	**Predictor Specific Period Used to Create Interpolation**	**Reliability Comment***
January	1970, 1973, 1975, 1977-Present	NA	NA	NA	NA	NA	NA
February	1969-1970, 1972, 1974-Present	NA	NA	NA	NA	NA	NA
March	1969-1973, 1975-Present	NA	NA	NA	NA	NA	NA
April	1969-1972, 1974-Present	NA	NA	NA	NA	NA	NA
May	1969-1972, 1974-1990, 1992-Present	1991	Hawkins Lake, Mount Odlum	0.80	Hawkins/Odlum 1991	1990-2012	Reliable
June	1970-1982, 1983-Present	1983	Poorman Creek, Stahl Peak	0.69	Poorman/Stahl 1983	1984-2012	Unreliable

* Reliability Comment **Very Unreliable < Unreliable < Potentially Reliable < Reliable < Very Reliable**
R^2 Range 0-.64 < .65-.69 < .70-.74 < .75-.84 < .85-1

Predictand SWE Site	**Moyie Mountain**						
Interpolation Month	**Predictand Period Of Known Record**	**Predictand Years Missing**	**Predictor Sites**	**Predictor R^2**	**Predictor Specific Periods Used to Fill In Missing Predictand Years**	**Predictor Period Used to Create Interpolation Regression**	**Reliability Comment***
January	1972-1995, 1997-2011, 2013-Present	1996, 2012	Mount Odlum, Poorman Creek	0.68	Mount Odlum 1996, Poorman/Odlum 2012	1990-2012	Unreliable
February	1969-2011, 2013-Present	2012	Poorman Creek, Hawkins Lake	0.81	Poorman/Hawkins 2012	1984-2012	Reliable
March	1969-Present	NA	NA	NA	NA	1984-2012	NA
April	1969-Present	NA	NA	NA	NA	1984-2012	NA
May	1969-1970, 1971-Present	NA	NA	NA	NA	1984-2012	NA
June	1970, 1972-1992, 1995-Present	1993-1994	Three Isle Lake, Akamina Pass	0.49	Three Isle/Akamina 1993-1994	1985-2012	Very Unreliable

* Reliability Comment **Very Unreliable < Unreliable < Potentially Reliable < Reliable < Very Reliable**

R^2 Range 0-.64 < .65-.69 < .70-.74 < .75-.84 < .85-1

Predictand SWE Site	Redfish Creek						
Interpolation Month	**Predictand Period Of Known Record**	**Predictand Years Missing**	**Predictor Sites**	**Predictor R^2**	**Predictor Specific Period Used to Create Interpolation**	**Predictor Specific Period Used to Create Interpolation**	**Reliability Comment***
January	2001-2011, 2013-Present	1984-2000, 2012	NA	NA	NA	NA	NA
February	2001-2011, 2013-Present	1984-2000, 2012	NA	NA	NA	NA	NA
March	2001-Present	1984-2000	NA	NA	NA	NA	NA
April	2001-Present	1984-2000	NA	NA	NA	NA	NA
May	2001-Present	1984-2000	NA	NA	NA	NA	NA
June	2001-Present	1984-2000	NA	NA	NA	NA	NA
		Did not interpolate, large amounts of missing data and short period of record					

Predictand SWE Site	Garver Creek						
Interpolation Month	**Predictand Period Of Known Record**	**Predictand Years Missing**	**Predictor Sites**	**Predictor R^2**	**Predictor Specific Period Used to Create Interpolation**	**Predictor Period Used to Create Interpolation Regression**	**Reliability Comment***
January	1969-Present	None	NA	NA	NA	NA	NA
February	1969-Present	None	NA	NA	NA	NA	NA
March	1969-Present	None	NA	NA	NA	NA	NA
April	1969-Present	None	NA	NA	NA	NA	NA
May	1969-Present	None	NA	NA	NA	NA	NA
June	1969-Present	None	NA	NA	NA	NA	NA

* Reliability Comment **Very Unreliable < Unreliable < Potentially Reliable < Reliable < Very Reliable**

R^2 Range 0-.64 < .65-.69 < .70-.74 < .75-.84 < .85-1

Predictand SWE Site	Grave Creek						
Interpolation Month	**Predictand Period Of Known Record**	**Predictand Years Missing**	**Predictor Sites**	**Predictor R^2**	**Predictor Specific Period Used to Create Interpolation**	**Predictor Specific Period Used to Create Interpolation**	**Reliability Comment***
January	1971-Present	None	NA	NA	NA	NA	NA
February	1971-Present	None	NA	NA	NA	NA	NA
March	1971-Present	None	NA	NA	NA	NA	NA
April	1971-Present	None	NA	NA	NA	NA	NA
May	1971-Present	None	NA	NA	NA	NA	NA
June	1976-Present	None	NA	NA	NA	NA	NA

Predictand SWE Site	Hawkins Lake						
Interpolation Month	**Predictand Period Of Known Record**	**Predictand Years Missing**	**Predictor Sites**	**Predictor R^2**	**Predictor Specific Period Used to Create Interpolation**	**Predictor Period Used to Create Interpolation Regression**	**Reliability Comment***
January	1969-Present	None	NA	NA	NA	NA	NA
February	1969-Present	None	NA	NA	NA	NA	NA
March	1969-Present	None	NA	NA	NA	NA	NA
April	1969-Present	None	NA	NA	NA	NA	NA
May	1969-Present	None	NA	NA	NA	NA	NA
June	1969-Present	None	NA	NA	NA	NA	NA

* Reliability Comment **Very Unreliable < Unreliable < Potentially Reliable < Reliable < Very Reliable**

R^2 Range 0-.64 < .65-.69 < .70-.74 < .75-.84 < .85-1

Predictand SWE Site	Hand Creek						
Interpolation Month	**Predictand Period Of Known Record**	**Predictand Years Missing**	**Predictor Sites**	**Predictor R^2**	**Predictor Specific Period Used to Create Interpolation**	**Predictor Specific Period Used to Create Interpolation**	**Reliability Comment***
January	1977-Present	None	NA	NA	NA	NA	NA
February	1977-Present	None	NA	NA	NA	NA	NA
March	1977-Present	None	NA	NA	NA	NA	NA
April	1977-Present	None	NA	NA	NA	NA	NA
May	1977-Present	None	NA	NA	NA	NA	NA
June	1977-Present	None	NA	NA	NA	NA	NA

Predictand SWE Site	Stahl Peak						
Interpolation Month	**Predictand Period Of Known Record**	**Predictand Years Missing**	**Predictor Sites**	**Predictor R^2**	**Predictor Specific Period Used to Create Interpolation**	**Predictor Specific Period Used to Create Interpolation**	**Reliability Comment***
January	1971-Present	None	NA	NA	NA	NA	NA
February	1971-Present	None	NA	NA	NA	NA	NA
March	1971-Present	None	NA	NA	NA	NA	NA
April	1971-Present	None	NA	NA	NA	NA	NA
May	1971-Present	None	NA	NA	NA	NA	NA
June	1971-Present	None	NA	NA	NA	NA	NA

* Reliability Comment **Very Unreliable < Unreliable < Potentially Reliable < Reliable < Very Reliable**

R^2 Range 0-.64 < .65-.69 < .70-.74 < .75-.84 < .85-1

Predictand SWE Site	Poorman Creek						
Interpolation Month	**Predictand Period Of Known Record**	**Predictand Years Missing**	**Predictor Sites**	**Predictor R^2**	**Predictor's Specific Period Used to Create Interpolation**	**Predictor Specific Period Used to Create Interpolation**	**Reliability Comment***
January	1969-1987, 1999-Present	1988-1998	Hand Creek, Moyie Mountain	0.74	Hand/Moyie 1988-1995, Hand 1996, Hand/Moyie 1997-1998	1984-2012	Potentially Reliable
February	1969-1987, 1999-Present	1988-1998	Gardiner Creek, Moyie Mountain	0.83	Moyie/Gardiner 1988-1998	1987-2012	Reliable
March	1969-1987, 1999-Present	1988-1998	Moyie Mountain, Akamina Pass	0.89	Moyie/Akamina 1988-1998	1984-2012	Very Reliable
April	1969-1987, 1999-Present	1988-1998	Moyie Mountain, Grave Creek	0.92	Moyie/Grave 1988-1998	1984-2012	Very Reliable
May	1969-1987, 1999-Present	1988-1998	Moyie Mountain, Grave Creek	0.82	Moyie/Grave 1988-1998	1984-2012	Reliable
June	1969-1987, 1999-Present	1988-1998	Morrissey Ridge, East Creek	0.87	Morrissey/East 1988-1992, Morrissey 1993, Morrissey/East 1994, Morrissey 1995, Morrissey/East 1996-1998	1985-2012	Very Reliable

* Reliability Comment **Very Unreliable < Unreliable < Potentially Reliable < Reliable < Very Reliable**

R^2 Range 0-.64 < .65-.69 < .70-.74 < .75-.84 < .85-1

Appendix B. Precipitation Data

Stations

Monthly precipitation data from 17 climate stations (Figure 6 and Table 11) were reviewed for this study. Figure 6 shows the geographic distribution of these gages across the basin. Precipitation gages from British Columbia, Montana, and Idaho were included. The stations considered include stations currently appearing in the forecast, and other nearby, currently active stations that have a mostly complete period of record extending back at least to the early 1980's. The monthly precipitation data was obtained from the NOAA's National Climatic Data Center (NCDC, http://www.ncdc.noaa.gov[1]). The NCDC was established in 1950 by the 81st Congress via Public Law 754, which designated the NCDC as the official United States Archive for climatic data records. It currently serves as the official historical archive for all NOAA data (including NWS COOP and SWE stations) and incorporates data from other domestic and international sources. The NCDC has the additional benefit of providing all U.S. and Canadian data in a single reliable repository.

While the NCDC is the most complete quality controlled repository, it was missing some values at some locations. To provide the most complete coverage possible, NCDC data records were merged with data from the Western Regional Climate Center (WRCC, http://www.wrcc.dri.edu/climsum.html) and the Government of Canada National Climate Data and Information Service (http://climate.weatheroffice.gc.ca/climateData/canada_e.html).

[1] http://www.ncdc.noaa.gov/cdo-web/search to access, select "Monthly Summaries" in the observation type, set the beginning of the date range to October, 1980, and search by station name. Select desired station from the map that appears then select "Add to Cart," then select "View Cart" and "Check Out.")

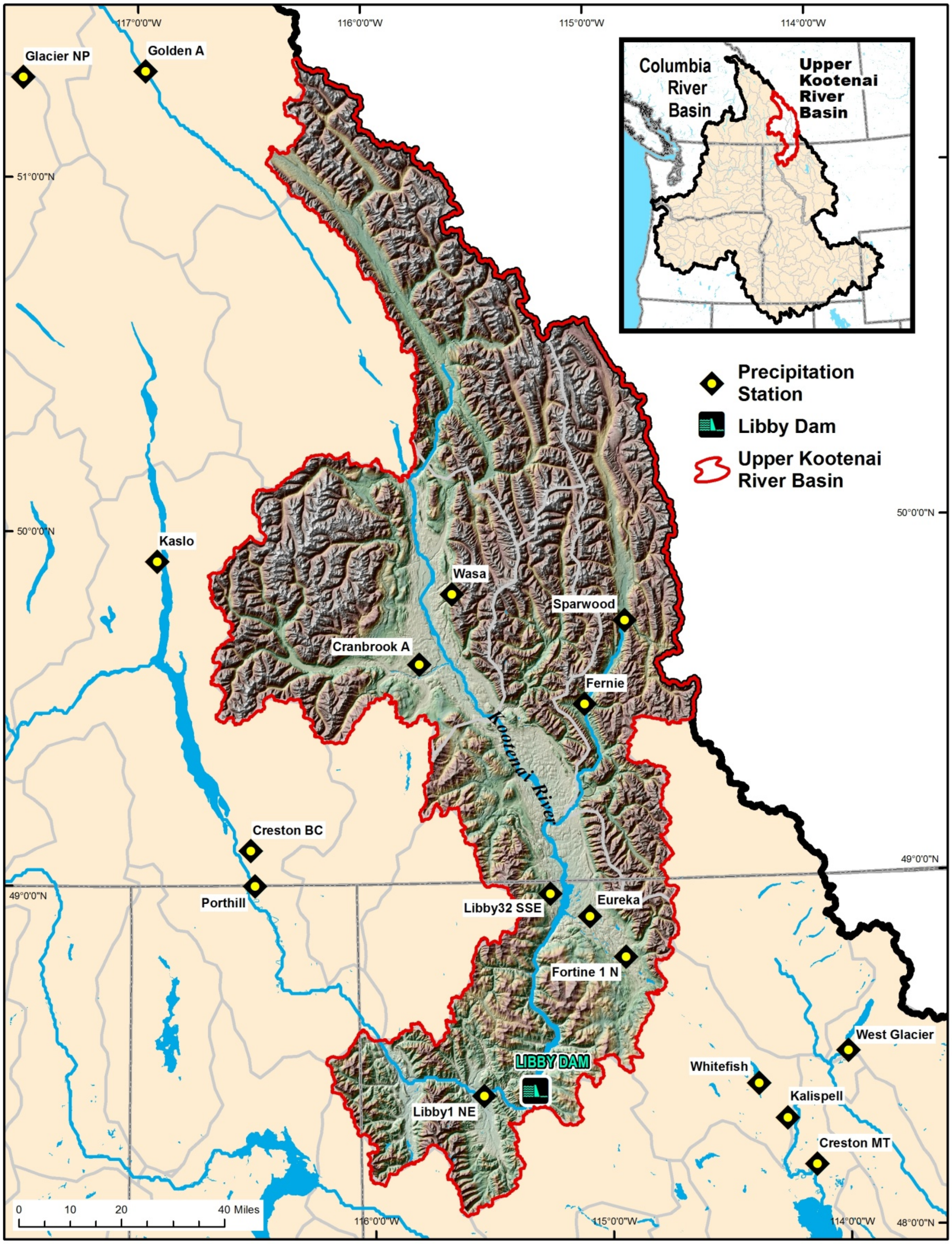


Figure 6. Map of 17 precipitation stations considered for the 2014PCReg equations

Table 11. Candidate climate stations for the Libby Dam water supply forecast equations

Precipitation Station	Station ID	Location	Latitude	Longitude	Elevation	Period of Record
Cranbrook A	1152102	British Columbia, Canada	49.62 N	115.78 W	3084 ft (940 m)	1938-Present
Creston BC	1142160	British Columbia, Canada	49° 6'	116°31'	2003 ft (610 m)	1913-Present
Fernie	1152850	British Columbia, Canada	49° 30'	115°4'	3284 ft (1001 m)	1913-Present
Glacier NP	1173191	British Columbia, Canada	51° 17'	117°31'	4341 ft (1322 m)	1965-2013?
Golden A	1173210	British Columbia, Canada	51° 18'	116° 58'	2582 ft (787 m)	1914-Present
Kaslo	1143900	British Columbia, Canada	49° 55'	116°55'	1939 ft (591 m)	1914-Present
Sparwood	1157630	British Columbia, Canada	49° 44'	114°53'	3733 ft (1138 m)	1979-Present
Wasa	1158730	British Columbia, Canada	49° 49'	115°38'	3051 ft (930 m)	1924-Present
Porthill	107264	Idaho, United States	49°0'	116° 30'	1775 ft (541 m)	1917-Present
Creston MT	242104	Montana, United States	48° 11'	114° 8'	2940 ft (591 m)	1949-Present
Eureka	242827	Montana, United States	48° 54'	115° 4'	2532 ft (2104 m)	1960-Present
Fortine 1 N	243139	Montana, United States	48°47'	114° 55'	3000 ft (914 m)	1913-Present
Kalispell	244558	Montana, United States	48°19'	114° 15'	2957 ft (901 m)	1913-Present
Libby1 NE	245015	Montana, United States	48° 24'	115° 32'	2096 ft (639 m)	1913-Present
Libby32 SSE	245020	Montana, United States	48° 58'	115° 14'	3465 ft (1056 m)	1949-Present
West Glacier	248809	Montana, United States	48°30'	113° 59'	3154 ft (961 m)	1949-Present
Whitefish	248902	Montana, United States	48° 25'	114° 22'	3100 ft (945 m)	1939-Present

Between the NCDC database, the Canadian weather service database, and the WRCC database over 98% of all desired readings were available (4416/4488 monthly readings between 1981 and 2013). While most readings matched across data sources, there were 250 monthly readings for which the readings between the databases differed by 10% or more (~6% of all readings). In such cases, values in the official climate archive at NCDC were preferred. Six stations (Eureka, Kalispell, Libby1, Sparwood, West Glacier and Whitefish) were serially complete during October-May season from WY 1981 to WY 2013. These six stations were used as the candidate predictands in VIPER PC regression to fill in the 72 missing values from other stations. Of the 11 precipitation stations missing some amount of data, the average number of missing values was seven (<3%). Wasa, BC required the most data to be filled in through regression with 14 missing values (5%).

Summary information regarding what data was filled in is shown in Table 12. The "Weighted Average R^2" provides a metric for the strength of the correlations at that station and is calculated by averaging the correlations used, weighted by the number of monthly readings filled with each correlation. For instance, if a station had one December reading filled in with a correlation of

0.5, and two January readings filled in with a correlation of 0.8, the weighted average R^2 for that station would be (0.5*1 + 0.8*2)/3 = 0.7.

Further details on data quality, including which monthly readings differed between datasets, which specific monthly readings were hindcasted, and the associated regression correlations can be found in each precipitation station's CSV file, in the CSV data archives that Seattle District can make available.

Table 12. Precipitation data hindcasting summary, including the total number of hindcasted months, hindcasting regression correlations (Weighted Average R^2), and consistency between source databases for each station.

Station	Notes	Weighted Average R^2
Cranbrook	1 month filled in, 6 months available in only one database or the other (2%), 24 months wherein databases differed by 10% or more (9%)	0.71
Creston BC	8 months filled in (3%), 0 months available in only one database or the other, 10 months wherein databases differed by 10% or more (4%)	0.63
Creston, MT	1 month filled in, 0 months available in only one database or the other, 6 months wherein databases differed by 10% or more (2%)	0.86
Eureka	0 months filled in, 0 months available in only one database or the other, 3 months wherein databases differed by 10% or more (1%)	*n/a*
Fernie	6 months filled in (2%), 0 months available in only one database or the other, 50 months wherein databases differed by 10% or more (19%)	0.69
Fortine	4 months filled in (2%), 21 months available in only one database or the other (8%), 4 months wherein databases differed by 10% or more (2%)	0.30
Glacier Rogers NP	Correlation with Libby Dam inflow volume has deprecated since 2004 see Fall Precipitation section below -	-
Golden	10 months filled in (4%), 1 month available in only one database or the other (<1%), 13 months wherein databases differed by 10% or more (5%)	0.39
Kalispell	0 months filled in, 0 months available in only one database or the other, 3 months wherein databases differed by 10% or more (1%)	*n/a*
Kaslo	8 months filled in (3%), 0 months available in only one database or the other, 27 months wherein databases differed by 10% or more (10%)	0.50
Libby1	0 months filled in, 6 months available in only one database or the other (2%), 10 months wherein databases differed by 10% or more (4%)	*n/a*
Libby31	3 months filled in (1%), 0 months available in only one database or the other, 6 months wherein databases differed by 10% or more (2%)	0.73
Porthill	10 months filled in (4%), 2 months available in only one database or the other (1%), 22 months wherein databases differed by 10% or more (8%)	0.64
Sparwood	0 months filled in, 9 months available in only one database or the other (3%), 5 months wherein databases differed by 10% or more (2%)	*n/a*
Wasa	14 months filled in (5%), 0 months available in only one database or the other, 34 months wherein databases differed by 10% or more (13%)	0.46
West Glacier	0 months filled in, 1 month available in only one database or the other (<1%), 3 months wherein databases differed by 10% or more (1%)	*n/a*
Whitefish	0 months filled in, 38 months available in only one database or the other (14%), 10 months wherein databases differed by 10% or more (4%)	*n/a*

Precipitation stations have lower intra-correlation than do SWE stations. While SWE is inherently cumulative, precipitation totals are reset every month. Erratic strong storms may shift the record of a single station in a single month, reducing its correlations with other stations in the basin. In some cases (e.g. Golden, Kaslo, and Wasa) it was not possible to find "strong" correlations for all months. Lower correlation between predictors and predictand implies that less of the predictand variability is explained by fluctuations in the predictors. The resulting prediction for missing values in the predictand series will tend to be closer to historical average. Six missing readings were filled in using regressions with $R^2 < 0.25$: Golden in January ($R^2 = 0.14$, used for 2 readings), Golden in May (R^2=0.24, 1 reading), Kaslo in April (R^2=0.18, 1 reading) and Wasa in April (R^2=0.20, 2 readings). As expected, hindcasted values for these stations in these months were close to average. (92% - 124% of average)

Precipitation gages in the final forecast will be selected based on their contribution to the overall forecast performance, as measured by CVSE and/or Standard Error. Consideration will also be given to month-to-month forecast stability (consistent input predictors over the forecast season) and geographic distribution. Geographic location of gages is important in the Kootenai River basin because of the sparse network of SWE sites. For example, precipitation data from Cranbrook may act as a proxy for snowpack through the winter on the west side of the basin above Libby Dam where there are only two SWE sites (East Creek and Moyie Mountain).

Also shown in this appendix are the individual correlations between each of the gages and the Inflow Volume (Table 13) Correlations are shown with varying monthly summation ranges for each candidate station to give a first cut glance at their relationship to the Libby Dam April-August inflow volume. The May and June forecast correlations were made against the May-August and the June-August volumes, respectively.

Including October to present in summation ranges improves correlations across all stations and all forecast issue months. Over the last five years, the relationship between fall precipitation totals and the Libby April-August inflow volume has been erratic. However, from 1981 to 2013 the correlations for each monthly forecast are stronger when Oct-Dec precipitation is retained in the summations all the way through June. Currently it is unknown the most recent five years of correlation establishes a new trend or not. The following section is a discussion of fall precipitation sums with and without October precipitation.

Table 13. Correlations (R): Inflow Volume vs. Varying summation periods at each precipitation station.

