Water Supply Forecasting Models for Libby, MT
2011 Update to the 2010 Revision

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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 constructed by the US Army Corps of Engineers (Corps) in the early 1970s as the sole US project under the Columbia River Treaty. Libby is operated by the Corps as a multi-purpose project for hydropower, flood control, 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, some 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 4,975,500 acre feet 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 control, with reservoir refill occurring during the spring months to provide water for multiple conservation purposes, including hydropower, environmental and recreation objectives. The water supply forecast (WSF) models attempt to provide advanced insight into the expected inflows to the reservoir during the spring-through-summer runoff season. These runoff forecasts, issued monthly from December to 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 million acre-feet each spring.

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Executive Summary

This review and update to the Libby water supply forecast (the "2010 revision") was undertaken to address the following objectives:

1. Consideration of new stations, discontinued stations, and additional years of data.
2. Consideration of additional climate variables.
3. Improved forecast consistency
4. Improved forecast performance

New statistical equations were developed to forecast the April-August inflow to Libby Dam, Montana. These forecast equations make use of three classes of hydro-meteorological variables: climate index variables ("CLX"), fall and winter precipitation variables ("PPT"), and snow water equivalent variables ("SWE"). The predictor variables, the new statistical forecast equations, and the forecast statistics are summarized in Table 1, 2, 3 and 4, found on pages 8 and 9.

The "2011 Update to the 2010 Revision" extends the calibration dataset through water year 2010 and updates the dataset of climate variables. Details of this update are provided in Appendix I.

The following factors and issues are related to the new forecast equations and discussed further in subsequent sections of this report:

- 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.
- A single climate variable (SOI) used in the previous model has been enhanced with the addition of two other climate variables (QBO and PNA).
- The QBO climate index is a measure of the winds in the tropical stratosphere. The QBO measured one year in advance of the runoff season influences the winter atmospheric circulation patterns of the following year and relates to the ensuant Libby runoff volume.
- Three of the four precipitation stations used in the new equations were used in the 2004 equations. Four additional precipitation stations from the 2004 equations are no longer utilized.
- The 2004 equations are no longer usable due to station closures. One snow and one precipitation station used in the 2004 equations have been closed and the proxy site for the closed snow station is no longer being measured. (The Marble Canyon, BC site was closed in 2004 during review of the 2004 procedure. Vermillion River #3 site was reopened in 2005 to use as a proxy for the Marble Canyon site, however, as of 2010, Parks Canada is no longer taking measurements at this location.)
- All four of snow pillow stations used in the in the 2004 equations are also used in the new equations. None of the four snow course sites from 2004 are utilized in the new

equations. (Two of the snow courses no longer being used, Sullivan Mine and Moyie Mountain, were only utilized with the 1-June issue date).

- Eight Alberta pillows near the Kootenay 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 Kootenay 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 have been considered in the Libby forecast.
- Nine automated snow pillow sites are now utilized (with no snow course sites).
- The use of the Alberta snow pillow sites limits 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 are 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.
- There is much more variability in the flows in the recent 25 year dataset (1985-2010) than in the longer 36 year (1975-2010) dataset. The most recent 21 years (1990-2010) show the greatest variability.
- The sample chosen to calibrate the statistical model affects the forecast performance. Forecast performance statistics are not easily comparable when they have been derived from different sample sets.

All SWE measurements are from snow pillow stations for the first time in the history of the Libby forecast. In addition 4 of the 9 snow pillow stations in the new equations are newer stations located in the Province of Alberta along the Continental Divide adjacent to the east basin boundary. Forecasts developed using these Alberta snow stations show a greater predictive ability than any equations developed from the sparse selection of stations located directly in the East Kootenay basin. However, the limited data record for the Alberta stations (from 1985 to date) restricts the forecast calibration period to the years when these stations are available. Appendix D, Comparison of Model Performance Statistics, analyzes and discusses the relationship of the sample set sizes (20-year, 25-year, and 30-year samples) and the predictive ability of the equations.

The new forecast equations provide both improved forecasts with smaller forecast standard errors and better month-to-month forecast consistency. The forecast consistency is achieved through more consistency in the variable sets used from one month to the next.

Subsequent sections of this report will review the history of the Libby statistical forecast procedure, the recommended new forecast equations, the issues of note identified during this review, and recommendations for future work efforts.

Libby Forecast Procedure History

The initial Libby 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 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 (Marsden and Davis, 1968; Stedinger, et al, 1988; Wortman, 1989; Wortman, 1990; Garen, 1992; McCuen, 2003).

3) Consideration of climate variables in the pool of predictor variables (i.e. SOI/ENSO) (Redmond and Koch, 1991; Garen, 1998; Hamlet and Lettenmaier, 1999; NMFS, 2000).

4) Utilizing the cross-validation standard error as a performance statistic in evaluating and comparing forecast models (Efron, 1982; Michaelson, 1987; Garen, 1992; Wortman, 2006).

Statistical Forecast Equations

New statistical forecast equations were developed based on principal components regression models built on variables related to "moisture input" for the East Kootenay basin (Marsden and Davis, 1968; Stedinger, et al 1988; Garen, 1992). Regression models were developed for each of the eight forecast issue dates of 1-November to 1-June, inclusively. The candidate predictor ("independent") variables were developed from three types of "moisture input" variables: 1) climate index variables, 2) precipitation variables, and 3) snow variables. The climate variables are all dimensionless numbers; precipitation values and snow values (snow water equivalent) are all converted to American units (inches), if necessary.

The climate variables were developed from review of 10 climate indices, with 72 variables developed for each index. The 72 variables were derived to consider multiple-month durations of each climate variable as well as lag times from 1-month to 6-months. These 720 variables derived from the 10 climate indices were reviewed and filtered into 25 candidate variables. The review and filtering process for these climate variables is discussed below in the section titled C*limate indices and derived climate variables*, with additional details provided in Appendix A.

The monthly precipitation variables were developed after a review of all available climate station sites in or near the East Kootenay basin. This review resulted in consideration of monthly precipitation data from 25 climate stations. Ten stations were selected for consideration as candidates for use in the statistical forecast model. The precipitation variables developed from these 10 sites included the observed monthly values and monthly accumulations for durations from 2 to 6 months. Appendix B contains a listing of the 10 climate stations used for monthly precipitation data for this study, including notations on the reasons individual stations were not selected for use.

Snow data is considered in the context of "snow water equivalent" (SWE) as reported monthly at snow course sites, or for the 1^{st}-of-month observations for snow pillow sites. In addition to the snow course and snow pillow sites included in previous Libby forecast studies, eight snow pillow sites in Alberta, near the eastern boundary of the Kootenay basin, were included, for a total of 101 snow stations reviewed. The eight Alberta snow pillows are discussed more thoroughly in the subsequent section S*now pillow stations outside the Kootenay basin, in Alberta.* The overall review and selection of snow stations is presented in Appendix C.

The variable to be predicted in the Libby forecast equations is the cumulative April-to-August runoff (or inflow) volume, in thousands of acre-feet (KAF). The Apr-Aug volume is utilized as the dependent variable for the six forecasts issued from 1-November to 1-April. For the two forecasts issued subsequent to 1-April the dependent variable is the residual runoff volume, i.e. the May-to-August volume for the 1-May forecast and the June-to-August volume for the 1-June forecast. Observed monthly streamflow volumes during the runoff season were also available as candidate predictor variables for issue dates on or after 1-April.

The REG software program from the National Resources and Conservation Service was utilized for the majority of the statistical forecasting model development work (Garen, 1992; Garen, 2004) following the techniques and methods of the NRCS Water Supply Forecasting Program (USDA-NRCS 2004, USDA-NRCS 2010). The NRCS REG program provides a highly efficient procedure to search through extensive pools of candidate predictor variables and produce a capacitated list of the 30 most efficient principal components regression models that can be developed from the candidate variables. The program has been peer-reviewed and has been in widespread use by several federal agencies for over 15 years. The *Statsgraphics Plus 5* software program from Manugistics was utilized to independently validate the multivariate procedures in REG and also to confirm several of the forecast models produced by the REG software. In REG, each nominated model is developed using principal components (PC) regression, a procedure which transforms the original intercorrelated variables into orthogonal (independent) principal components and then performs the least-squares regression modeling on the principal components. REG tests and retains only statistically significant PC variables, insuring that the models produced are statistically sound and robust. REG transforms the "best" PC regression models back into terms of the original variables and reports the associated regression coefficients and performance statistics. The program utilizes the cross-validation standard error (CVSE, also called the Jackknife standard error) as the performance metric to evaluate the candidate models. Additional discussion of using principal components regression in water supply forecasting can be found in Lettenmaier and Garen (1979), Hawley, et al (1980), McCuen (2003), Wortman (2004). Additional discussions of the CVSE in comparing forecast model performance can be found in Garen (1992) and Wortman (2006).

The statistical literature contains extensive discussions on considerations involved in variable selection and model selection with regression models (e.g. Breiman and Freedman, 1983; Hocking, 1976; Mosteller and Tukey, 1977). The variable selection process evaluates the "t-statistic" (or the equivalent F-statistic) for a given model to validate that each and every variable fit is statistically significant, and that the model is parsimonious, i.e. does not contain an over abundance of variables that fail to add any additional information to the forecast. The model selection process is predominately focused around evaluating any of several "goodness of fit" statistics (e.g. standard error, r-square, PRESS), which are all a measure of the forecast model's "accuracy". The water supply forecasting problem is additionally challenged by the desire for "consistency" in the month-to-month series of forecasts as one progresses through the forecast season. As there is no consensus on a metric for month-to-month forecast consistency, the modeling community (and this study) has adapted the concept that utilizing a consistent set of forecast stations from one month to the next serves as a reasonable proxy for the objective of forecast consistency.

The forecast equations for the Libby water supply forecast model were developed as follows:

- A pre-screening process develops a pool of candidate variables within each of several "influence" categories (i.e. climate variables, precipitation variables, snow water variables). Variables are retained based on their length of record, completeness of record, and a statistically significant level of correlation with the runoff volume.

- The initial round of variable selection uses the pre-screened variables in the NRCS REG model. For each forecast issue date, REG is run for one or more pools of candidate variables, initially based on the broader variable type (e.g. climate variables), to investigate and narrow the pool of candidate variables. For example, the 1-Jan model analysis shows that variables based on the cumulative Oct-Nov-Dec precipitation at the candidate stations consistently performs better than variables based on Oct, Oct-Nov, or Nov-Dec durations. Variables are retained based on length of record, completeness of record, and minimum CVSE within a statistically significant principal component. Variables with inconsistent presence across multiple forecast dates are dropped (e.g. if Oct-Dec precipitation frequently appears as a high-performing variable in 1-Jan and 1-Feb and 1-Apr forecasts, the use of December-only precipitation in the 1-Mar forecast model would not be permitted).
- The next round iterates between variable selection and model selection. The pools the best variables from the previous analyses are processed by REG to develop lists of best candidate models for each forecast date based on lowest CVSE statistic. These monthly lists of best models are then reviewed to determine which models utilize essentially the same variables across multiple forecast dates. The large number of variables results in many combinations of variables that all produce similarly high-performing models. Within the list of high-performing models, however, there is generally no model that appears with exactly the same list of stations/variables for multiple months. The list of candidate variables for each forecast data is then trimmed to more closely correspond with the high-performing list looking across several months, and REG is rerun to develop a new list of high-performing models. The trimming of variables invariably produces sub-optimal (in terms of goodness-of-fit statistics, i.e. accuracy) models, but satisfies the objective for maximizing the month-to-month station consistency.
- A tertiary objective (after station consistency and minimum CVSE) is for the CVSE series to show improvement as the forecasts proceed through the season. The CVSE statistic is relatively flat during the 1-Feb to 1-May span of forecasts, demonstrating that the additional snow and precipitation information added during this period does little, if anything, to improve on the ability to forecast the entire April-August volume, which may indicate that the unknown future spring-summer precipitation introduces more variability to the model than is gained through refining one's knowledge of the winter snowpack. Calibration to differing periods of record on different issue dates will also change the CVSE slightly.
- Additional objectives include making the use of as many observations (years) as possible, in consideration of the soft objective of using the same number of years for all issue dates. Snow data, the most useful variable in water supply forecasting, is typically the variable with the most limited data record, thus the winter and spring forecast equations

that rely on snow have fewer years of data available than the fall forecast equations that do not use snow.

- In all cases the selected models must have standard errors improving on climatology.

Forecast models calibrated on the same period of record can be directly compared using the CVSE statistic (preferred), if available, or the Standard Error statistic (which is equivalent to the RMSE statistic calculated for the years used for calibration). The RMSE statistic can be used to evaluate and compare the performance of forecast models applied to data outside the calibration period. The limited size of the historic datasets (generally N<50) results in all of the performance statistics (CVSE, SE, RMSE) being easily influenced by several closely spaced series of years with abnormal variation. The performance statistics are best compared when applied to a consistent set of years.

The regression variables and their use in the forecast equations are summarized along with the forecast statistics in Table 1, 2, 3 and 4 below. A discussion of the performance statistics and the effect of the sample selection is provided in Appendix D. The output reports from the REG models are provided in Appendix E.

Regression Variables		Forecast Issue Date							
Type	VarName	1-Nov	1-Dec	1-Jan	1-Feb	1-Mar	1-Apr	1-May	1-Jun
CLX	SOI	JunJul	JunJul						
	QBO	JFM	JFM	JFM	JFM	JFM	JFM	JFM	JFM
	PNA						ONDJ	ONDJ	ONDJ
PPT	Eureka, MT	Oct	ON	OND	ONDJ	ONDJF			
	Libby 1NE RS, MT	Oct	ON	OND	ONDJ	ONDJF			
	West Glacier, MT	Oct	ON	OND	ONDJ	ONDJF	DJFM	JFMA	JFMAM
	Fernie, BC	Oct	ON	OND	ONDJ	ONDJF	DJFM	JFMA	JFMAM
SWE	Floe Lake, BC			1-Jan	1-Feb	1-Mar			
	Sunshine Village, AB			1-Jan	1-Feb	1-Mar	1-Apr	1-May	
	East Creek, 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
	Gardiner Creek, AB			1-Jan	1-Feb	1-Mar	1-Apr	1-May	1-Jun
	Three Isle Lake, AB			1-Jan	1-Feb	1-Mar	1-Apr		
	Lost Creek South, AB			1-Jan	1-Feb	1-Mar			
	Morrissey Ridge, BC			1-Jan	1-Feb	1-Mar			
	Hawkins Lake, MT			1-Jan	1-Feb	1-Mar			
Depen-dent	Libby Inflow (in KAF)	AprAug	AprAug	AprAug	AprAug	AprAug	AprAug	MayAug	JunAug

Table 1 – Variables in the Libby WSF model

Regression Coefficients		Forecast Issue Date							
	Variable/Site	1-Nov	1-Dec	1-Jan	1-Feb	1-Mar	1-Apr	1-May	1-Jun
	Constant	4701.513	3782.376	2561.460	1423.013	1473.321	247.944	18.458	526.231
CLX	SOI	25.605	62.313						
	QBO	-1.251	-1.698	-7.413	-7.866	-10.207	-1.834	-3.008	-1.817
	PNA						-83.948	-87.205	-72.391
PPT	Eureka, MT	307.695	233.435	77.293	62.168	68.645			
	Libby 1NE RS, MT	185.113	148.234	60.709	54.677	51.513			
	West Glacier, MT	125.041	99.755	31.806	32.314	33.713	51.347	83.416	87.243
	Fernie, BC	68.877	44.480	13.292	13.876	11.493	41.412	39.157	35.920
SWE	Floe Lake, BC			9.401	10.899	6.383			
	Sunshine Village, AB			24.329	22.352	17.813	52.445	57.780	
	East Creek, BC			5.828	7.006	4.760	25.837	27.650	21.934
	Stahl Peak, MT			22.577	19.658	15.238	27.280	30.150	22.045
	Gardiner Creek, AB			21.800	16.575	13.159	18.126	17.618	16.254
	Three Isle Lake, AB			28.677	29.682	26.123	51.234		
	Lost Creek South, AB			17.773	16.922	14.694			
	Morrissey Ridge, BC			24.439	23.923	18.602			
	Hawkins Lake, MT			36.454	32.919	22.833			

Note: CLX variables are dimensionless values reported by NOAA.
PPT and SWE values are all in inches (converted from mm, if necessary).

Table 2 – Regression coefficients for the Libby WSF model

Forecast Model Statistics	Forecast Issue Date							
	1-Nov	1-Dec	1-Jan	1-Feb	1-Mar	1-Apr	1-May	1-Jun
Number of Years	36	36	23	23	23	26	27	27
Number of Principal Components	1	1	2	2	2	1	1	1
Adjusted R-Square	0.267	0.526	0.727	0.870	0.896	0.867	0.861	0.863
Model Standard Error	1126	905	747	515	460	500	463	398
Cross-Validation Std Error	1191	947	841	564	527	532	487	418
Skewness of Forecast Residuals	-0.09	0.07	-0.59	0.16	0.07	-0.84	-0.89	-1.06

Table 3 – Libby WSF model statistics

Group	Variable/ Station Name	Station ID	Recommended data source(s) - Current data values
CLX	SOI		http://www.cpc.noaa.gov/products/CDB/CDB_Archive_pdf/CDB.monthly_color.pdf http://www.cpc.noaa.gov/data/indices/soi
	QBO		http://www.esrl.noaa.gov/psd/data/correlation/qbo.data
	PNA		http://www.cpc.noaa.gov/products/CDB/CDB_Archive_pdf/CDB.monthly_color.pdf ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/tele_index.nh http://www.esrl.noaa.gov/psd/data/correlation/pna.data
PPT	Eureka RS, MT	242827	http://www.wcc.nrcs.usda.gov/cgibin/precip.pl?state=montana (Select BSPR)
	Libby 1NE RS, MT	245015	http://www.wcc.nrcs.usda.gov/cgibin/precip.pl?state=montana (Select BSPR)
	West Glacier, MT	248809	http://www.wcc.nrcs.usda.gov/cgibin/precip.pl?state=montana (Select BSPR)
	Fernie, BC	1152850	http://climate.weatheroffice.gc.ca/climateData/canada_e.html (Customized Search)
SWE	Floe Lake, BC	2C14P	http://a100.gov.bc.ca/pub/aspr/
	Sunshine Village, AB	05BB803	http://www.environment.alberta.ca/apps/basins/Map.aspx?Basin=10&DataType=4
	East Creek, BC	2D08P	http://a100.gov.bc.ca/pub/aspr/
	Stahl Peak, MT	14A12S (MT787)	http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=787&state=mt
	Gardiner Creek, AB	05AA809	http://www.environment.alberta.ca/apps/basins/Map.aspx?Basin=10&DataType=4
	Three Isle Lake, AB	05BF824	http://www.environment.alberta.ca/apps/basins/Map.aspx?Basin=10&DataType=4
	Lost Creek South, AB	05BL811	http://www.environment.alberta.ca/apps/basins/Map.aspx?Basin=10&DataType=4
	Morrissey Ridge, BC	2C09Q	http://a100.gov.bc.ca/pub/aspr/
	Hawkins Lake, MT	15A03S(MT516)	http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=516&state=mt
INFLOW	Libby Inflow (in KAF)	LIB QIDRXZZAZD	http://www.nwd-wc.usace.army.mil/perl/dataquery.pl (Input "LIB")

Note: The online data source for Alberta snow data maintains real-time SWE data for only the most recent 48 to 72 hours. Data older than this is not readily available. Per Stephanie Smith, BC Hydro is making arrangements for the Canadian Ministry of Environment to include the Alberta stations in existing reports that are automatically generated and provided to BC Hydro. We should be able to then have reliable access to the data through BC Hydro at the Canadian Entity to the Columbia River Treaty (email to R. Wortman from S. Smith, 5/26/2010)

Table 4 - Stations/Variables used in Libby forecast equations, with data sources

2010 Review

Several significant issues were identified during the 2010 review of the Libby WSF:

- Libby Dam inflow – A variety of source(s) for the streamflow record
- Non-stationarity of the Libby inflow streamflow variable
- First-time consideration of additional climate indices and derived climate variables
- Discontinued stations - Availability of precipitation and snow water equivalent data
- First-time consideration of snow pillow stations in Alberta
- Performance of the new equations in comparison to previous models

These issues are summarized below.

Libby Dam inflow

The original forecast models utilized available streamflow and meteorological data back to 1948. As the potential for a dam at the site was not even a proposal for at least another decade, there was no gauged measurement at the site until the dam was constructed and project flows were utilized. Prior to the construction of Libby dam the inflow was calculated using values from gauging stations located in the Canadian portion of the Kootenay River multiplied by a factor related to basin area. Following construction of Libby Dam the inflow was calculated as outflow minus change-of-storage. For this study the daily inflow from CROHMS (SHEF code QIDRXZZAZD) was utilized to calculate daily Libby inflow values. In the rare instance where daily inflow values were not available or suspect daily outflow and change-of-storage values were used to calculate daily inflow. Seasonal volumes for use in the water supply forecast models were computed from the daily inflows.

Appendix F contains additional details on the issues related to inflow measurements for Libby Dam.

Non-Stationarity of the Libby Dam inflow series

A comparison of the various data sources shows relatively minor discrepancies in streamflow values regardless of data source (Figure 10, Appendix F), thus for the purpose of analyzing seasonal runoff volumes, all sources are deemed equally reliable. However, an analysis of the long term record of seasonal runoff values showed a distinct, statistically significant upward shift in the mean April-August volumes in the 1948 to 1974 era (Figure 1, below). This shift (non-stationarity in the mean) is consistent regardless of the data source. A cumulative mass plot (Searcy and Hardison, 1960) displays the same shift as a change in slope (Figure 2, below).

Although this shift in streamflow volume closely corresponds with the “cool” phase of the PDO regime (see Kennedy, et al, 2009, and Hamlet and Lettenmaier, 1999), the causes of the PDO are

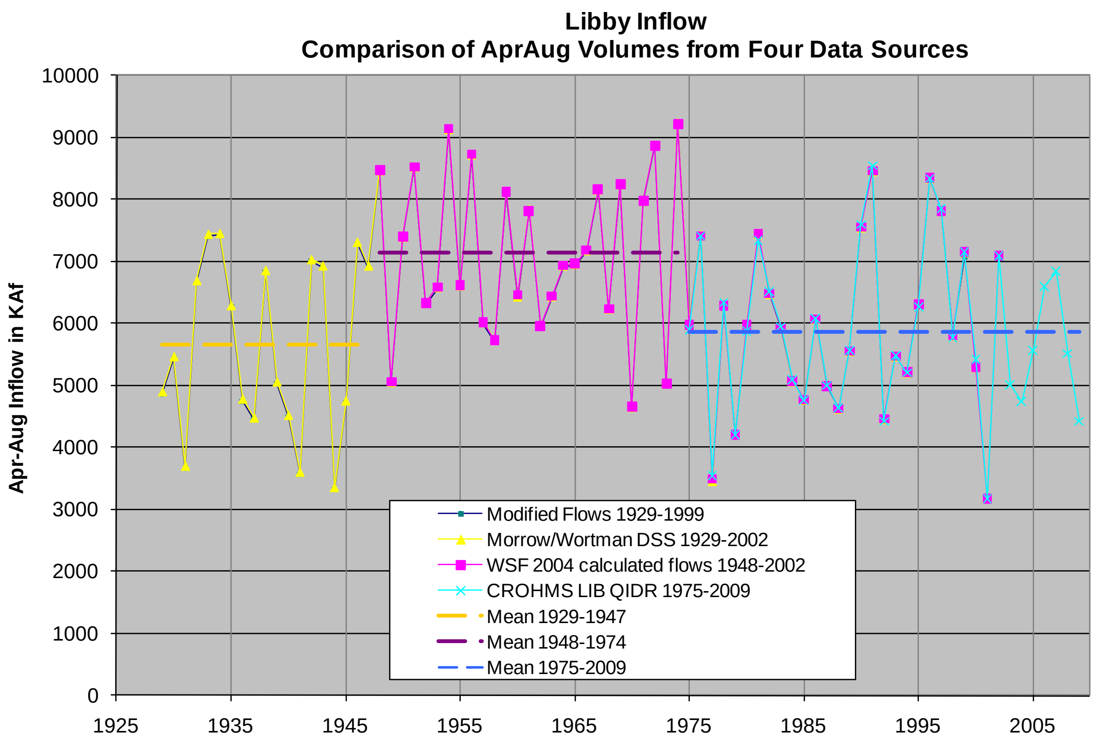

Figure 1 – Historic seasonal runoff volume at Libby Dam

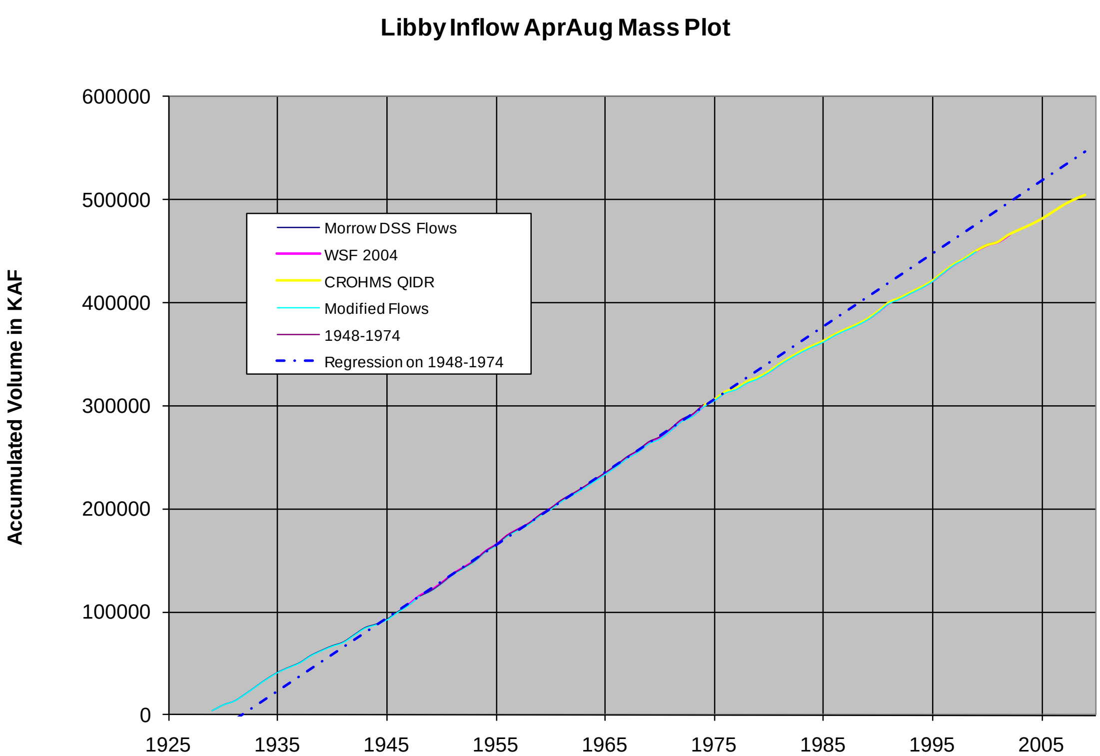

Figure 2 – Cumulative mass plot of seasonal runoff volumes at Libby Dam

not currently known (Mantua, 2010). Determination of the root cause of this shift in streamflow volume is beyond the scope of this water supply forecast study. As discussed previously in the 2004 Libby forecasting report (ibid, pages 11-12), the determination of the current PDO regime is quite problematic, as the PDO frequently allows short series of monthly values to cross-over into adjacent regimes, without the base regime actually changing. The long periodicity of the PDO also leads to there being relatively few transitions in the historic record leading to considerably difficulty in determining if and when the PDO has transitioned into a new regime.

However, since the April-August runoff volume is the key variable that the water supply forecast model is attempting to predict, this distinct shift in the streamflow record remains a substantial concern. Stationarity in the variables is a necessary condition for use in a statistical model and the sample set must represent the population. Due to the shift (non-stationarity) noted in the critical April-August flow volume variable, it was concluded that this analysis should only include data from Water Year 1975 forward. The Libby water supply forecast model should be reviewed and possibly recalibrated if it is determined that the PDO has returned to the "cool" phase.

Climate indices and derived climate variables

Many research papers during the last 19 years have investigated the use of climatic variables in water supply forecasting (e.g., Redmond and Koch, 1991; Garen, 1998; Hamlet and Lettenmaier, 1999; Kennedy, et al, 2009; Gobena, 2010). RPA Action 36 in the FCRPS BiOp (NMFS 2000 BiOp) specifically requested the investigation of climate variables such as the Southern Oscillation Index for its usefulness to the Libby runoff volume forecast. The 2004 forecast review examined the SOI and PDO climate indices and selected the four-month sum of the June-through-September SOI as a useful variable in the 1-Nov and 1-Dec forecast equations.
Over the past decade or so many additional climatic indices and variables have been developed and are being investigated for a wide range of purposes. A review of the indices published by either of the NOAA Earth System Research Lab (ESRL, 2010) or the NOAA Climate Prediction Center (CPC, 2010) resulted in list of 10 climate indices for consideration as a predictor variable in the Libby WSF equations.

The following 10 climate variables were included in this study:

MEI, Nino3.4, NOI, QBO, SOI, ONI, PDO, PNA, WP and BEST

Descriptions and explanations of these indices can be found at the following web sites:

- NOAA Climate Prediction Center - http://www.cpc.noaa.gov/products/CDB/CDB_Archive_pdf/CDB.monthly_color.pdf
- NOAA Earth System Research Laboratory - http://www.esrl.noaa.gov/psd/data/climateindices/list/

For each climate index monthly value, additional climate variables can be derived by constructing cumulative multi-month values and by providing for various time lags between the observation of the climate variable and the runoff season (i.e. the 3-month sum of the monthly values, centered 6 months prior to the current month). This study looked at 72 climate variables that can be derived from each of the 10 climate indices and at the correlations of the climate variables with the Libby runoff volume. The details of this correlation analysis for the climate variables are documented in Appendix A.

The real-time availability of data is an additional pragmatic concern in operational forecasting. Unlike traditional hydrometeorological variables that are typically observed in near real-time, three distinct steps are usually involved before one can use the climate variable value: 1) the ocean and/or atmospheric data must be measured, often at multiple sites, 2) the climate index value must be calculated, often using principal components or other multivariable statistical methods, and finally 3) the calculated index value must be published. A review of the publication history during winter and spring 2010 showed that there is at best a two week delay, but more typically a two to three month delay before a value is published on a NOAA web site. This publication lag provided an additional filter on which variable could be considered for each water supply forecast issue date.

In consideration of the results from the correlation analysis and the reliable availability of the forecast data for real-time use, Table 5 presents the best climate index forecast variables to be considered as predictor variables in the Libby water supply forecast equations:

	Forecast Issue Date						
Climate Index	**1-Oct**	**1-Nov**	**1-Dec**	**1-Jan**	**1-Feb**	**1-Mar**	**1-Apr**
MEI		O					
Nino34	AS S						
NOI		JJASO					
QBO	F JF JFM JFMA						
SOI	JJ JJA						
ONI	A	AS	ASO	ASON			
PDO				N ON	D ND OND	DJ NDJ ONDJ	DJ NDJ NDJF
PNA					ND OND	NDJ ONDJ	NDJ ONDJ
WP						DJ NDJ	DJF NDJF
BEST	J						

Table 5 - Best Climate Index Variables

Note that in several cases, e.g. PNA for the 1-Mar issue date, multiple durations of the climate variable are suitable for consideration.

Discontinued stations - Availability of precipitation and snow water equivalent data

Statistical analysis is totally reliant on the data that is available in the historic record in order to analyze and develop a statistical forecasting model. In operational use, the forecast model is totally dependent on the continued availability of the data from the stations used in the forecast equations. There has been an unfortunate series of station closures throughout the history of the Libby water supply forecasts:

- Elko, BC (precipitation) – station closed in 1983
- Morrissey Ridge, BC (snow course 2C09) – discontinued in June, 1988 and replaced by Morrissey Ridge (snow course 2C09A)
- Red Mountain, MT (snow course) 1-March readings discontinued in 1991
- Morrissey Ridge, BC (snow course 2C09A) discontinued in 1995 and replaced by snow pillow (2C09Q)
- Banff, Campbell-Scientific (precipitation) – station relocated in March, 1995
- Kimberly, BC (snow course) discontinued in April 1995
- Polebridge, MT (precipitation) – station closed in July 2000
- Multiple changes in schedules for reading snow stations, i.e. changes at Kicking Horse, Bush River, Gray Creek Lower, Gray Creek Upper, and Mt. Templeman – Feb 2004
- Brisco, BC (precipitation) – station closed April 2004
- Marble Canyon, BC (snow course) – station closed after extensive fire damage – Sep 2004
- Fortine 1N, MT (precipitation) – station closed Feb 2009
- Vermillion River #3 (snow course) – station is no longer being read – Nov 2009

The Marble Canyon snow course was utilized in the 2004 equations, however, at approximately the same time the equations were finalized, the site was closed due to a large wildfire that destroyed the gauging site and caused extensive damage to the surrounding basin. The nearby Vermillion River #3 snow course site, which had been closed for 24 years, was recommissioned in the fall of 2004 to serve as a proxy for the Marble Canyon site. From 2005 to 2009 the Vermillion River #3 SWE values have been used to estimate Marble Canyon SWE, which is then used in the 2004 Libby WSF equations. Unfortunately, there has been no way to properly validate the relationship between the two sites as there are limited concurrent observations. The equations used to estimate the Marble Canyon SWE values from Vermillion River observation are thus suspect. There are only three 1-January readings in common between the two sites, and these three values are coincidentally exactly collinear (an r-squared value of 0.9999). There are, however, 11 1-April SWE values in common between the two sites, and they have a good, but not nearly as perfect, linear relationship, with an r-squared statistic of 0.86. BC Hydro informed the Corps in fall 2009 that Parks Canada would no longer be taking observations at the site due to concerns over tourists blocking traffic and creating safety issues when Parks' staff was taking the snow measurements.

Collection of precipitation data for this review was hampered by a two-year delay (since Feb 2007) in Environment Canada publishing much of the data on their web site. Some of the data was retrieved from published daily records and supplemented by data made available to us by BC Hydro. During the data collection activities for this review the following station closure was also discovered:

The Fortine 1N, Montana station is used in the current (2004 Update) Libby WSF equations. It was discovered during the data collection for this study that the Fortine 1N station was closed after December 2009. Although there is a new Fortine 2NE station, the Missoula WSO meteorologist reports that the precipitation data are not compatible with the Fortine 1N station (email from Ray Nickless, May 14, 2010). Apparently the Northwest River Forecast Center has been estimating monthly precipitation values for Fortine 1N and forwarding these estimated values to the Corps for use in our water supply forecast efforts, without any notification that the values that they were providing were estimates and not actual observed values. This same scenario occurred previously when the Polebridge, Montana was closed in July 2000, with the NWRFC sending the Corps synthesized monthly precipitation numbers for over two years before it was brought to the Corps' attention that the station was no longer in operation.

Water supply forecasting models remain highly dependent on the availability of a continuous record of data. Real life operations must remain flexible and make allowances for the fiscal (constrained funding of gauges and observers) and physical (fire, avalanche, safety) realities that disrupt real time operations and challenge existing forecasting models and assumptions.

Snow pillow stations outside the Kootenay basin, in Alberta

During the process of data collection for this review it was discovered that the Province of Alberta has 8 automated snow pillow stations located quite close to the continental divide on the eastern boundary of the Kootenay basin. Five of these stations have been in operation since January 1985, with the remaining three sites coming online between 1987 and 1991. Although these sites are located slightly to the east of a political (provincial) boundary, and technically outside the Kootenay watershed boundary, they are physically much closer to the Kootenay basin than several of the snow sites utilized in earlier versions of the forecast model. These 8 sites along the western crest of Alberta are all more consistently highly correlated with the Libby seasonal water supply than any of the existing snow stations in British Columbia. It is seen as an added benefit that these are snow pillow stations, programmed to report hourly, and are being posted in near real-time with a publication lag of less than 2 hours. These automated stations usually far outperform traditional snow course stations in their reliability to deliver data near the first day of the month. Table 6, below, provides a listing of the snow stations with the highest correlations between the first-of-month SWE and the Apr-Aug runoff – 15 of the 24 are snow pillow (Snotel/ASP) stations, with all 8 of the Alberta stations represented. Table 7 provides a corresponding listing of the station metadata.

Appendix C contains a complete listing of snow stations reviewed for this study, along with maps of the snow station locations, and a discussion of the procedures used for data estimation.

Station Name	Site ID	1-Dec	1-Jan	1-Feb	1-Mar	1-Apr	1-May	1-Jun
ST. LEON CREEK, BC	2B08		0.8121	0.8004	0.8133	0.8239	0.8218	
ST. LEON CREEK, BC	2B08P		0.6565	0.7767	0.8039	0.8228	0.8167	0.5826
SULLIVAN MINE, BC	2C04		0.5389	0.6720	0.7271	0.7836	0.6338	0.6710
MORRISSEY RIDGE, BC	2C09Q		0.5376	0.6996	0.8003	0.7564	0.7640	0.5655
MOYIE MOUNTAIN, BC	2C10P		0.5052	0.6297	0.6364	0.5203	0.5634	0.3606
FLOE LAKE, BC	2C14		0.6981	0.8084	0.7646	0.7667	0.8107	
FLOE LAKE, BC	2C14P		0.6570	0.7872	0.7402	0.7452	0.7664	0.6710
MOUNT ASSINIBOINE, BC	2C15		0.7285	0.8440	0.8352	0.8291	0.8247	
MOUNT JOFFRE, BC	2C16		0.6200	0.7876	0.8330	0.8256	0.7560	
THUNDER CREEK, BC	2C17		0.6299	0.7340	0.7817	0.7604	0.7100	
GRAY CREEK (LOWER), BC	2D05		0.6214	0.6014	0.6882	0.5925	0.5677	0.5356
EAST CREEK, BC	2D08P		0.7127	0.8182	0.7795	0.7742	0.7992	0.6906
MOUNT TEMPLEMAN, BC	2D09		0.8350	0.8068	0.8410	0.8011	0.8372	
GRAY CREEK (UPPER), BC	2D10		0.5211	0.8072	0.7910	0.7193	0.7265	0.5808
HAWKINS LAKE, MT	HAWKM	0.4975	0.6260	0.7708	0.7822	0.7434	0.7219	0.6645
STAHL PEAK, MT	STHLM	0.4751	0.6503	0.8105	0.8419	0.7969	0.8041	0.7593
AKAMINA PASS AB	AKAMI	0.4660	0.5332	0.6931	0.6567	0.4869	0.4650	0.2734
GARDINER CREEK, AB	GARDI	0.3446	0.5072	0.7004	0.7706	0.5885	0.5394	0.5834
S. RACEHORSE CREEK, AB	SRACE	0.6979	0.5720	0.7830	0.8186	0.8378	0.6844	0.5620
SUNSHINE VILLAGE, AB	SUNSH	0.7025	0.7487	0.8322	0.7966	0.8238	0.7792	0.6015
THREE ISLE LAKE, AB	TISLE	0.6084	0.6728	0.8085	0.7953	0.7252	0.5926	0.5419
MT ODLUM, AB	ODLUM	0.7349	0.7739	0.8400	0.8347	0.8468	0.7096	0.6649
LOST CREEK SOUTH, AB	LOSTC	0.7424	0.8126	0.8156	0.8346	0.7902	0.7078	0.5837
SKOKI LODGE, AB	SKOKI	0.4747	0.5615	0.6751	0.6920	0.6892	0.7056	0.5892

Table 6 – Active Snow Stations with the most significant correlations between Snow Water Equivalent and Apr-Aug Runoff (Filtered to only include stations with a minimum of 20 years of data)

Station Name	Site ID	Latitude	Longitude	Elev. (m)	Elev. (ft)	Snow-Course or Pillow
ST. LEON CREEK, BC	2B08	50.433	-117.700	1800	*5905*	Snow Course
ST. LEON CREEK, BC	2B08P	50.433	-117.700	1800	*5905*	Snow Pillow
SULLIVAN MINE, BC	2C04	49.717	-116.017	1550	*5085*	Snow Course
MORRISSEY RIDGE, BC	2C09Q	49.450	-114.967	1800	*5905*	Snow Pillow
MOYIE MOUNTAIN, BC	2C10P	49.250	-115.767	1930	*6332*	Snow Pillow
FLOE LAKE, BC	2C14	51.050	-116.133	2090	*6857*	Snow Course
FLOE LAKE, BC	2C14P	51.050	-116.133	2090	*6857*	Snow Pillow
MOUNT ASSINIBOINE, BC	2C15	50.900	-115.617	2230	*7316*	Snow Course
MOUNT JOFFRE, BC	2C16	50.533	-115.117	1750	*5741*	Snow Course
THUNDER CREEK, BC	2C17	50.050	-115.233	2010	*6594*	Snow Course
GRAY CREEK (LOWER), BC	2D05	49.617	-116.683	1550	*5085*	Snow Course
EAST CREEK, BC	2D08P	50.633	-116.933	2030	*6660*	Snow Pillow
MOUNT TEMPLEMAN, BC	2D09	50.717	-117.200	1860	*6102*	Snow Course
GRAY CREEK (UPPER), BC	2D10	49.617	-116.650	1910	*6266*	Snow Course
HAWKINS LAKE, MT	HAWKM	48.967	-115.950	1966	*6450*	Snow Pillow
STAHL PEAK, MT	STHLM	48.900	-114.850	1838	*6030*	Snow Pillow
AKAMINA PASS AB	AKAMI	49.028	-114.053	1800	*6085*	Snow Pillow
GARDINER CREEK, AB	GARDI	49.361	-111.800	1970	*6660*	Snow Pillow
S. RACEHORSE CREEK, AB	SRACE	49.783	-114.600	1920	*6491*	Snow Pillow
SUNSHINE VILLAGE, AB	SUNSH	51.079	-115.780	2230	*7539*	Snow Pillow
THREE ISLE LAKE, AB	TISLE	50.631	-115.279	2160	*7303*	Snow Pillow
MT ODLUM, AB	ODLUM	50.486	-114.907	2130	*7201*	Snow Pillow
LOST CREEK SOUTH, AB	LOSTC	50.171	-114.713	2160	*7303*	Snow Pillow
SKOKI LODGE, AB	SKOKI	51.541	-116.056	2060	*6965*	Snow Pillow

Table 7 -- Metadata for active Snow Stations most significantly correlated with Runoff

Performance of the new equations in comparison to previous models

Many challenges exist in developing statistical forecast models and the evaluation of such models in terms of accuracy and precision (Weber, et al. 1973; Lettenmaier and Garen, 1979; Hawley, et al, 1980, Wortman, 2006). The performance of a forecasting model is evaluated using statistics developed from the forecast “errors” - the differences between the historical observations and the forecasts produced by the model. The most useful and typical performance statistics are based on the RMSE (root-mean-squared-error) calculation. The RMSE of the “naïve forecast” (lacking any other foresight and using the average of the historic series as the forecast) is the Standard Deviation statistic. The RMSE of the forecasts corresponding to the sample used to calibrate the forecast equation is the Standard Error statistic. Several researchers prefer the use of the Cross-Validation (or Jackknife) Standard Error statistics, which is the RMSE of the errors derived from the Leave-One-Out (Jackknife) forecast models. The CVSE is part of the NRCS REG model utilized in this study and was highly influential in comparing and selecting which forecast models to consider. If one is evaluating the performance of a model calibrated to a given dataset, and applied to future forecasts, the RMSE can be calculated for both the calibration series (e.g. the standard error) and the combined calibration and forecast series and compared.

The new forecast equations cannot generate forecasts for any years prior to 1985 due to lack of snow data at the Alberta snow pillows, which leaves the Standard Error and CVSE statistics based on the calibration data as the only statistics available for comparison with the 2004 model. A strict comparison of the statistics from the new shorter-term (approximately 25-year) models and the previous 2004 models (using forecast series ranging from 29 years to 55 years) shows a marked reduction (improvement) in the new models’ Standard Error and CVSE values. However, the influences of the diversity of samples and sample sizes warrant caution and reserving judgment of this evaluation.

Appendix D examines the RMSE forecast performance statistic for the 2004 forecast equations under four sampling scenarios, along with a comparison with the Standard Error of the new forecast equations. This analysis and comparison confirms that the new forecast equations based on the 25 year dataset provide a reliable set of forecasting models.

Appendix G provides plots year-by-year, side by side comparisons of the forecasts from the (previous) 2004 Libby model with the forecasts from the 2011 model.

Recommendations for Future Work Efforts

The following are the author's recommendations for consideration in future work efforts:

1. Conduct a review the historic average daily inflow data for Libby Dam (*LIB QIDRXZZAD* in CROHMS and *CWMS-LIB.Flow-In.Ave.1Day.1Day.CBT-REV* in CWMS), performing necessary quality control to ensure that the series is complete and free of obvious errors.
2. Implement an ongoing quality control process to ensure that the Libby Dam average daily inflow series remains complete and free of errors.
3. Create an official time series for *pre-project* inflow above the Libby Dam site. The daily natural flow inflow to Libby Dam in the latest Modified Flows study could provide the data for this time series. This would eliminate repeated attempts to recreate the pre-project flows using a variety of methods (see Appendix F – Libby Dam Inflow) along with confusion as to which method and resulting numbers are "correct".
4. The author estimates that 80% to 90% of the effort in this study is related to data collection and data estimation work, with the remaining 10% to 20% of the effort being focused on the statistical forecasting work. Action: Implement access to a database of quality assured snow station data. This database would match historic published records for relevant snow course sites and snow pillow sites in both the United States and Canada. The database would include records for snow data estimated by procedures jointly approved by the NRCS National Water and Climate Center and the Columbia River Treaty Hydromet Committee. It is recommended that this objective be accomplished through a cooperative effort with the NRCS NWCC and, as much as possible, leverage their existing database(s) and automated data collection procedures. If possible, the Corps should avoid duplicating work being done by the NRCS.
5. Conduct further investigations into the water supply forecasting procedures used by the NRCS NWCC, BC Hydro, and the NWRFC. Consider to what extent their procedures may be beneficial to the Corps' water supply forecasting needs and to what extent closer collaboration could be useful.
6. Background - One of the most challenging aspects of developing the water supply forecast models is attempting to incorporate some consideration of "month-to-month forecast consistency", which is a different objective from developing the "best" forecast. The "best" forecast can be developed based on any of several standard goodness-of-fit statistics, and the NRCS REG procedure provides a very useful listing of the 30 "best" models for a given issue date. There is not currently any standard statistic to measure forecast consistency. It is not unusual for the final recommended model for a given issue date to not appear on the 30-best list, but to be constructed from a model that appears on the list, plus an additional variable or two that forces the model into a similar variable set as the models in preceding and/or subsequent months.

Recommendation – Investigate the capabilities of the operations research technique of dynamic programming to address the problem of choosing the "best" water supply forecast model for a given month to maximize a goal for month-to-month forecast consistency. Dynamic programming excels in providing the optimal solution to a problem that can be cast as a sequence of decisions, and the choice of which of the "best" models to choose for each forecast date may be resolved by this technique. (The public domain "CSUDP" software package from Colorado State University has the capabilities to address this type of problem, and has recently been added to the Corps' list of software applications approved for use by the Hydraulics and Hydrology Community of Practice.)

7. Background - The historical monthly precipitation data used in this study comes from different sources than the precipitation data used in operational water supply forecasting. The data in this study comes from either of two official government archives (see Appendix B) and has received extensive quality control review prior to publication. The precipitation data used in operational forecasting is provided to the Corps from other official government offices (usually the Northwest River Forecasting Center and Environment Canada), but should be recognized as "real-time" data. Real-time, operational data has gone through a less rigorous level of quality control and may contain "on-the-fly" daily precipitation estimates to fulfill the needs of real-time hydrologic forecasting models. In practice, although much of the daily precipitation data is received in a timely fashion, some sites reporting monthly data may not be instrumented for automated electronic transfer, and their data may actually be phoned or mailed into the local climate office. Estimated precipitation values provided by the NWRFC may actually change daily as observed values received from additional sites are incorporated into the estimation procedure. (Precipitation data from the Corps' CROHMS database is not used by this author as it has little or no quality control and is quite poorly correlated with the historic climate records published by the Western Regional Climate Center.)

   Recommendation - Review the current data exchange procedures and policies between the Corps and the National Weather Service Northwest River Forecast Center. Investigate opportunities and benefits of the NWRFC providing direct access to the NWS COOP climate data. The Corps needs to be assured that procedures are in place to 1) identify which, if any, values are estimated monthly precipitation values, and 2) identify stations that have been closed or are otherwise no longer in service (see *Discontinued Stations*, pages 14-15, for several examples of climate stations whose closure was not disclosed to the Corps).

8. Investigate the relationship of climate variables constructed from the multi-month differences in climate index values (e.g. the 3-month *change* in PNA or QBO). There is a reasonable argument that larger changes in particular climate indices may correspond to

(or be responding to) atmospheric perturbations that will carry through and be seen in the local hydrologic response.

9. Investigate the relationship of the climate variables to the moisture input variables in the water supply forecast equations. It could be useful to understand if a particular climate variable is more related to rain or snow, and if the relationship shows a seasonal component (e.g. Does the climate variable have a relationship with summer precipitation?)

10. Investigate forecast model development and performance based on ENSO-year classification (reference UW/CIG website http://cses.washington.edu/cig/pnwc/compensopdo.shtml#pdoensoyears).

11. Investigate additional innovative approaches, such as those that consider the forecasts from multiple forecast procedures on each issue date and employ objective procedures to 1) review and filter out anomalous forecast values, and 2) calculating an optimal weighted-average of the remaining forecasts. (Confidence limits on the combined forecasts may be difficult to determine.)

12. Investigate the capabilities of non-linear models, such as neural net models, as an alternative to the current linear regression models. (This could be combined with the multiple-model approach discussed above).

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Appendix H: Reviewer’s Comments and Author’s Responses

Appendix I: Details of the 2011 Update to the 2010 Revision

Appendix A. Correlation Analysis of Climate Index Variables

This section examines the relationship (correlation) between each climate variable and the seasonal runoff volume above Libby Dam. Since each climate variable is recorded as a monthly value, the initial analysis is the single-month analysis, e.g. the correlation between the July SOI and the April-August runoff volume for the following season. It is also desirable to examine the correlations for multi-month accumulated values of the climate variable, e.g. July+Aug SOI. This study looked at single-month values and accumulations of up to 6 months in duration. Thus, for each climate variable, a starting month (January to December) and a duration (1-month to 6-month) were used to construct 72 series which were examined for their correlation with the runoff volume.

A convention was required to identify each of the 72 accumulation series. For purposes of charting the correlations it is necessary to assign a single-month designation to each series, rather than attempting to incorporate the multi-month duration. A multi-month accumulation could be labeled by the starting month or by the ending month (a "central month" doesn't work for series with an even number of months). For purposes that are more apparent when looking at the correlation plots, there are advantages for each labeling scheme, so for each climate variable a correlation chart is presented for both starting-month and ending-month schemes.

The figures at the end of Appendix A show the correlations between the 72 climate variables constructed from each climate index and the Libby AprAug runoff volume based on data for water years 1975 to 2010. Each duration (e.g. 3-month sum) is presented as a series, with the series displaying a range of lag times. Each climate index chart is presented twice – once from the perspective of beginning month, and once from the perspective of ending month. The 12 starting months were defined as occurring in the calendar year prior to the water year. The ending month sums use the same correlation values, however the horizontal plotted position is shifted to be relative to the ending month. This arrangement allowed investigation of time-lags between the climate variable and the runoff season ranging from 2 months to 18 months.