	Dec Forecast (April-Aug inflow volume)		Jan Forecast (April-Aug inflow volume)			Feb Forecast (April-Aug inflow volume)				March Forecast (April-Aug inflow volume)				
Location	**Oct-Nov**	**Nov**	**Oct-Dec**	**Nov-Dec**	**Dec**	**Oct-Jan**	**Nov-Jan**	**Dec-Jan**	**Jan**	**Oct-Feb**	**Nov-Feb**	**Dec-Feb**	**Jan-Feb**	**Feb**
Cranbrook	0.51	0.33	0.55	0.40	0.29	0.63	0.52	0.45	0.43	0.71	0.63	0.59	0.60	0.39
Creston, BC	0.60	0.46	0.56	0.46	0.25	0.59	0.52	0.33	0.25	0.67	0.62	0.49	0.47	0.51
Creston, MT	0.55	0.30	0.56	0.35	0.26	0.57	0.38	0.31	0.22	0.53	0.35	0.28	0.19	0.08
Eureka	0.63	0.48	0.66	0.51	0.27	0.66	0.55	0.41	0.32	0.65	0.54	0.42	0.34	0.25
Fernie	0.56	0.54	0.60	0.57	0.33	0.65	0.64	0.52	0.35	0.69	0.68	0.58	0.48	0.46
Fortine	0.69	0.45	0.67	0.43	0.20	0.74	0.54	0.38	0.39	0.73	0.56	0.44	0.39	0.25
Glacier	0.45	0.37	0.43	0.35	0.15	0.58	0.54	0.41	0.28	0.62	0.59	0.48	0.41	0.45
Golden	0.53	0.57	0.57	0.55	0.09	0.60	0.57	0.19	0.18	0.66	0.63	0.34	0.36	0.40
Kalispell, MT	0.55	0.38	0.61	0.49	0.43	0.65	0.54	0.51	0.42	0.64	0.54	0.51	0.43	0.26
Kaslo	0.54	0.47	0.53	0.41	0.17	0.54	0.44	0.23	0.12	0.60	0.52	0.37	0.32	0.47
Libby1	0.48	0.39	0.49	0.40	0.19	0.54	0.48	0.36	0.35	0.55	0.50	0.41	0.39	0.29
Libby32	0.58	0.47	0.66	0.54	0.35	0.73	0.61	0.48	0.37	0.72	0.61	0.51	0.46	0.35
Porthill	0.53	0.37	0.53	0.41	0.24	0.52	0.41	0.23	0.07	0.56	0.48	0.35	0.28	0.43
Sparwood	0.57	0.55	0.60	0.51	0.20	0.65	0.57	0.32	0.29	0.70	0.61	0.41	0.41	0.33
Wasa	0.46	0.36	0.42	0.30	0.07	0.47	0.37	0.23	0.29	0.56	0.47	0.43	0.51	0.41
West Glacier	0.60	0.48	0.64	0.55	0.33	0.67	0.61	0.48	0.36	0.71	0.64	0.54	0.46	0.39
Whitefish	0.56	0.36	0.58	0.41	0.30	0.61	0.46	0.36	0.30	0.56	0.42	0.33	0.27	0.13
Top 6 Average	***0.61***	***0.52***	***0.64***	***0.54***	***0.34***	***0.69***	***0.59***	***0.47***	***0.39***	***0.71***	***0.64***	***0.54***	***0.50***	***0.46***

	April Forecast (April-Aug inflow volume)						May Forecast (May-Aug inflow volume)						
Location	**Oct-Mar**	**Nov-Mar**	**Dec-Mar**	**Jan-Mar**	**Feb-Mar**	**Mar**	**Oct-April**	**Nov-April**	**Dec-April**	**Jan-April**	**Feb-April**	**Mar-April**	**April**
Cranbrook	0.75	0.70	0.71	0.71	0.55	0.32	0.74	0.67	0.66	0.59	0.41	0.21	(-0.08)
Creston, BC	0.69	0.63	0.54	0.54	0.56	0.22	0.70	0.64	0.54	0.51	0.52	0.21	0.03
Creston, MT	0.52	0.32	0.25	0.15	0.02	(-0.04)	0.42	0.26	0.18	0.06	(-0.06)	(-0.12)	(-0.11)
Eureka	0.67	0.57	0.44	0.38	0.30	0.19	0.63	0.53	0.40	0.32	0.25	0.18	0.09
Fernie	0.78	0.76	0.71	0.60	0.57	0.29	0.77	0.75	0.72	0.61	0.58	0.36	0.31
Fortine	0.73	0.60	0.48	0.43	0.35	0.33	0.66	0.53	0.41	0.34	0.26	0.19	(-0.01)
Glacier	0.61	0.59	0.45	0.36	0.35	0.16	0.61	0.57	0.46	0.38	0.34	0.17	0.07
Golden	0.72	0.70	0.47	0.49	0.58	0.40	0.70	0.67	0.47	0.45	0.48	0.26	(-0.00)
Kalispell, MT	0.67	0.57	0.57	0.49	0.33	0.18	0.61	0.51	0.50	0.39	0.25	0.12	(-0.01)
Kaslo	0.64	0.56	0.44	0.43	0.56	0.30	0.63	0.55	0.44	0.42	0.53	0.28	0.04
Libby1	0.62	0.56	0.49	0.50	0.43	0.28	0.61	0.56	0.49	0.52	0.46	0.33	0.17
Libby32	0.74	0.64	0.54	0.52	0.48	0.31	0.73	0.65	0.56	0.53	0.49	0.36	0.18
Porthill	0.54	0.47	0.36	0.33	0.45	0.13	0.55	0.47	0.37	0.30	0.39	0.11	0.01
Sparwood	0.72	0.64	0.46	0.44	0.39	0.25	0.68	0.60	0.45	0.41	0.36	0.23	0.08
Wasa	0.67	0.60	0.57	0.56	0.48	0.35	0.65	0.56	0.50	0.44	0.34	0.22	(-0.06)
West Glacier	0.72	0.68	0.58	0.52	0.47	0.24	0.76	0.72	0.64	0.58	0.56	0.39	0.37
Whitefish	0.59	0.45	0.36	0.31	0.18	0.12	0.53	0.39	0.31	0.22	0.07	(-0.01)	(-0.13)
Top 6 Average	***0.74***	***0.69***	***0.61***	***0.57***	***0.55***	***0.33***	***0.73***	***0.68***	***0.60***	***0.56***	***0.53***	***0.33***	***0.20***

	June Forecast (June-Aug Volume)							
Location	**Oct-May**	**Nov-May**	**Dec-May**	**Jan-May**	**Feb-May**	**Mar-May**	**April-May**	**May**
Cranbrook	0.75	0.70	0.67	0.63	0.59	0.52	0.33	0.33
Creston, BC	0.71	0.69	0.61	0.57	0.62	0.37	0.30	0.29
Creston, MT	0.51	0.39	0.35	0.28	0.20	0.15	0.21	0.30
Eureka	0.59	0.52	0.45	0.39	0.34	0.30	0.26	0.23
Fernie	0.70	0.69	0.66	0.57	0.56	0.34	0.26	0.12
Fortine	0.66	0.56	0.48	0.42	0.37	0.32	0.21	0.22
Glacier	0.60	0.54	0.42	0.29	0.22	0.05	(-0.1)	(-0.1)
Golden	0.72	0.69	0.56	0.54	0.56	0.42	0.26	0.33
Kalispell, MT	0.64	0.57	0.57	0.51	0.42	0.37	0.38	0.41
Kaslo	0.65	0.57	0.47	0.47	0.63	0.34	0.14	0.21
Libby1	0.61	0.58	0.54	0.55	0.47	0.34	0.20	0.13
Libby32	0.71	0.64	0.58	0.55	0.50	0.35	0.19	0.13
Porthill	0.48	0.44	0.35	0.30	0.40	0.21	0.19	0.16
Sparwood	0.69	0.64	0.53	0.53	0.49	0.40	0.37	0.39
Wasa	0.56	0.52	0.51	0.51	0.51	0.43	0.25	0.28
West Glacier	0.75	0.73	0.69	0.64	0.61	0.46	0.45	0.29
Whitefish	0.49	0.38	0.35	0.31	0.20	0.17	0.14	0.24
Top 6 Average	***0.72***	***0.69***	***0.63***	***0.59***	***0.60***	***0.43***	***0.35***	***0.34***

Fall Precipitation

After the 2010 and 2012 water years, the influence of fall precipitation in the Libby April-August inflow volume forecast came into question. In 2010, the Apr-Aug inflow volume was 4.5 MAF, or 76 percent of average. The May forecast of 4.9 MAF triggered release of water for sturgeon, and Libby Dam failed to refill. The October-December precipitation totals at Kaslo and Glacier NP Rogers Pass gages totaled 105 percent of average and contributed to the May forecast being closer to average than the eventual observed inflow(75% of average). In 2012, the fall precipitation was 90% of average and contributed to springtime forecasts that were lower than the eventual observed April-August inflow volume (9.2 MAF, 156% of average). These events led to a discussion as to whether fall precipitation is a good predictor variable for Apr-Aug inflow volume.

During water year 2010, the 2004 water supply forecast procedure was used to set flood risk management and BiOp requirements. This forecast procedure included the use of October-December precipitation at Kaslo and Glacier NP Rogers Pass for each first of month forecast equation from January through June. Figure 7 shows that the sum of those two stations for the October-December totals had a decent correlation for April-August inflow volume when the forecast was produced in 2004. Since then, the correlation has deteriorated with the R^2 dropping to 0.27 from 0.55 when the period of record is shifted to 1980 to 2012.

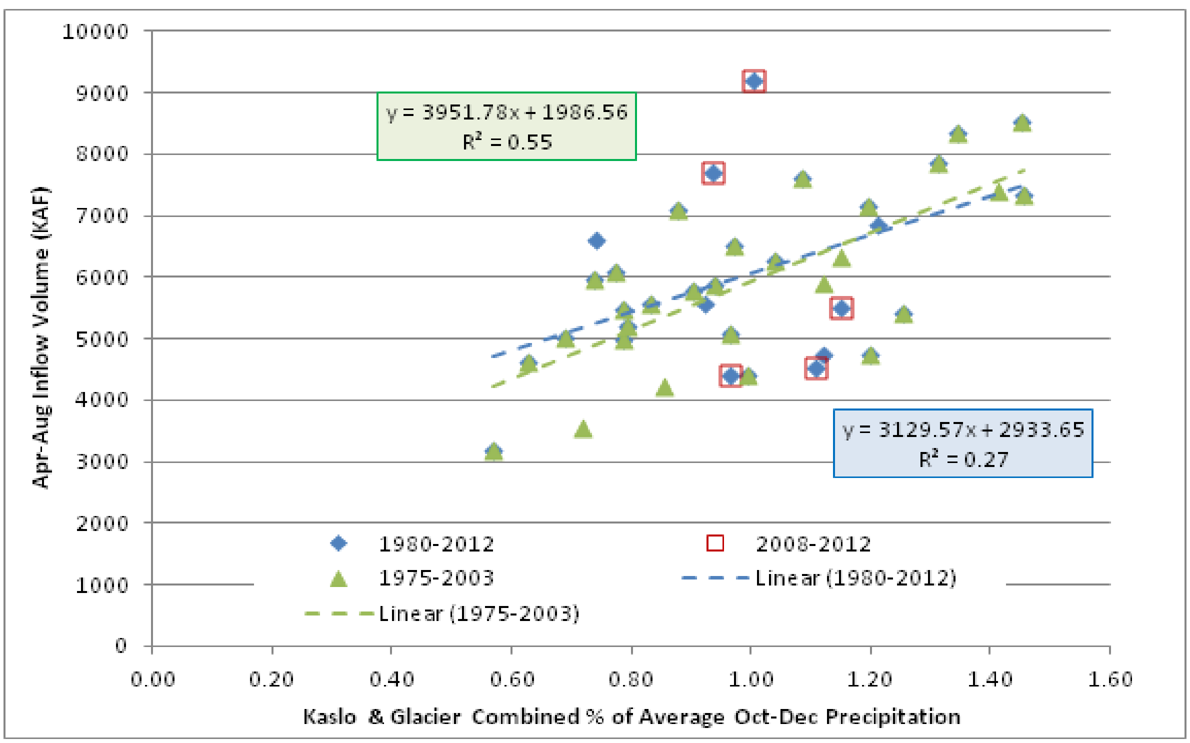


Figure 7. Scatter Plot of the sum of October-December Precipitation from Kaslo and Glacier NP Rogers Pass for 1980-2013 and 1975-2003.

Figure 8 shows six scatter plots of monthly precipitation totals using a six station index[2] and then summing the six stations yielding precipitation totals in the December (October-November or November sums), March (October-February or November-February sums), and May (October-April or November-April sums) forecasts. There are two plots for each of the months: one with October to Date and another with November to Date to see the effect on the R^2 and linear interpolation to the April-August inflow volume for the 1981 to 2013 period of record. In general, the scatter plots show a fairly tight positive correlation with the exception of water year 2012, the 9.2 MAF point, that is consistently well outside of the trend in the cluster of points and does not fall into the above average position of the cloud until the May forecast precipitation totals. Also note that the R^2 values are less for the aggregated monthly totals that start in November than for those that start in October, which is consistent with Table 13.

Conclusion

The use of October precipitation, Figure 8, improves the performance of the forecast for the April-August inflow volume of Libby Dam. The issue with the prediction of the May 2010 water supply forecast was because the correlation diminished between the inflow volume and the precipitation accumulations at the Kaslo and Glacier NP Rogers Pass gages since the 2003 forecast model was developed after 2004.

In the 2012 Libby Dam operations review, fall precipitation was highlighted as one of the predictor variables that caused a discrepancy in the forecast relative to 2011, a year with similar snowpack to 2012. The 2012 forecast was below average in February and March issuing forecasts but the snow pack was above average this discrepancy ultimately led to the forecast underpredicting the April-August inflow volume in 2012. Also, precipitation has a better correlation to the April-August inflow volume than climatic indices, so the risk of being misled by precipitation variables in the forecast is much less than that of climatic indices.

This precipitation analysis suggests that precipitation variables, even in the month of October, are good candidate variables for the forecast. However, as can be seen with the Kaslo and Rogers Pass issues, individual gages still must be checked for changes in their utility as predictor variables.

[2] The six station index comprised the sum of the following stations Cranbrook, BC, Eureka, MT, Fernie, BC, Libby 1NE Ranger Station, MT, Sparwood, BC, and West Glacier, MT

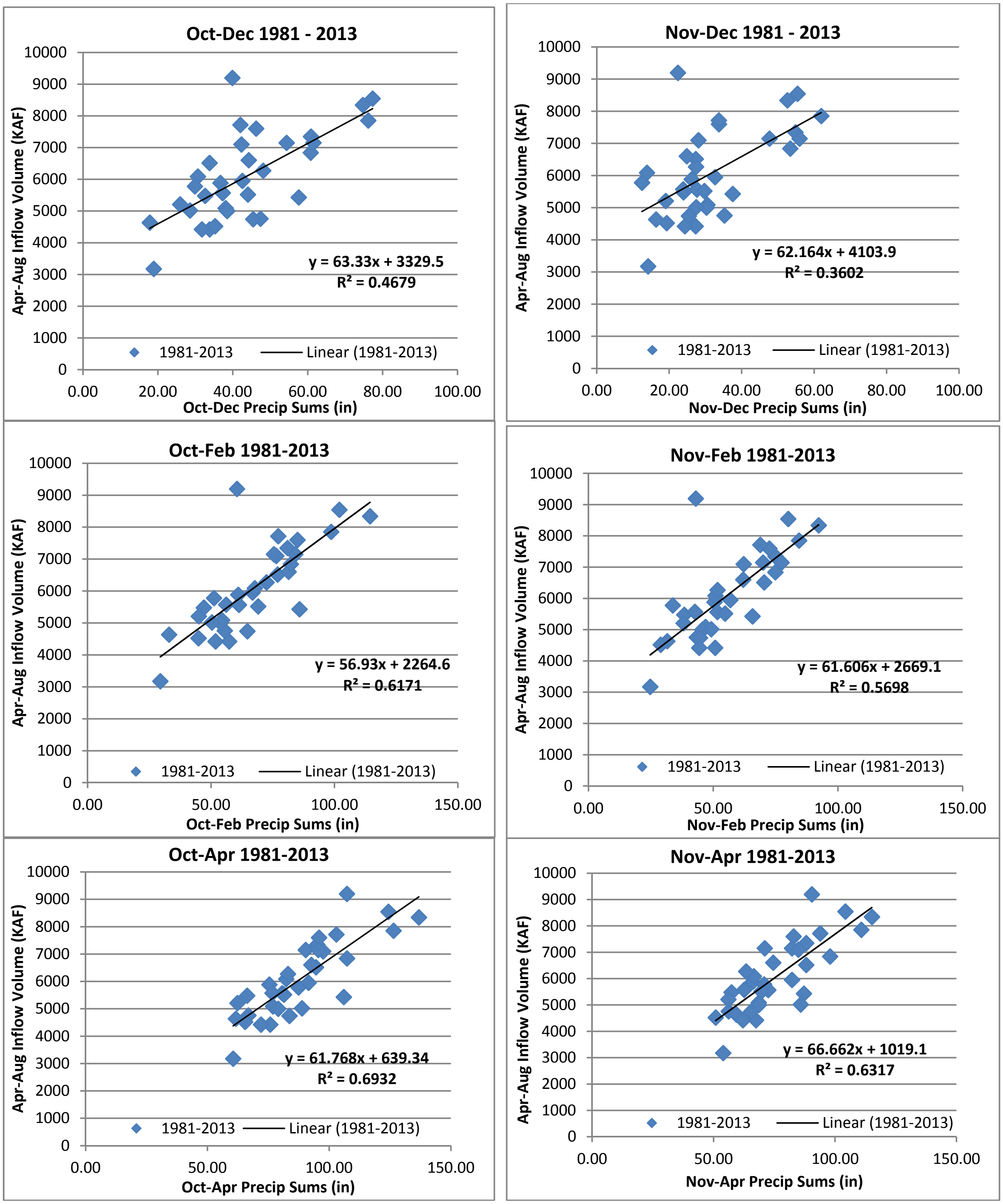


Figure 8. Scatter plots comparing October to Date versus November to Date Precipitation totals of six Kootenai Basin gages for the January, March and May forecasts.

Appendix C. Climatic Indices

Introduction

Climatic indices can be indicators of potential weather patterns, but their correlations to flow in the Kootenai River watershed are weak relative to precipitation and snowpack. Ideally, using climatic indices only in the early season (December to January forecasts of the Apr-Aug inflow) can decrease the risk of over- or under-drafting the reservoir at the beginning of the drawdown. At the same time, these predictor variables can swing a forecast in the opposite direction of more clearly related variables, such as snowpack, and result in a significant adjustment in the reservoir drawdown.

The 2011 Update to the Libby Dam water supply forecast identified eight climatic indices (Table 5) that had some correlation to the April-August inflow volume for Libby Dam. The final forecast equations used the SOI, QBO, and PNA, which all reduced the cross-validation standard error (CVSE). However, in practical application, the QBO created a capricious difference in the forecast between two water years with similar snowpack. For more details, see the QBO section.

This appendix is a consideration of the three indices used in the 2011 update. One goal of this forecast update was to ensure that the variables have a clear, defensible connection to a physical process that creates inflow to Libby Dam. Climatic indices were considered only for the early season, December and January forecasts, because there is a general lack of skilled predictor variables at that time of the year. Determination of which of the three indices is selected for use in the December forecast is based on:

- If there is actual clear connection to weather patterns that affect the Kootenai Basin
- Whether there any points that do not fall within general trend or what is the potential for the variable to significantly reduce the forecast in what turns out to be clearly a high inflow year, or vice versa

Quasi-Biennial Oscillation (QBO)

The current forecast uses the Quasi-Biennial Oscillation (QBO) as a predictor variable. The QBO is an index formed by averaging wind speeds at 3 equatorial stations (Singapore, the Maldives, and Canton Island). The index shows cyclic behavior with a period of approximately 27 months. Westerly winds are given a positive index and easterlies have a negative index. Including the sum of the January through March monthly QBO values from the previous year slightly reduces the Cross-Validation Standard Error (CVSE) in the principal components regression (PCR). The variable is used as a predictor for all months of the WSF. However, there is currently no peer-reviewed research that conclusively demonstrates any mechanism by which the QBO may influence precipitation in northern latitude basins. It may be the case that QBO and precipitation co-vary with some other climactic forcing, but this second-hand covariation appears to be marginal and possibly coincidental. Unlike the link between variables such as snowpack or precipitation and inflow to Lake Koocanusa, the QBO lacks of a clear, physical connection to the inflow process. This creates a higher potential for the forecast to be influenced in the incorrect direction, even if on average it provides some amount of forecasting ability.

When treated as a standalone variable, the summed index shows only a faint negative correlation (R^2 =0.06) to the April-Aug inflow volume (Figure 1). This skill is partly the result of above average inflow year's corresponding to highly negative QBO in 1996 and 2012. While the QBO may improve the error statistics it does have a tendency to mislead lead the forecasts in very wet years that could lead to poor operational decisions at Libby Dam.

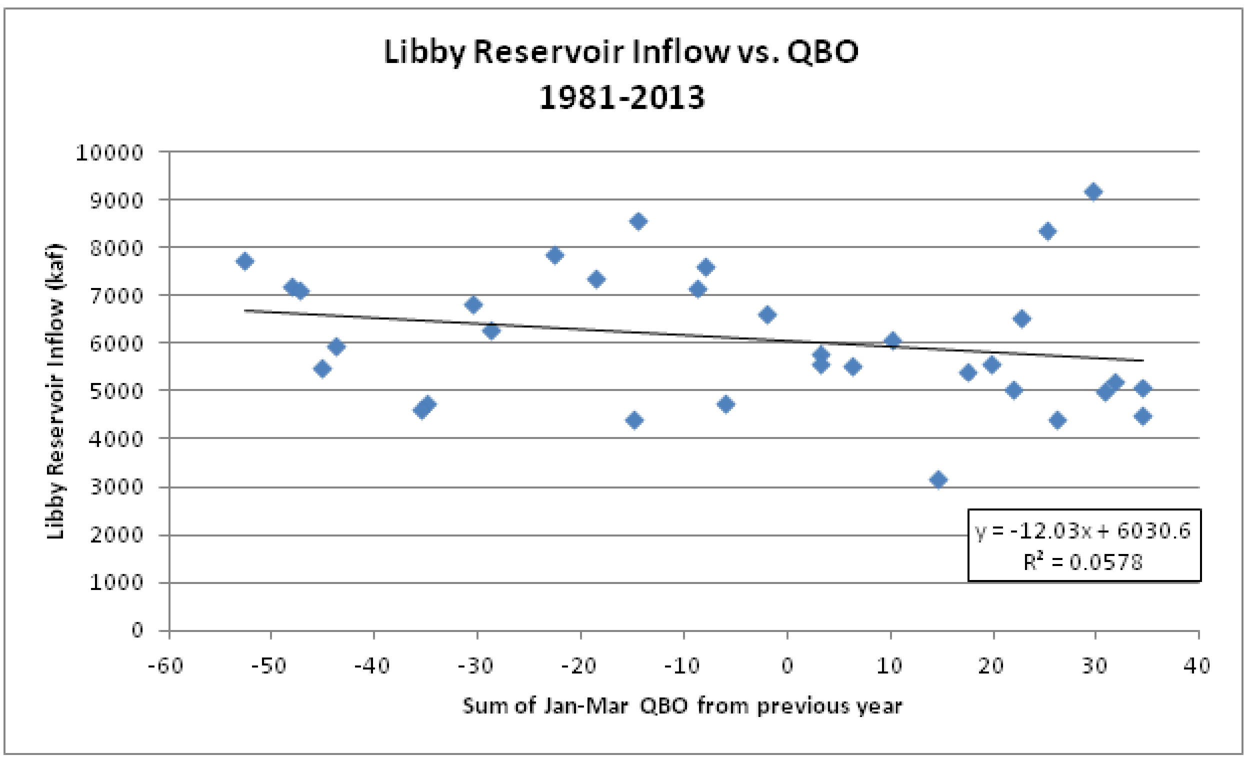


Figure 9. Scatter plot of the QBO vs. Inflow Volume, 1981 – 2013

Positive QBO years appear to be less tightly clustered than negative QBO years. With the lowest five QBO years removed, there is essentially no skill left in this correlation (Figure 10). This suggests that there may be some small predictive value when the QBO is very low but less as it increases – i.e. that the relationship between QBO and inflow volume is nonlinear and thus not well-suited for a linear model such as principle components regression.

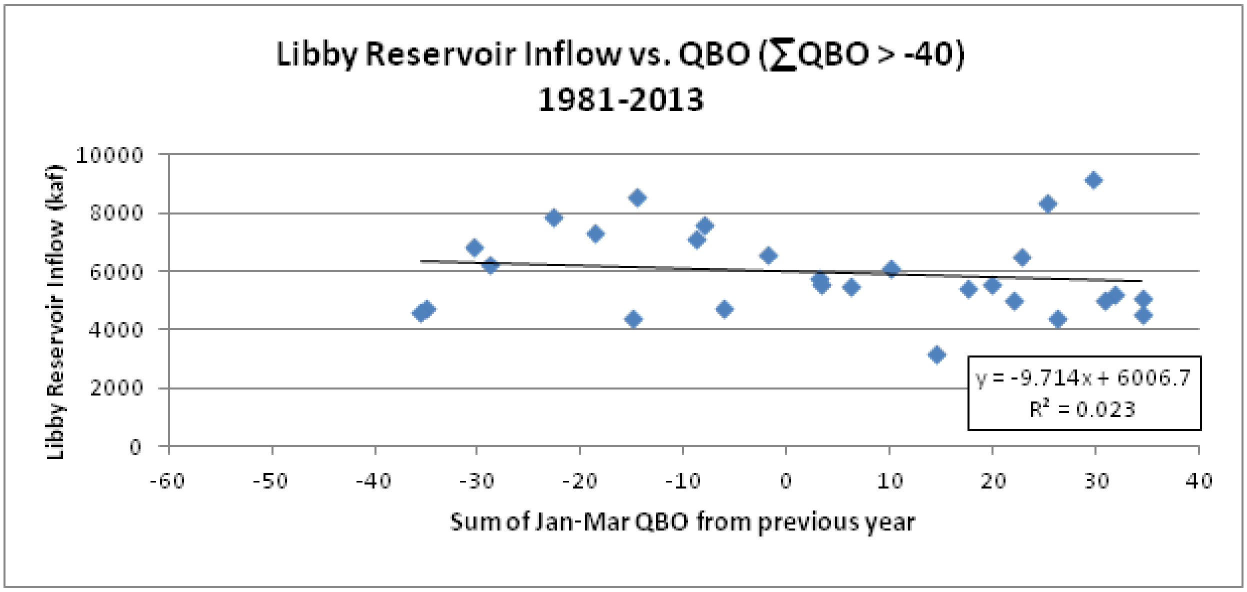


Figure 10. Scatter plot of the QBO vs. Inflow Volume, 1981 – 2013, including only years when the sum of the QBO was greater than -40

The correlations between the QBO and the May through August and June through August inflow volumes, the respective forecasting periods for the May and June forecasts, are similarly weak. The best correlation of the three is QBO versus June through August inflow volume, with an R^2 of 0.12. Normally the PCR algorithm discards variables with an R^2 below 0.09, which would eliminate the QBO for all forecasts except June. This default option was overridden in the production of the 2011 forecast procedure in order to force the model to retain the QBO as a predictor. It is possible for variables with low standalone skill to decrease error in a principal components regression, but this does not necessarily mean that they are improving the forecast. Since the model produces strictly linear equations, there is no way to capture t only he cluster of above average inflow (low QBO) years without also depressing the forecast in years when the QBO is positive.

The regression coefficient for QBO returned by PCR in the March equations was -10. The QBO's contribution to the forecast in historical years would therefore have ranged from -350 KAF to +530 KAF (Figure 11). The WY2012 forecast is an example of a strong positive QBO and the effect on the February and March issued water supply forecasts. Snowpack is the dominant source of water for Libby Dam during the spring freshet. In 2011 and 2012, the snowpack variables for March 1 averaged 110% and 109%, respectively, but the March forecasts between the two years differed by 1500 KAF. Fall and early winter were wetter in WY2011, which contributed somewhat to a higher March forecast in that year. The single biggest difference, however, was the QBO (Figure 11).

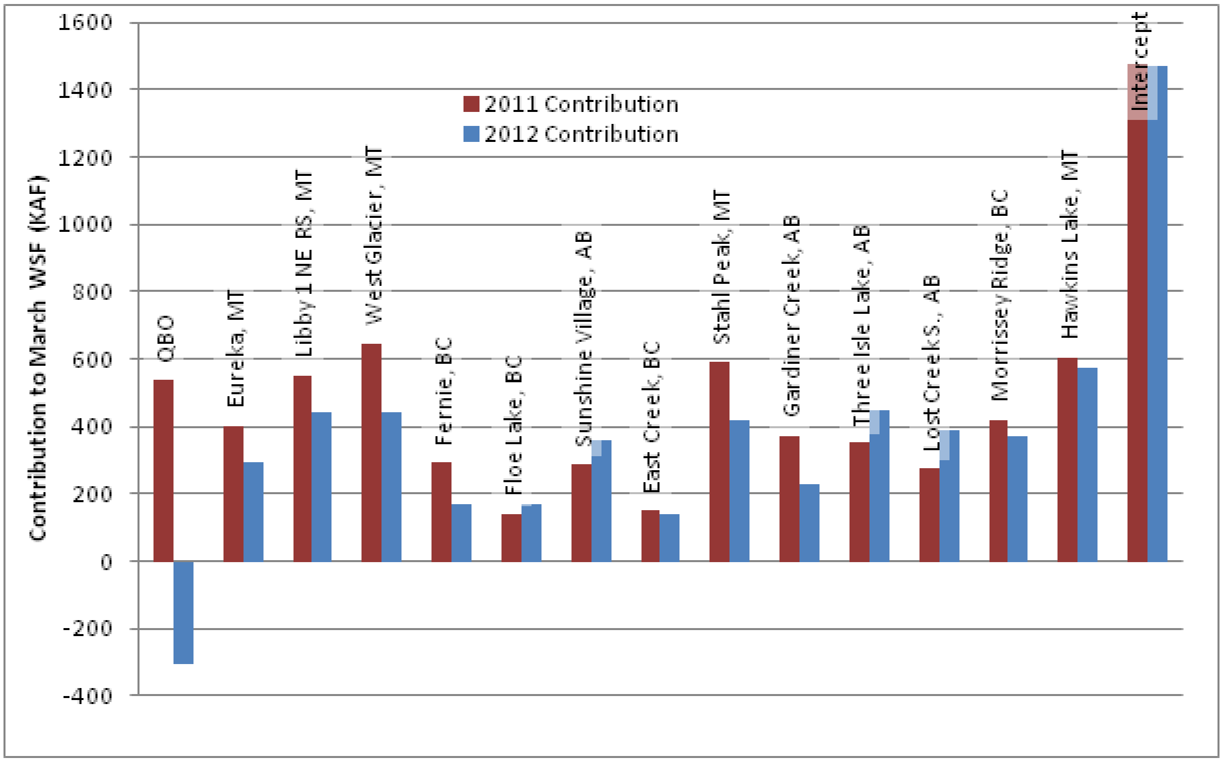


Figure 11. QBO, precipitation, and SWE contributions to the March water supply forecasts in 2011 and 2012

In a year (2012) with 109% of average snowpack, the QBO subtracted 300 KAF from the forecast volume, resulting in a below average forecast (Table 14). Compared to the high positive contribution the QBO made in 2011, this represented an 800 KAF swing despite the similarity in snowpack. The QBO has its highest influence on forecasts in the February and March forecasts, which set the end-of-month flood risk management (FRM) elevations for Libby Dam and are critical months for drafting the reservoir prior to the freshet. This type of capricious forecast model behavior, demonstrates the risk of including a predictor which can reduce the forecast even when snowpack has already accumulated in the basin, and therefore fails to establish a clear mechanism describing how the QBO might affect inflow during the remainder of the year.

Table 14. Predictor Variables Used in the March Issued Water Supply Forecast - WY2011 and WY2012

		2011 - March Forecast of April – August Water Supply Forecast				2012 - March Forecast of April – August Water Supply Forecast			
Variable	**Month(s)**	**Observed Value**	**Percent of Average**	**Regression Coefficient**	**Marginal Runoff (KAF)**	**Observed Value**	**Percent of Average**	**Regression Coefficient**	**Marginal Runoff (KAF)**
		A		B	=A*B	A		B	=A*B
QBO	∑Jan:Mar	**-52.68**		**-10.2**	**539**	**29.67**	**0%**	**-10.2**	**-303**
Eureka, MT	∑Oct:Feb Prcp	5.74 in	115%	70.2	403	4.30 in	86%	68.6	295
Libby 1 NE RS, MT	∑Oct:Feb Prcp	10.60 in	117%	52.0	551	8.65 in	95%	51.5	446
West Glacier, MT	∑Oct:Feb Prcp	19.21 in	133%	33.6	645	13.23 in	92%	33.7	446
Fernie, BC	∑Oct:Feb Prcp	27.14 in	107%	10.8	294	14.78 in	58%	11.5	170
Floe Lake, BC	1-Mar SWE	24.53 in	106%	5.8	141	26.87 in	116%	6.4	172
Sunshine Village, AB	1-Mar SWE	18.16 in	98%	15.9	288	20.20 in	109%	17.8	360
East Creek, BC	1-Mar SWE	29.82 in	104%	5.0	151	29.23 in	102%	4.8	139
Stahl Peak, MT	1-Mar SWE	37.20 in	128%	15.9	590	27.60 in	95%	15.2	421
Gardiner Creek, AB	1-Mar SWE	25.48 in	140%	14.7	374	17.24 in	95%	13.2	227
Three Isle Lake, AB	1-Mar SWE	14.42 in	94%	24.6	355	17.20 in	112%	26.1	449
Lost Creek S., AB	1-Mar SWE	18.06 in	94%	15.4	278	26.65 in	138%	14.7	392
Morrissey Ridge, BC	1-Mar SWE	22.74 in	100%	18.5	420	20.08 in	88%	18.6	374
Hawkins Lake, MT	1-Mar SWE	26.00 in	129%	23.3	605	25.20 in	125%	22.8	575
Intercept		1.00		1,476	1476	1.00		1,473	1473
				2011 1-Mar Forecast (KAF) =	**7111**			**2012 1-Mar Forecast (KAF) =**	**5635**

Pacific-North American (PNA) Index

The PNA pattern is one of the most prominent modes of low-frequency variability in the Northern Hemisphere extratropics. The PNA pattern reflects a quadripole pattern of 500 millibar height anomalies, with anomalies of similar sign located south of the Aleutian Islands and over the southeastern United States. Anomalies with sign opposite to the Aleutian center are located near Hawaii and over the intermountain region of North America (central Canada) during the winter and fall. The positive phase of the PNA pattern is associated with above-average temperatures over western Canada and the extreme western United States. The PNA tends to have little impact on surface temperature variability over North America during summer. The associated precipitation anomalies include above-average totals in the Gulf of Alaska extending into the Pacific Northwestern United States, and below-average totals over the upper Midwestern United States.

Although the PNA pattern is a natural internal mode of climate variability, it is also strongly influenced by the El Niño/ Southern Oscillation (ENSO) phenomenon. The positive phase of the PNA pattern tends to be associated with Pacific warm episodes (El Niño), and the negative phase tends to be associated with Pacific cold episodes (La Niña). (http://www.cpc.ncep.noaa.gov/data/teledoc/pna.shtml)

The current forecast uses the October-January sums of the PNA for the May and June forecasts. It is not clear from the previous report what uncertainty the forecast procedure was trying to predict in the April to August inflow volume other than it looked to improve the CVSE. Figure 12 shows a scatter plot of PNA sums in the forecast versus the observed April-August inflow volume. There is a general negative correlation between the PNA and the target volume for each year. 1981 and 2012 are highlighted because they are outside of the general trend of the correlation. 1981, an above average year, lands in an area when the freshet should be a dry year. 2012, a very wet year of 9.2 MAF, is placed in the plot where the average volume years should lie. In both cases using PNA in these years subtract volume from the forecast when volume should be added.

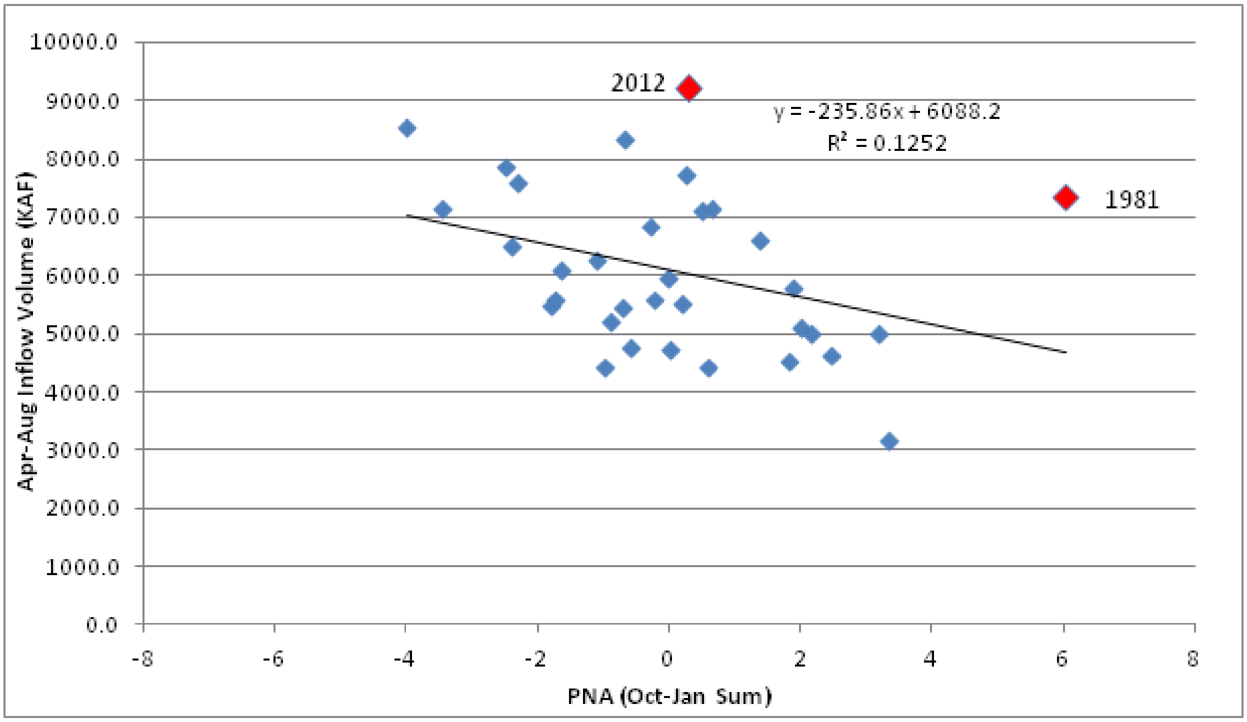


Figure 12. Scatter plot of Apr-Aug inflow volume versus Oct-Jan sums of the PNA from 1981 to 2013

Southern Oscillation Index (SOI)

The Southern Oscillation, a "seesaw of atmospheric pressure between the eastern equatorial Pacific and Indo–Australian areas", is closely linked with El Niño. During an El Niño–Southern Oscillation (ENSO) event, the Southern Oscillation is reversed. Generally, when pressure is high over the Pacific Ocean, it tends to be low in the eastern Indian Ocean, and vice versa. It is measured by gauging sea-level pressure in the east (at Tahiti) and west (at Darwin, Australia) and calculating the difference. This is then put into an index called the Southern Oscillation Index (SOI) or Tahiti–Darwin Index. High negative values of the SOI represent an El Niño, or "warm event". ENSO events are those in which a Southern Oscillation extreme and an El Niño occur together. El Niño and Southern Oscillation often occur together, but also happen separately. (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensocycle/soi.shtml)

Preliminary tests using PCReg showed that the SOI was a better-skilled predictor than the ENSO index itself. For this forecast update the SOI is being used in the December and January forecasts to account for precipitation after the forecast has been issued. The SOI can inform the December forecast since there is little to no snowpack data when the forecast is issued. The SOI is used in the January forecast as a transition to a more snow based forecast for better month-to-month consistency in forecast variables.

The SOI is used in the current forecast in the month of December. Figure 13 shows of scatter plot of the SOI June-July sum versus the Apr-August inflow volume. The SOI is used as an indicator for possible precipitation through the winter and in the spring. The SOI shows a positive correlation to the inflow volume and an R^2 of 0.17. The SOI also plots against the inflow volume with the scatter plot showing a general positive trend and almost all data points land in relation to the upward trend of the inflow volumes. Year 2012, the 9.2 MAF data point, is a positive year for the SOI that adds volume to the forecast whereas the PNA and QBO both reduce the volume in an above-average year.

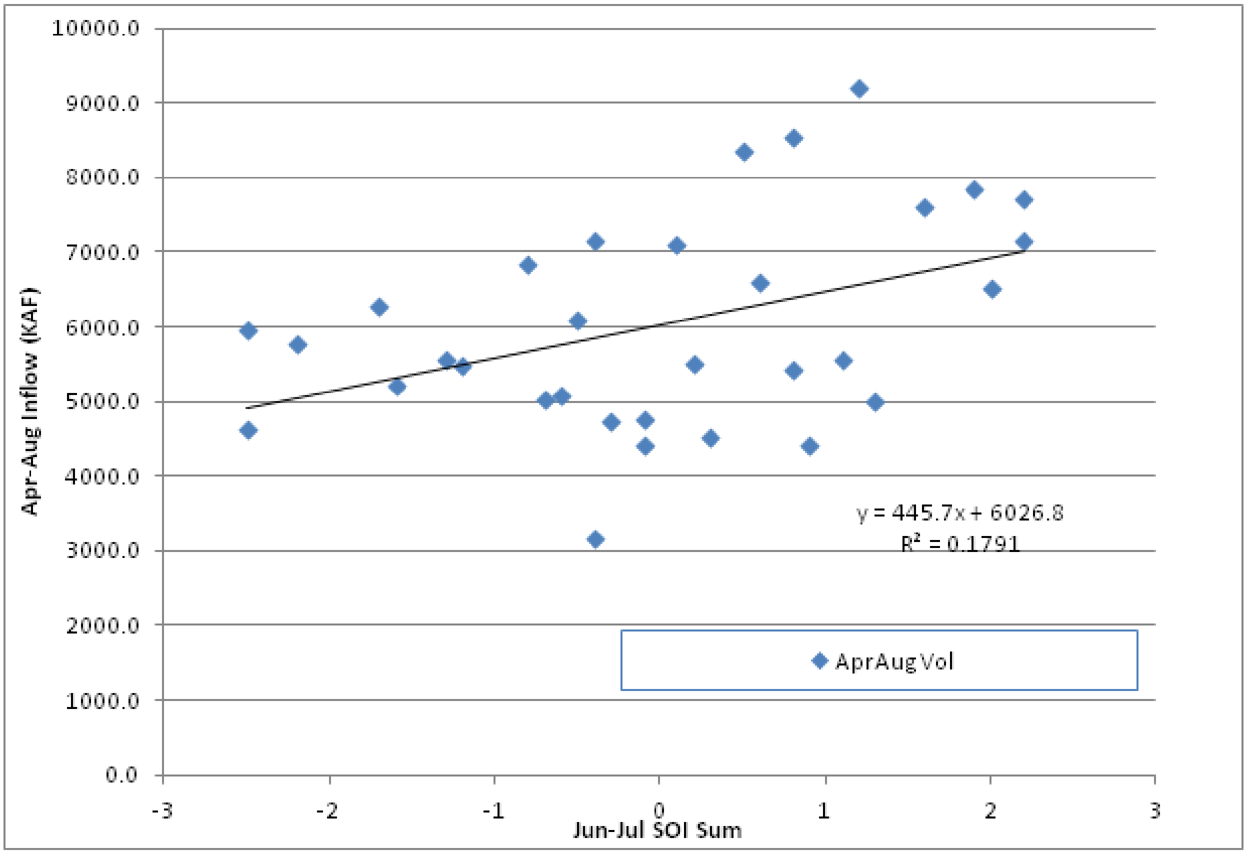


Figure 13. Scatterplot of Jun-Jul SOI Sum versus Apr-Aug inflow volume

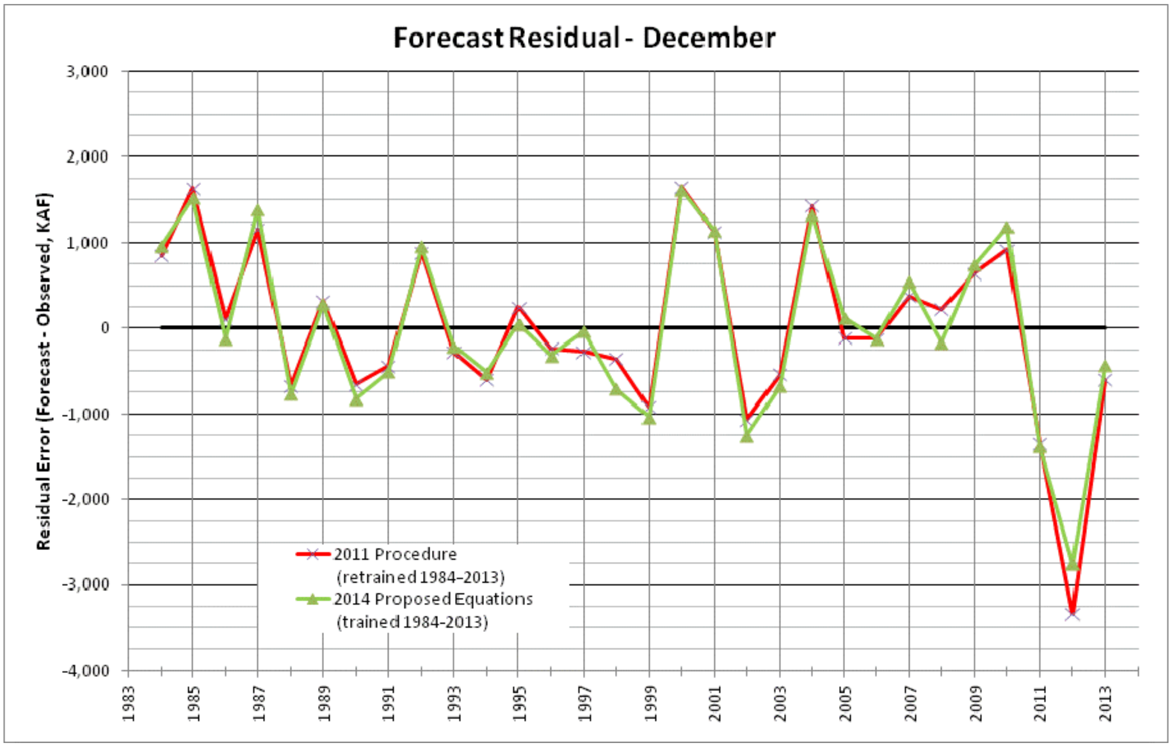
Conclusion

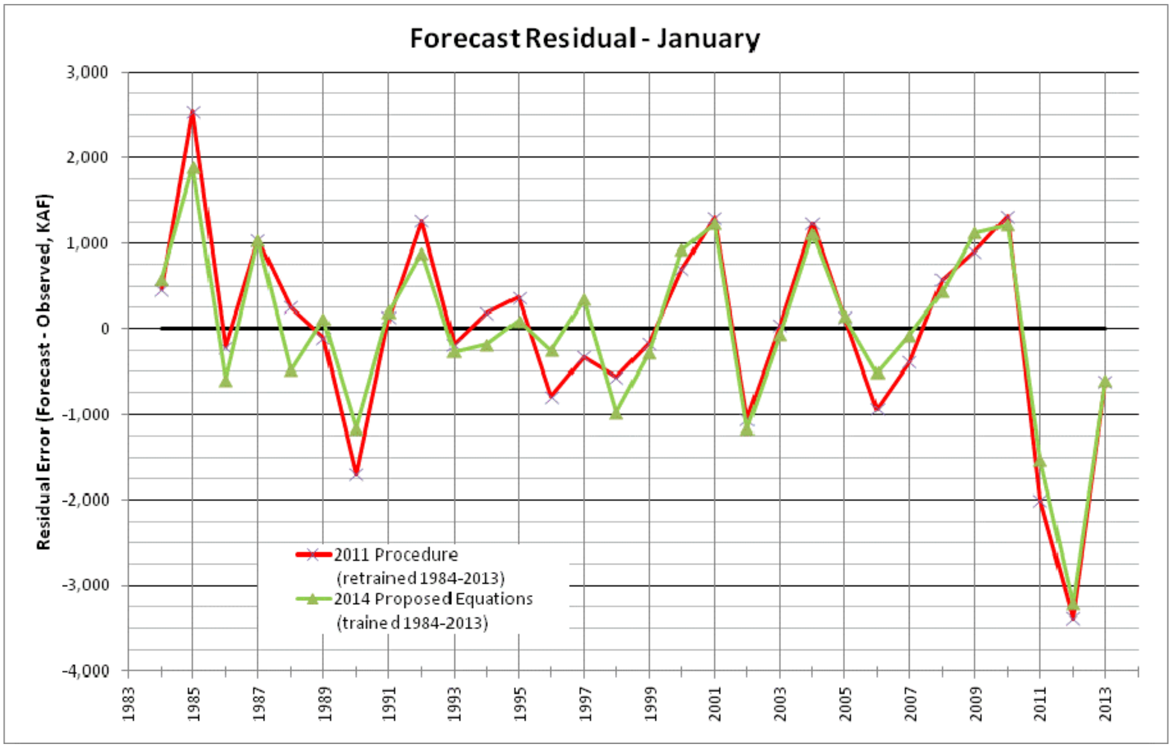
In the current forecast, for much of the drawdown period (January through March), the QBO and the PNA can incorrectly decrease the forecast. Using the PNA or the QBO in the forecast can mislead the forecasts against the expected climatic trends, and thus exposes the Libby Dam of not reserving enough storage space for the upcoming freshet and summer runoff. Removing the QBO and PNA from the forecast may increase the error statistics in the forecasts but given the capricious performance of QBO and PNA, the forecasts are more reliable without either of those climate indices.