The factors involved in the analysis of the correlation charts for a climate index can be summarized by the following two questions:

1. What is the shortest aggregation period for climate indices that will result in a smooth transition in the strength of the correlation with seasonal inflow volume throughout the calendar year prior to the target period (i.e. Sharp month-to-month variations are not desirable and a short-duration series is preferable over a longer duration series, given that their correlations are comparable.)
2. Given a consistent signal, which of the 72 climate variables show the strongest relationships (largest absolute value of the correlation)?

Summary of the correlation plot analysis:

- MEI – Extremely smooth plots with very high month-to-month consistency for all durations of 2 months or more. Near zero correlation during previous winter season (Jan to Mar), with correlations increasing slightly during Mar to Dec seasons. The best MEI correlations are slightly over -0.25, which is considered insignificant.
- Nino3.4 – (Similar to MEI) Very smooth plots with very high month-to-month consistency for all durations of 2 months or more. Near zero correlation during previous winter season (Jan to Mar), with correlations increasing slightly during Mar to Dec seasons. The best Nino3.4 correlations are near -0.25, which is considered insignificant.
- NOI – Inconsistent month-to-month signal. Fair consistency (smoothness) observed with durations of 4 months or more; Good consistency for 6-month sums. Near zero correlation during previous winter season (Jan to Mar), with correlations increasing slightly during summer season. The best NOI correlations are slightly over +0.20, which is considered insignificant.
- QBO – Extremely smooth plots with very high month-to-month consistency for all durations. Highest correlation during previous winter season (Jan to Mar), with correlations decreasing toward mid-summer and increasing again moving toward winter. The best QBO correlations are around -0.40 in the previous winter season (shorter durations that include the early winter months are better) and +0.40 in the recent winter season (longer durations that include the current spring months are required).
- SOI – Inconsistent month-to-month signal until working with at least 2-month sums; longer durations preferred. Signals from the previous winter and recent fall are near zero. The best correlations, around +0.32, use mid-summer signals (June and July).
- ONI – (Similar to MEI) Extremely smooth plots with very high month-to-month consistency for all durations. Near zero correlation during previous winter season (Jan to Mar), with correlations increasing slightly during Mar to Oct seasons. The best ONI correlations are near -0.23, which is considered insignificant.
- PDO – Inconsistent month-to-month signal until working with at least 3-month sums; longer durations preferred. Near zero correlations with signals from the previous winter through summer, increasing as fall values are included. The best PDO correlations are around -0.46, using Nov to Jan values.
- PNA – Highly inconsistent month-to-month values until working with 3 months (or longer) durations. Poor correlations (< 0.2) throughout most of the year. Correlations improve to a maximum of around -0.40 with the addition of fall-winter (Nov to Jan) values.
- WP – Inconsistent month-to-month signal (especially irregular when using June values). Correlations remain negligible throughout most of the year until recent winter values (Jan and Feb) are involved, resulting in reasonable correlations around -0.36.
- BEST – Slightly inconsistent month-to-month signal with fair smoothness for 2-month sums and very good smoothness for all durations of 3 months or greater. Unfortunately,

all correlations are negligible, with the best correlation around -0.25 using summer (June and July) values.

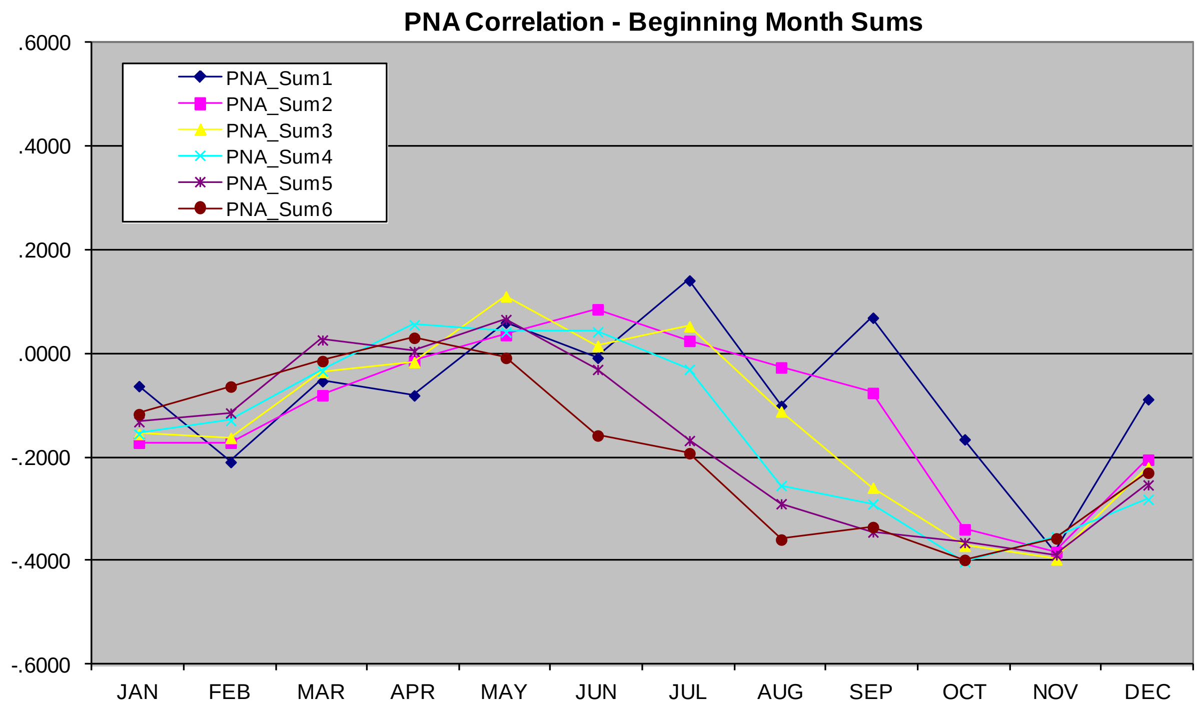
The results of the climate variable correlation analysis are summarized in Table 8 below, with the series presented in order of the best correlation value:

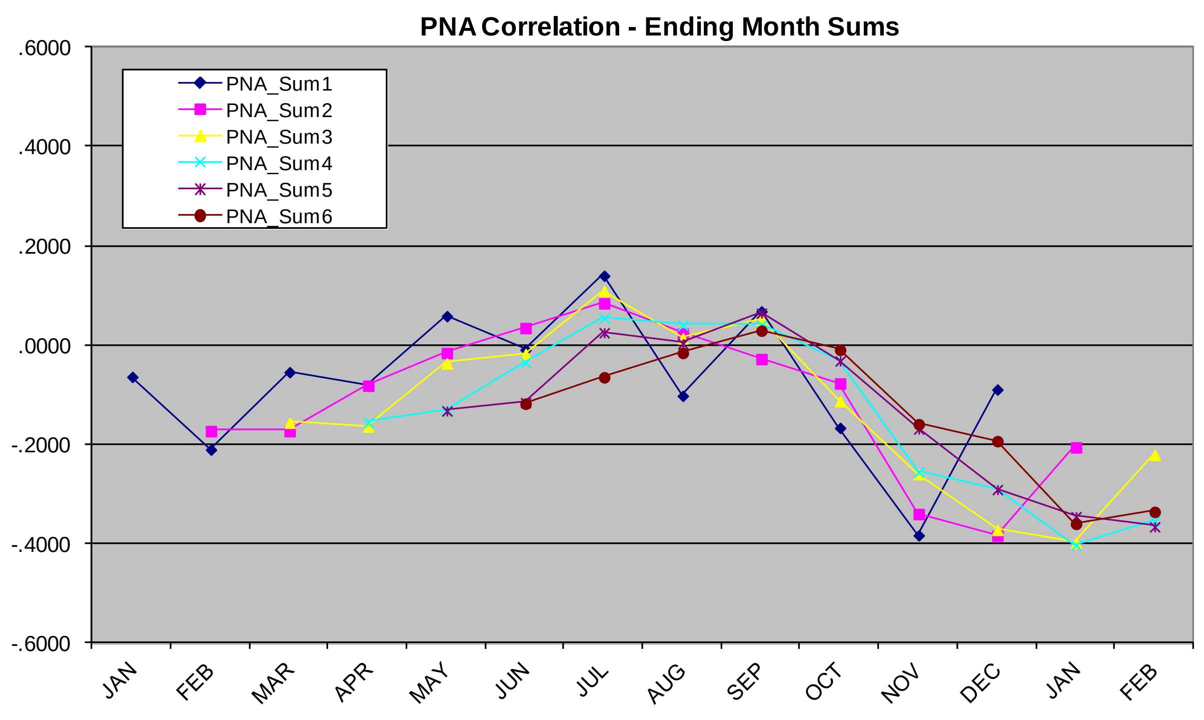
Climate Index	Best N-month Correlation	Ending month(s) for best Correlation	Seasonal Trend Smoothness
PDO	-0.457	NDJFM	3-month+
QBO	-0.404	JFMA	Excellent
PNA	-0.401	NDJFMA	2-months+
WP	-0.359	JF	2-months+
BEST	-0.255	July	2-months+
MEI	-0.255	Oct	Excellent
Nino34	-0.249	SO	Excellent
ONI	-0.229	ASON	Excellent
NOI	0.203	Oct	at least 4-months
SOI	0.320	July	2-month+
QBO	0.404	AM (current WY)	Excellent

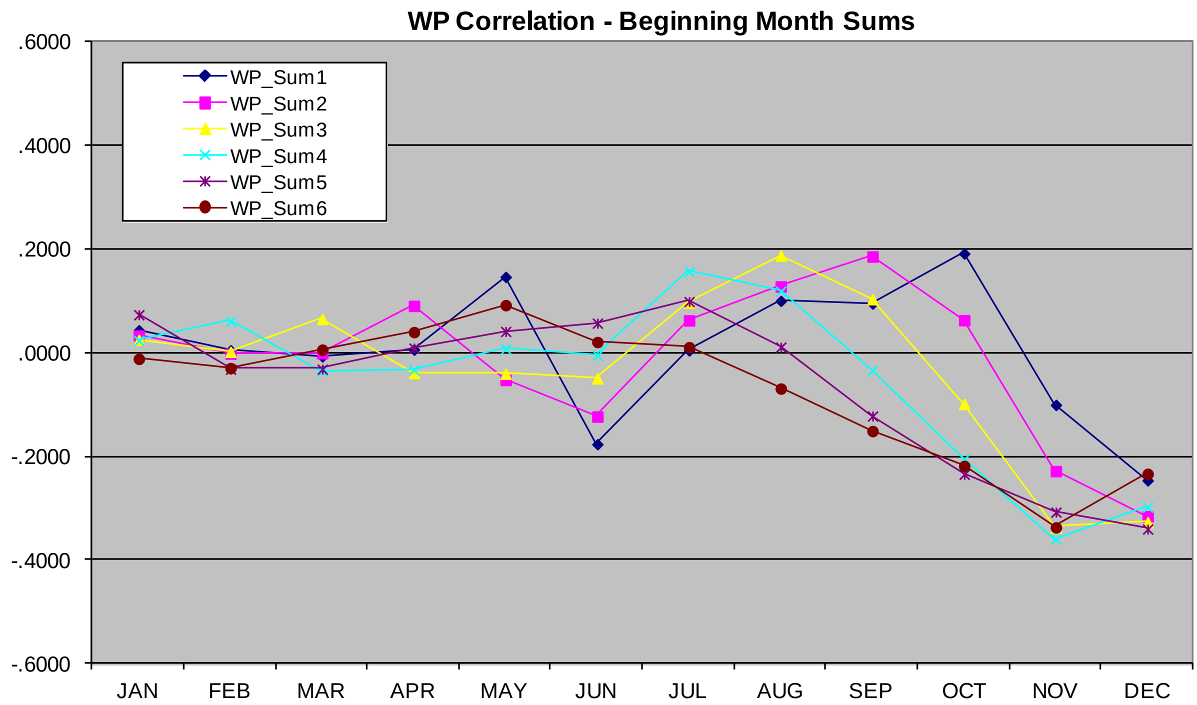
Table 8 - Best correlations between climate variables and Libby inflow

This table shows that for five of the climate indices (shown in grey in the middle of the table), the best correlation for any of the 72 durations and lags was less than 0.25, certainly not significant. PDO, PNA, and WP all had at least one marginally significant correlation for variables developed from the multiple-month durations. SOI showed a marginal correlation with a signal from the previous summer. QBO shows a very smooth and consistent signal, regardless of duration, with strong results displayed for two different lag times: a negative correlation from the winter season 14+ months prior, and a positive correlation from the current winter season. QBO is defined as the dominant mode of interannual stratospheric variability in the tropics, i.e. a measure of the high altitude winds. Garfinkel and Hartmann (2010) discuss the ENSO teleconnection and the relationship to the easterly and westerly phases of QBO, along with describing the physical mechanisms that may cause the QBO to influence the ENSO response. A composite analysis of the winter circulation patterns by Gobena (2010, personal communication) confirms a relationship between the previous year's QBO and the subsequent tropospheric circulation patterns that influence runoff from Pacific Northwest basins.

The plots below show the correlations between the 72 climate variables constructed from each climate index and the Libby AprAug runoff volume, based on data for water years 1975 to 2010.



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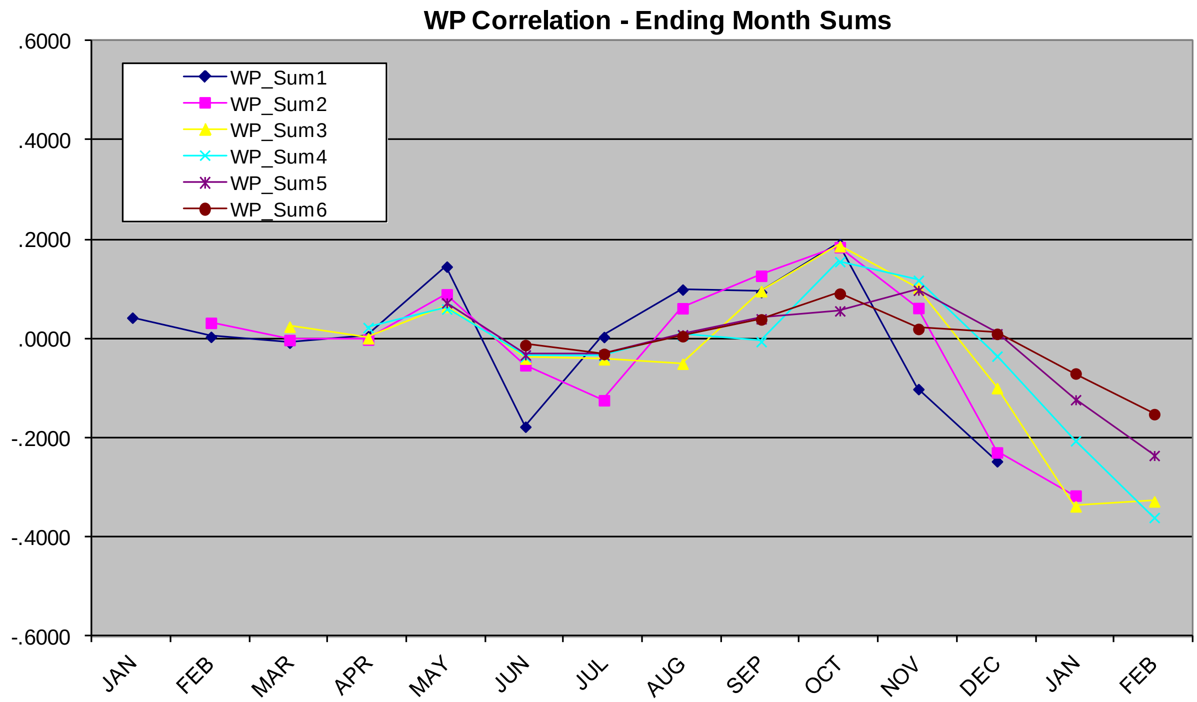
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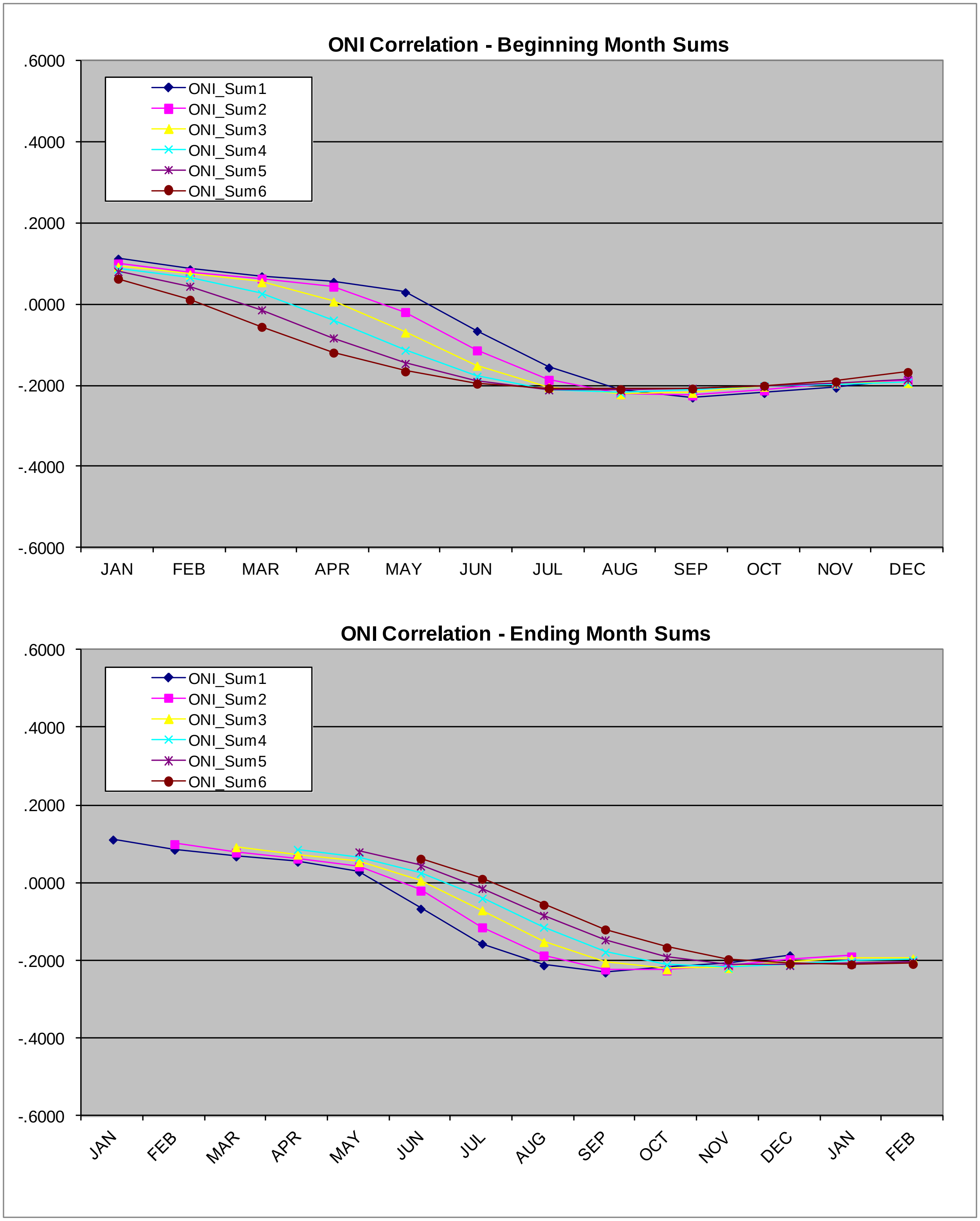
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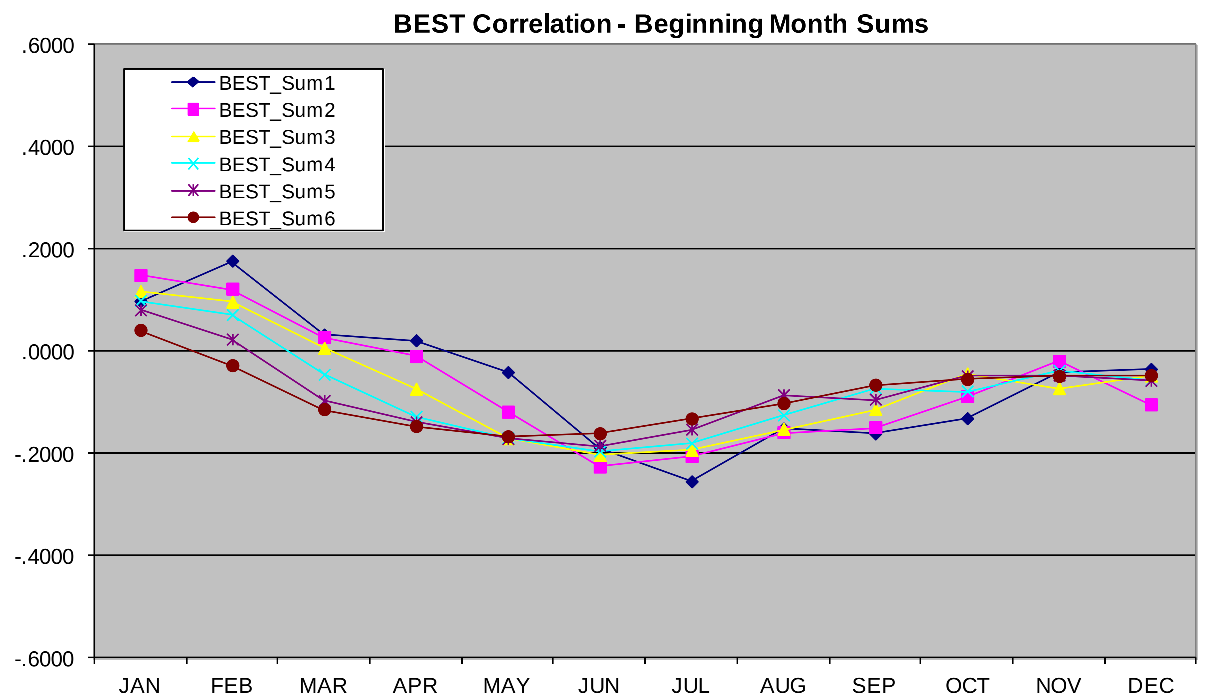
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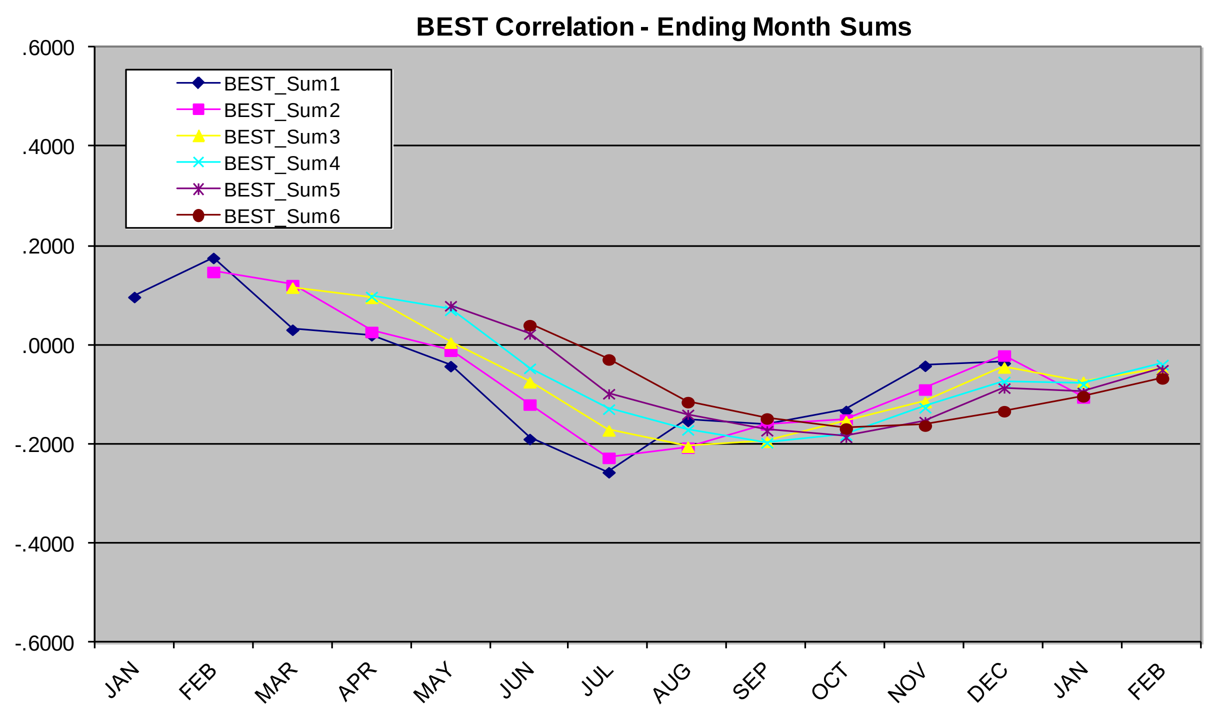
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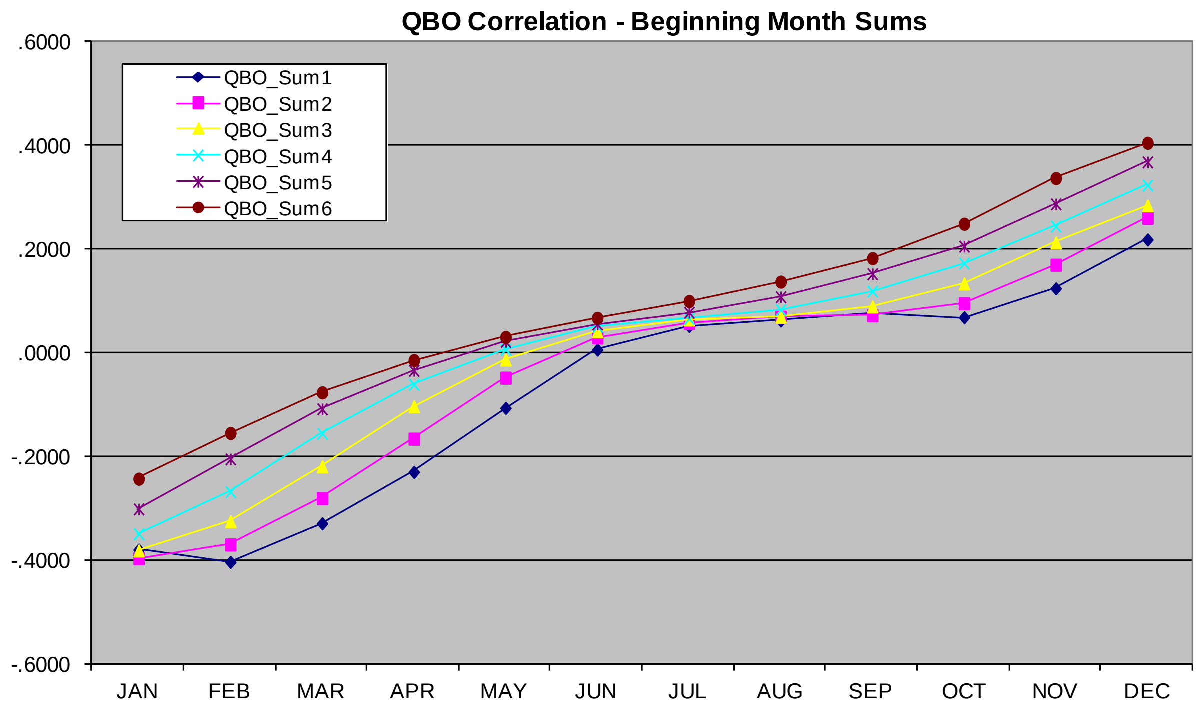
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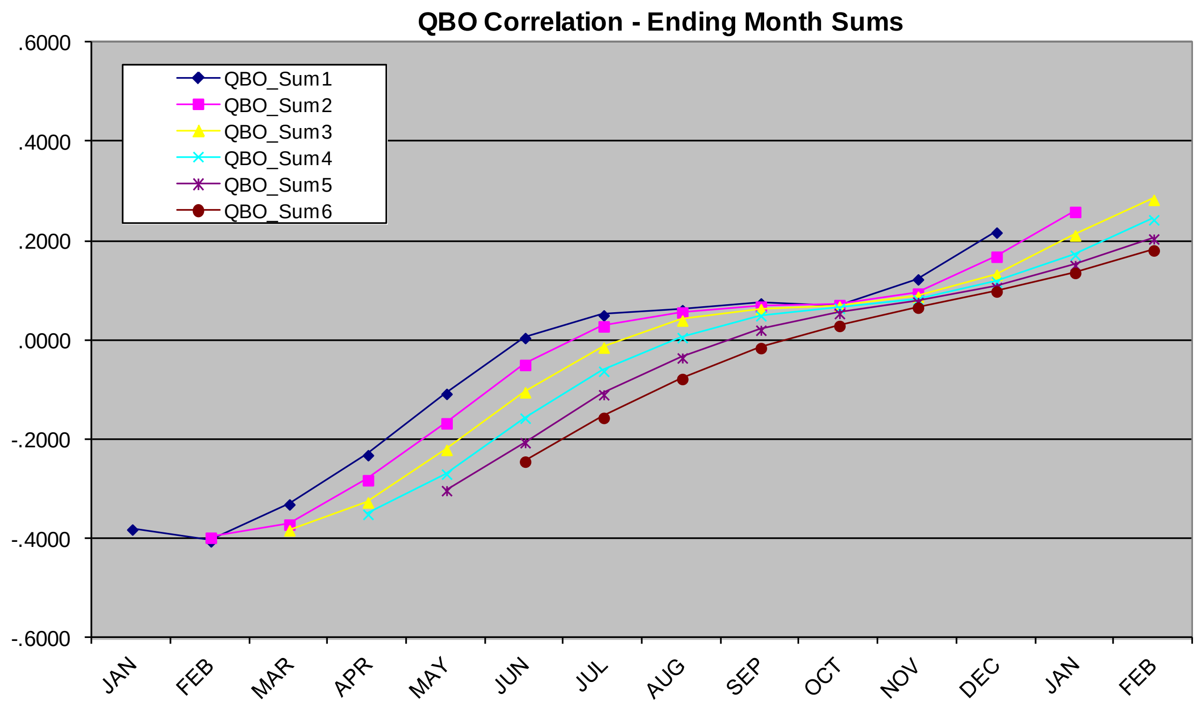
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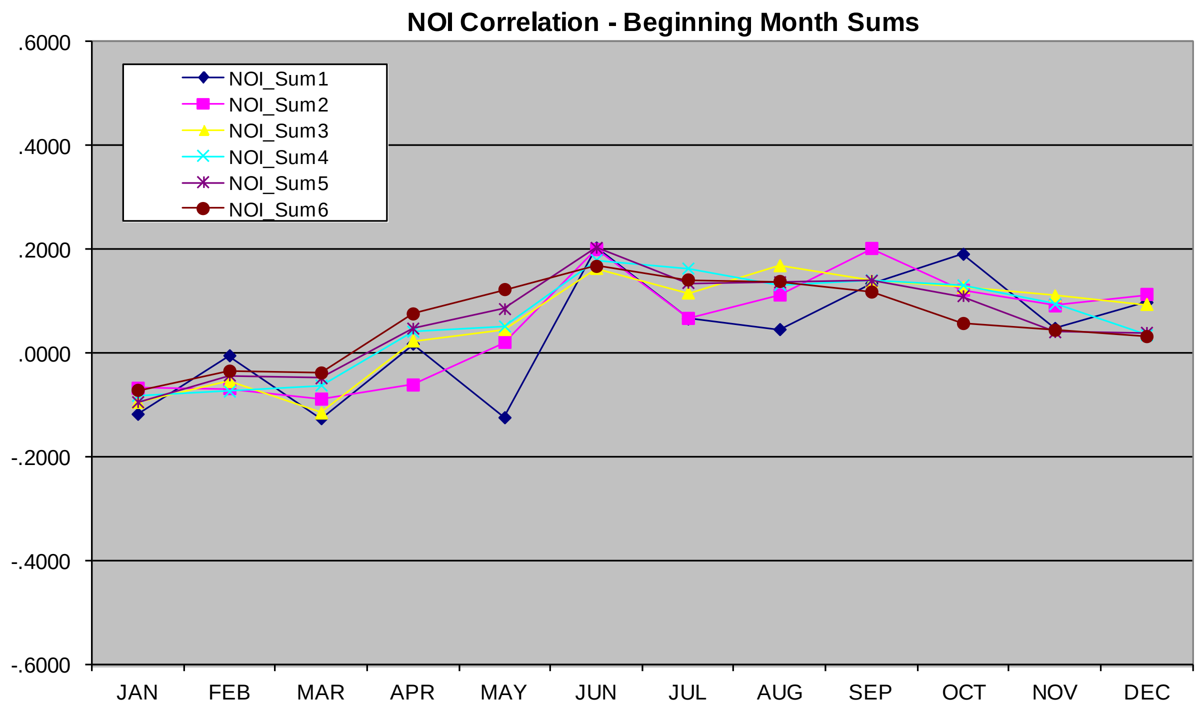
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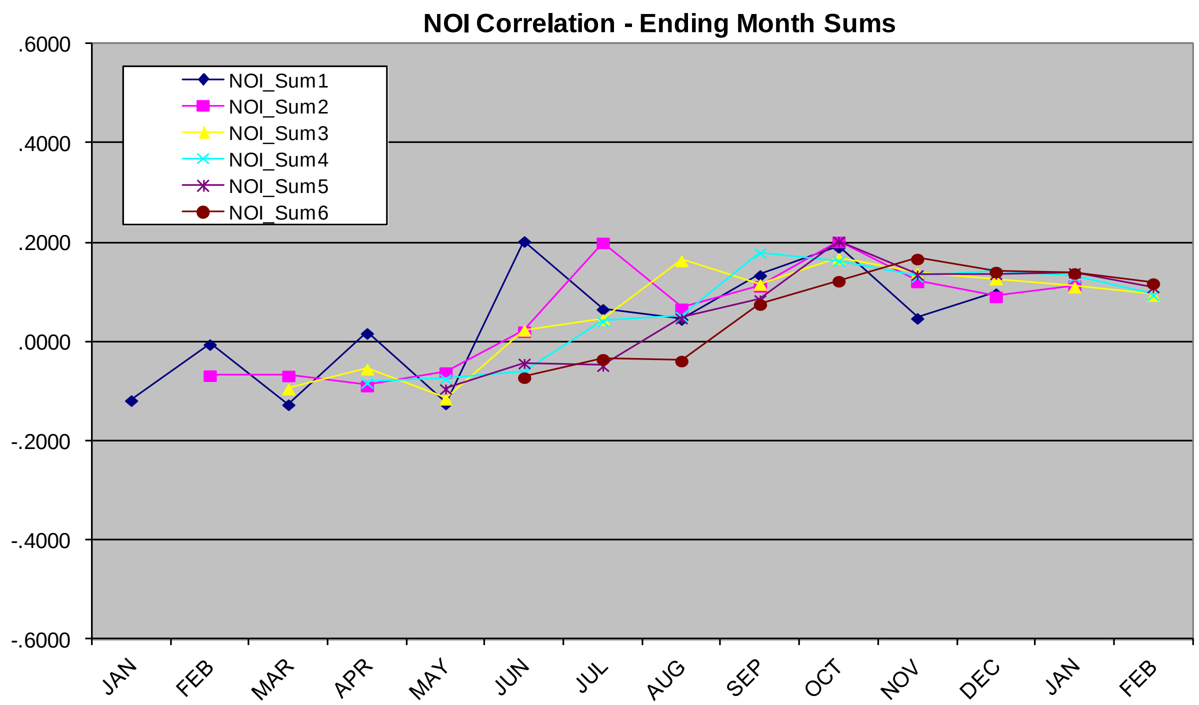
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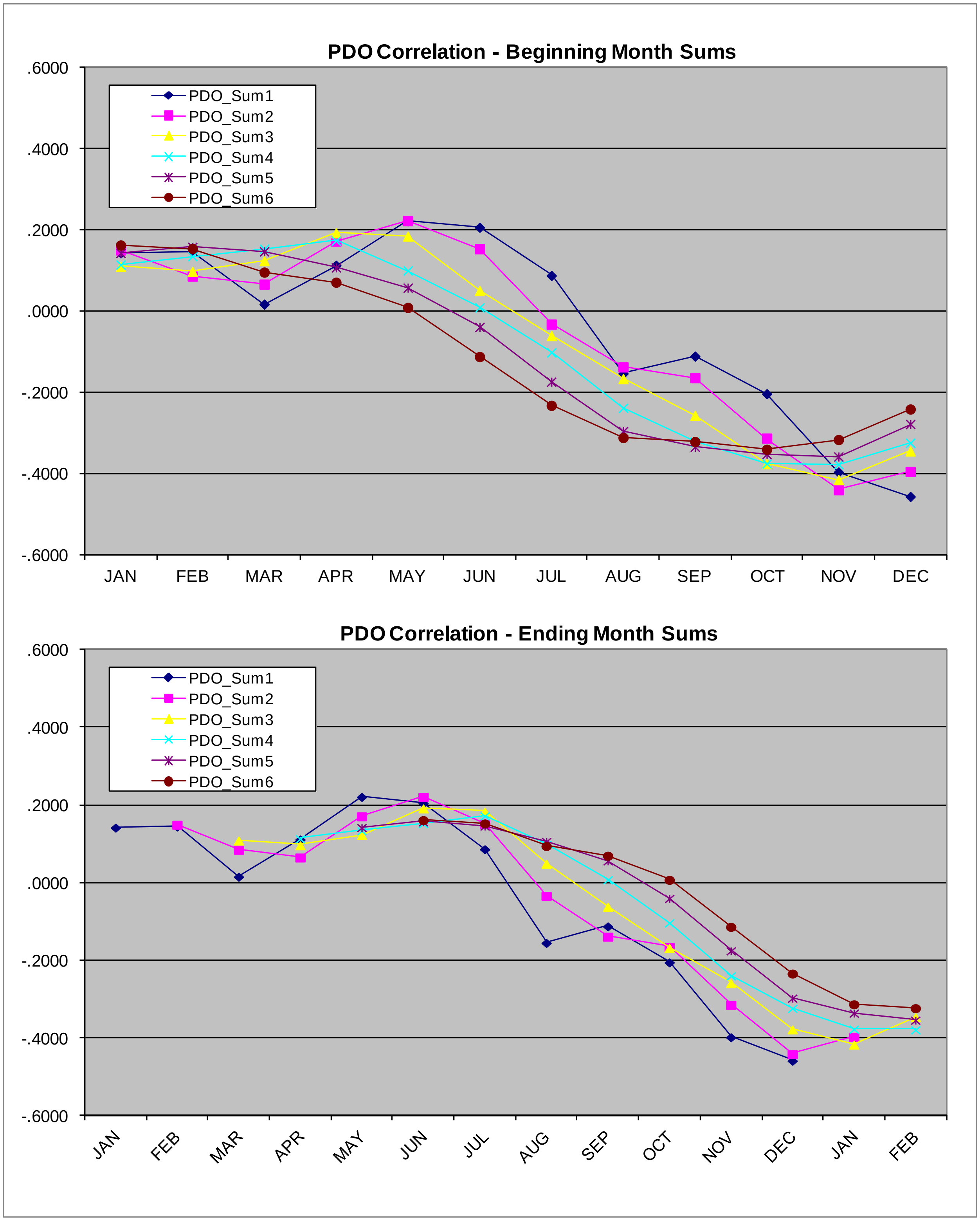

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PDO Correlation - Ending Month Sums
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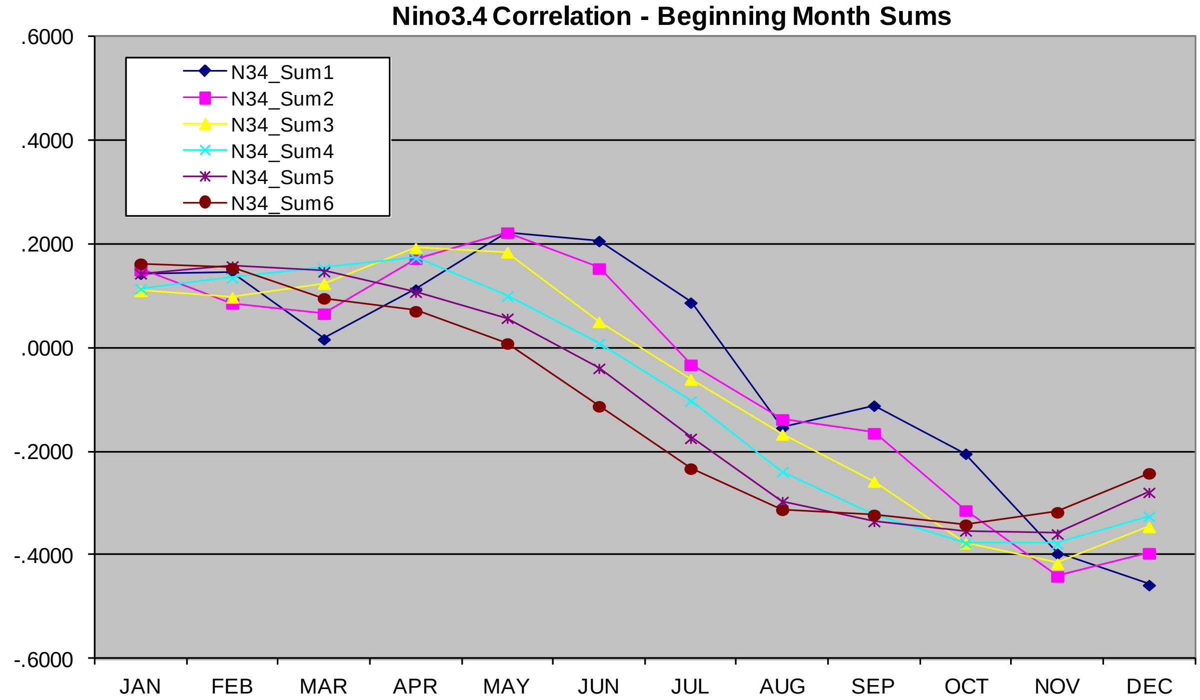
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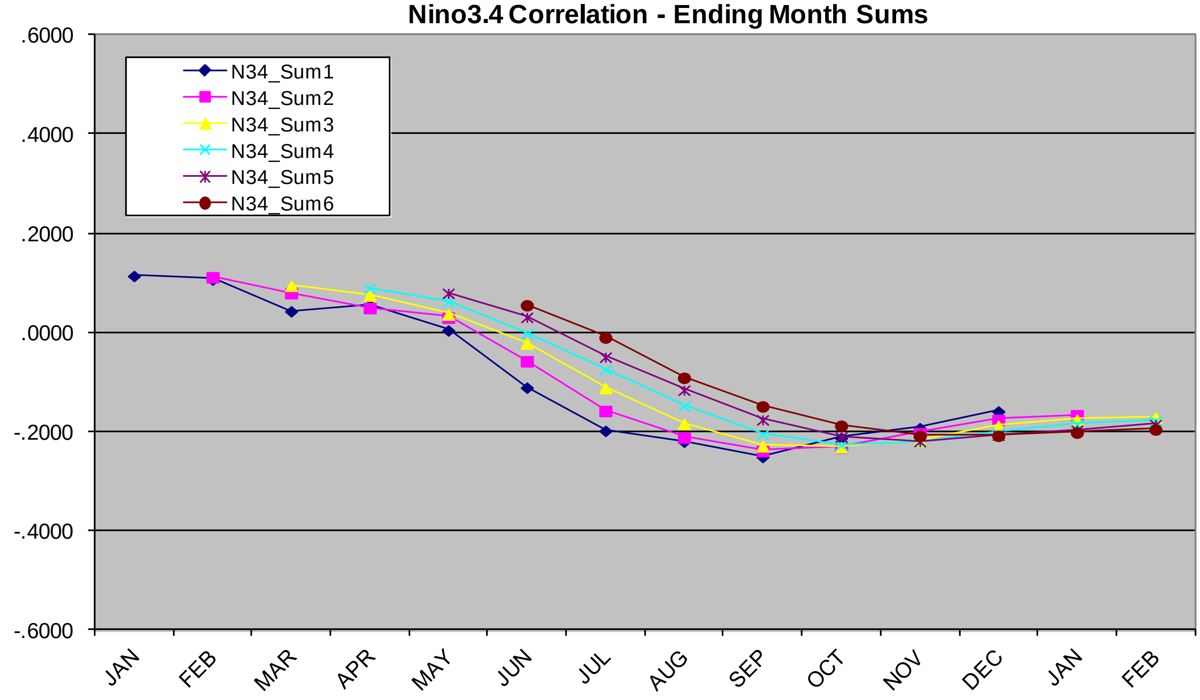
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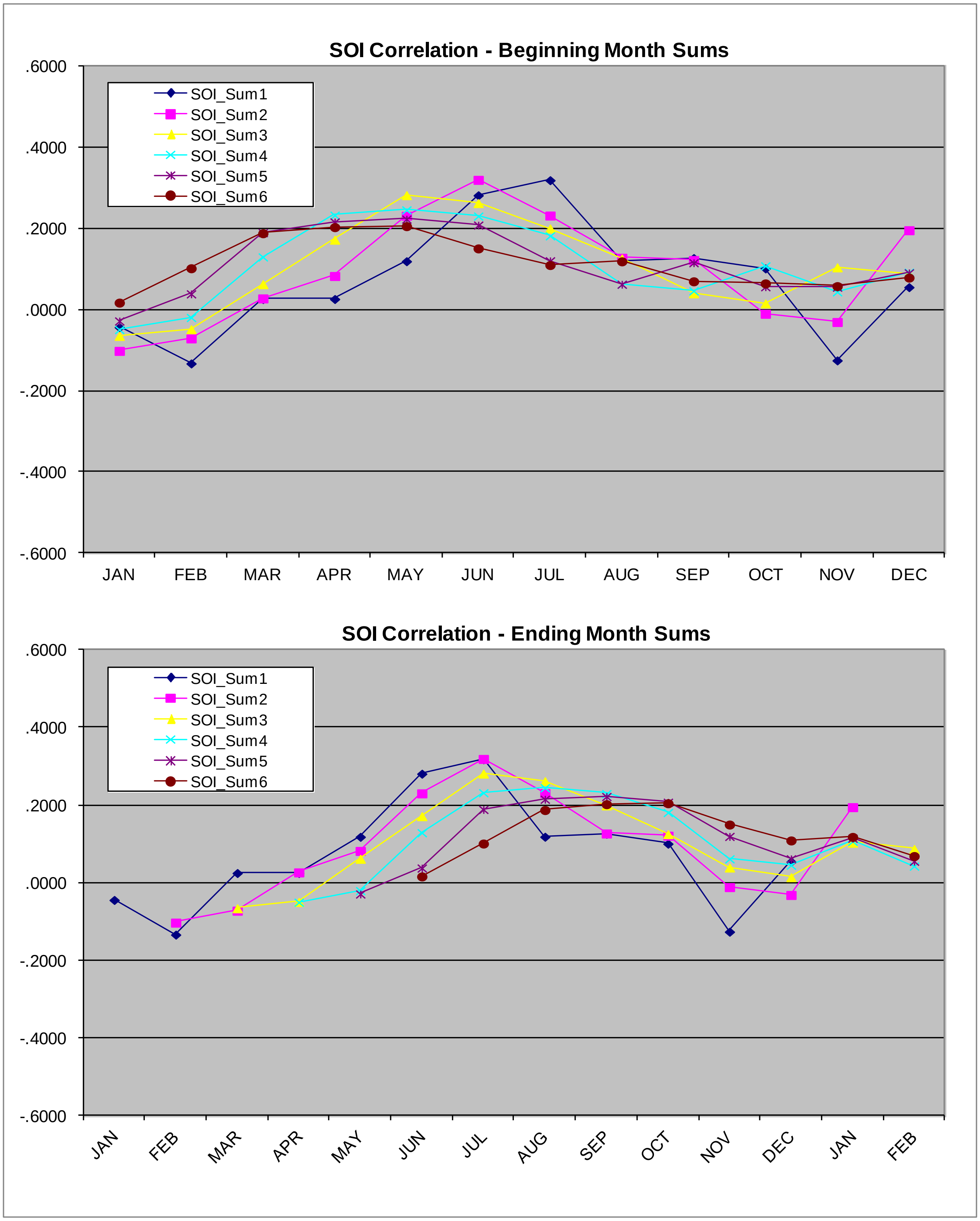
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JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
SOI Correlation - Ending Month Sums
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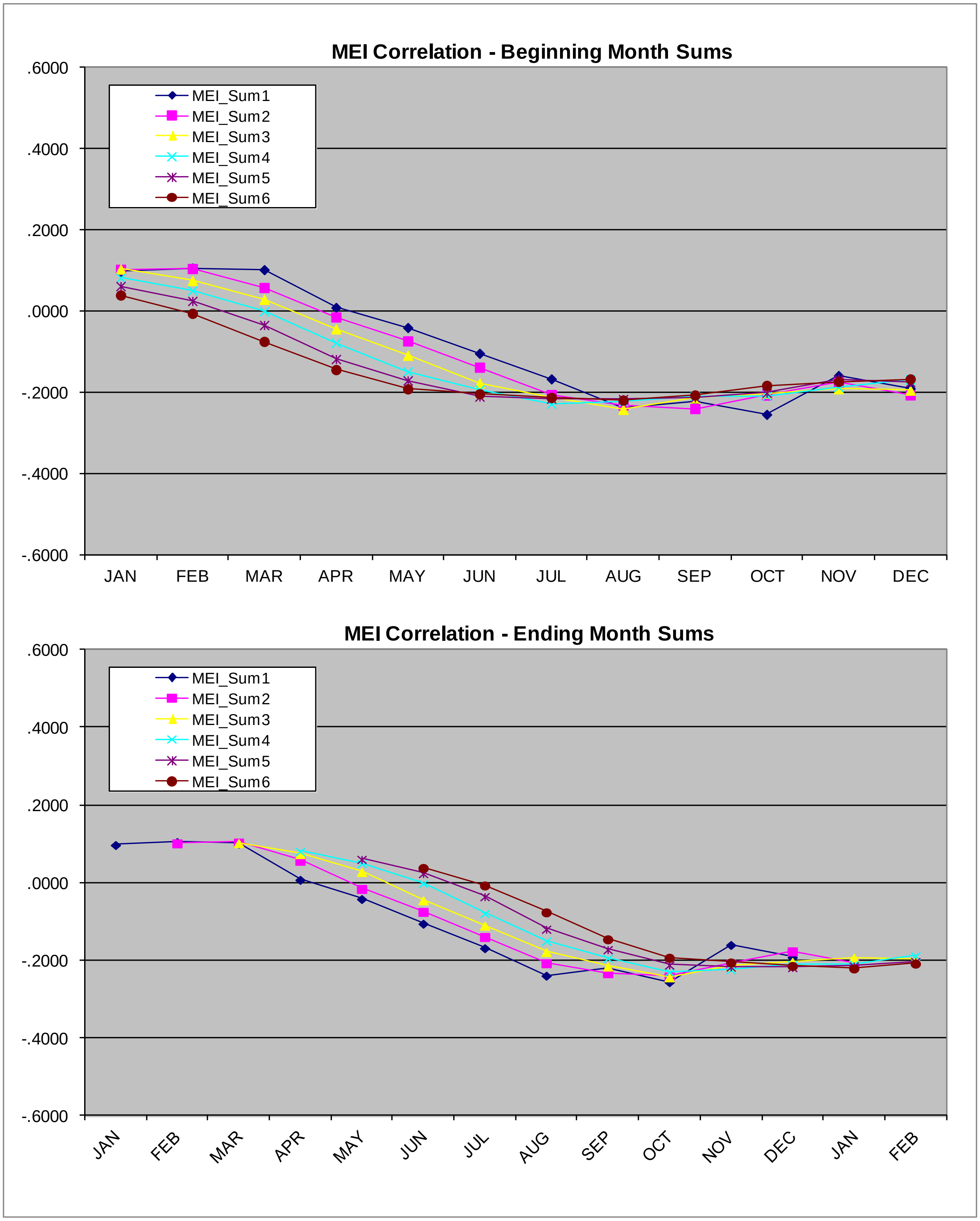
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MEI Correlation - Ending Month Sums
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Appendix B. Prescreening of Precipitation Data

Monthly precipitation data from 25 climate stations, shown in Figure 3, were reviewed for this study. The monthly precipitation data was obtained from either of two official government online archives:

- The NOAA Western Regional Climate Center at http://www.wrcc.dri.edu/climsum.html
- The Government of Canada National Climate Data and Information Service at http://climate.weatheroffice.gc.ca/climateData/canada_e.html

Monthly precipitation data for several Canadian stations had not been published since Feb 2007, presumably due to incomplete data during particular months. Where possible, the daily data for these stations was reviewed and used to estimate a monthly value. Ten of the original stations were not usable due to excessive missing data or station closure. Table 9 shows a summary of the stations in the climate station review with the ten stations unavailable for use in this study shown as shaded.