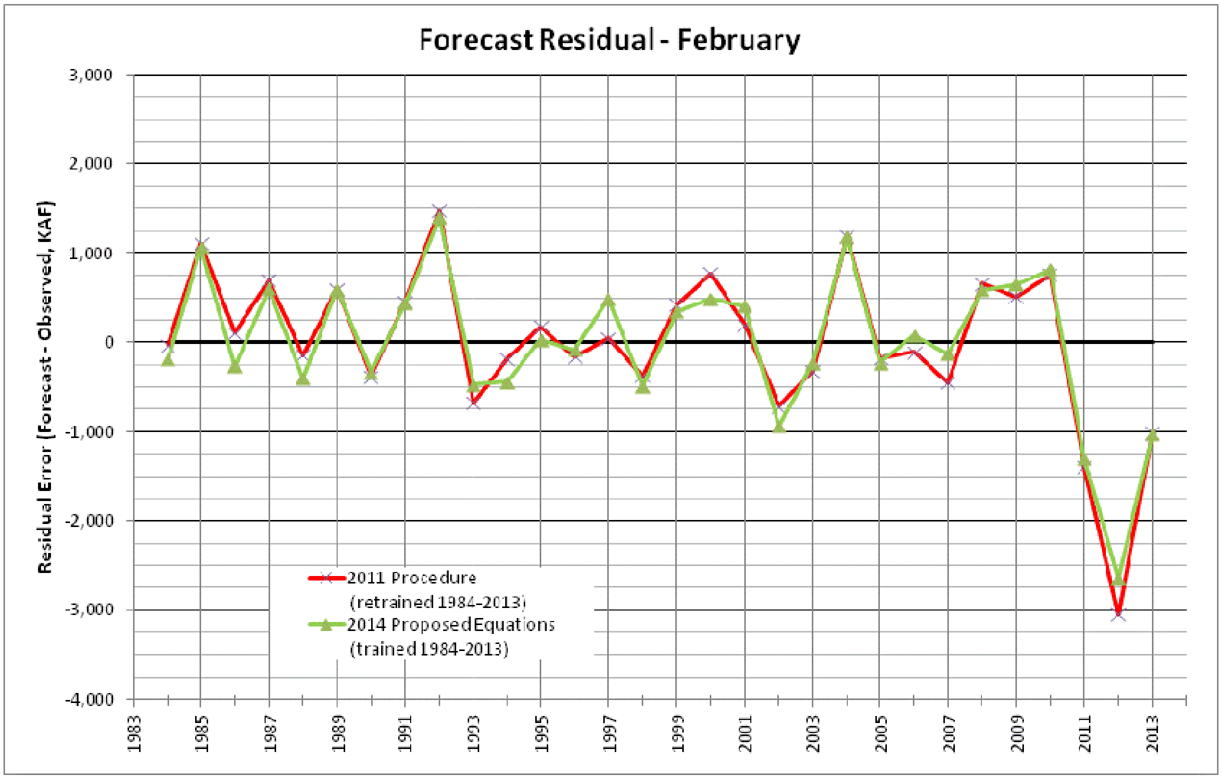
The SOI is more strongly and directly linked (better R^2) predictor for the December forecast with the scatter plot showing little to no exposure to misleading the forecast. Even if the variable does cause a misleading in the forecast in December, there is enough time to draw the reservoir down through April prior to the upcoming freshet in the Kootenai Basin. Given the low skill (R^2 of less than 0.2) climatic indices should be used only in the December and January forecasts, after which the forecasts should be based on more reliable predictors (SWE and precipitation). SWE and precipitation sums show greater skill than climatic indices (stronger correlation) to the Apr-Aug inflow volume and generally indicate if the year is going to be wet, dry or moderate by the time the February forecast is issued.

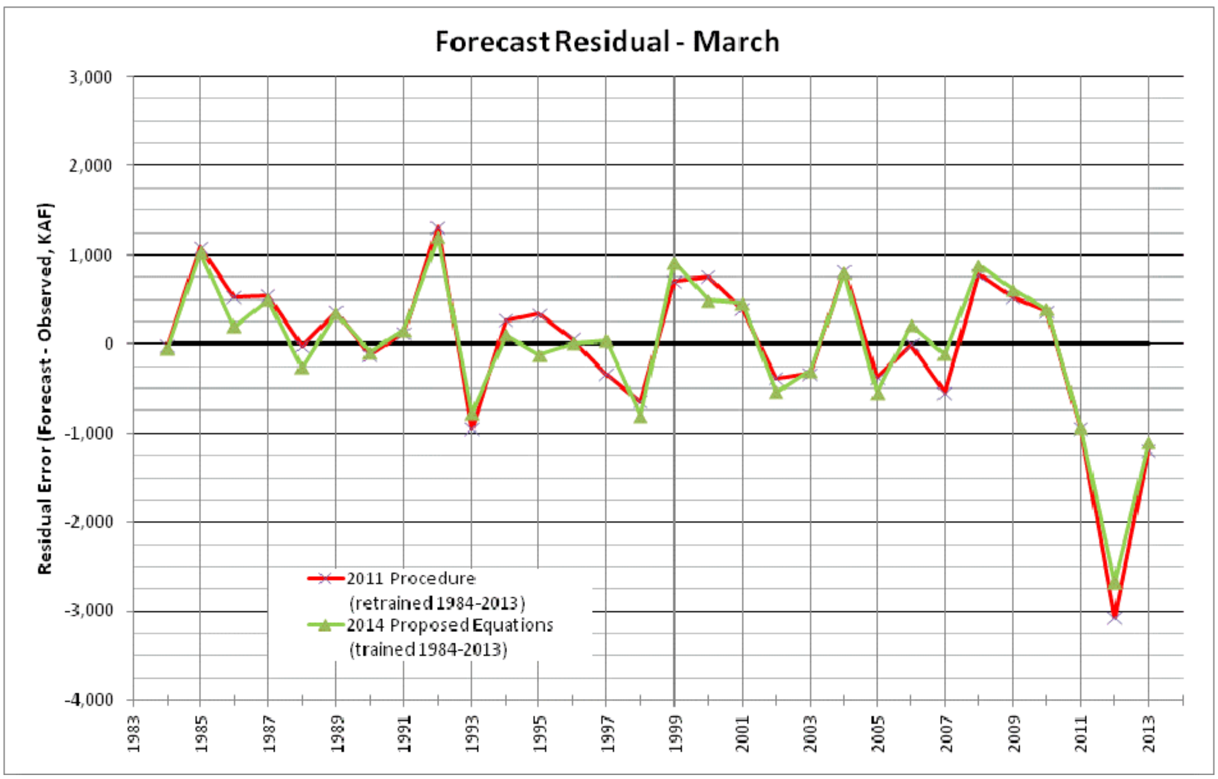
Appendix D. Monthly Residuals and Yearly Plots – Current vs. Proposed Equations

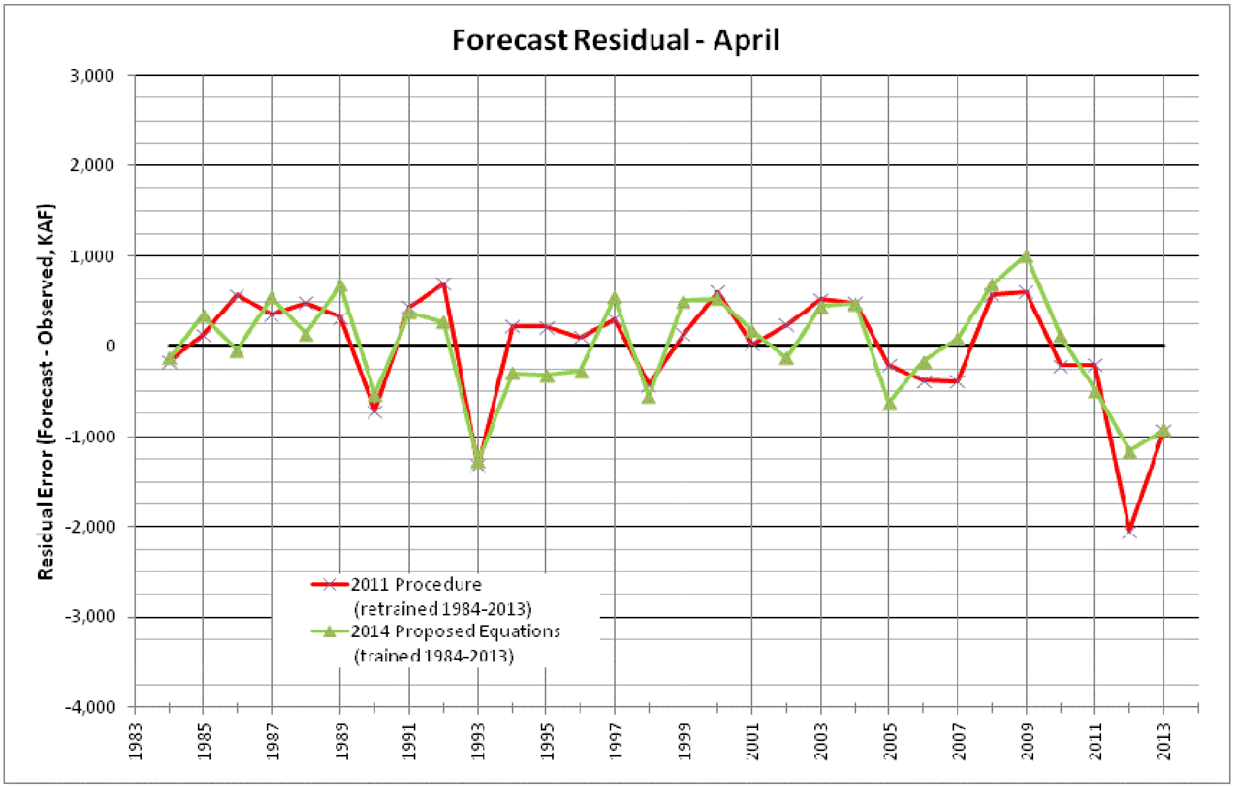
Month by Month Residual Plots



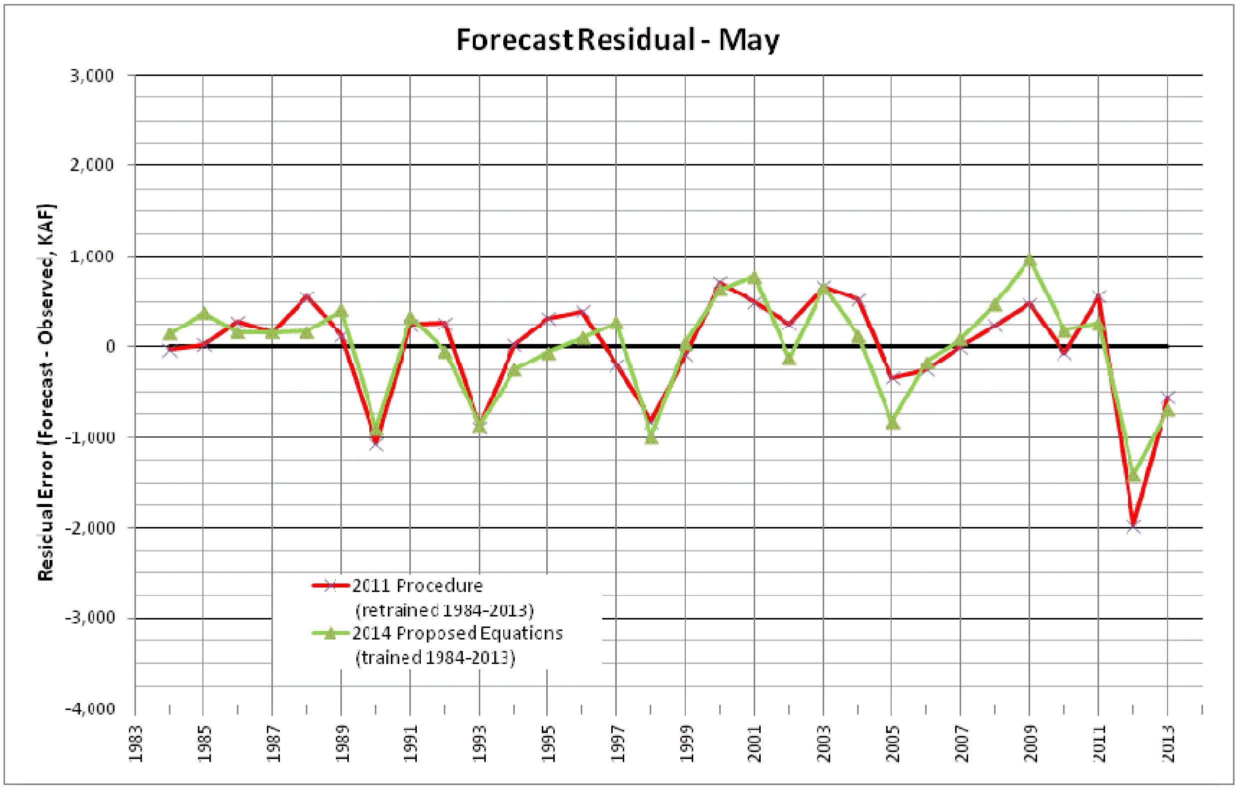



Forecast Residual - February
Residual Error (Forecast - Observed, KAF)
3,000
2,000
1,000
0
-1,000
-2,000
-3,000
-4,000
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2011 Procedure (retrained 1984-2013)
2014 Proposed Equations (trained 1984-2013)

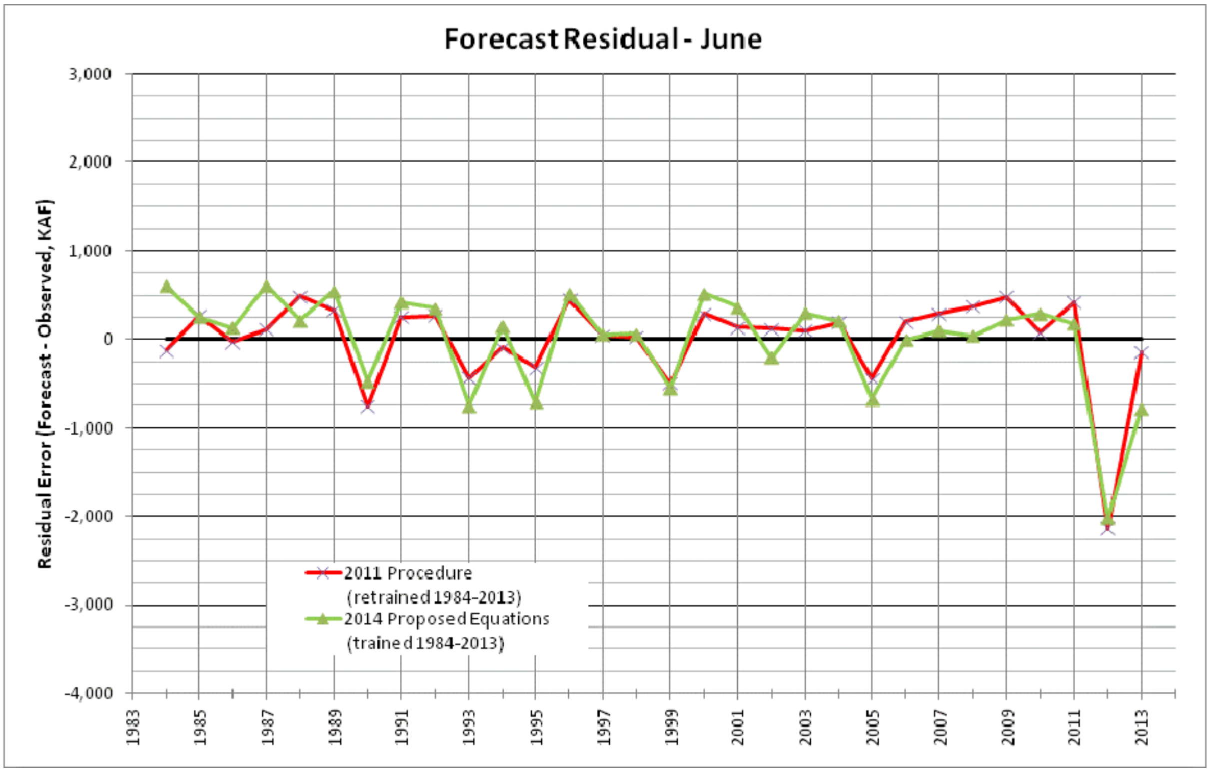

Forecast Residual - March
Residual Error (Forecast - Observed, KAF)
3,000
2,000
1,000
0
-1,000
-2,000
-3,000
-4,000
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2011 Procedure (retrained 1984-2013)
2014 Proposed Equations (trained 1984-2013)



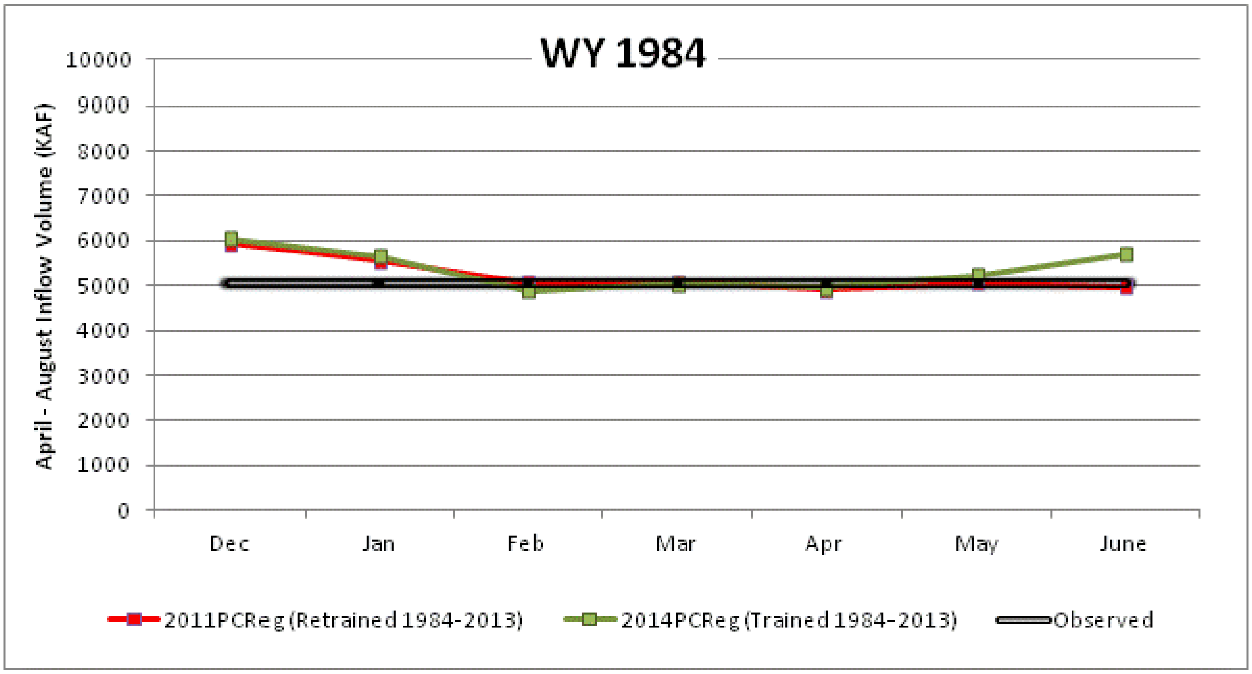
Forecast Residual - April
Resicual Error (Forecast - Observed, KAF)
3,000
2,000
1,000
0
-1,000
-2,000
-3,000
-4,000
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2011 Procedure
(retrained 1984-2013)
2014 Proposed Equations
(trained 1984-2013)

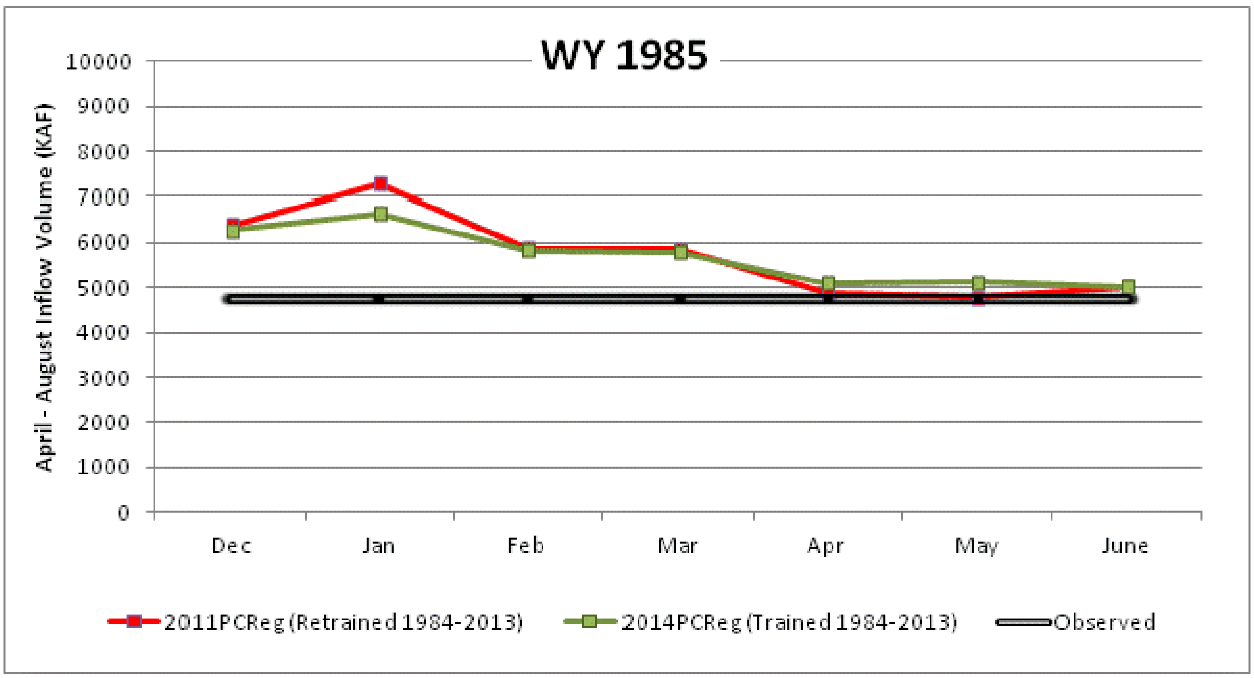


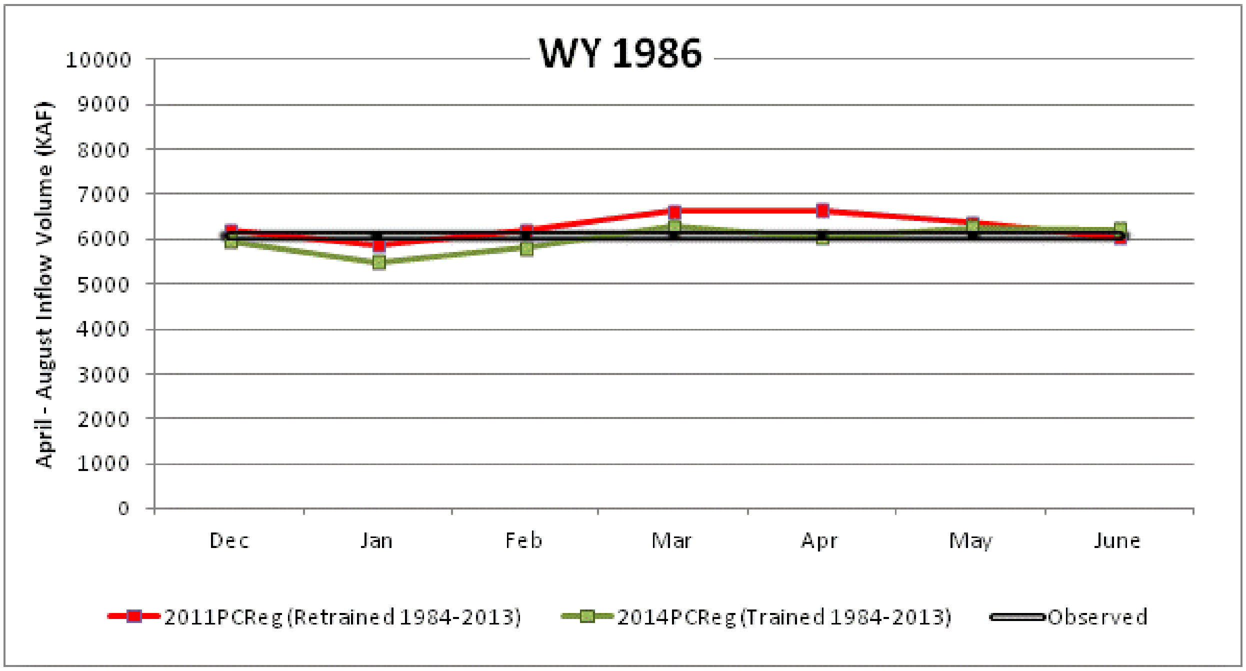
Forecast Residual - May
Resicual Error (Forecast - Observec, KAF)
3,000
2,000
1,000
0
-1,000
-2,000
-3,000
-4,000
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2011 Procedure
(retrained 1984-2013)
2014 Proposed Equations
(trained 1984-2013)