Figure 3 - Climate Stations

Station Name	Station_ID	State/ Province	Elevation (ft)	Station Considered	Notes
Creston	242104	MT	2940	Yes	Complete
Eureka RS	242827	MT	2530	Yes	Complete
Fortine 1N	243139	MT	3000	No	Station closed. Excessive missing data.
Kalispell WSO	244558	MT	2970	**Yes**	Complete
Libby 1NE	245015	MT	2100	**Yes**	Complete
Libby 32 SSE	245020	MT	3600	**Yes**	Complete
Olney	246218	MT	3170	No	Excessive missing data
Polebridge	246615	MT	3520	No	Station closed
West Glacier	248809	MT	3150	**Yes**	Complete
Whitefish	248902	MT	3100	No	Excessive missing data
Banff CS	3050519	AB	4583	**Yes**	Used by combining with Banff 3050520
Sunshine CS	3056267	AB	7175	No	Excessive missing data
Brisco	1171020	BC	2700	No	Station closed
Cranbrook A	1152102	BC	3081	**Yes**	Complete
Creston	1142160	BC	1959	**Yes**	Complete
Fernie	1152850	BC	3284	**Yes**	Complete
Glacier NP Rogers Pass	1173191	BC	4340	**Yes**	Complete
Golden A	1173210	BC	2575	**Yes**	Complete
Kaslo	1143900	BC	1939	**Yes**	Complete
Wasa	1158730	BC	3051	**Yes**	Excessive missing 1994
Kimberley PCC	1154203	BC	2917	No	Missing data after Feb 2007
Kootenay NP Westgate	1154410	BC	2950	**Yes**	Complete
Marysville	1154909	BC	3100	No	Missing data after Feb 2007
Wardner Kootenay Hatchery	1158692	BC	2500	No	Excessive missing data
Fording River	1152899	BC	5200	No	Excessive missing data

Table 9 - Climate Stations

Appendix C. Prescreening of Snow Water Equivalent Data

The historical record for 134 snow pillows and snow course stations in or near the East Kootenay basin was reviewed. Records for both active and inactive stations were included, as inactive stations could be useful in estimating missing values for nearby active stations. The 33 snow courses in northwestern Montana were removed from further consideration due to three factors: 1) the very small, if any, contributing basin area and little direct influence of the local snowpack on Libby inflow, 2) comparatively poor correlation with Libby April-August runoff volume, and 3) sufficient regional coverage by SNOTEL stations. The remaining 101 snow stations are grouped and summarized in Table 10. The correlations (monthly SWE with Apr-Aug runoff) for the active stations are shown in Table 11.

Figure 4 shows a clip taken from the British Columbia snow survey network map, including the watershed boundaries for the subbasins (BC snow stations use the subbasin number in their site ID). The complete map can be found at http://bcrfc.env.gov.bc.ca/maps/snow_wallmap.pdf.

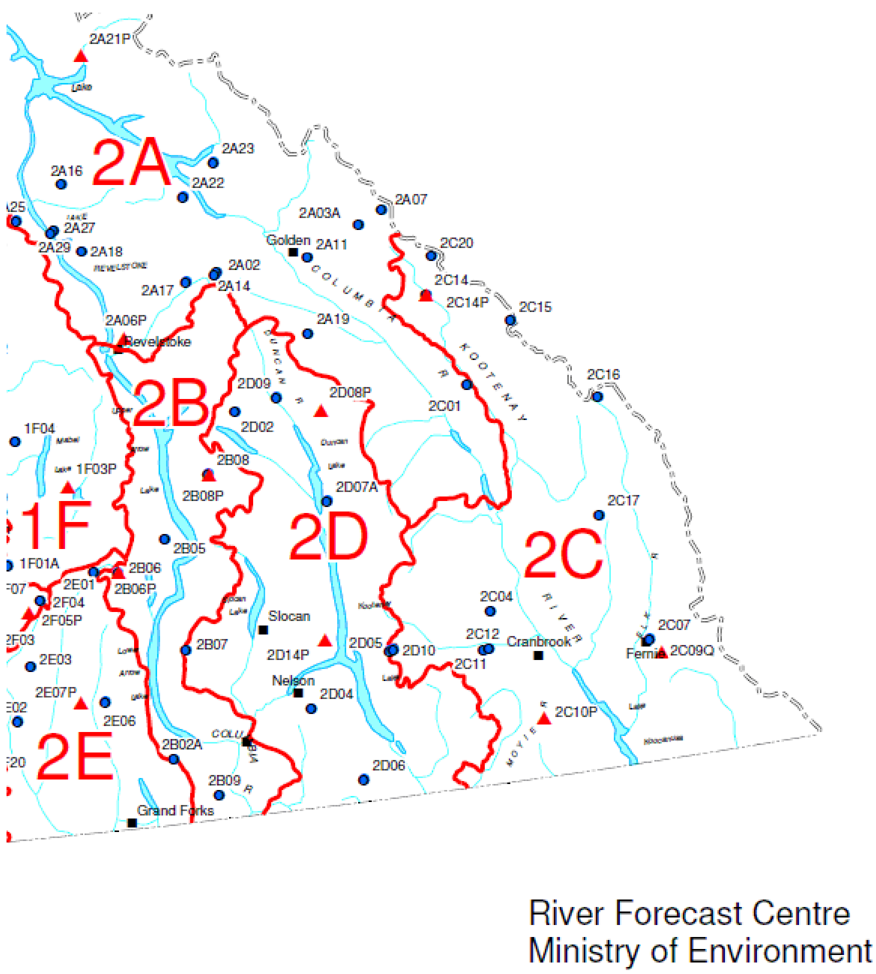


Figure 4 - BC Snow Survey Network (near Kootenay Basin)

A map of the active snow pillows (yellow) and active snow courses (dark dots) is shown in Figure 5.

Figure 5 - Active Snow Stations

Province /State	Sub - Region	Basin	No. Active	No. In-Active	SNOTEL /ASP	Snow Course	Active and N-Yrs >=20 for 1-Feb
BC	**2A**	Mica	17	18	2	33	17
BC	**2B**	Arrow Lakes	7	2	2	7	7
BC	**2C**	East Kootenay	13	14	3	24	9
BC	**2D**	West Kootenay	10	6	2	14	7
AB	**--**	SW Alberta	8	0	8	0	8
MT	**--**	NW Montana	6	0	6	0	6
		Totals	**61**	**40**	**23**	**78**	**54**

Table 10 - Snow Station Counts by Region, Status and Type

A complete dataset of 101 snow stations, with first-of-month snow water equivalent (SWE) values for issue dates of 1-January to 1-June for the 35 years from 1975 to 2009, would cover some 21,000 values. Many snow courses have schedules that only included particular months, with other months, especially January, entirely missing from the record. The actual historic dataset has numerous missing values. Considerable effort was made to determine reasonable and valid estimates for the missing snow data utilizing the following guidelines:

- 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 one or more nearby stations were highly correlated (r-squared > 0.8) then these stations were used to estimate the missing value. This was the criteria set by NRCS (Garen, 2002) for the 2002 effort to fill in missing data at snow pillow stations for the 2004 Libby WSF.

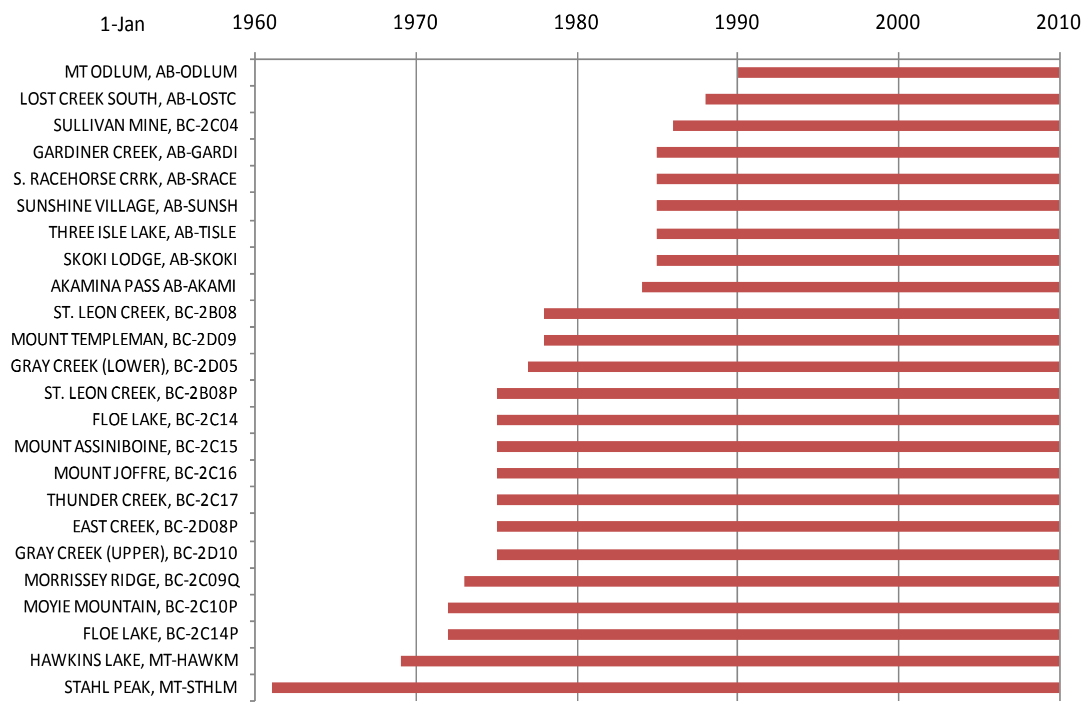
Figure 6 provides a graphical presentation of the availability of snow data for the 1-January and 1-February issue dates for the 24 snow stations with the most significant correlation with runoff (see Tables 6 and 7, pages 16-17). The 1-January date was chosen as it is typically the earliest issue date with significant snow data, however the 1-January date is also often the most limited of the winter dates. (The 1-December snow values are frequently mostly zeros and which make them not particularly useful as regression variables.) The 1-February date is presented to serve to show the availability of snow data for any of the 1-February to 1-May issue dates, as these dates typically all have very similar availability. The 1-June issue date is an anomaly - since the snowpack has been entirely melted by 1-June at many sites the 1-June observation is often not made. At those stations that do include 1-June observations the recorded value is often 0.00 mm, which is not particularly useful to the regression analysis if it is essentially a constant value. To balance the desires to 1) include most of the highly correlated Alberta snow pillow stations, and 2) maintain a substantial length of station record, the station selection process included all stations with 25 or more years of data, excluding only Mt Odlum, AB and Lost Creek South, AB.

A total of 932 SWE estimates were made for the 58 active snow stations (5 estimates for Montana snow pillows, 92 for Alberta snow pillows, 217 in BC from the previous Garen estimates, and 618 new BC estimates). Over 4,000 monthly values remain as missing due to the inability to derive a reliable estimate. The active snow stations are listed below in Table 11.

Station Name	Site ID	1-Dec	1-Jan	1-Feb	1-Mar	1-Apr	1-May	1-Jun
Canoe River, BC	2A01A			0.467	0.355	0.357	0.137	
Glacier,, BC	2A02		0.491	0.629	0.654	0.646	0.524	0.458
Field, BC	2A03A			0.509	0.486	0.509	0.346	
Mount Revelstoke, BC	2A06P		0.648	0.721	0.740	0.680	0.727	0.539
Kicking Horse, BC	2A07		0.349	0.600	0.614	0.504	0.681	
Beaverfoot, BC	2A11		0.648	0.739	0.763	0.735	0.783	
Mount Abbot,BC	2A14		0.614	0.736	0.712	0.742	0.691	0.557
Goldstream, BC	2A16		0.639	0.684	0.704	0.711	0.706	
Fidelity Mountain, BC	2A17		0.569	0.653	0.693	0.664	0.654	0.602
Keystone Creek, BC	2A18		0.627	0.658	0.677	0.617	0.612	
Vermont Creek, BC	2A19		0.649	0.700	0.687	0.677	0.650	
Molson Creek, BC	2A21P		0.566	0.646	0.676	0.659	0.699	0.396
Sunbeam Lake, BC	2A22		0.694	0.702	0.730	0.703	0.717	
Bush River, BC	2A23		0.582	0.636	0.655	0.678	0.635	
Kirbyville Lake	2A25		0.660	0.685	0.756	0.677	0.702	
Downie Slide (Lower), BC	2A27		0.613	0.711	0.538	0.597	0.470	
Downie Slide (Upper), BC	2A29		0.633	0.668	0.598	0.546	0.610	
Farron, BC	2B02A		0.266	0.431	0.506	0.500	0.372	
Whatshan (Upper), BC	2B05		0.552	0.661	0.671	0.660	0.618	
Barnes Creek, BC	2B06		0.434	0.551	0.511	0.551	0.518	
Barnes Creek, BC	2B06P		0.525	0.589	0.557	0.528	0.533	
Koch Creek, BC	2B07			0.580	0.636	0.596	0.616	
St. Leon Creek, BC	2B08			0.800	0.813	0.824	0.822	
St. Leon Creek, BC	2B08P		0.657	0.777	0.804	0.823	0.817	0.583
Sinclair Pass, BC	2C01				0.609	0.564	0.539	
Sullivan Mine, BC	2C04		0.539	0.672	0.727	0.784	0.634	0.671
Fernie East, BC	2C07		0.232	0.620	0.525	0.417	0.317	
Morrissey Ridge, BC	2C09Q		0.538	0.700	0.800	0.756	0.764	0.566
Moyie Mountain, BC	2C10P		0.505	0.630	0.636	0.520	0.563	0.361
Kimberley (Upper) VOR, BC	2C11				0.795	0.810	0.753	
Kimberley (Middle)VOR, BC	2C12				0.643	0.657	0.534	
Floe Lake, BC	2C14		0.698	0.808	0.765	0.767	0.811	
Floe Lake, BC	2C14P		0.657	0.787	0.740	0.745	0.766	0.671
Mount Assiniboine, BC	2C15		0.729	0.844	0.835	0.829	0.825	
Mount Joffre, BC	2C16		0.620	0.788	0.833	0.826	0.756	
Thunder Creek, BC	2C17		0.630	0.734	0.782	0.760	0.710	
Ferguson, BC	2D02		0.450	0.676	0.619	0.678	0.582	0.431
Sandon, BC	2D03				0.579	0.482	0.409	
Nelson, BC	2D04		0.283	0.453	0.397	0.409	0.258	
Gray Creek (Lower), BC	2D05		0.621	0.601	0.688	0.593	0.568	0.536
Char Creek, BC	2D06		0.260	0.543	0.576	0.551	0.545	0.474
East Creek, BC	2D08P		0.713	0.818	0.780	0.774	0.799	0.691
Mount Templeman, BC	2D09			0.807	0.841	0.801	0.837	
Gray Creek (Upper), BC	2D10		0.521	0.807	0.791	0.719	0.727	0.581
Banfield Mountain, MT	BANFM	0.364	0.494	0.681	0.661	0.608	0.576	0.438
Garver Creek, MT	GARVM	0.311	0.399	0.587	0.543	0.482	0.254	
Grave Creek, MT	GRAVM	0.119	0.180	0.452	0.499	0.384	0.292	0.233
Hand Creek, MT	HANDM	0.350	0.321	0.507	0.417	0.384	0.225	-0.035
Hawkins Lake, MT	HAWKM	0.497	0.626	0.771	0.782	0.743	0.722	0.664
Stahl Peak, MT	STHLM	0.475	0.650	0.810	0.842	0.797	0.804	0.759
Akamina Pass AB	AKAMI	0.466	0.533	0.693	0.657	0.487	0.465	0.273
Gardiner Creek, AB	GARDI	0.345	0.507	0.700	0.771	0.589	0.539	0.583
S. Racehorse Creek, AB	SRACE	0.698	0.572	0.783	0.819	0.838	0.684	0.562
Sunshine Village, AB	SUNSH	0.702	0.749	0.832	0.797	0.824	0.779	0.602
Three Isle Lake, AB	TISLE	0.608	0.673	0.809	0.795	0.725	0.593	0.542
Mt Odlum, AB	ODLUM	0.735	0.774	0.840	0.835	0.847	0.710	0.665
Lost Creek South, AB	LOSTC	0.742	0.813	0.816	0.835	0.790	0.708	0.584
Skoki Lodge, AB	SKOKI	0.475	0.561	0.675	0.692	0.689	0.706	0.589

Table 11 – Active Snow Stations - Correlations of monthly SWE with Apr-Aug runoff

First Available Years for 1-Jan Snow Stations



First Available Years for 1-Feb Snow Stations

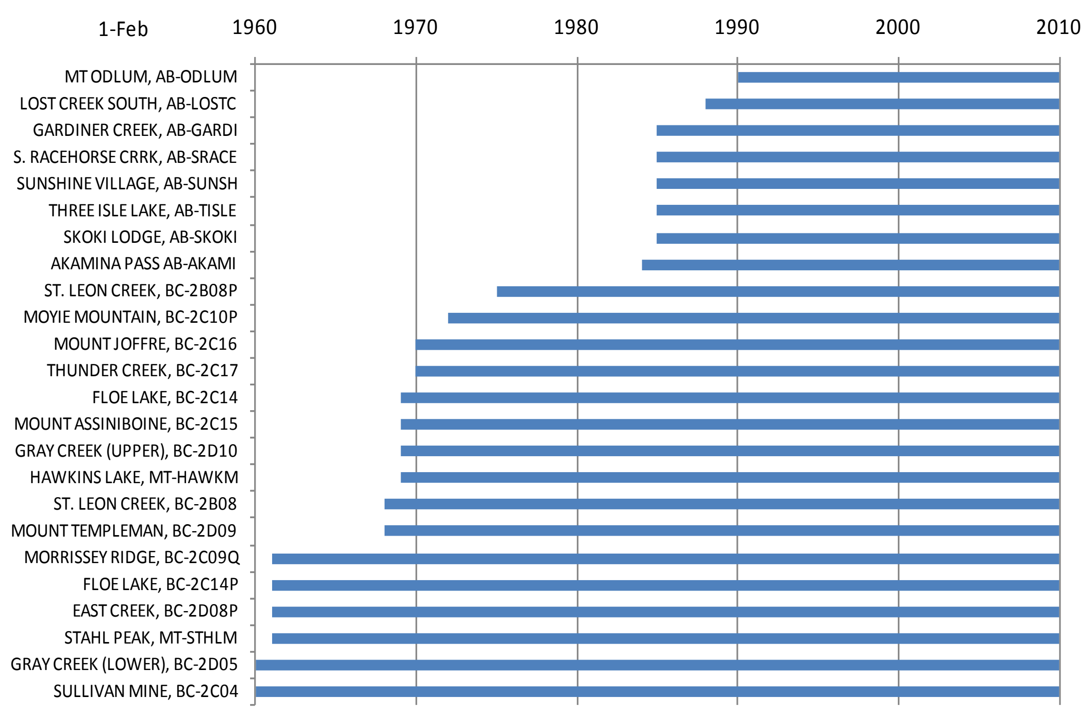


Figure 6 – Available Years for Highly Correlated Snow Stations

Appendix D. Comparison of Model Performance Statistics

Each set of statistical forecast models (i.e. the 2004 set of Libby WSF equations) that has been developed is able to generate a series of forecasts for each monthly forecast date. The calculation of the RMSE for the forecast errors for each monthly forecast provides a metric to compare the "goodness-of-fit", i.e. performance, of a given collection of monthly models. (Note that none of the standard model statistics of the RMSE, CVSE, standard error, or adjusted R-Square provide any measure of the *consistency* between the monthly forecasts. *Forecast consistency* does not have a standard performance metric, although reservoir operators unilaterally agree that it is an important criterion. The desire for consistency in the month-to-month statistical forecast has been addressed indirectly, by seeking to maintain consistency in the input variables from one month to the next. This is not a statistically robust solution, but rather a pragmatic solution.) The series of monthly RMSE errors for a given statistical forecast model can be then be compared to the series of monthly RMSE errors for another model set to contrast the performance differences between one or more model sets.

Figure 7 below provides a comparison of the RMSE performance statistics for the 2004 Libby WSF equations for two related sets of data - the original calibration dataset and the same

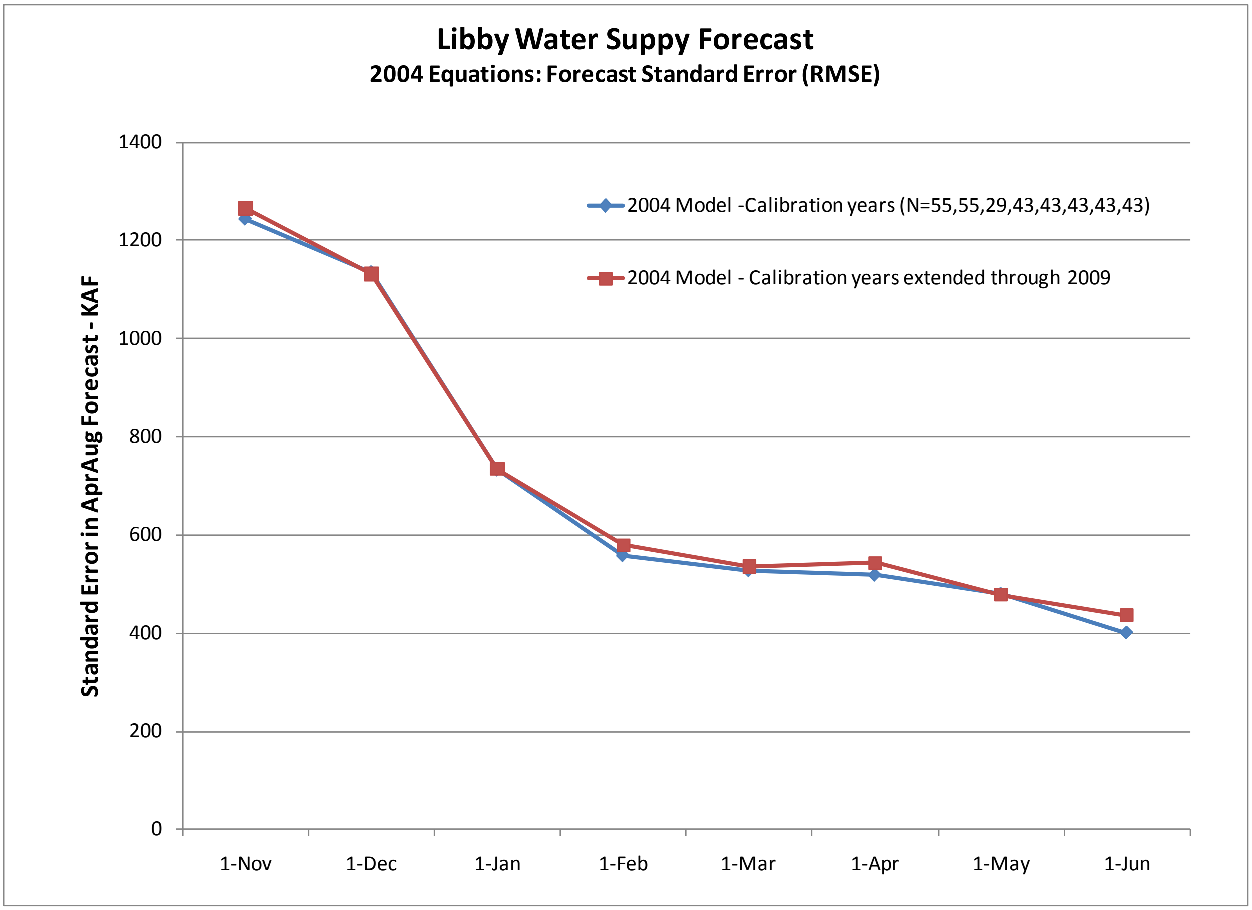


Figure 7 - Performance statistics for the 2004 Libby WSF model

calibration dataset extended to include the most recent 6 years. This comparison verifies that the addition of the most recent six more years has negligible effect on the RMSE performance statistic. Note that for the 2004 statistical model, the number of years used in the calibration datasets varied widely- from 55 years (Nov and Dec equations), to 29 years (Jan equation), to 43 years (Feb to Jun equations).

The next comparison continues to use the 2004 equations, but with additional (strategically selected) subsets taken from the total number of available years. Figure 8 adds the RMSE statistics for the 2004 model forecasts for the 35-year sample (most recent 35 years, lime green curve) and for the 25-year sample (most recent 25 years, purple curve). This figure shows that the 1-December forecast shows a better fit (lower RMSE) for the recent 25-year and 35-year data sets than in the 55 year calibration set. However, for all the winter and spring forecasts utilizing snow variables, the 2004 equations show a higher RMSE, reflecting larger average errors. This suggests that the most recent 25 years represent a sample set with somewhat different characteristics than the calibration set sample, possibly showing a greater variability and/or changes in the central tendency than the calibration set sample.