Forecast Residual - June
Residual Error (Forecast - Observed, KAF)
3,000
2,000
1,000
0
-1,000
-2,000
-3,000
-4,000
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2011 Procedure (retrained 1984-2013)
2014 Proposed Equations (trained 1984-2013)

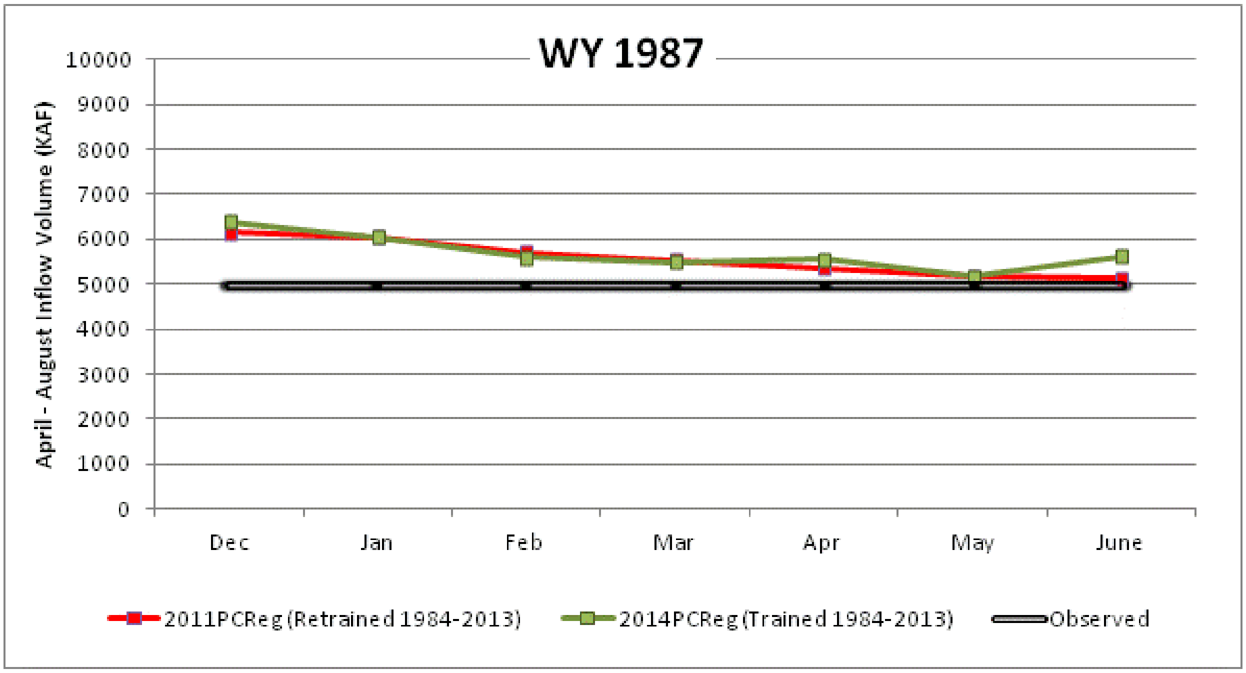
Annual Forecast Plots



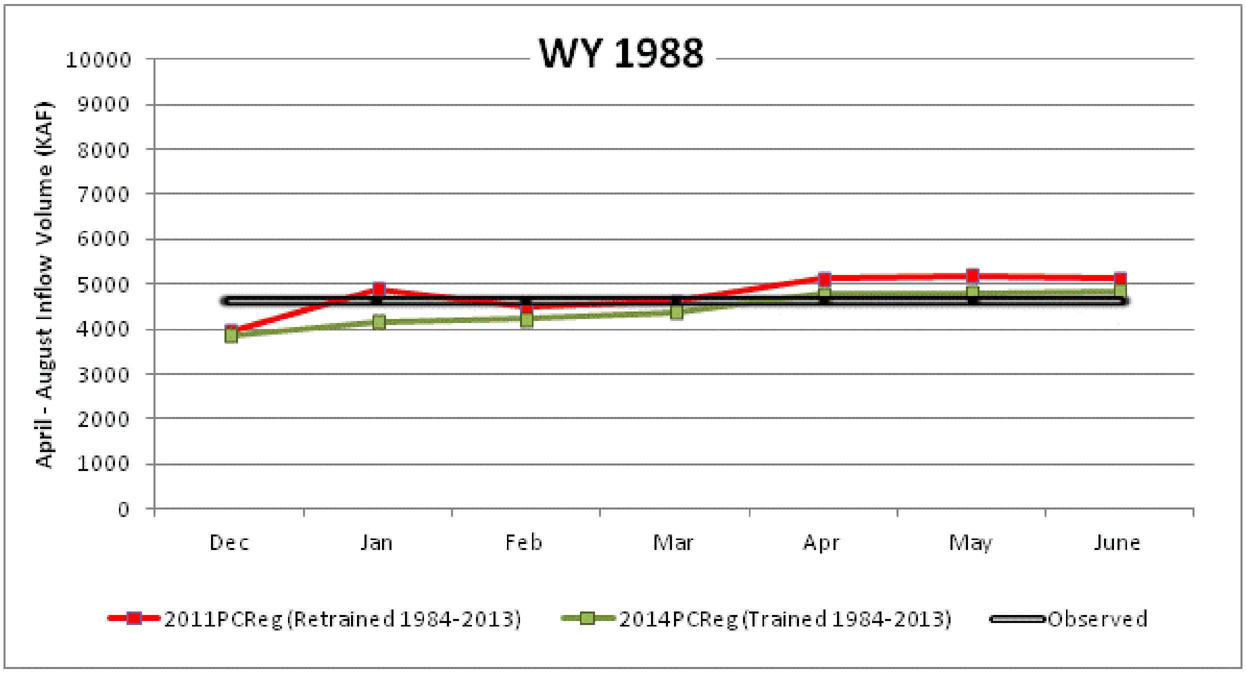


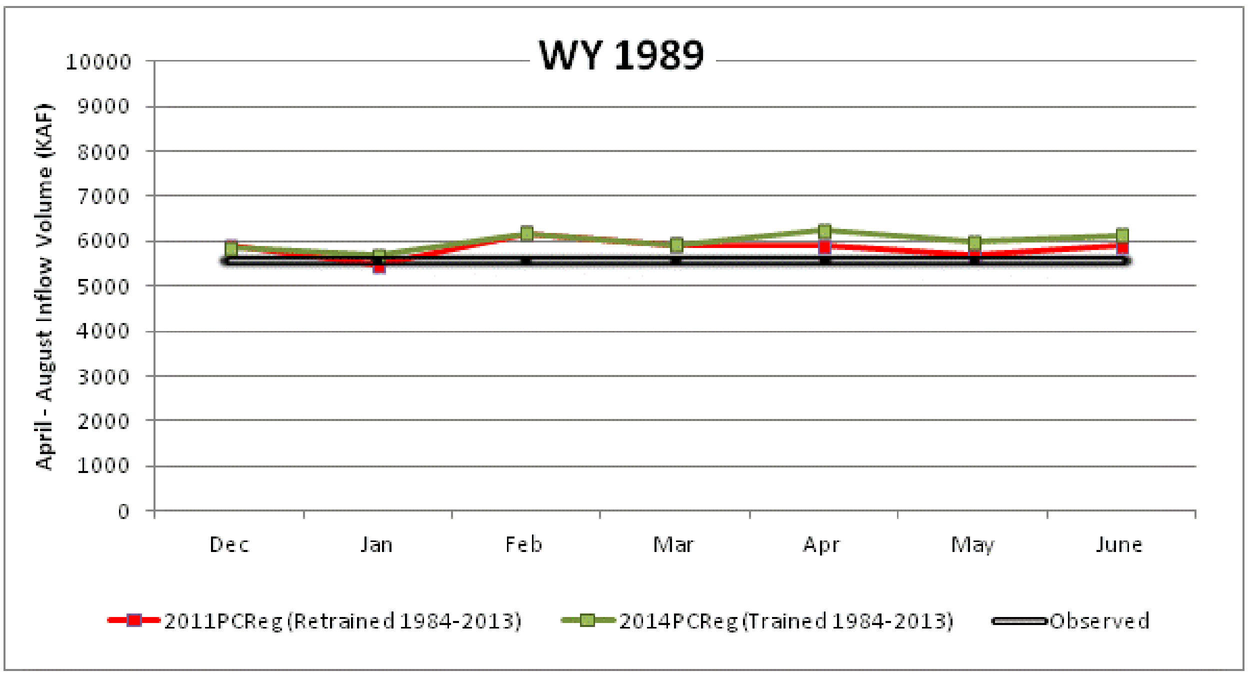


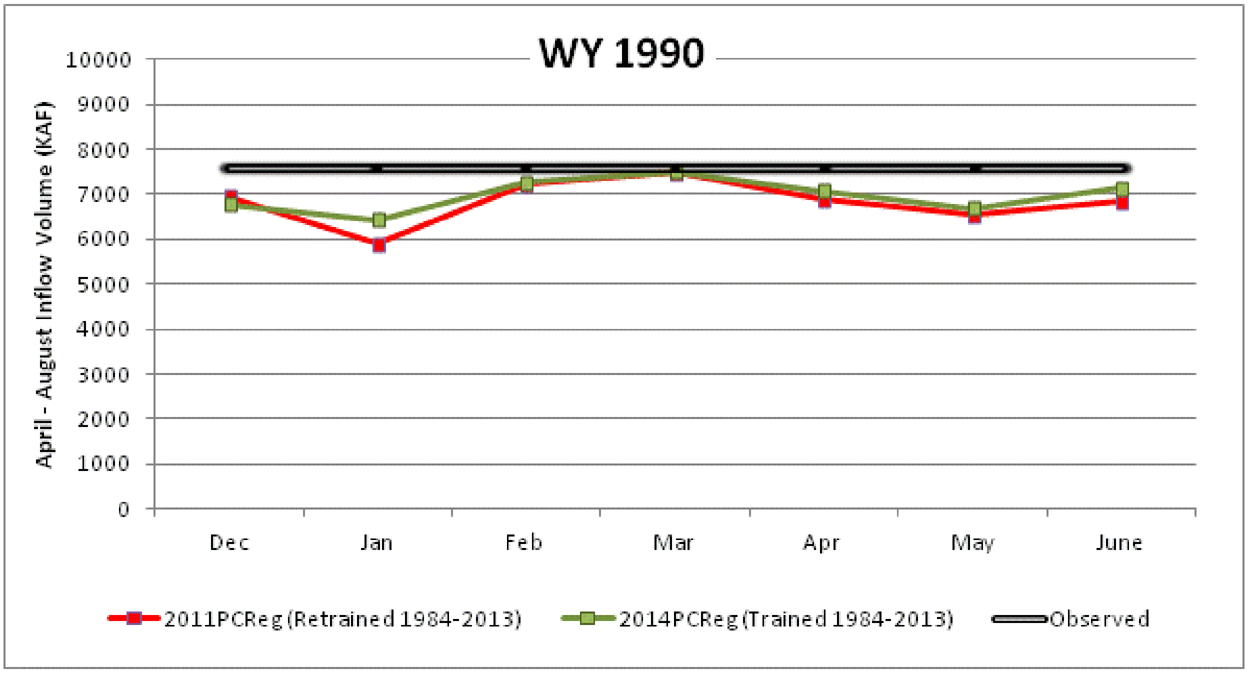
WY 1986
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed

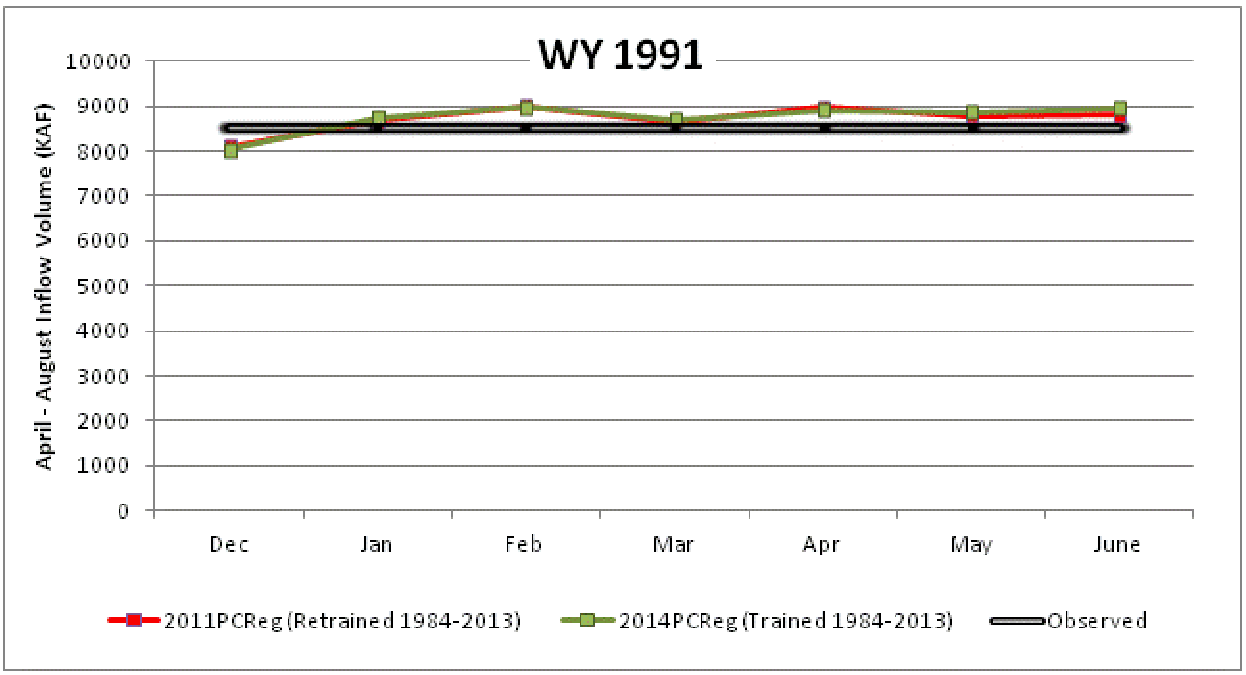


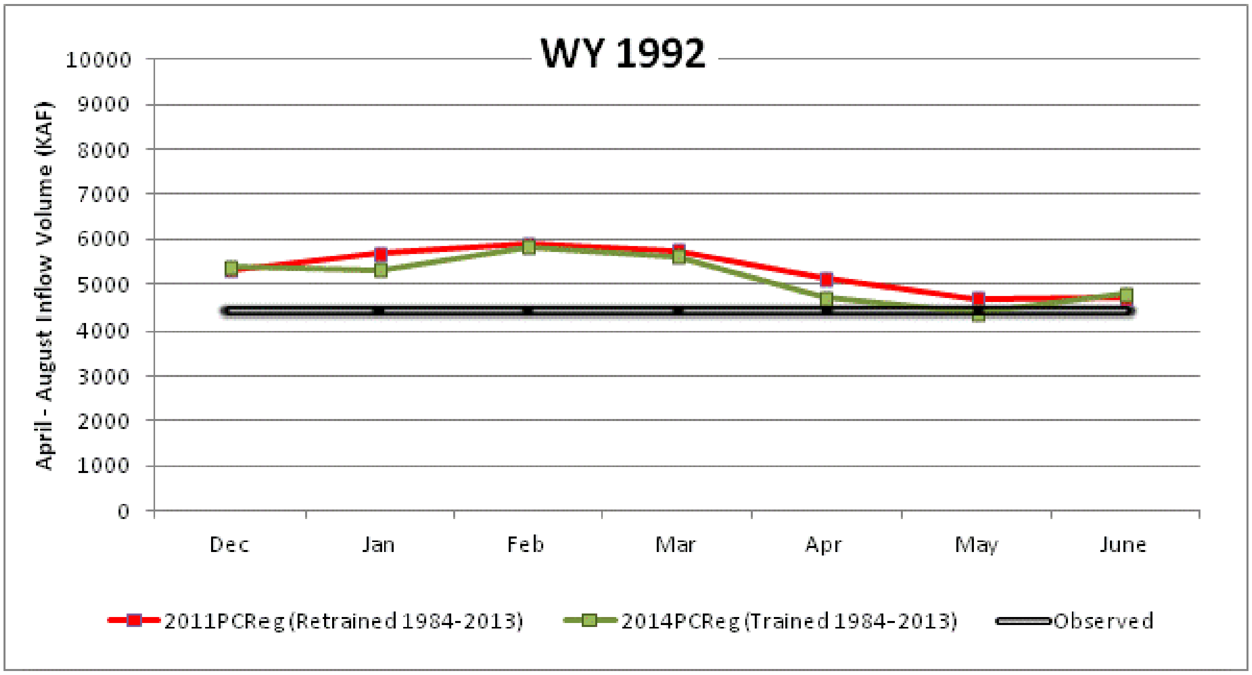
WY 1987
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed

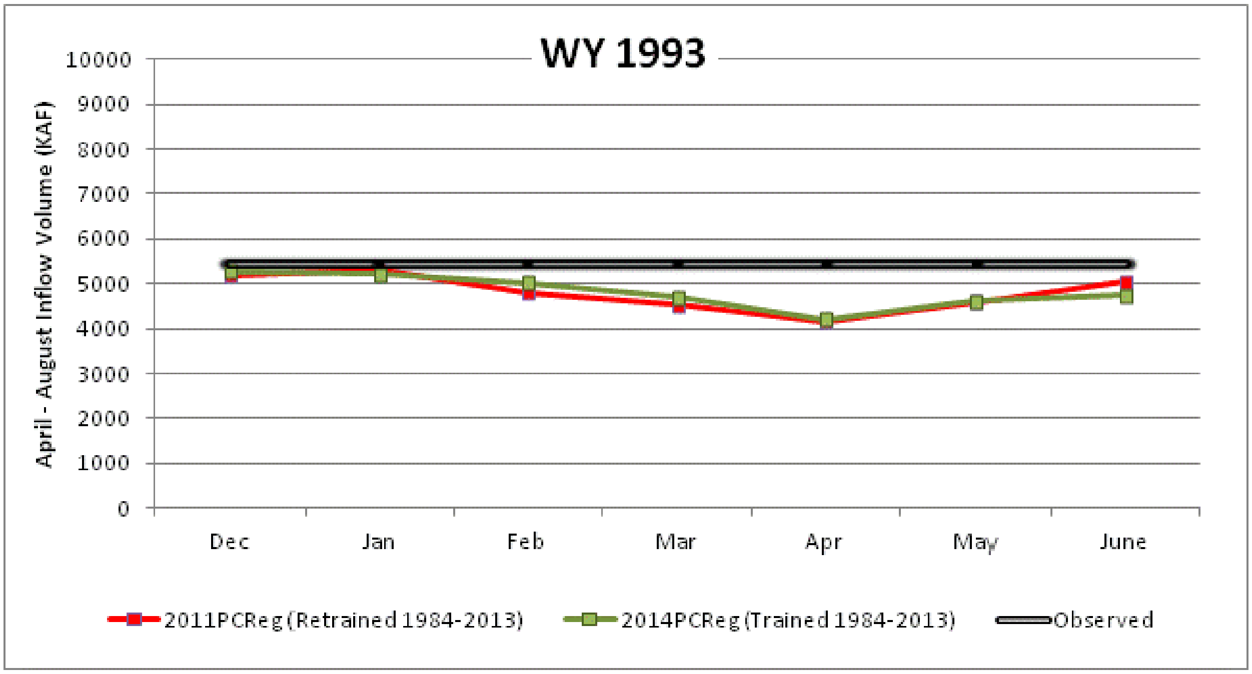

WY 1988
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed

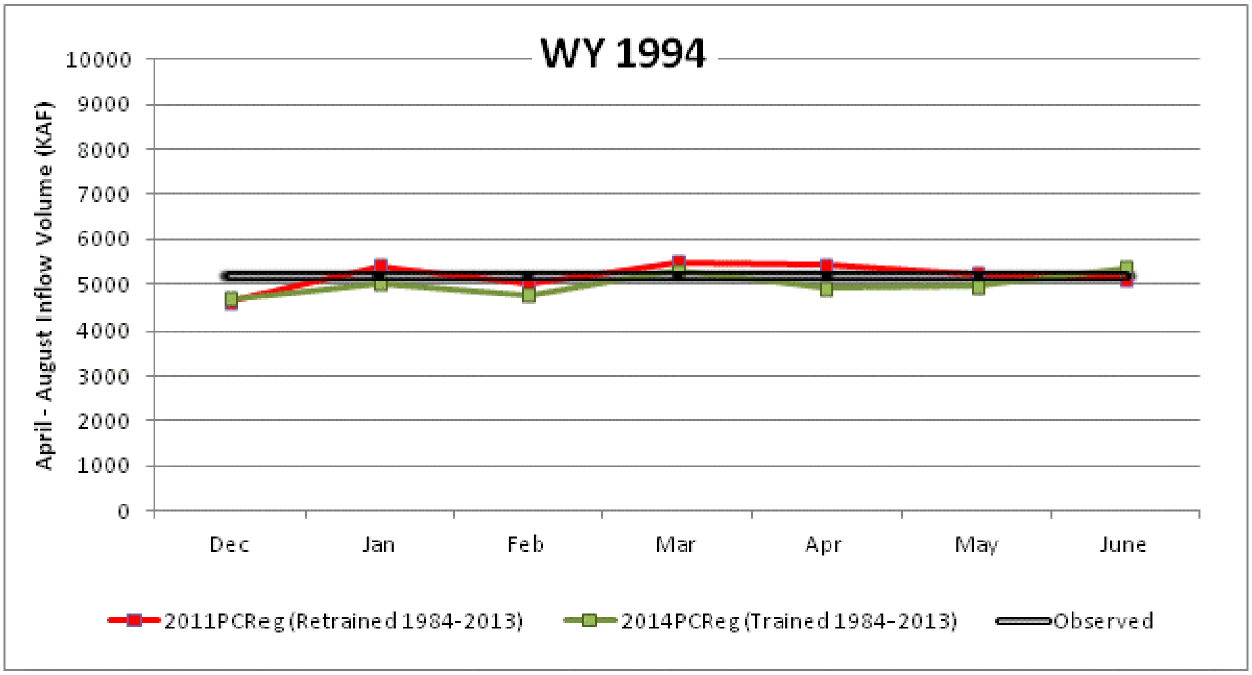

WY 1989
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed

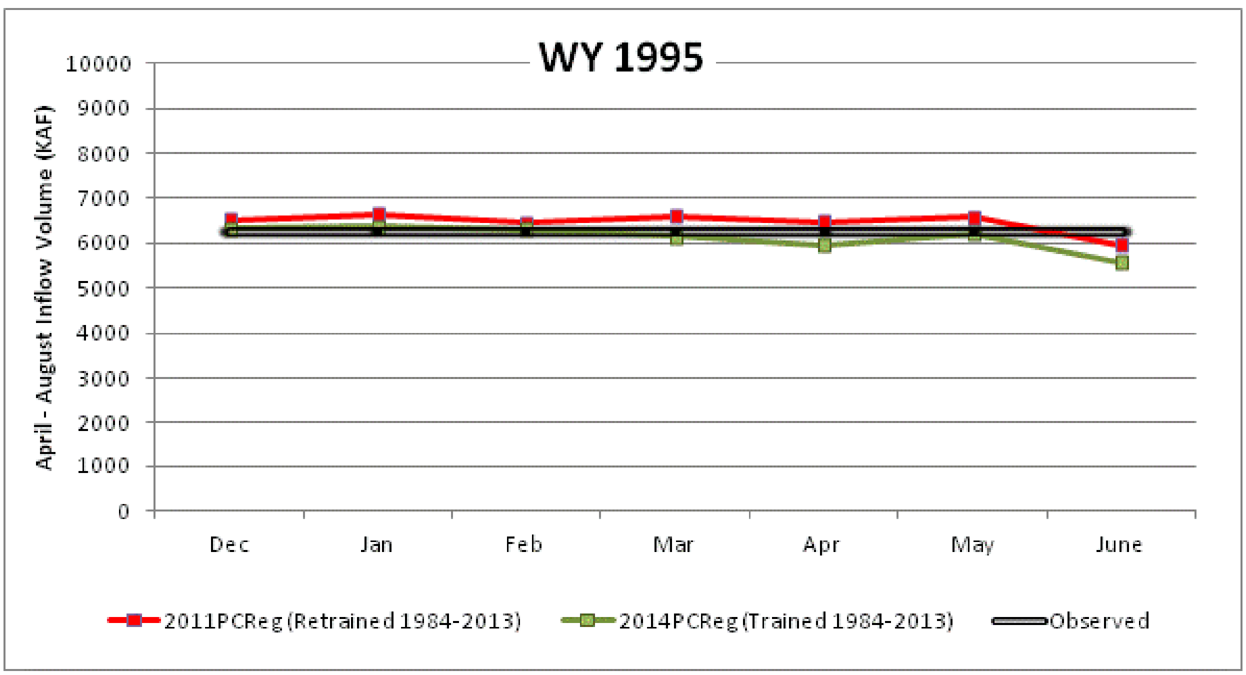

WY 1990
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed

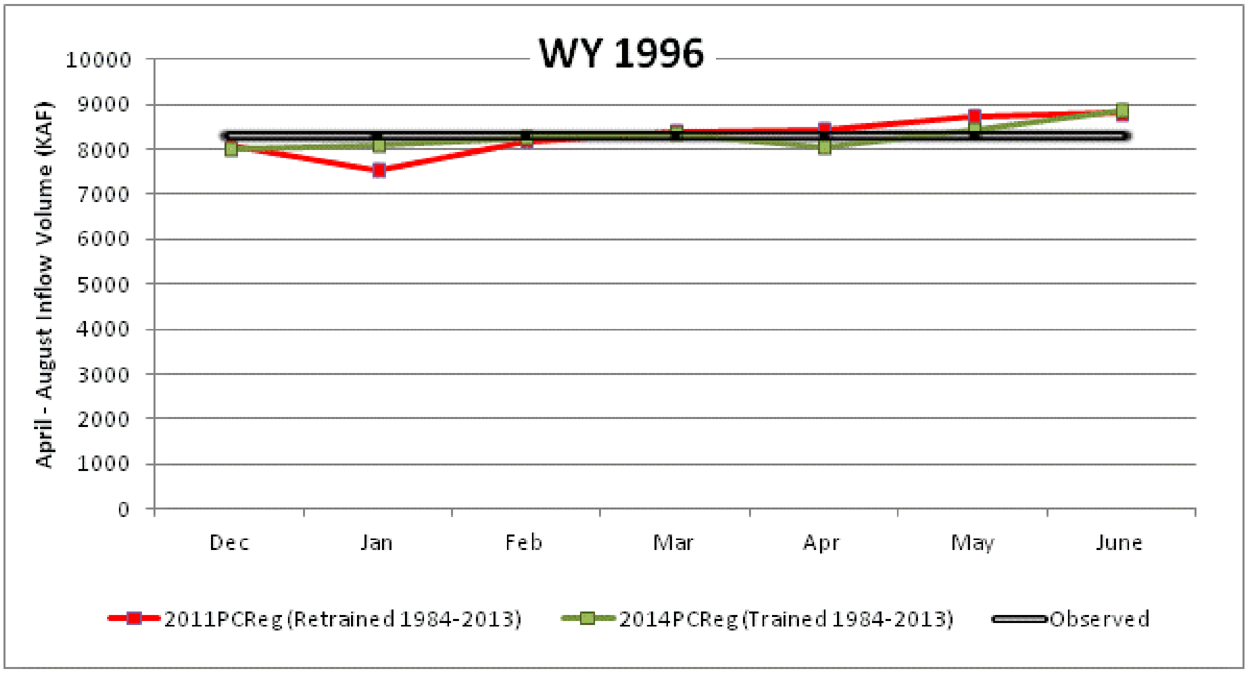

WY 1991
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 1992
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 1993
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 1994
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 1995
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 1996
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
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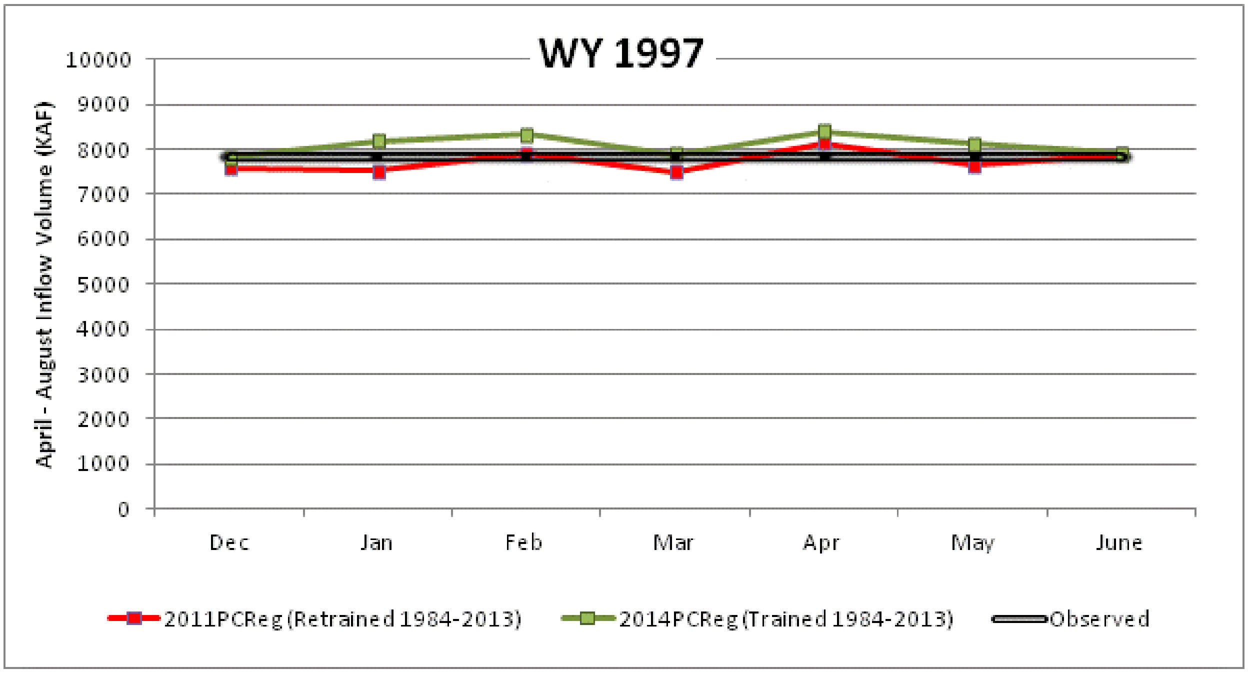
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 1997
April - August Inflow Volume (KAF)
10000
9000
8000
7000
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Dec
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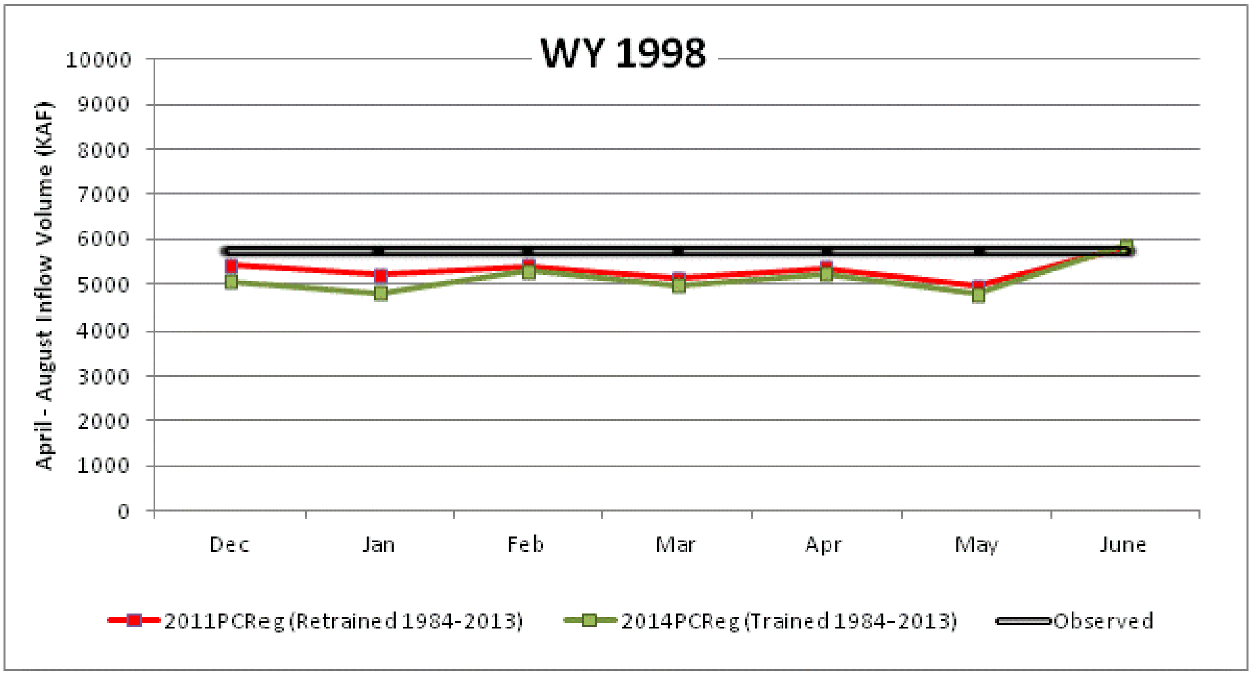
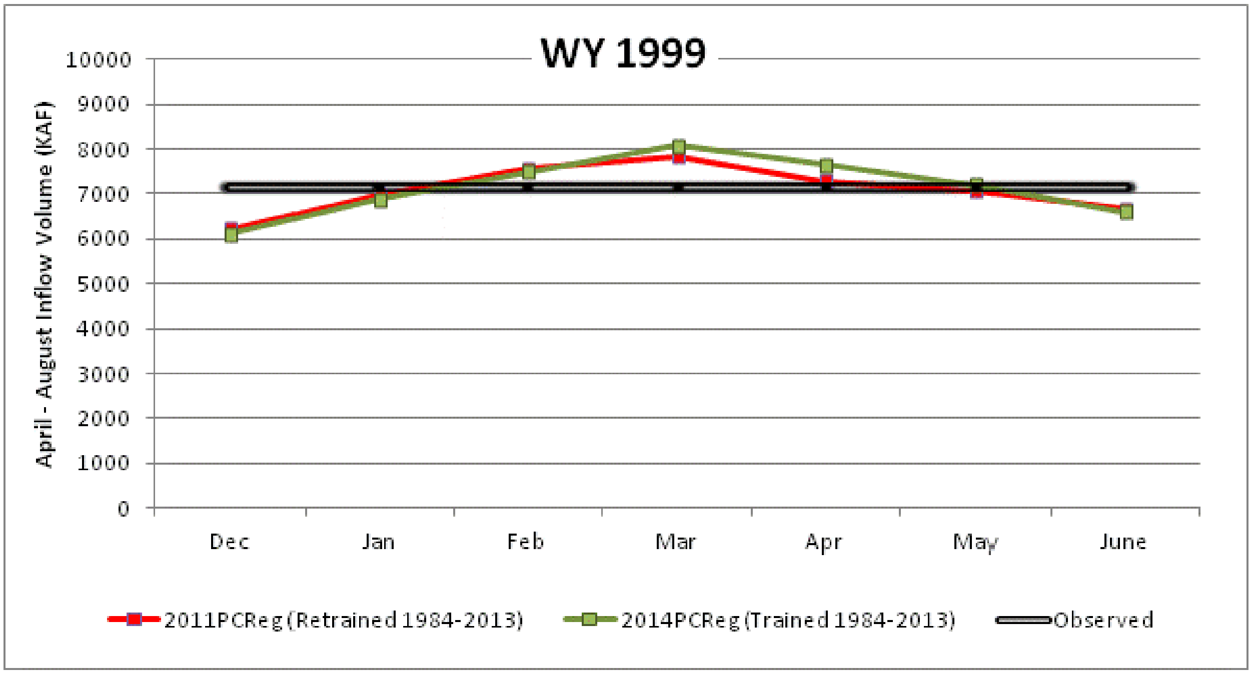
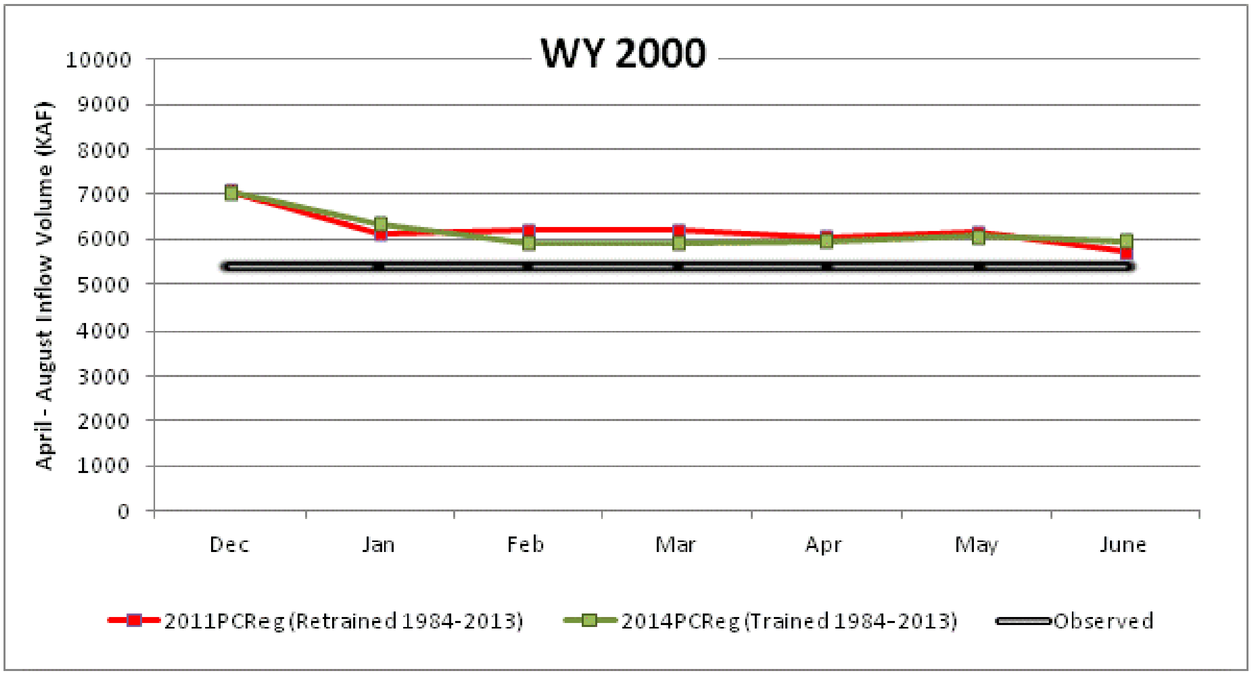
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 1998
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 1999
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 2000
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
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1000
0
Dec
Jan
Feb
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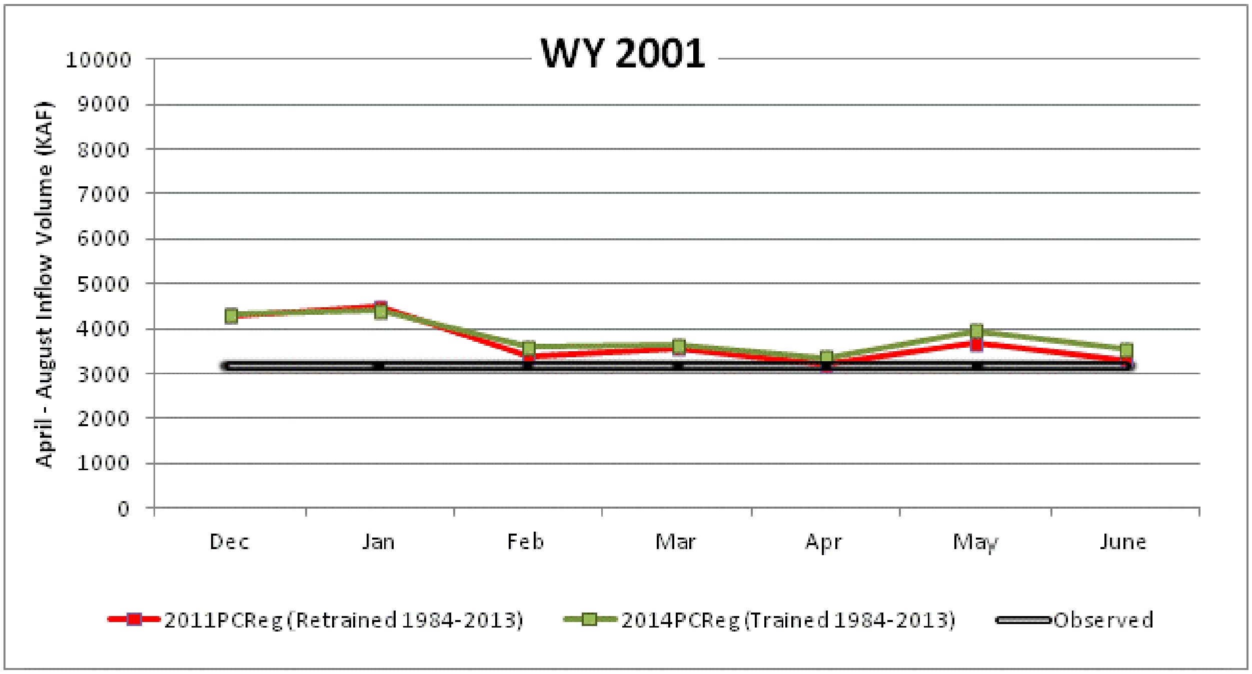
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 2001
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
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0
Dec
Jan
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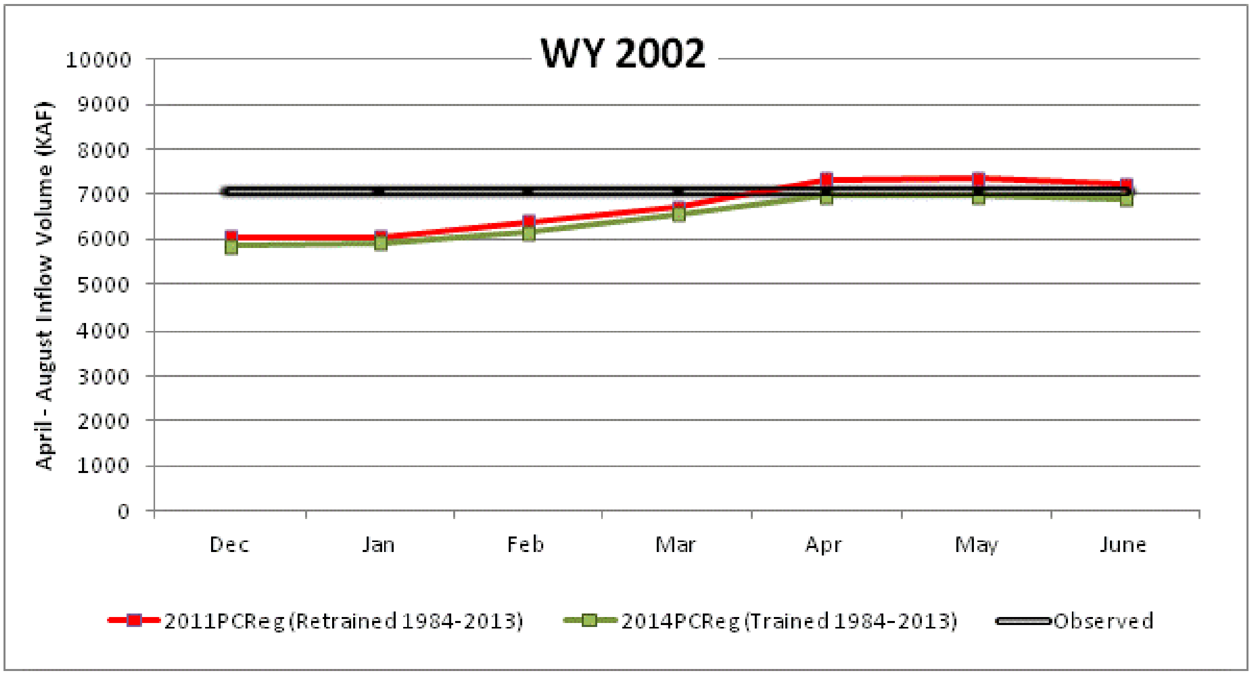
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 2002
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
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1000
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Dec
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Feb
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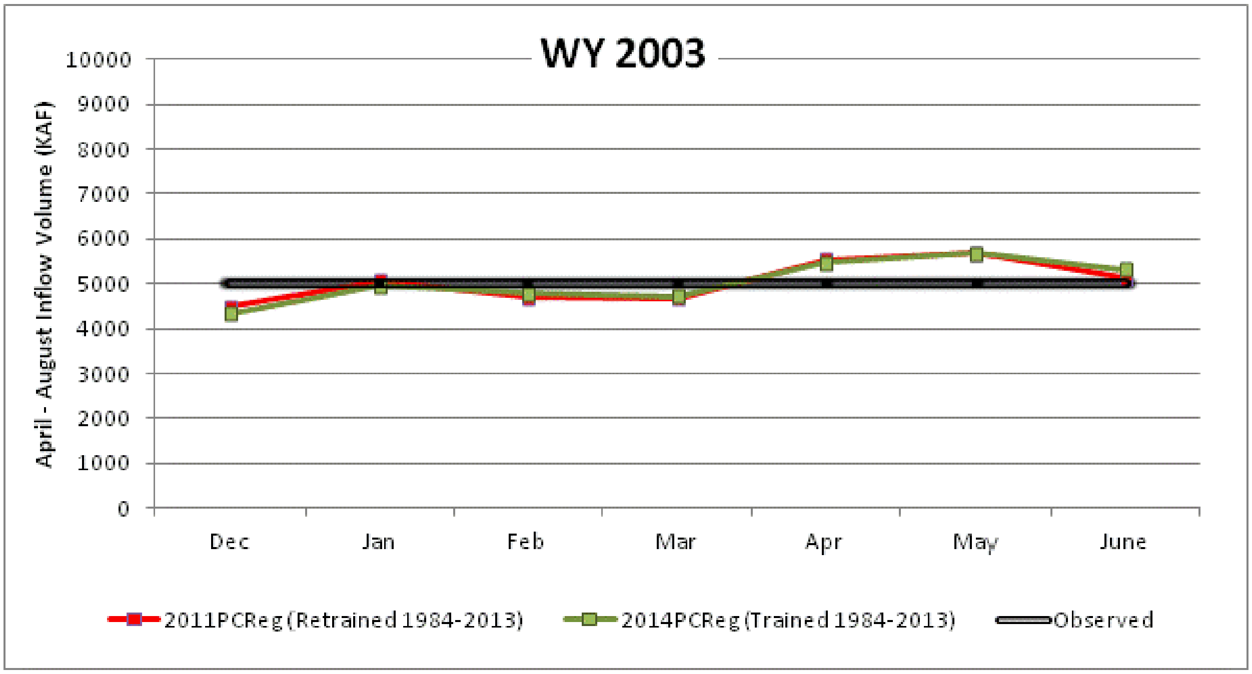
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 2003
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
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1000
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Dec
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Feb
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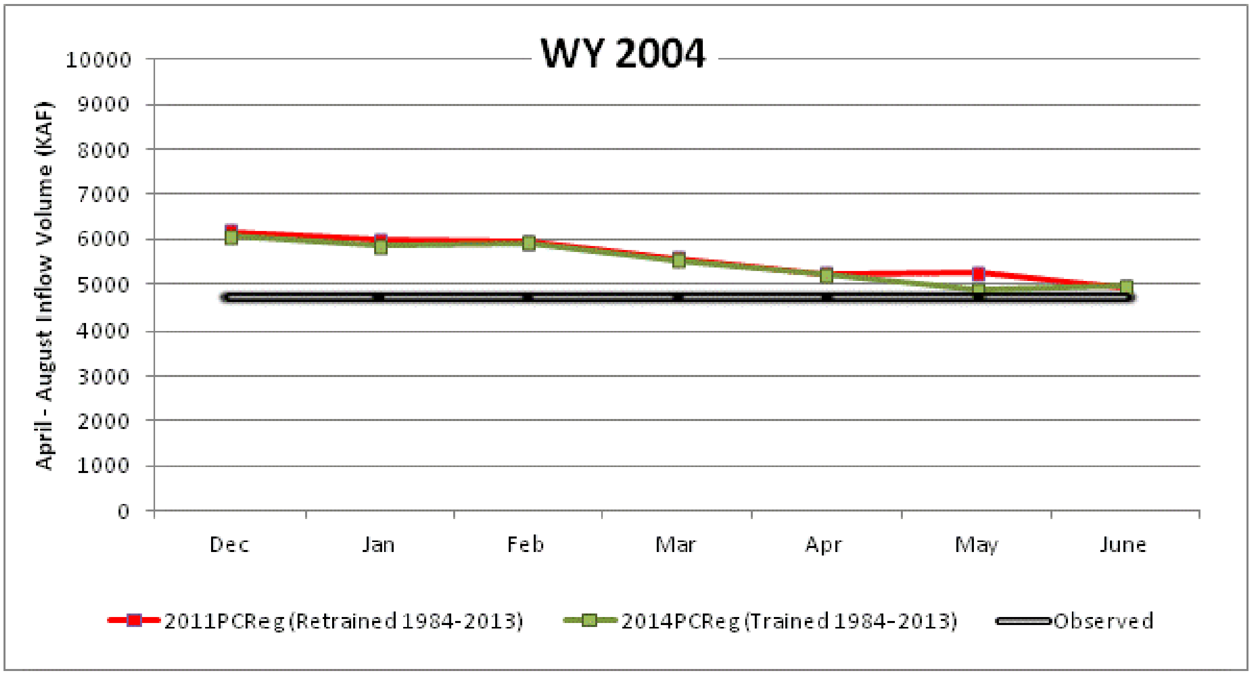
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 2004
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
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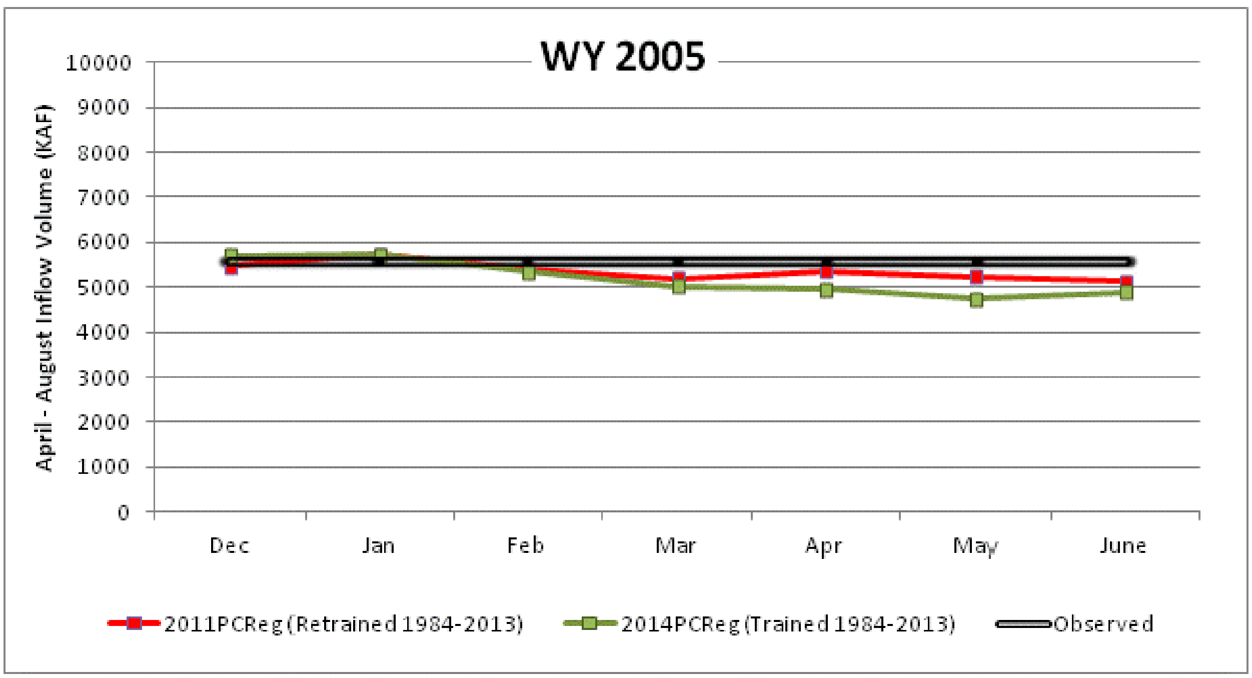
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 2005
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
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4000
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2000
1000
0
Dec
Jan
Feb
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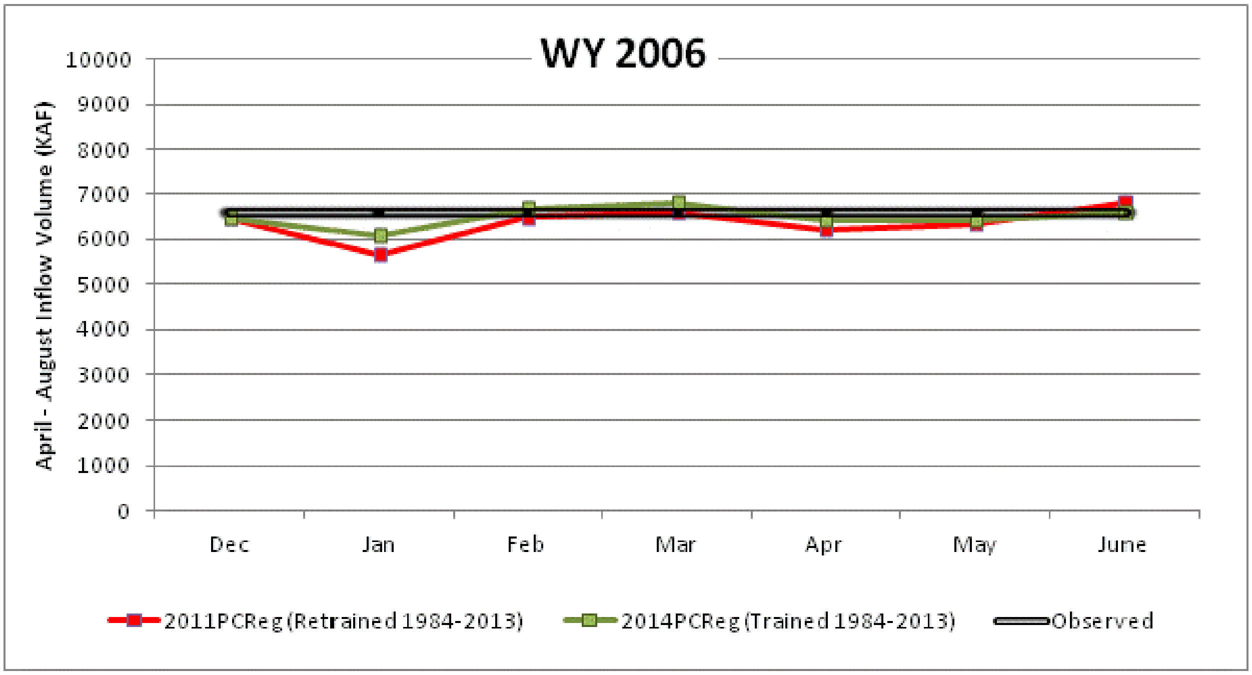
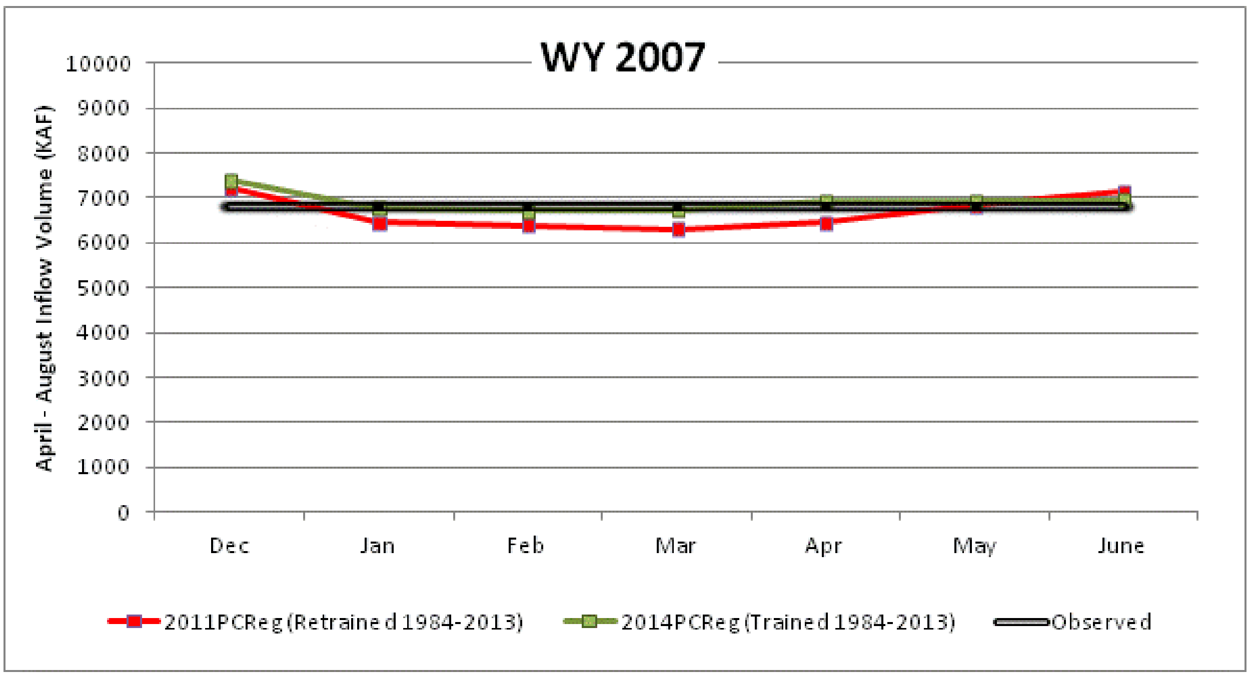
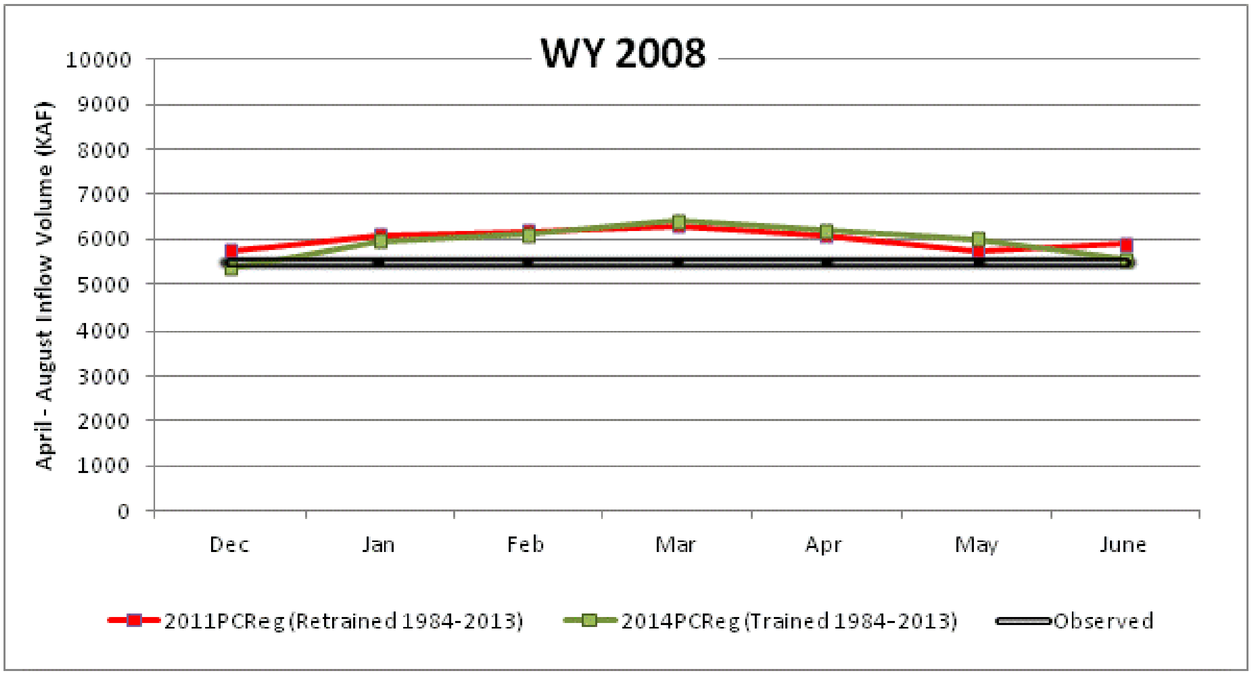
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed