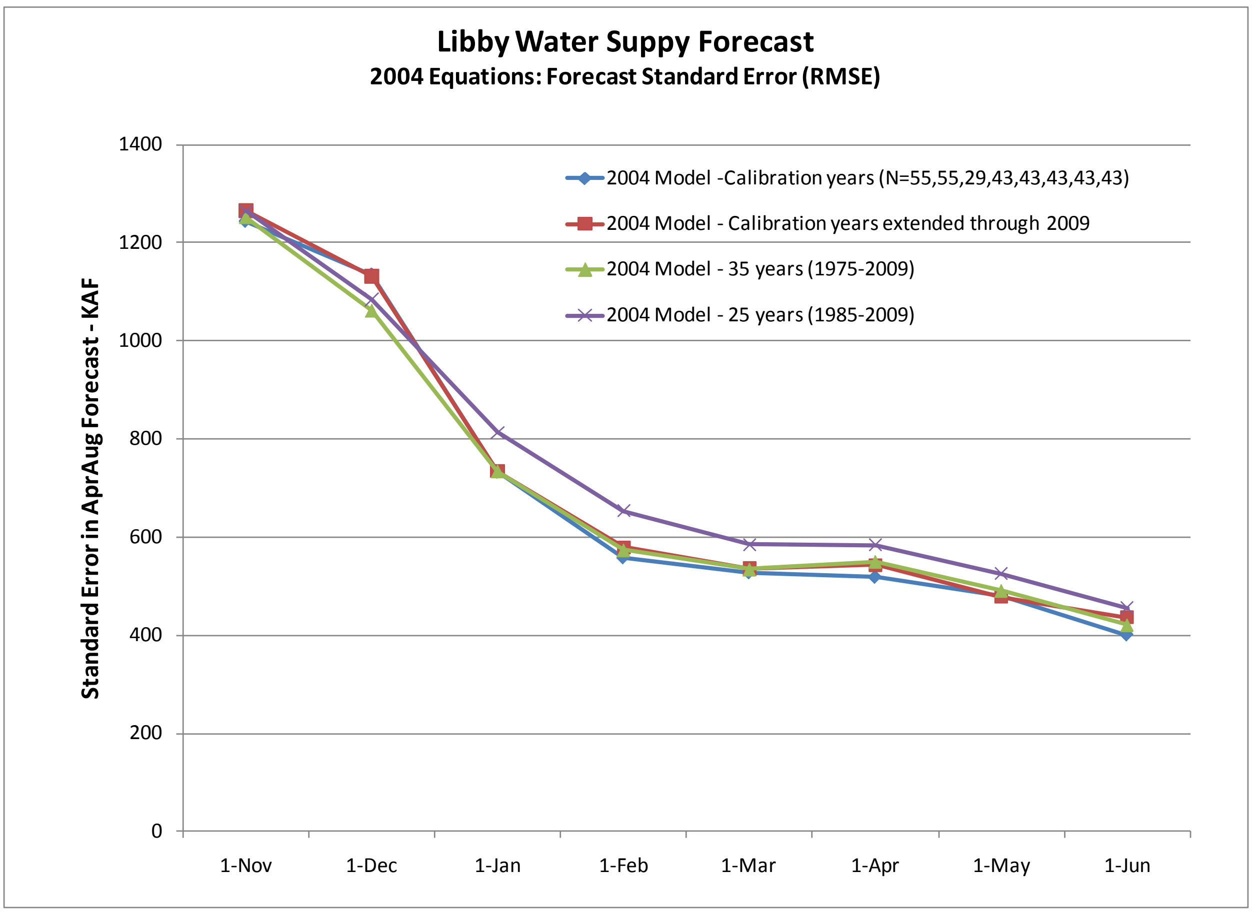


Figure 8 – Performance statistics for the 2004 Libby WSF model for four sample data sets

The third and final comparison adds the RMSE statistics for the new forecast equations, which, as previously discussed, are limited to operating on from 22 to 26 years of data for the winter forecasts. Figure 9 shows the RMSE statistic in the lower (cyan) curve. This comparison shows that RMSE statistic for the new equations are distinctly better (smaller) than the statistics for the forecasts of the exact same years using the 2004 equations (purple curve). The statistics suggest that the new model set, developed using the Alberta snow pillow stations on and after 1-January, has an average error that is smaller than any of the other models for each and every forecast date. It also implies that, if the data used in the calibration are representative of the future years yet to be observed, that the new equations should continue to provide forecasts with smaller forecast errors, on average, than any of the previously considered models.

Appendix G provides plots year-by-year, side by side comparisons of the forecasts from the (previous) 2004 Libby model with the (proposed) 2010 model.

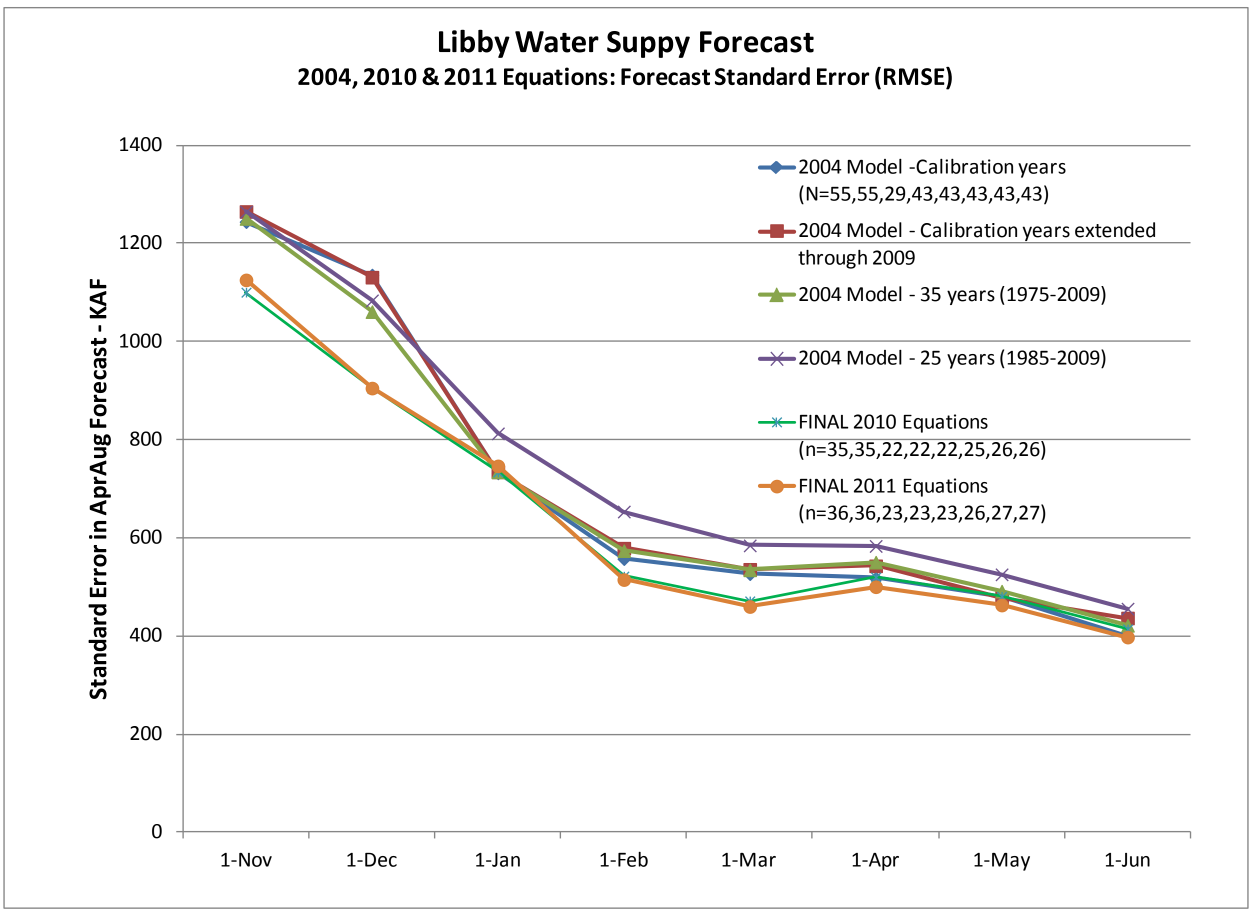


Figure 9 - Performance statistics of 2004, 2010 and 2011 Libby WSF models compared

Appendix E. Principal Components Regression Models

1-NOVEMBER FORECAST MODEL

VARIABLES:

Y1	LIB_KAF
X1	SOI_JJ
X2	QBO_PrevJANMAR
X3	PPT_EUREM_Oct
X4	PPT_LIB1M_Oct
X5	PPT_WGLAM_Oct
X6	PPT_FERNB_Oct

REGRESSION EQUATION:

var	coef
----	----
X1	25.605
X2	-1.251
X3	307.695
X4	185.113
X5	125.041
X6	68.877
C	4701.513

PCREG STATISTICS:

#obs	36
#pc	1
jr	0.430
jse	1190.753
r	0.517
se	1125.683

1-NOVEMBER FORECAST MODEL

PCREG FORECASTS:

YEAR	OBSERVED	JCKREG COMPUTED	JCKREG ERROR	STDREG COMPUTED	STDREG ERROR
1975	5903.69	4743.72	-1159.97	4836.21	-1067.48
1976	7412.81	6818.46	-594.35	6981.89	-430.92
1977	3550.47	5398.12	1847.65	5308.80	1758.33
1978	6338.38	5207.72	-1130.66	5222.84	-1115.54
1979	4209.52	5138.52	929.00	5063.08	853.56
1980	5882.98	5905.28	22.30	5903.11	20.13
1981	7344.99	5117.78	-2227.21	5229.09	-2115.90
1982	6514.31	5265.46	-1248.85	5298.43	-1215.88
1983	5950.02	5642.59	-307.43	5642.73	-307.29
1984	5087.40	5484.26	396.86	5463.32	375.92
1985	4756.36	6316.43	1560.07	6262.00	1505.64
1986	6085.88	6557.71	471.83	6524.88	439.00
1987	4999.93	5388.07	388.14	5358.88	358.95
1988	4632.99	4886.30	253.31	4802.37	169.38
1989	5566.02	5681.32	115.30	5676.25	110.23
1990	7597.29	5887.68	-1709.61	5935.18	-1662.11
1991	8543.01	6645.61	-1897.40	6825.14	-1717.87
1992	4421.55	5082.70	661.15	5024.63	603.08
1993	5477.75	5516.35	38.60	5496.87	19.12
1994	5207.70	5421.87	214.17	5401.64	193.94
1995	6269.36	6825.38	556.02	6814.90	545.54
1996	8339.31	6982.82	-1356.49	7170.84	-1168.47
1997	7851.11	6361.06	-1490.05	6454.31	-1396.80
1998	5777.65	6366.22	588.57	6361.14	583.49
1999	7148.85	5490.33	-1658.52	5532.82	-1616.03
2000	5428.17	6607.86	1179.69	6540.83	1112.66
2001	3174.55	5299.56	2125.01	5178.73	2004.18
2002	7097.87	6345.47	-752.40	6397.72	-700.15
2003	5016.79	4777.63	-239.16	4779.27	-237.52
2004	4739.90	6606.80	1866.90	6478.55	1738.65
2005	5572.36	6086.87	514.51	6066.91	494.55
2006	6601.39	6544.39	-57.00	6547.95	-53.44
2007	6838.81	5403.87	-1434.94	5449.67	-1389.14
2008	5517.22	6182.56	665.34	6155.00	637.78
2009	4421.36	5467.91	1046.55	5426.69	1005.33
2010	4520.13	6235.44	1715.31	6185.21	1665.08

1-DECEMBER FORECAST MODEL

VARIABLES:

Y1	LIB_KAF
X1	SOI_JJ
X2	QBO_PrevJANMAR
X3	PPT_EUREM_ON
X4	PPT_LIBRS_ON
X5	PPT_WGLAM_ON
X6	PPT_FERNB_ON

REGRESSION EQUATION:

var	coef
----	----
X1	62.313
X2	-1.698
X3	233.435
X4	148.234
X5	99.755
X6	44.480
C	3782.376

PCREG STATISTICS:

#obs	36
#pc	1
jr	0.694
jse	947.382
r	0.725
se	905.234

1-DECEMBER FORECAST MODEL

PCREG FORECASTS:

YEAR	OBSERVED	JCKREG COMPUTED	JCKREG ERROR	STDREG COMPUTED	STDREG ERROR
1975	5903.69	5379.51	-524.18	5392.27	-511.42
1976	7412.81	6474.86	-937.95	6530.39	-882.42
1977	3550.47	4734.97	1184.50	4630.72	1080.25
1978	6338.38	5238.62	-1099.76	5249.50	-1088.88
1979	4209.52	5084.10	874.58	5023.89	814.37
1980	5882.98	4989.45	-893.53	5003.42	-879.56
1981	7344.99	5194.09	-2150.90	5272.99	-2072.00
1982	6514.31	5385.67	-1128.64	5400.00	-1114.31
1983	5950.02	5616.01	-334.01	5627.54	-322.48
1984	5087.40	5944.52	857.12	5923.34	835.94
1985	4756.36	6436.66	1680.30	6380.85	1624.49
1986	6085.88	6272.09	186.21	6262.14	176.26
1987	4999.93	6079.52	1079.59	6055.57	1055.64
1988	4632.99	4240.55	-392.44	4215.28	-417.71
1989	5566.02	5854.32	288.30	5845.73	279.71
1990	7597.29	6752.47	-844.82	6805.62	-791.67
1991	8543.01	7927.52	-615.49	8002.45	-540.56
1992	4421.55	5275.06	853.51	5235.92	814.37
1993	5477.75	5269.37	-208.38	5249.11	-228.64
1994	5207.70	4717.28	-490.42	4724.45	-483.25
1995	6269.36	6519.53	250.17	6539.33	269.97
1996	8339.31	7878.07	-461.24	7952.29	-387.02
1997	7851.11	7373.38	-477.73	7444.62	-406.49
1998	5777.65	5489.12	-288.53	5503.47	-274.18
1999	7148.85	6021.92	-1126.93	6050.43	-1098.42
2000	5428.17	7134.36	1706.19	7016.34	1588.17
2001	3174.55	4571.89	1397.34	4438.90	1264.35
2002	7097.87	5953.88	-1143.99	5983.62	-1114.25
2003	5016.79	4523.63	-493.16	4549.31	-467.48
2004	4739.90	6255.56	1515.66	6204.53	1464.63
2005	5572.36	5577.68	5.32	5576.27	3.91
2006	6601.39	6381.97	-219.42	6389.63	-211.76
2007	6838.81	7145.97	307.16	7149.82	311.01
2008	5517.22	5704.53	187.31	5697.53	180.31
2009	4421.36	5060.57	639.21	5027.81	606.45
2010	4520.13	5478.20	958.07	5442.82	922.69

1-JANUARY FORECAST MODEL

VARIABLES:

Y1	LIB_KAF
X1	QBO_PrevJANMAR
X2	PPT_EUREM_OND
X3	PPT_LIBRS_OND
X4	PPT_WGLAM_OND
X5	PPT_FERNB_OND
X6	SWE-P_FLOEK_1Jan
X7	SWE-P_SUNSH_1Jan
X8	SWE-P_EASTK_1Jan
X9	SWE-P_STAHL_1Jan
X10	SWE-P_GARDI_1Jan
X11	SWE-P_TISLE_1Jan
X12	SWE-P_LOSTC_1Jan
X13	SWE-P_MORRQ_1Jan
X14	SWE-P_HAWKL_1Jan

REGRESSION EQUATION:

var	coef
----	----
X1	-7.413
X2	77.293
X3	60.709
X4	31.806
X5	13.292
X6	9.401
X7	24.329
X8	5.828
X9	22.577
X10	21.800
X11	28.677
X12	17.773
X13	24.439
X14	36.454
C	2561.460

1-JANUARY FORECAST MODEL

PCREG STATISTICS:

#obs	23
#pc	2
jr	0.821
jse	840.726
r	0.860
se	746.633

PCREG FORECASTS:

YEAR	OBSERVED	JCKREG COMPUTED	JCKREG ERROR	STDREG COMPUTED	STDREG ERROR
1988	4632.99	4877.14	244.15	4857.00	224.01
1989	5566.02	5235.66	-330.36	5254.15	-311.87
1990	7597.29	5890.39	-1706.90	5966.50	-1630.79
1991	8543.01	9808.72	1265.71	9156.04	613.03
1992	4421.55	5349.56	928.01	5206.50	784.95
1993	5477.75	5544.06	66.31	5530.31	52.56
1994	5207.70	4922.94	-284.76	4847.44	-360.26
1995	6269.36	6783.38	514.02	6747.10	477.74
1996	8339.31	7445.42	-893.89	7482.35	-856.96
1997	7851.11	7843.31	-7.80	8282.39	431.28
1998	5777.65	4716.21	-1061.44	4804.82	-972.83
1999	7148.85	7080.89	-67.96	7081.31	-67.54
2000	5428.17	5897.20	469.03	5834.35	406.18
2001	3174.55	4252.55	1078.00	4088.46	913.91
2002	7097.87	6165.55	-932.32	6262.42	-835.45
2003	5016.79	4724.04	-292.75	4746.39	-270.40
2004	4739.90	5549.52	809.62	5534.06	794.16
2005	5572.36	5487.30	-85.06	5490.04	-82.32
2006	6601.39	5497.52	-1103.87	5556.20	-1045.19
2007	6838.81	6482.31	-356.50	6527.27	-311.54
2008	5517.22	5963.18	445.96	5929.64	412.42
2009	4421.36	5204.72	783.36	5156.99	735.63
2010	4520.13	5593.92	1073.79	5419.42	899.29

1-FEBRUARY FORECAST MODEL

VARIABLES:

Y1	LIB_KAF
X1	QBO_PrevJANMAR
X2	PPT_EUREM_ONDJ
X3	PPT_LIBRS_ONDJ
X4	PPT_WGLAM_ONDJ
X5	PPT_FERNB_ONDJ
X6	SWE-P_FLOEK_1Feb
X7	SWE-P_SUNSH_1Feb
X8	SWE-P_EASTK_1Feb
X9	SWE-P_STAHL_1Feb
X10	SWE-P_GARDI_1Feb
X11	SWE-P_TISLE_1Feb
X12	SWE-P_LOSTC_1Feb
X13	SWE-P_MORRQ_1Feb
X14	SWE-P_HAWKL_1Feb

REGRESSION EQUATION:

var	coef
----	----
X1	-7.866
X2	62.168
X3	54.677
X4	32.314
X5	13.876
X6	10.899
X7	22.352
X8	7.006
X9	19.658
X10	16.575
X11	29.682
X12	16.922
X13	23.923
X14	32.919
C	1423.013

1-FEBRUARY FORECAST MODEL

PCREG STATISTICS:

#obs	23
#pc	2
jr	0.923
jse	564.465
r	0.936
se	514.911

PCREG FORECASTS:

YEAR	OBSERVED	JCKREG COMPUTED	JCKREG ERROR	STDREG COMPUTED	STDREG ERROR
1988	4632.99	4559.47	-73.52	4618.10	-14.89
1989	5566.02	5865.41	299.39	5835.33	269.31
1990	7597.29	6877.69	-719.60	6925.20	-672.09
1991	8543.01	9043.60	500.59	8857.83	314.82
1992	4421.55	5530.23	1108.68	5369.04	947.49
1993	5477.75	5015.65	-462.10	5194.70	-283.05
1994	5207.70	4451.86	-755.84	4494.96	-712.74
1995	6269.36	6343.80	74.44	6344.98	75.62
1996	8339.31	7762.15	-577.16	7706.84	-632.47
1997	7851.11	8060.71	209.60	8122.78	271.67
1998	5777.65	5197.33	-580.32	5228.75	-548.90
1999	7148.85	7340.46	191.61	7276.97	128.12
2000	5428.17	6021.53	593.36	5961.07	532.90
2001	3174.55	3311.74	137.19	3258.80	84.25
2002	7097.87	6494.54	-603.33	6582.57	-515.30
2003	5016.79	4518.77	-498.02	4558.72	-458.07
2004	4739.90	5459.65	719.75	5498.70	758.80
2005	5572.36	5104.01	-468.35	5131.38	-440.98
2006	6601.39	6441.85	-159.54	6453.58	-147.81
2007	6838.81	6421.65	-417.16	6465.27	-373.54
2008	5517.22	6062.40	545.18	6035.83	518.61
2009	4421.36	5021.87	600.51	4983.47	562.11
2010	4520.13	4921.73	401.60	4856.27	336.14

1-MARCH FORECAST MODEL

VARIABLES:

Y1	LIB_KAF
X1	QBO_PrevJANMAR
X2	PPT_EUREM_ONDJF
X3	PPT_LIBRS_ONDJF
X4	PPT_WGLAM_ONDJF
X5	PPT_FERNB_ONDJF
X6	SWE-P_FLOEK_1Mar
X7	SWE-P_SUNSH_1Mar
X8	SWE-P_EASTK_1Mar
X9	SWE-P_STAHL_1Mar
X10	SWE-P_GARDI_1Mar
X11	SWE-P_TISLE_1Mar
X12	SWE-P_LOSTC_1Mar
X13	SWE-P_MORRQ_1Mar
X14	SWE-P_HAWKL_1Mar

REGRESSION EQUATION:

var	coef
----	----
X1	-10.207
X2	68.645
X3	51.513
X4	33.713
X5	11.493
X6	6.383
X7	17.813
X8	4.760
X9	15.238
X10	13.159
X11	26.123
X12	14.694
X13	18.602
X14	22.833
C	1473.321

1-MARCH FORECAST MODEL

PCREG STATISTICS:

#obs	23
#pc	2
jr	0.933
jse	527.388
r	0.949
se	459.983

PCREG FORECASTS:

YEAR	OBSERVED	JCKREG COMPUTED	JCKREG ERROR	STDREG COMPUTED	STDREG ERROR
1988	4632.99	4727.02	94.03	4773.31	140.32
1989	5566.02	5549.62	-16.40	5536.07	-29.95
1990	7597.29	7227.36	-369.93	7261.86	-335.43
1991	8543.01	8517.10	-25.91	8480.42	-62.59
1992	4421.55	5296.91	875.36	5152.40	730.85
1993	5477.75	4606.74	-871.01	5091.20	-386.55
1994	5207.70	5018.70	-189.00	4831.01	-376.69
1995	6269.36	6566.81	297.45	6556.65	287.29
1996	8339.31	8168.65	-170.66	7984.95	-354.36
1997	7851.11	7588.66	-262.45	7805.25	-45.86
1998	5777.65	4906.42	-871.23	4963.27	-814.38
1999	7148.85	7700.30	551.45	7545.09	396.24
2000	5428.17	6032.86	604.69	5965.90	537.73
2001	3174.55	3528.26	353.71	3430.50	255.95
2002	7097.87	6949.44	-148.43	6997.77	-100.10
2003	5016.79	4441.75	-575.04	4484.93	-531.86
2004	4739.90	5207.76	467.86	5248.65	508.75
2005	5572.36	4892.94	-679.42	4937.90	-634.46
2006	6601.39	6568.72	-32.67	6571.50	-29.89
2007	6838.81	6451.07	-387.74	6503.03	-335.78
2008	5517.22	6157.80	640.58	6115.28	598.06
2009	4421.36	5138.49	717.13	5092.70	671.34
2010	4520.13	4443.58	-76.55	4431.54	-88.59

1-APRIL FORECAST MODEL

VARIABLES:

Y1	LIB_KAF
X1	QBO_PrevJANMAR
X2	PNA_ONDJ
X3	PPT_WGLAM_DJFM
X4	PPT_FERNB_DJFM
X5	SWE-P_SUNSH_1Apr
X6	SWE-P_EASTK_1Apr
X7	SWE-P_STAHL_1Apr
X8	SWE-P_GARDI_1Apr
X9	SWE-P_TISLE_1Apr

REGRESSION EQUATION:

var	coef
----	----
X1	-1.834
X2	-83.948
X3	51.347
X4	41.412
X5	52.445
X6	25.837
X7	27.280
X8	18.126
X9	51.234
C	247.944

PCREG STATISTICS:

#obs	26
#pc	1
jr	0.921
jse	532.285
r	0.931
se	500.334

1-APRIL FORECAST MODEL

PCREG FORECASTS:

YEAR	OBSERVED	JCKREG COMPUTED	JCKREG ERROR	STDREG COMPUTED	STDREG ERROR
1985	4756.36	5309.52	553.16	5259.40	503.04
1986	6085.88	6661.74	575.86	6627.71	541.83
1987	4999.93	5294.92	294.99	5270.67	270.74
1988	4632.99	5082.82	449.83	5040.60	407.61
1989	5566.02	5926.90	360.88	5916.87	350.85
1990	7597.29	6684.44	-912.85	6772.73	-824.56
1991	8543.01	8854.56	311.55	8805.84	262.83
1992	4421.55	5081.82	660.27	5034.69	613.14
1993	5477.75	4189.37	-1288.38	4209.63	-1268.12
1994	5207.70	5500.84	293.14	5488.61	280.91
1995	6269.36	6264.16	-5.20	6273.89	4.53
1996	8339.31	7733.50	-605.81	7854.62	-484.69
1997	7851.11	7870.52	19.41	7887.78	36.67
1998	5777.65	5148.82	-628.83	5183.40	-594.25
1999	7148.85	6935.51	-213.34	6952.31	-196.54
2000	5428.17	6007.26	579.09	5980.18	552.01
2001	3174.55	3256.93	82.38	3216.85	42.30
2002	7097.87	6981.39	-116.48	7020.61	-77.26
2003	5016.79	5368.48	351.69	5344.94	328.15
2004	4739.90	4646.10	-93.80	4704.04	-35.86
2005	5572.36	5435.92	-136.44	5431.98	-140.38
2006	6601.39	5990.80	-610.59	5985.45	-615.94
2007	6838.81	6236.12	-602.69	6267.21	-571.60
2008	5517.22	5976.69	459.47	5949.53	432.31
2009	4421.36	4947.11	525.75	4904.99	483.63
2010	4520.13	4217.22	-302.91	4218.80	-301.33

1-MAY FORECAST MODEL

VARIABLES:

Y1	LIB_KAF_MayAug
X1	QBO_PrevJANMAR
X2	PNA_ONDJ
X3	PPT_WGLAM_JFMA
X4	PPT_FERNB_JFMA
X5	SWE-P_SUNSH_1May
X6	SWE-P_EASTK_1May
X7	SWE-P_STAHL_1May
X8	SWE-P_GARDI_1May

REGRESSIONEQUATION:

var	coef
----	----
X1	-3.008
X2	-87.205
X3	83.416
X4	39.157
X5	57.780
X6	27.650
X7	30.150
X8	17.618
C	18.458

PCREG STATISTICS:

#obs	27
#pc	1
jr	0.920
jse	487.313
r	0.928
se	463.011

1-MAY FORECAST MODEL

PCREG FORECASTS:

YEAR	OBSERVED	JCKREG COMPUTED	JCKREG ERROR	STDREG COMPUTED	STDREG ERROR
1984	4710.55	4331.45	-379.10	4340.53	-370.02
1985	4337.45	4503.35	165.90	4518.53	181.08
1986	5490.05	6032.01	541.96	5997.87	507.82
1987	4360.86	4510.09	149.23	4492.54	131.68
1988	4096.46	4568.80	472.34	4511.37	414.91
1989	5017.79	5212.42	194.63	5203.99	186.20
1990	6749.55	5630.21	-1119.34	5730.49	-1019.06
1991	7840.86	7880.96	40.10	7937.21	96.35
1992	3952.46	4240.66	288.20	4199.41	246.95
1993	5132.43	4194.56	-937.87	4145.53	-986.90
1994	4457.75	4595.35	137.60	4581.20	123.45
1995	5928.60	6122.72	194.12	6150.23	221.63
1996	7453.09	7360.68	-92.41	7458.52	5.43
1997	7238.42	6822.67	-415.75	6894.58	-343.84
1998	5302.87	4298.43	-1004.44	4370.80	-932.07
1999	6587.56	6368.26	-219.30	6373.66	-213.90
2000	4796.23	5608.24	812.01	5578.24	782.01
2001	2950.21	3445.54	495.33	3351.09	400.88
2002	6631.93	6698.11	66.18	6741.15	109.22
2003	4525.88	5095.49	569.61	5068.82	542.94
2004	4111.54	4251.20	139.66	4271.17	159.63
2005	5118.94	4808.64	-310.30	4808.90	-310.04
2006	5987.11	5638.16	-348.95	5610.18	-376.93
2007	6157.09	6025.47	-131.62	6030.83	-126.26
2008	5299.44	5521.10	221.66	5517.02	217.58
2009	4117.69	4489.70	372.01	4466.93	349.24
2010	4155.77	4178.14	22.37	4157.79	2.02

1-JUNE FORECAST MODEL

VARIABLES:

Y1	LIB_KAF_JunAug
X1	QBO_PrevJANMAR
X2	PNA_ONDJ
X3	PPT_WGLAM_JFMAM
X4	PPT_FERNB_JFMAM
X5	SWE-P_EASTK_1Jun
X6	SWE-P_STAHL_1Jun
X7	SWE-P_GARDI_1Jun

REGRESSION EQUATION:

var	coef
----	----
X1	-1.817
X2	-72.391
X3	87.243
X4	35.920
X5	21.934
X6	22.045
X7	16.254
C	526.231

PCREG STATISTICS:

#obs	27
#pc	1
jr	0.921
jse	417.917
r	0.929
se	397.726

1-JUNE FORECAST MODEL

PCREG FORECASTS:

YEAR	OBSERVED	JCKREG COMPUTED	JCKREG ERROR	STDREG COMPUTED	STDREG ERROR
1984	3893.16	3539.53	-353.63	3560.57	-332.59
1985	2618.18	2971.67	353.49	2928.33	310.15
1986	3850.71	4151.79	301.08	4138.63	287.92
1987	2332.17	2681.79	349.62	2607.85	275.68
1988	2712.60	3036.31	323.71	2983.76	271.16
1989	3479.80	3883.04	403.24	3872.17	392.37
1990	5243.11	4372.25	-870.86	4447.87	-795.24
1991	5663.80	5514.53	-149.27	5630.61	-33.19
1992	2523.77	2723.92	200.15	2687.86	164.09
1993	3400.46	2532.00	-868.46	2475.52	-924.94
1994	2844.20	2866.36	22.16	2842.01	-2.19
1995	4626.45	4034.37	-592.08	4088.08	-538.37
1996	5853.88	6300.03	446.15	6316.77	462.89
1997	4935.59	4661.65	-273.94	4705.50	-230.09
1998	3174.53	3342.95	168.42	3311.30	136.77
1999	5115.43	4410.87	-704.56	4442.61	-672.82
2000	3417.32	3795.00	377.68	3784.94	367.62
2001	1936.26	2166.05	229.79	2083.76	147.50
2002	5191.54	5021.74	-169.80	5124.51	-67.03
2003	3291.57	3583.92	292.35	3600.27	308.70
2004	3011.90	3019.30	7.40	3016.91	5.01
2005	3676.17	3140.93	-535.24	3148.39	-527.78
2006	3606.74	3879.10	272.36	3846.47	239.73
2007	4107.17	4150.70	43.53	4145.02	37.85
2008	3551.80	3925.70	373.90	3913.05	361.25
2009	3092.43	3399.20	306.77	3391.01	298.58
2010	3217.59	3287.68	70.09	3274.55	56.96

Appendix F. Libby Dam Inflow

The following gauging stations and calculations were used to compute and approximate Libby Dam inflow prior to the construction of the dam:

- KNWG: Kootenay River at Newgate (USGS Station #12300000)
- KLIB: Kootenai River at Libby (USGS Station #12303000)
- KWRB: Kootenai River at Worland Bridge (USGS Station #12301850)

Oct 1930 to Sep 1961: Libby Inflow = KNWG + 0.5136 * (KLIB – KNWG)

Oct 1961 to Sep 1971: Libby Inflow = KWRB + 0.069 * (KLIB-KWRB)

Oct 1971 to present: Libby Dam Outflow (daily average) – midnight-to-midnight change of storage in Lake Koocanusa.

The Corps of Engineers does not currently maintain an official, quality-controlled record of project data. Typical project data would include, as a minimum, project inflow, outflow, and elevation values, on at least a daily frequency. The Northwestern Division Water Control Data System collects and stores real-time hourly and daily values for Libby dam and reservoir, but lacks a consistent process to review and correct deviant values. Project data reviewed included the following:

- LIB - Average daily inflow - CWMS-LIB.Flow-In.Ave.1Day.1Day.CBT-REV
- LIB - Modified Flows daily inflow -LIB.Flow-In-Mod.Ave.1Day.1Day.DEPLETION-2000-LEVEL (107592)
- LIB - Average daily inflow - CROHMS Inflow Discharge (KCFS), Daily, Manual Collection (QIDRXZZAZD)
- LIB - Hourly inflow – CROHMS Inflow Discharge (KCFS), One Hourly, Best Quality (QIHRAZZ ZD)
- LIB – Six-hourly inflow – CROHMS Inflow Discharge (KCFS), Six Hourly, Processed (QIQPAZZ ZD)
- LIB – Six-hourly inflow – CROHMS Inflow Discharge (KCFS), Six Hourly, Non-Specific Processed Data (QIQPZZZAZD)

In addition, three digital datasets of Libby project data developed in previous studies (a DSS file from Russ Morrow, data from a SAS file used by Wortman in the 1986 review, and an Excel file from Wortman and used in the 2004 review) were examined and compared to other sources of data.

Conclusions—Libby Dam Inflow:

1. The pre-project streamflow values (calculated using basin-area factors) should be considered as rough estimates, probably in the range of +/- 5%.
2. Various uncorrected errors (negative outflows, negative elevation) and vagaries (missing values, stuck gages, time-stamp errors, etc.) exist in all the project records.
3. A comparison of "corrected" post-project records showed most seasonal volume differences within +/- 0.25%, however there were typically 3 or 4 years with differences between 1% and 4%.
4. The comparison of pre-project streamflow, Figure 10, does not show any one source to be superior, and confirms that all sources are within a very reasonable tolerance. Since the Modified Flows record is a published, documented and publicly accessible record, it is recommended for use as the official record of pre-project streamflow.
5. The CROHMS daily average discharge data (QIDRXZZAD) had the most consistent and error free record (I located one missing value and one negative value since the 1-Nov 1974 beginning of record). This record is recommended for use as the official post-project inflow record and was used in this study.

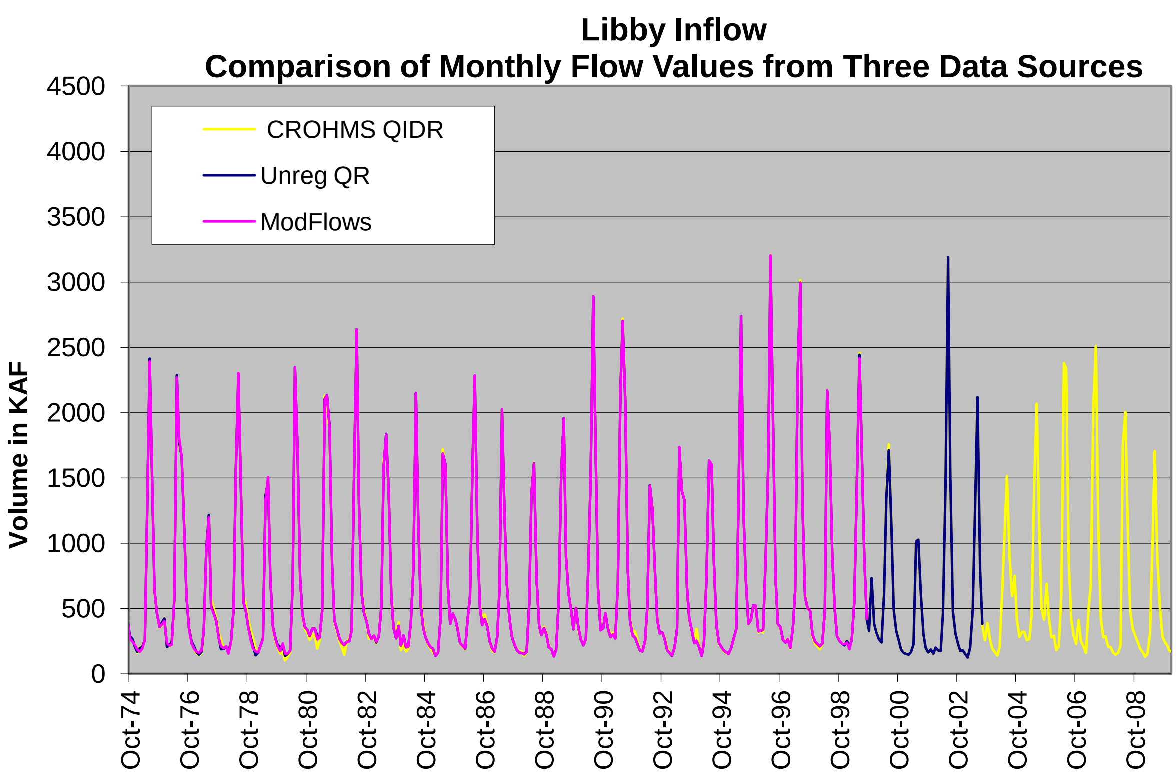


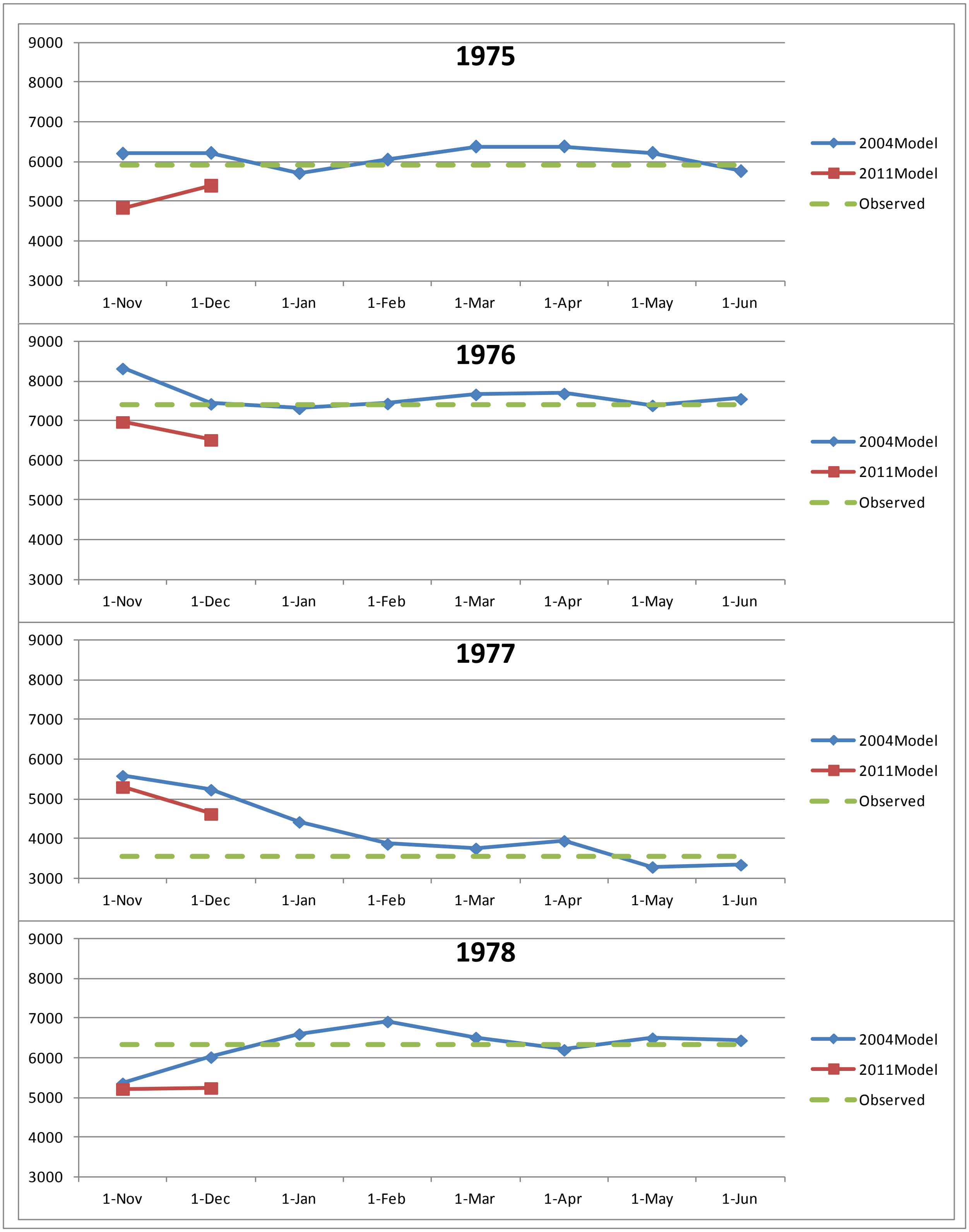
Figure 10 - Libby Inflow Comparison

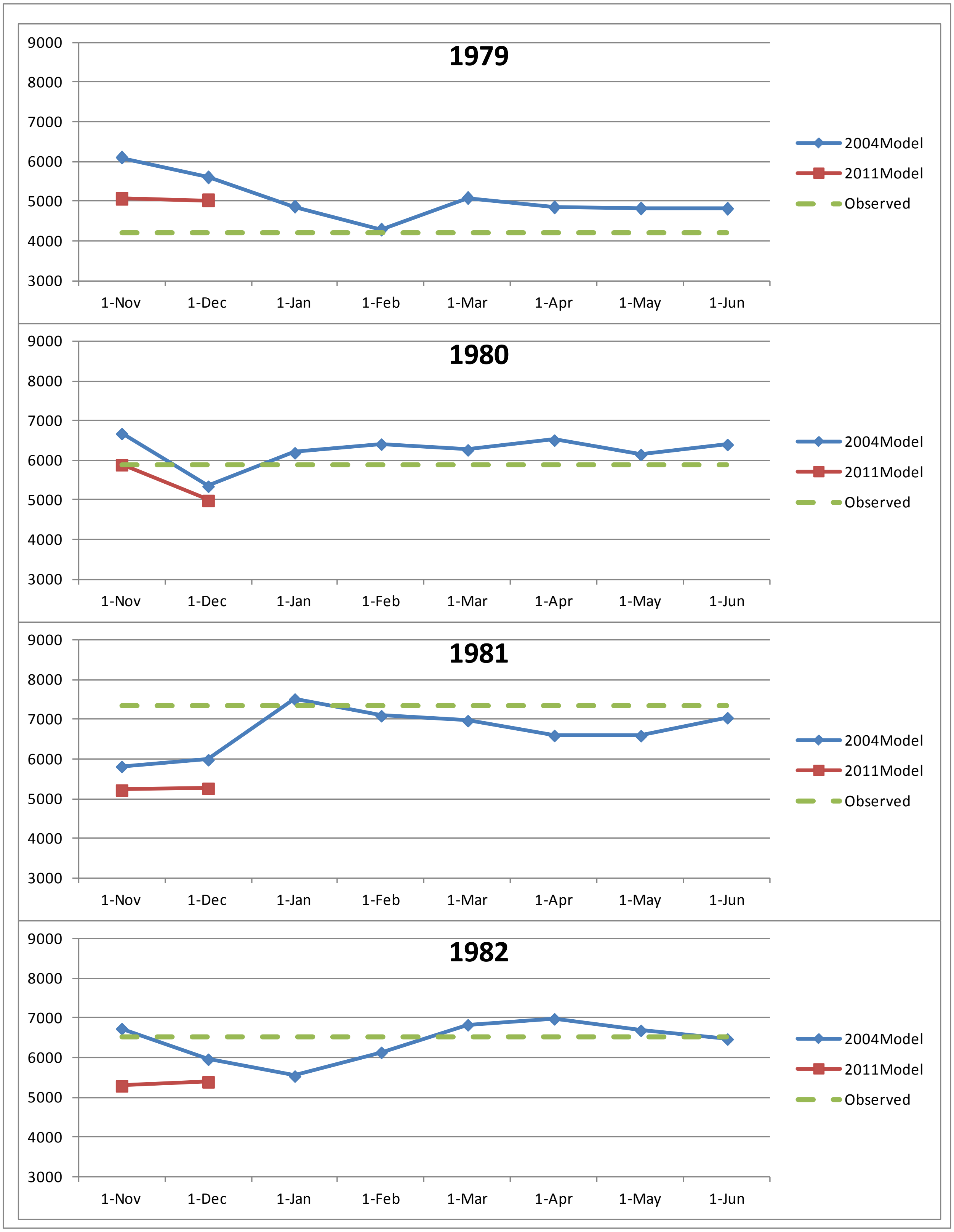
Appendix G. Comparison of Observed and Monthly Forecasts from 2004 and 2011 Models

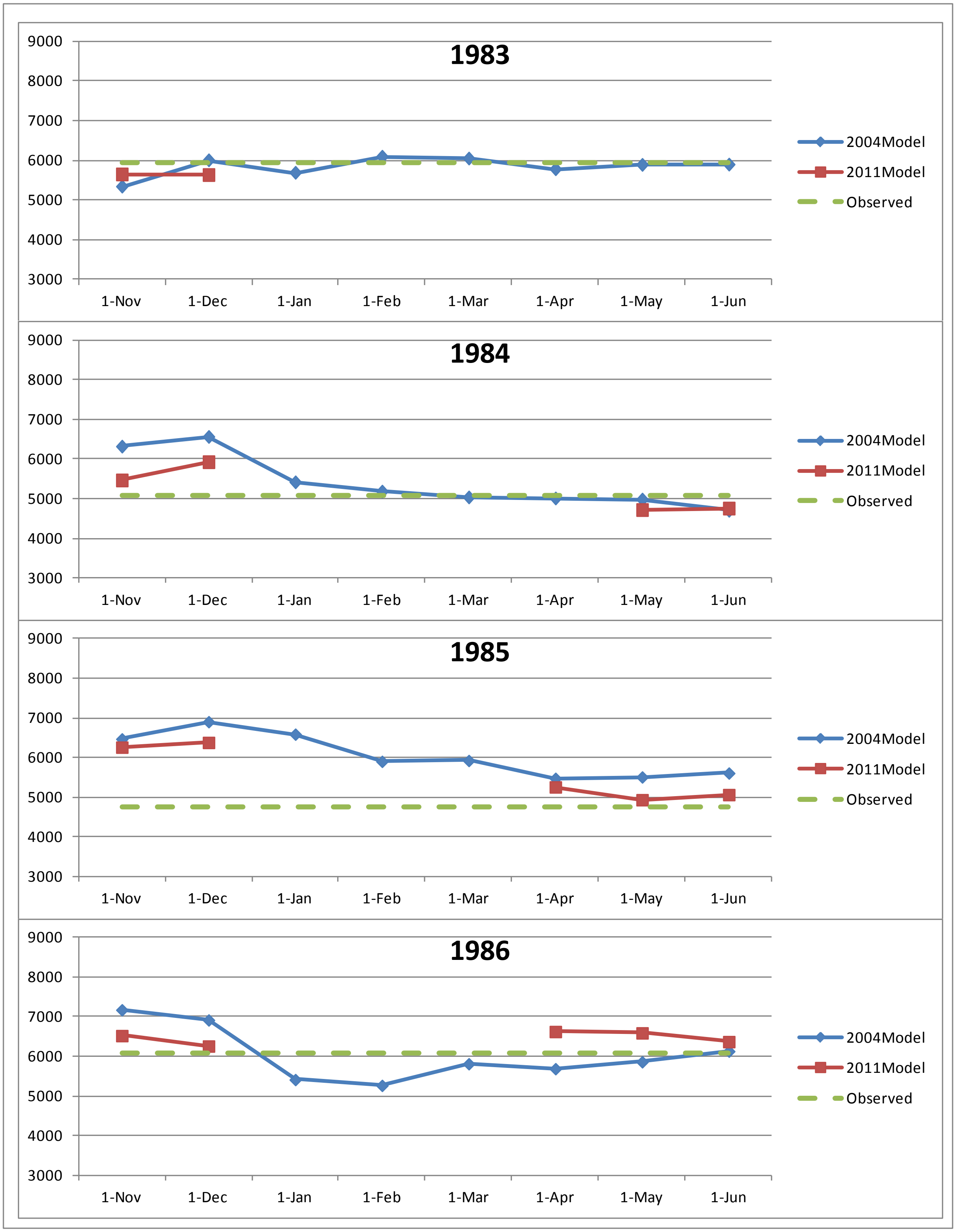
36 Charts – from 1975 to 2010

Note: Forecasts were not able to be calculated for the following issue-dates and years since snow observations were not taken at one or more requisite snow pillow sites.