WY 2006
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed



WY 2007
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 2008
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
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1000
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Dec
Jan
Feb
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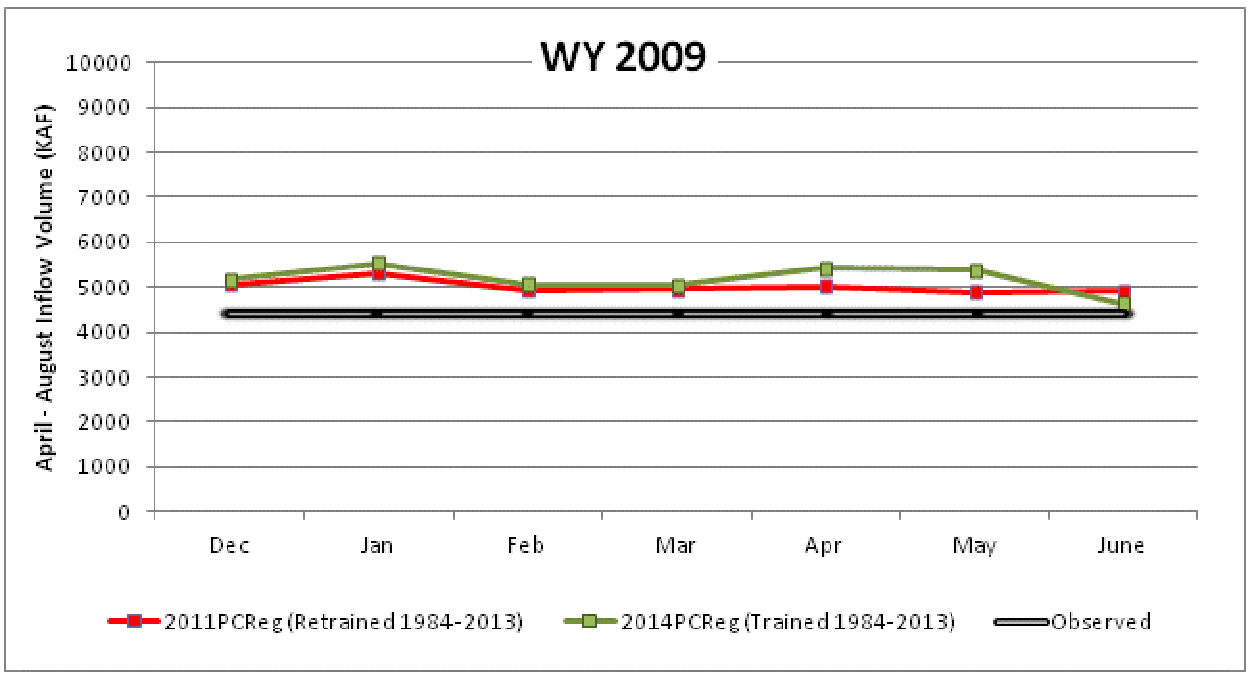
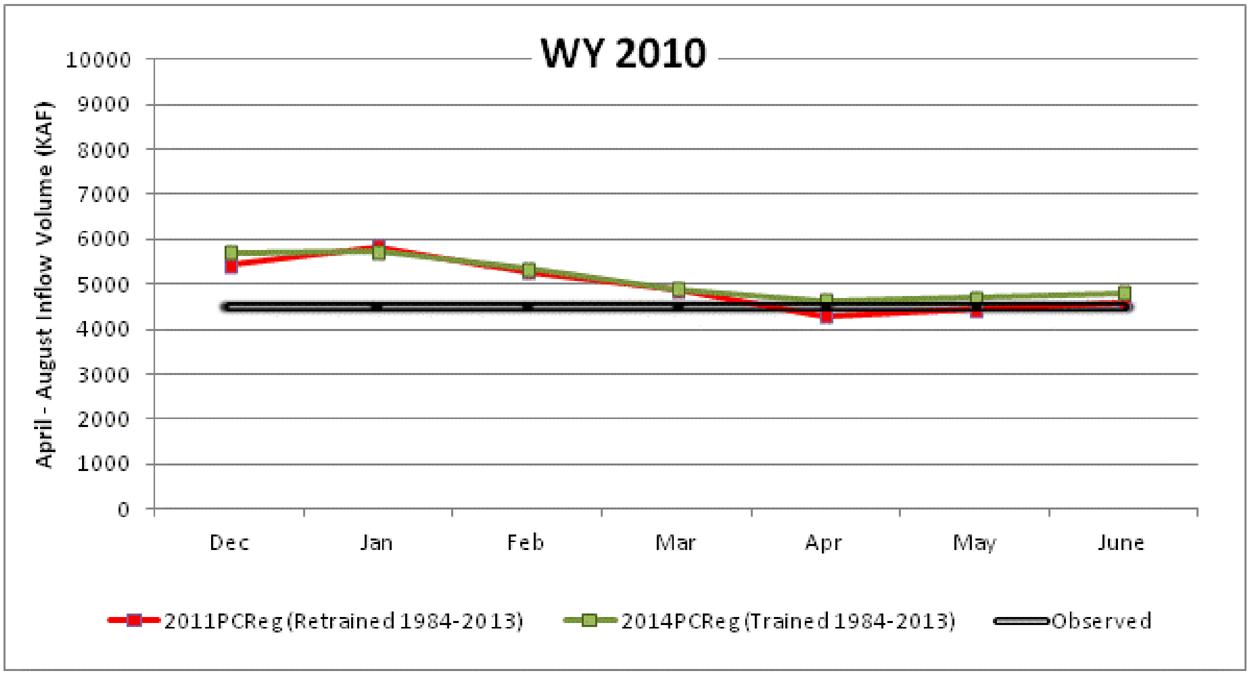
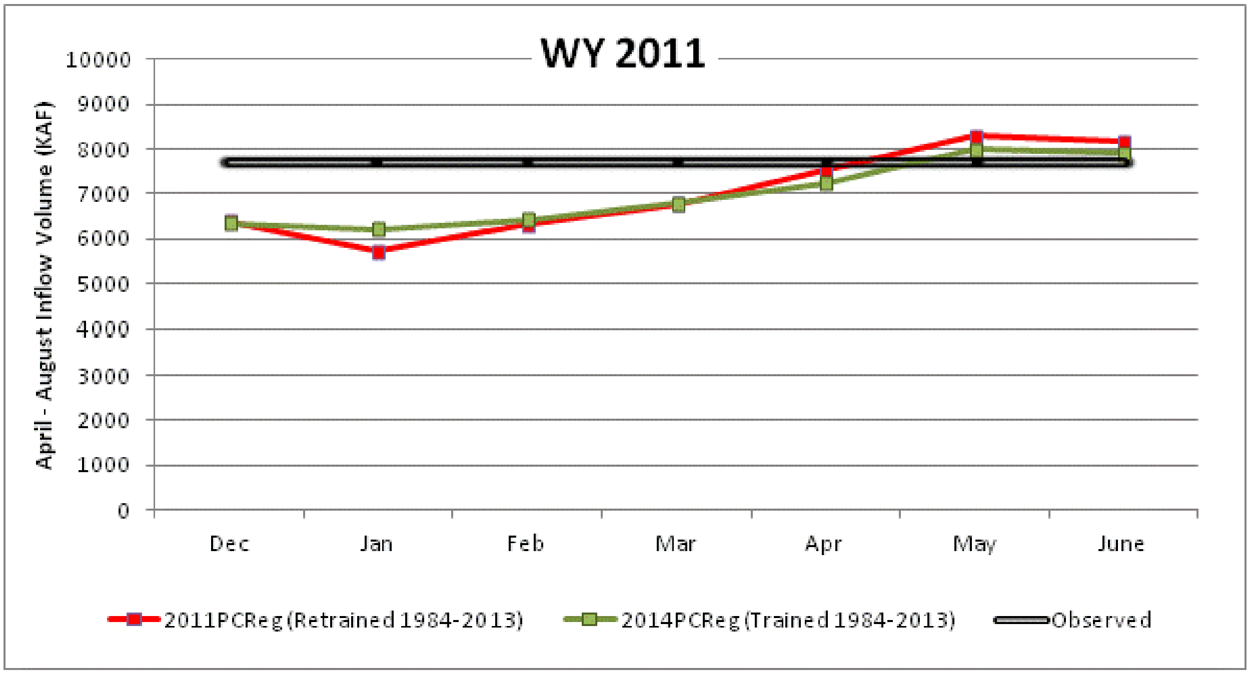
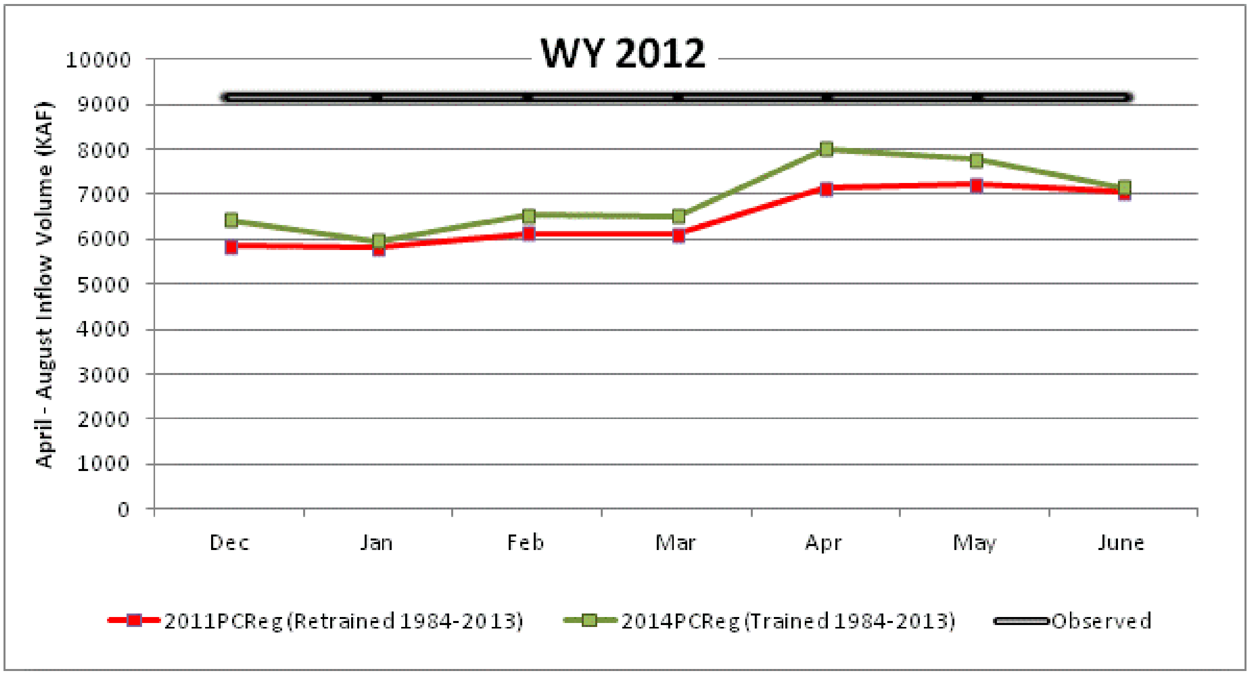
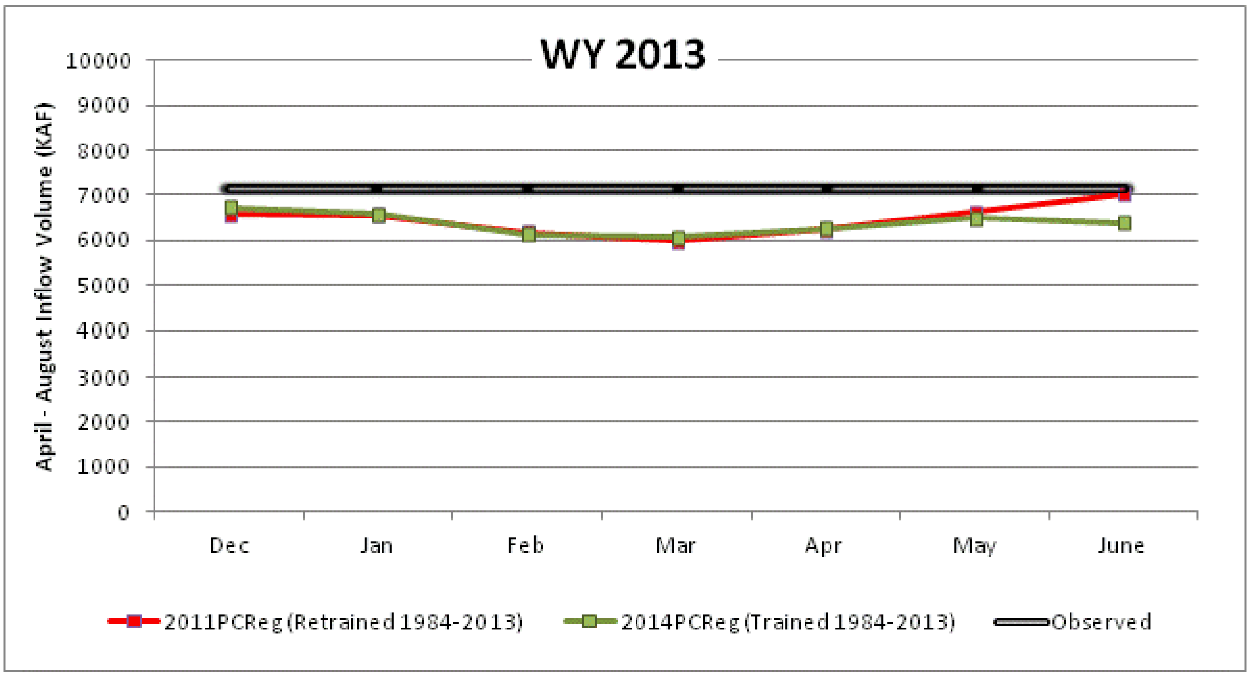
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 2009
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 2010
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 2011
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 2012
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed


WY 2013
April - August Inflow Volume (KAF)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Dec
Jan
Feb
Mar
Apr
May
June
2011PCReg (Retrained 1984-2013)
2014PCReg (Trained 1984-2013)
Observed

Appendix E: 2014 Forecast Data by Month

1-December Forecast

Variable Name	COEFFICIENTS
Climatic Variables	
JunJul SOI	*133.38*
Precip Variables	
Cranbrook Ap	*8.79*
Eureka	*267.66*
Fernie	*1.95*
West Glacier	*105.96*
Equation Variables	
Constant	*3704.61*

December Forecast Statistics					
Observations	Number of Principal Components	Jackknife Standard Error (CVSE)	Jackknif e R	Standard Error	R
30.00	1.00	1076.65	0.69	1024.72	0.72

1-December - cont'd

YEAR	OBSERVED	JCK REG COMPUTED	JCK REG ERROR	STD REG COMPUTED	STD REG ERROR
1984	5087.40	6087.94	1000.53	6052.80	965.39
1985	4756.36	6332.71	1576.35	6277.05	1520.68
1986	6085.88	5964.66	-121.23	5961.59	-124.29
1987	4999.93	6454.09	1454.16	6394.28	1394.35
1988	4632.99	3733.40	-899.59	3862.42	-770.57
1989	5566.02	5862.23	296.21	5846.04	280.02
1990	7597.29	6723.88	-873.41	6774.21	-823.08
1991	8543.01	7986.25	-556.75	8028.88	-514.12
1992	4421.55	5422.58	1001.02	5376.55	955.00
1993	5477.75	5251.46	-226.29	5261.46	-216.29
1994	5207.70	4638.21	-569.49	4687.46	-520.24
1995	6269.36	6288.72	19.37	6315.64	46.28
1996	8339.31	7991.78	-347.52	8021.21	-318.10
1997	7851.11	7809.85	-41.26	7811.52	-39.60
1998	5777.65	5014.31	-763.34	5069.28	-708.37
1999	7148.85	6106.17	-1042.68	6107.20	-1041.65
2000	5428.17	7162.46	1734.30	7046.57	1618.40
2001	3174.55	4476.34	1301.79	4314.79	1140.25
2002	7097.87	5798.02	-1299.86	5848.74	-1249.14
2003	5016.79	4241.70	-775.09	4340.41	-676.38
2004	4739.90	6119.56	1379.66	6071.83	1331.92
2005	5572.36	5697.97	125.60	5692.32	119.95
2006	6601.39	6475.90	-125.49	6480.73	-120.66
2007	6838.81	7446.10	607.29	7384.10	545.29
2008	5517.22	5340.85	-176.37	5352.13	-165.09
2009	4421.36	5222.16	800.81	5167.25	745.89
2010	4510.27	5742.01	1231.74	5694.68	1184.41
2011	7729.00	6325.58	-1403.42	6351.46	-1377.54
2012	9186.00	6346.75	-2839.25	6437.92	-2748.08
2013	7173.30	6744.10	-429.20	6738.67	-434.63

1-January Forecast

Variable Name	COEFFICIENTS
Climatic Variables	
JunJul SOI	*95.28*
Precip Variables	
Cranbrook Ap	*4.58*
Eureka	*141.74*
Fernie	*1.20*
West Glacier	*58.42*
SWE Variables	
Moyie Mountain	*1.59*
Stahl Peak	*34.63*
Sunshine Village	*2.14*
Equation Variables	
Constant	*2724.44*

January Forecast Statistics					
Observations	Number of Principal Components	Jackknife Standard Error (CVSE)	Jackknife R	Standard Error	R
30.00	1.00	1086.49	0.68	1039.80	0.71

1-January - cont'd

YEAR	OBSERVED	JCK REG COMPUTED	JCK REG ERROR	STD REG COMPUTED	STD REG ERROR
1984	5087.40	5691.89	604.49	5667.04	579.63
1985	4756.36	6746.78	1990.42	6648.78	1892.41
1986	6085.88	5481.04	-604.85	5489.15	-596.74
1987	4999.93	6074.94	1075.01	6039.32	1039.39
1988	4632.99	4091.60	-541.39	4154.16	-478.83
1989	5566.02	5693.79	127.78	5683.60	117.58
1990	7597.29	6387.23	-1210.06	6440.41	-1156.87
1991	8543.01	8831.89	288.88	8739.50	196.49
1992	4421.55	5353.42	931.87	5307.08	885.53
1993	5477.75	5200.33	-277.42	5212.88	-264.87
1994	5207.70	5009.99	-197.71	5024.96	-182.74
1995	6269.36	6346.79	77.44	6364.42	95.06
1996	8339.31	8062.00	-277.31	8091.01	-248.30
1997	7851.11	8231.61	380.49	8193.43	342.32
1998	5777.65	4711.81	-1065.85	4801.82	-975.83
1999	7148.85	6890.99	-257.86	6871.62	-277.23
2000	5428.17	6384.80	956.64	6350.00	921.84
2001	3174.55	4564.65	1390.11	4401.75	1227.20
2002	7097.87	5884.68	-1213.19	5926.60	-1171.27
2003	5016.79	4945.36	-71.43	4950.21	-66.59
2004	4739.90	5893.84	1153.94	5851.42	1111.52
2005	5572.36	5726.07	153.70	5721.29	148.93
2006	6601.39	6076.54	-524.84	6094.08	-507.31
2007	6838.81	6766.32	-72.49	6765.24	-73.57
2008	5517.22	5965.78	448.56	5956.85	439.62
2009	4421.36	5592.87	1171.51	5542.49	1121.14
2010	4510.27	5772.48	1262.21	5726.92	1216.65
2011	7729.00	6153.70	-1575.30	6206.20	-1522.80
2012	9186.00	5873.85	-3312.15	5971.11	-3214.89
2013	7173.30	6579.08	-594.22	6575.81	-597.49

1-February Forecast

Variable Name	COEFFICIENTS
Climatic Variables	
--	--
Precip Variables	
Cranbrook Ap	*2.84*
Eureka	*78.47*
Fernie	*0.72*
West Glacier	*30.95*
SWE Variables	
Akamina Pass	*1.27*
East Creek	*0.75*
Hawkins Lake	*30.61*
Moyie Mountain	*1.48*
Stahl Peak	*22.99*
Sunshine Village	*1.47*
Racehorse	*1.53*
Equation Variables	
Constant	*1291.48*

February Forecast Statistics					
Observations	Number of Principal Components	Jackknife Standard Error (CVSE)	Jackknife R	Standard Error	R
30.00	1.00	875.08	0.81	832.36	0.83

1-February Forecast cont'd

YEAR	OBSERVED	JCK REG COMPUTED	JCK REG ERROR	STD REG COMPUTED	STD REG ERROR
1984	5087.40	4868.69	-218.72	4896.22	-191.18
1985	4756.36	5864.54	1108.17	5820.54	1064.17
1986	6085.88	5818.82	-267.06	5818.17	-267.72
1987	4999.93	5619.43	619.49	5602.41	602.48
1988	4632.99	4173.16	-459.83	4227.68	-405.31
1989	5566.02	6184.42	618.40	6164.54	598.52
1990	7597.29	7239.21	-358.08	7260.05	-337.24
1991	8543.01	9138.81	595.80	8975.93	432.92
1992	4421.55	5866.19	1444.64	5818.89	1397.34
1993	5477.75	4966.02	-511.73	5007.07	-470.68
1994	5207.70	4736.23	-471.47	4769.44	-438.26
1995	6269.36	6301.61	32.26	6300.67	31.31
1996	8339.31	8270.61	-68.70	8258.33	-80.97
1997	7851.11	8512.76	661.65	8340.33	489.21
1998	5777.65	5265.76	-511.90	5290.70	-486.95
1999	7148.85	7576.40	427.56	7494.67	345.82
2000	5428.17	5932.69	504.52	5916.59	488.42
2001	3174.55	3667.38	492.83	3580.61	406.07
2002	7097.87	6118.89	-978.98	6155.41	-942.46
2003	5016.79	4768.23	-248.56	4787.92	-228.87
2004	4739.90	5966.35	1226.45	5924.97	1185.07
2005	5572.36	5326.76	-245.60	5346.59	-225.77
2006	6601.39	6694.71	93.32	6681.22	79.83
2007	6838.81	6722.97	-115.84	6713.66	-125.15
2008	5517.22	6119.93	602.71	6106.17	588.95
2009	4421.36	5105.67	684.32	5070.30	648.94
2010	4510.27	5366.53	856.26	5328.66	818.39
2011	7729.00	6381.59	-1347.41	6427.48	-1301.52
2012	9186.00	6435.69	-2750.31	6543.82	-2642.18
2013	7173.30	6112.50	-1060.80	6140.08	-1033.22

1-March Forecast

Variable Name	COEFFICIENTS
Climatic Variables	
--	--
Precip Variables	
Cranbrook Ap	*2.73*
Eureka	*65.87*
Fernie	*0.63*
West Glacier	*28.51*
SWE Variables	
Akamina Pass	*1.04*
East Creek	*0.65*
Hawkins Lake	*24.33*
Moyie Mountain	*1.27*
Stahl Peak	*19.11*
Sunshine Village	*1.26*
Racehorse	*1.40*
Equation Variables	
Constant	*1141.93*

March Forecast Statistics					
Observations	Number of Principal Components	Jackknife Standard Error (CVSE)	Jackknife R	Standard Error	R
30.00	1.00	835.74	0.83	791.94	0.84

1-March Forecast cont'd

YEAR	OBSERVED	JCK REG COMPUTED	JCK REG ERROR	STD REG COMPUTED	STD REG ERROR
1984	5087.40	5037.29	-50.11	5042.46	-44.95
1985	4756.36	5837.11	1080.75	5791.01	1034.65
1986	6085.88	6313.22	227.34	6280.69	194.80
1987	4999.93	5515.71	515.78	5498.49	498.55
1988	4632.99	4335.25	-297.74	4366.29	-266.71
1989	5566.02	5923.87	357.85	5913.48	347.46
1990	7597.29	7510.89	-86.40	7507.41	-89.88
1991	8543.01	8754.38	211.37	8698.47	155.46
1992	4421.55	5664.55	1242.99	5619.45	1197.90
1993	5477.75	4621.42	-856.33	4697.92	-779.83
1994	5207.70	5310.84	103.14	5304.45	96.75
1995	6269.36	6146.35	-123.00	6152.28	-117.07
1996	8339.31	8373.20	33.89	8345.95	6.65
1997	7851.11	7945.35	94.23	7890.62	39.51
1998	5777.65	4917.71	-859.94	4970.77	-806.88
1999	7148.85	8268.81	1119.96	8070.25	921.40
2000	5428.17	5937.80	509.64	5918.65	490.49
2001	3174.55	3724.58	550.03	3632.76	458.22
2002	7097.87	6536.85	-561.02	6558.79	-539.08
2003	5016.79	4690.07	-326.72	4715.88	-300.92
2004	4739.90	5572.53	832.63	5540.89	800.99
2005	5572.36	4980.72	-591.64	5019.90	-552.46
2006	6601.39	6825.18	223.79	6805.63	204.24
2007	6838.81	6748.85	-89.96	6729.07	-109.74
2008	5517.22	6427.09	909.87	6403.11	885.88
2009	4421.36	5066.52	645.16	5031.38	610.02
2010	4510.27	4922.05	411.78	4898.88	388.61
2011	7729.00	6745.55	-983.45	6787.28	-941.72
2012	9186.00	6404.93	-2781.07	6510.69	-2675.31
2013	7173.30	6036.81	-1136.49	6066.26	-1107.04

1-April Forecast

Variable Name	COEFFICIENTS
Climatic Variables	
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Precip Variables	
Cranbrook Ap	*2.99*
Eureka	*68.52*
Fernie	*0.71*
West Glacier	*29.47*
SWE Variables	
Akamina Pass	*0.72*
East Creek	*0.73*
Hawkins Lake	*22.43*
Moyie Mountain	*1.21*
Stahl Peak	*19.70*
Sunshine Village	*1.43*
Racehorse	*1.35*
Equation Variables	
Constant	*70.54*

April Forecast Statistics					
Observations	Number of Principal Components	Jackknife Standard Error (CVSE)	Jackknife R	Standard Error	R
30.00	1.00	619.94	0.91	575.38	0.92

1-April Forecast cont'd

YEAR	OBSERVED	JCK REG COMPUTED	JCK REG ERROR	STD REG COMPUTED	STD REG ERROR
1984	5087.40	4945.67	-141.74	4955.90	-131.50
1985	4756.36	5131.24	374.88	5103.16	346.80
1986	6085.88	6069.16	-16.72	6041.26	-44.62
1987	4999.93	5564.51	564.57	5543.95	544.01
1988	4632.99	4777.78	144.79	4774.72	141.73
1989	5566.02	6268.72	702.70	6244.60	678.58
1990	7597.29	7026.31	-570.98	7061.42	-535.87
1991	8543.01	9012.30	469.30	8916.63	373.62
1992	4421.55	4708.54	286.99	4688.06	266.51
1993	5477.75	4051.77	-1425.98	4205.36	-1272.39
1994	5207.70	4893.63	-314.08	4911.03	-296.67
1995	6269.36	5888.52	-380.84	5949.26	-320.09
1996	8339.31	8046.69	-292.61	8062.23	-277.07
1997	7851.11	8511.55	660.43	8394.60	543.48
1998	5777.65	5192.91	-584.74	5223.34	-554.31
1999	7148.85	7722.38	573.53	7653.96	505.12
2000	5428.17	5978.05	549.88	5959.44	531.28
2001	3174.55	3387.86	213.32	3350.80	176.25
2002	7097.87	6963.51	-134.36	6970.07	-127.80
2003	5016.79	5478.12	461.32	5460.78	443.98
2004	4739.90	5239.24	499.34	5216.48	476.58
2005	5572.36	4910.78	-661.59	4950.44	-621.92
2006	6601.39	6438.04	-163.35	6438.14	-163.25
2007	6838.81	6940.84	102.03	6921.19	82.38
2008	5517.22	6211.44	694.21	6199.56	682.33
2009	4421.36	5469.44	1048.09	5428.83	1007.48
2010	4510.27	4634.83	124.56	4629.22	118.95
2011	7729.00	7219.64	-509.36	7242.11	-486.89
2012	9186.00	7919.90	-1266.10	8022.89	-1163.11
2013	7173.30	6220.89	-952.41	6249.69	-923.61

1-May Forecast

Variable Name	COEFFICIENTS
Climatic Variables	
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Precip Variables	
Cranbrook Ap	*2.80*
Eureka	*57.45*
Fernie	*0.61*
West Glacier	*28.04*
SWE Variables	
Akamina Pass	*0.55*
East Creek	*0.57*
Hawkins Lake	*17.30*
Moyie Mountain	*0.91*
Stahl Peak	*16.74*
Sunshine Village	*1.26*
Racehorse	*0.83*
Equation Variables	
Constant	*408.07*

May Forecast Statistics					
Observations	Number of Principal Components	Jackknife Standard Error (CVSE)	Jackknife R	Standard Error	R
30.00	1.00	611.32	0.99	572.08	0.91

1-May Forecast cont'd

YEAR	OBSERVED	JCK REG COMPUTED	JCK REG ERROR	STD REG COMPUTED	STD REG ERROR
1984	4710.55	4865.63	155.08	4858.09	147.54
1985	4337.45	4734.04	396.58	4713.72	376.27
1986	5490.05	5681.64	191.59	5655.19	165.14
1987	4360.86	4523.84	162.99	4520.74	159.88
1988	4096.46	4278.05	181.59	4268.71	172.25
1989	5017.79	5442.48	424.70	5424.85	407.06
1990	6749.55	5814.03	-935.52	5847.96	-901.60
1991	7840.86	8250.93	410.07	8168.48	327.63
1992	3952.46	3893.28	-59.19	3907.09	-45.37
1993	5132.43	4195.05	-937.38	4266.11	-866.32
1994	4457.75	4186.37	-271.38	4207.65	-250.10
1995	5928.60	5856.53	-72.07	5868.53	-60.07
1996	7453.09	7591.11	138.02	7550.60	97.51
1997	7238.42	7578.93	340.51	7510.16	271.74
1998	5302.87	4235.37	-1067.50	4311.86	-991.01
1999	6587.56	6648.42	60.85	6634.12	46.56
2000	4796.23	5455.01	658.78	5434.95	638.72
2001	2950.21	3818.35	868.13	3730.77	780.56
2002	6631.93	6505.25	-126.69	6504.18	-127.75
2003	4525.88	5206.08	680.20	5182.77	656.88
2004	4111.54	4230.99	119.45	4236.02	124.48
2005	5118.94	4228.64	-890.30	4289.47	-829.47
2006	5987.11	5813.54	-173.56	5816.81	-170.30
2007	6157.09	6264.88	107.79	6242.67	85.58
2008	5299.44	5766.28	466.84	5773.08	473.64
2009	4117.69	5117.36	999.68	5086.42	968.73
2010	4145.10	4342.16	197.06	4330.21	185.11
2011	7430.00	7751.63	321.63	7689.63	259.63
2012	8389.00	6859.30	-1529.70	6973.54	-1415.46
2013	6634.30	5921.12	-713.18	5946.83	-687.47

1-June Forecast

Variable Name	COEFFICIENTS
Climatic Variables	
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Precip Variables	
Cranbrook Ap	*2.03*
Eureka	*37.66*
Fernie	*0.50*
West Glacier	*22.46*
SWE Variables	
Akamina Pass	*0.68*
East Creek	*0.43*
Hawkins Lake	*10.09*
Moyie Mountain	*0.85*
Stahl Peak	*10.31*
Sunshine Village	*0.62*
Racehorse	*0.64*
Equation Variables	
Constant	*978.00*

June Forecast Statistics					
Observations	Number of Principal Components	Jackknife Standard Error (CVSE)	Jackknif e R	Standard Error	R
30.00	1.00	618.22	0.86	574.65	0.88

1-June Forecast cont'd

YEAR	OBSERVED	JCK REG COMPUTED	JCK REG ERROR	STD REG COMPUTED	STD REG ERROR
1984	3893.16	4632.29	739.14	4500.72	607.56
1985	2618.18	2886.42	268.24	2869.10	250.92
1986	3850.71	3992.59	141.88	3982.99	132.28
1987	2332.17	2986.16	654.00	2946.43	614.27
1988	2712.60	2945.64	233.05	2931.56	218.97
1989	3479.80	4051.25	571.45	4031.95	552.15
1990	5243.11	4743.66	-499.45	4774.39	-468.72
1991	5663.80	6212.54	548.74	6083.05	419.25
1992	2523.77	2896.61	372.84	2875.91	352.14
1993	3400.46	2560.15	-840.31	2656.51	-743.96
1994	2844.20	2999.36	155.17	2993.50	149.30
1995	4626.45	3896.87	-729.57	3920.44	-706.01
1996	5853.88	6557.74	703.87	6374.07	520.20
1997	4935.59	5037.13	101.54	4987.83	52.24
1998	3174.53	3221.00	46.48	3240.43	65.91
1999	5115.43	4556.92	-558.52	4562.92	-552.51
2000	3417.32	3960.31	542.99	3937.99	520.67
2001	1936.26	2350.85	414.59	2307.17	370.90
2002	5191.54	4992.58	-198.96	4987.77	-203.76
2003	3291.57	3601.49	309.92	3588.54	296.96
2004	3011.90	3226.24	214.34	3216.66	204.76
2005	3676.17	2959.06	-717.10	3003.24	-672.92
2006	3606.74	3602.79	-3.95	3596.76	-9.98
2007	4107.17	4225.05	117.87	4205.54	98.36
2008	3551.80	3587.59	35.79	3592.83	41.03
2009	3092.43	3319.16	226.73	3311.77	219.34
2010	3210.55	3508.05	297.50	3498.45	287.90
2011	5749.00	5991.23	242.23	5927.24	178.24
2012	6464.00	4350.46	-2113.54	4443.70	-2020.30
2013	4499.30	3699.63	-799.67	3724.10	-775.20

Appendix F – Hedges for Variable Energy Content Curves (VECC)

Units KAF

Libby Dam	Statistic (units)	Aug-Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Jan-Jul 80 -yr volume	Median (KAF)	6386							
Jan-Jul 80 -yr volume	Standard Errror (KAF)	1448							
Apr-Aug 80 yr Volume	Median (KAF)	6330							
Aug 80 yr volume	Median (KAF)	556							
Degrees of Freedom		29	29	29	29	29	29	29	29
T-Statistic		1.699	1.699	1.699	1.699	1.699	1.699	1.699	1.699
Apr-Aug Forecast	CVSE (KAF)		1077	1089	875	836	620	611	618
Jan-July Forecast	adj. CVSE (KAF)		1040						
Date-July Forecast	adj. CVSE (KAF)			1072	865	821	597	581	566
Hedge (Jan-Jul/Date-Jul)	t(95%) X CVSE (KAF)	2460	1767	1821	1470	1396	1014	987	962

Units ksfd

Libby Dam	Statistic (units)	Aug-Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Jan-Jul 80 -yr volume	Median (ksfd)	3220							
Jan-Jul 80 -yr volume	Standard Errror (ksfd)	730							
Apr-Aug 80 yr Volume	Median (ksfd)	3191							
Aug 80 yr volume	Median (ksfd)	280							
Degrees of Freedom		29	29	29	29	29	29	29	29
T-Statistic		1.699	1.699	1.699	1.699	1.699	1.699	1.699	1.699
Apr-Aug Forecast	CVSE (ksfd)		543	549	441	421	313	308	312
Jan-July Forecast	adj. CVSE (ksfd)		524						
Date-July Forecast	adj. CVSE (ksfd)			540	436	414	301	293	286
Hedge (Jan-Jul/Date-Jul)	t(95%) X CVSE (ksfd)	1240	891	918	741	704	511	497	485