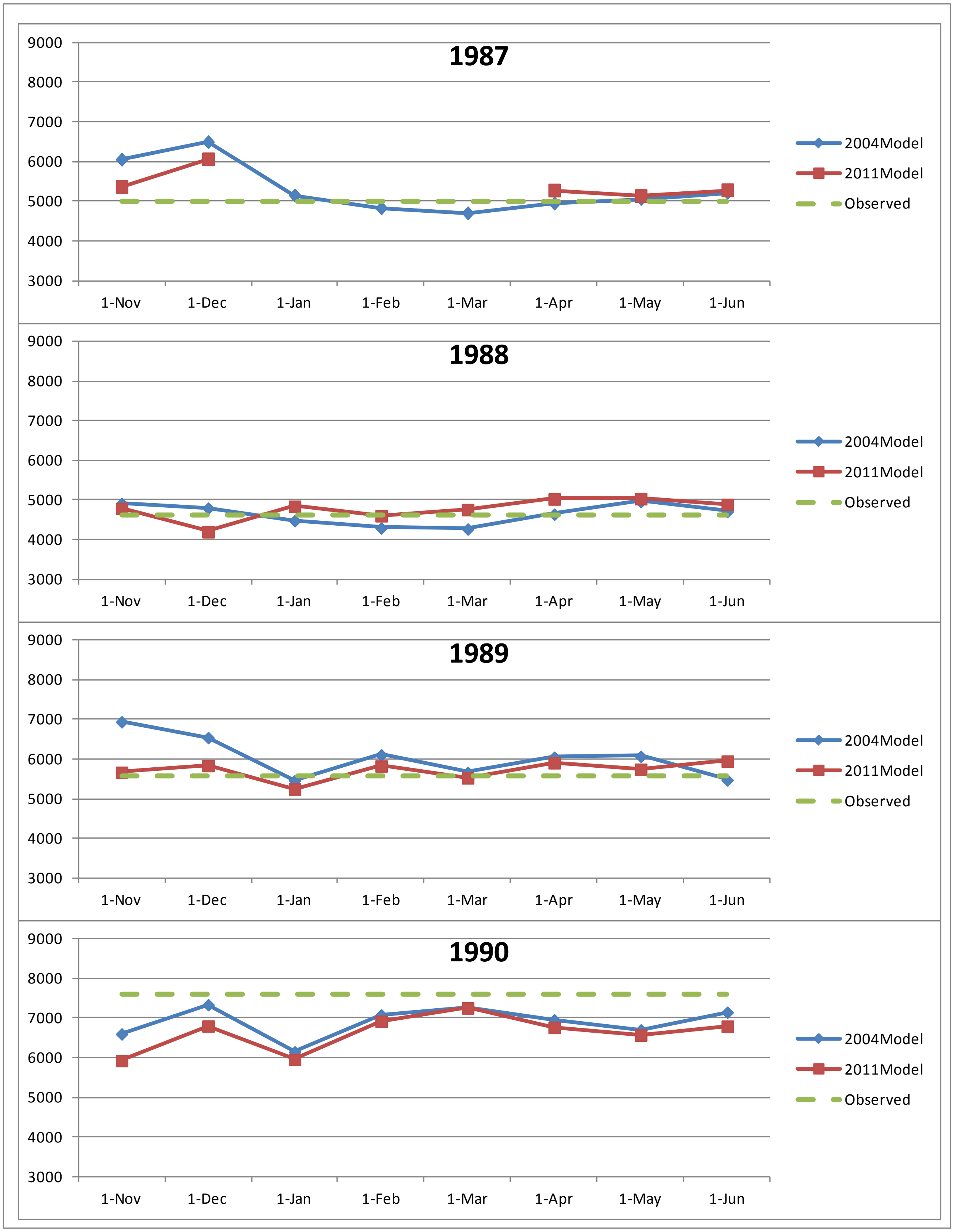
1975-to-1983	1-Jan, 1-Feb, 1-Mar, 1-Apr, 1-May, 1-Jun
1984	1-Jan, 1-Feb, 1-Mar, 1-Apr
1985-to-1988	1-Jan, 1-Feb, 1-Mar

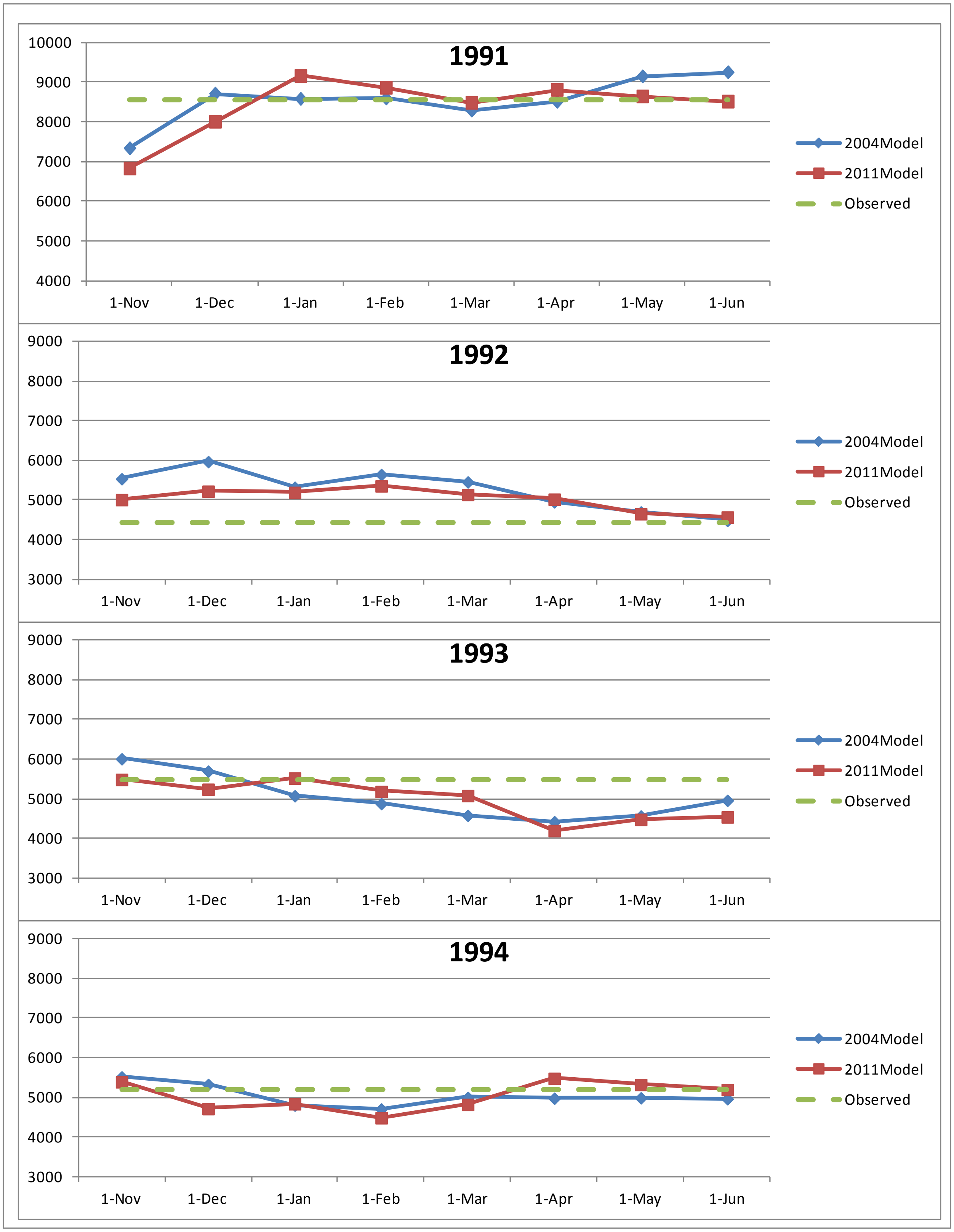

1975
1976
1977
1978
9000
8000
7000
6000
5000
4000
3000
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
2004Model
2011Model
Observed

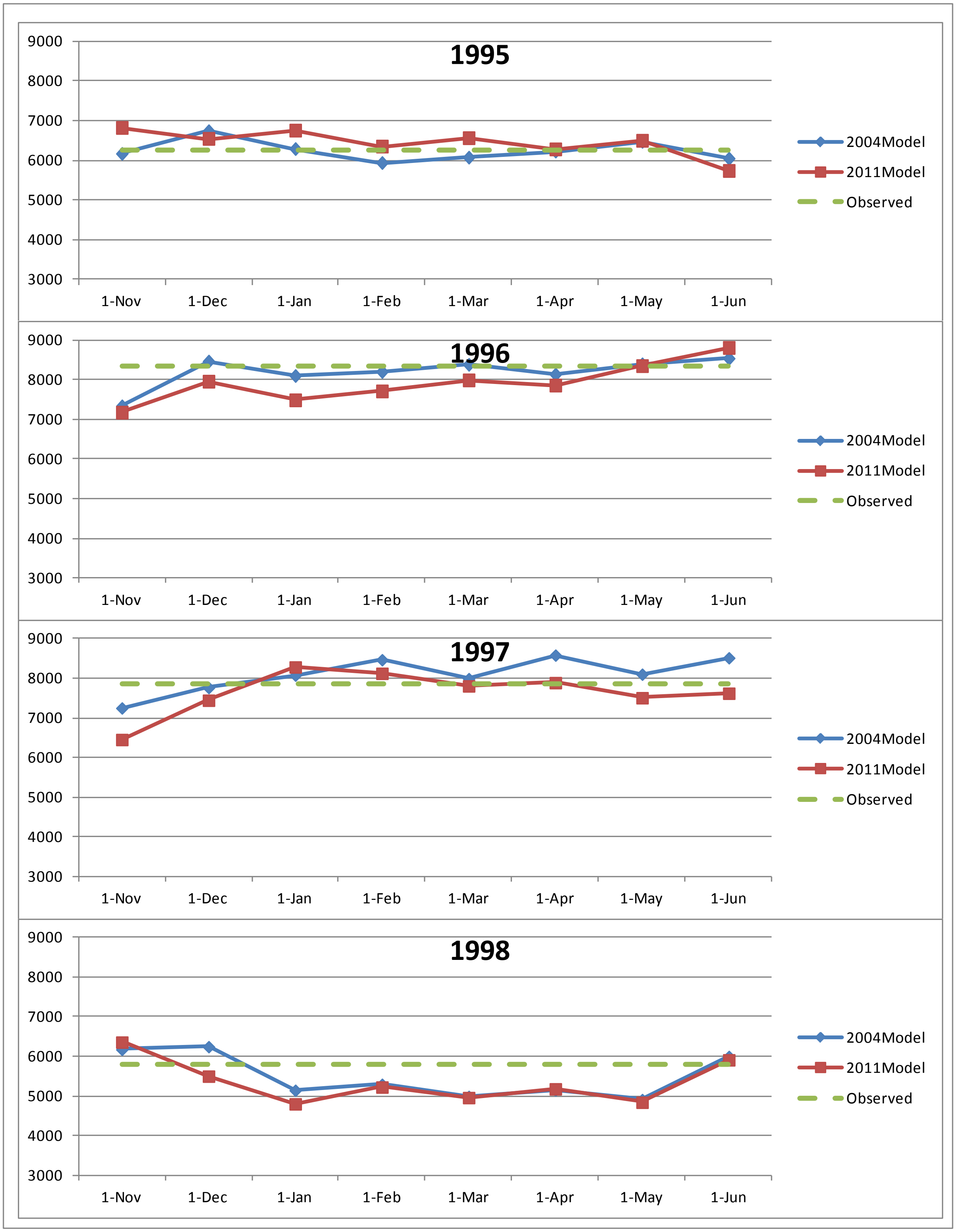

1979
1980
1981
1982
9000
8000
7000
6000
5000
4000
3000
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
2004Model
2011Model
Observed

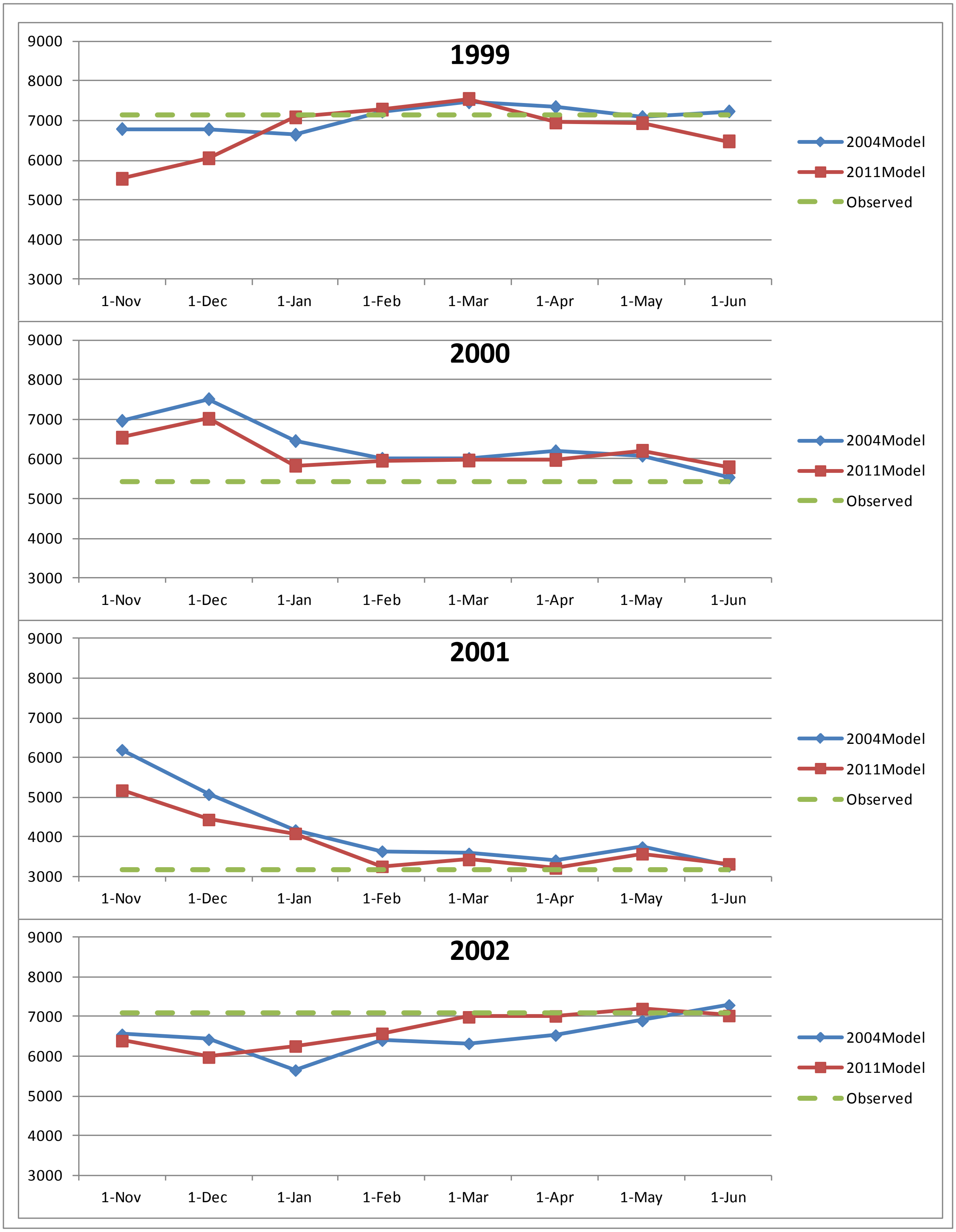


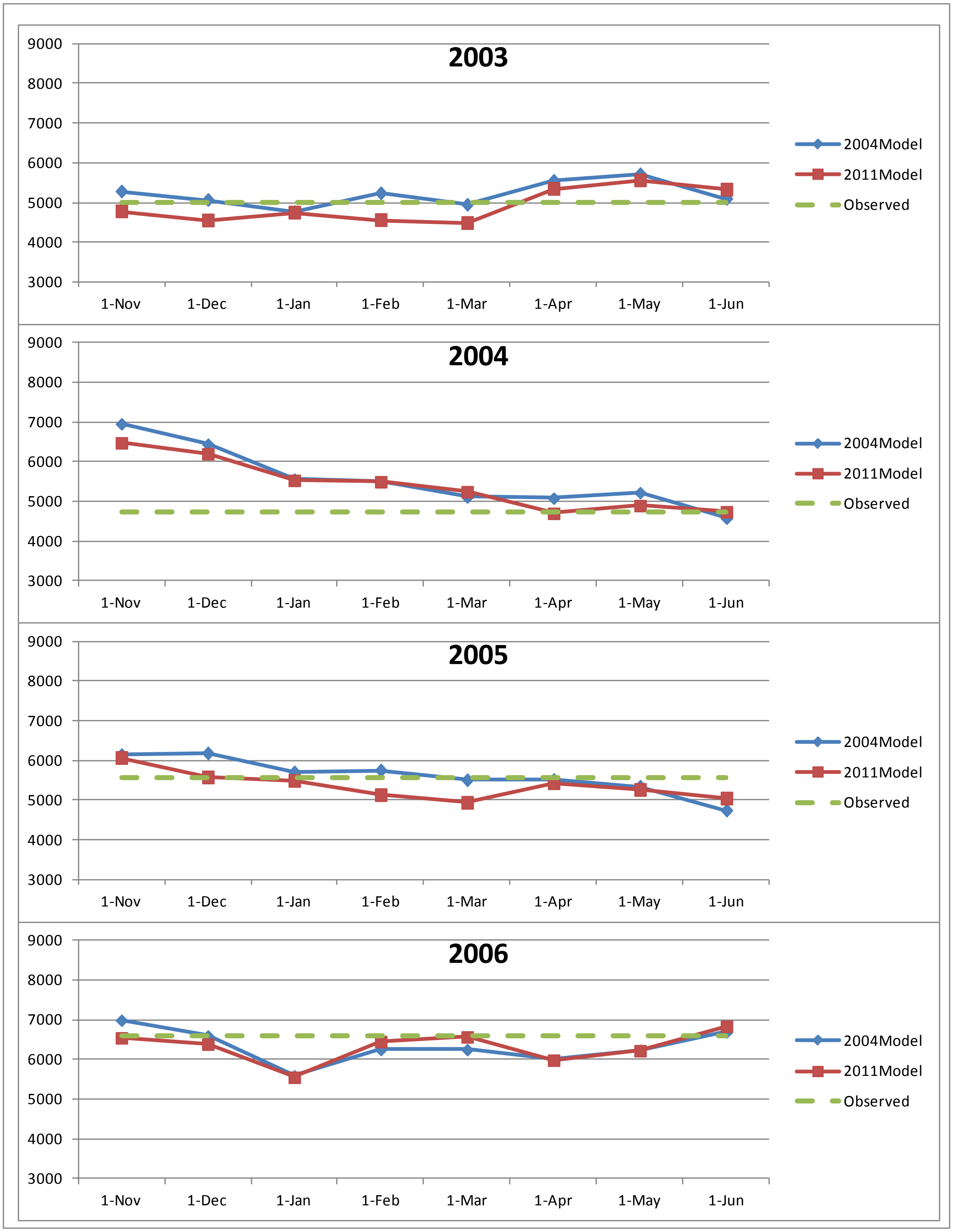
1983
1984
1985
1986
9000
8000
7000
6000
5000
4000
3000
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
2004Model
2011Model
Observed

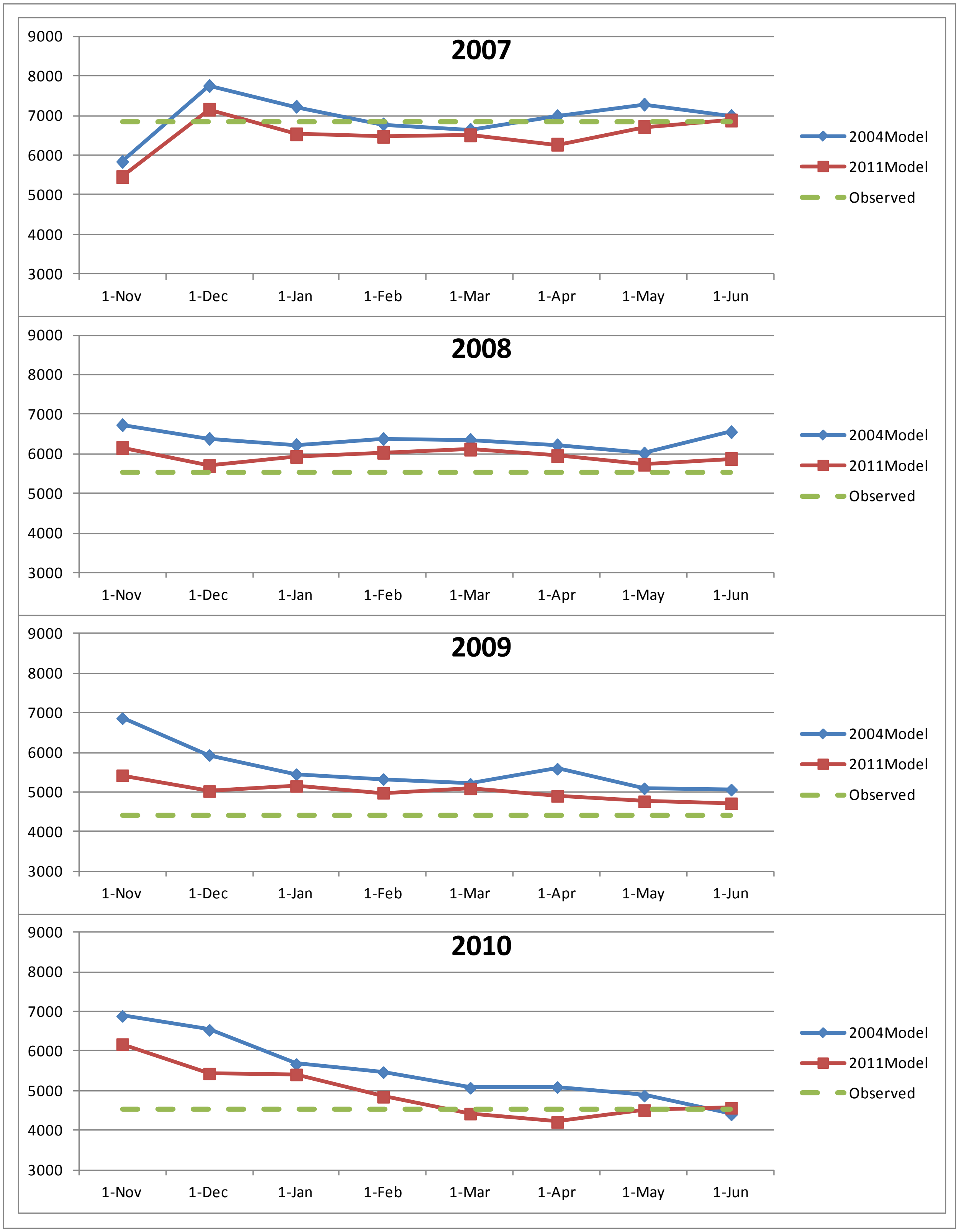

1987
1988
1989
1990
9000
8000
7000
6000
5000
4000
3000
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
2004Model
2011Model
Observed


1991
10000
9000
8000
7000
6000
5000
4000
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
2004Model
2011Model
Observed
1992
9000
8000
7000
6000
5000
4000
3000
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
2004Model
2011Model
Observed
1993
9000
8000
7000
6000
5000
4000
3000
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
2004Model
2011Model
Observed
1994
9000
8000
7000
6000
5000
4000
3000
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
2004Model
2011Model
Observed


1995
1996
1997
1998
9000
8000
7000
6000
5000
4000
3000
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
2004Model
2011Model
Observed


1999
2000
2001
2002
9000
8000
7000
6000
5000
4000
3000
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
2004Model
2011Model
Observed


2003
2004
2005
2006
9000
8000
7000
6000
5000
4000
3000
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
2004Model
2011Model
Observed



2007
2008
2009
2010
9000
8000
7000
6000
5000
4000
3000
1-Nov
1-Dec
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
2004Model
2011Model
Observed

Appendix H. Reviewer’s Comments and Author’s Responses

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
USACE/Jim Barton				
1	Exec. Summary (pp 1-3)	Suggest adding information regarding the purpose of the review and report, such as was it just a routine update since the last update was in 2004, was it based on a questions about forecasting procedure in 2010, etc.	Noted and addressed	A new paragraph on "objectives" added at the beginning of the Executive Summary
2		I'd like to see a table comparing the 2010 monthly: (1) NWS Libby Statistical Forecasts; (2) Corps forecasts based on 2004 procedure; (3) Corps forecasts based on proposed 2010 procedure; and (4) observed runoff data. Although I agree that when developing a new forecasting procedure we don't want to focus on a particular year, given the questions folks had about the Libby forecasts in 2010 this would be helpful to use to brief senior managers on how the new procedure would work in a year like 2010 compared to the existing procedure.	Noted. Substantially addressed.	Plots comparing the observed runoff, 2004-model forecasts, and 2010-model forecasts have been included for 1975-2010 (forecasts for 1975 to 1987 are incomplete due to lack of data). Forecast comparisons for 2010 will be performed by the Columbia River Forecast Group in the fall of the year. Comparisons of five USACE and NWRFC forecasts are already available at http://www.nwd-wc.usace.army.mil/tmt/documents/esp/2010/20100728_LIB_ForecastComparison.pdf These forecasts are updated weekly throughout the forecast season.
NRCS/Tama				
1	pg 2	wording: use May-Aug for consistency	Revised	
2	pg 2	The most recent 20 years is included in the 35 year data set so how could the shorter period be more variable?	Noted.	There is no problem with a subset showing greater variability than the superset. The statistical term for a changing variance is heteroscedasticity.
3	pg 3	This contradicts the 2nd to last bullet on the previous page	Noted. Substantially addressed.	Text reworded to provide clarification. Appendix D - Comparison of Model Performance Statistics provides additional clarification.

Comm ent #	Location	Reviewer's Comment	Disposition	Author's Response
4	pg 7 - Table 1 & 2	Why drop Oct/Nov ppt on 1 Apr?	Noted.	The equations and coefficients have been revised between the draft equations reviewed and the final equations. Two precipitation stations are still being dropped on 1 Apr, the Libby and Eureka gages. The modeling shows that retaining either of these stations after 1-Mar adds variability (noise) without a corresponding benefit to the forecast.
5	pg 7 - Table 2	The constant increases dramatically from 1 May to 1 Jun even though the target is getting smaller (and constant was also getting smaller through season). Alarming	Noted.	The equations and coefficients have been revised between the draft equations reviewed and the final equations. The final equations show a similar increase in the intercept ("constant"). The loss of one snow station between the 1-May and 1-Jun equations may be responsible.
6	pg 7 - Table 2	1 Apr coefficients change significantly for some variables - this could be something worth looking into a little deeper. Also, why drop West Glacier ppt?	Noted and addressed.	The equations and coefficients have been revised between the draft equations reviewed and the final equations. The change seen in the 1-Apr coefficients is the result of dropping 2 precipitation and 4 snow variables and adding the PNA climate variable. The West Glacier precipitation station is now being retained for all forecasts, however the Libby and Eureka stations are no longer used after 1-March.
7	pg 8	The CVSE shows increase here but on figure 8 (pg 44) RMSE shows decrease from Apr to May?		The comment is not entirely consistent- the CVSE in the draft report indeed increased between 1-Mar and 1-Apr, but decreased from 1-Apr to 1-May. The reviewer is correct that Figure 8 shows something different. The equations and coefficients have been revised between the draft equations reviewed and the final equations. The chart in the final report (now Figure 9) shows the correct data.

Comm ent #	Location	Reviewer's Comment	Disposition	Author's Response
8	App. A - Charts	Also, Rashawn pointed out an apparent problem with the climate index plots in Appendix A (starting on page 25). For the "beginning month sums" plots, shouldn't they have a staggered end point analogous to the staggered beginning point for the "ending month sums" plots? That is, you chopped off the climate indices at February, so, for example, the 6-month sum index for the "beginning" plot would have to end in September, not December. Or, did you not really chop it off at February?	Noted and addressed.	The reviewer is correct in that I "chopped off the climate indices" for some of the plots. The text in Appendix A has been revised to better clarify what is shown in the plots.
NRCS/Garen				
1	pg 2	Clarify the "stationarity conditions" refer to "streamflow"	Noted and revised	Changed text to "that met the streamflow stationarity conditions"
2	pg 3	Describing the shorter sample size as a "loss in variability" seems to contradict your assertion that the shorter period has more variability than the 35 year record. Can you clarify or reword what you mean here?	Noted and revised	The referenced phrase has been removed and the text rewritten to improve clarity.
3	pg 5, et al	You describe these stations as "new" throughout, yet these aren't really new -- they have been in existence for 20-25 years. They are new only in the sense that these sites have never been used for forecasting Libby before.	Noted and revised	For clarity, the document has been revised such that all references to the Alberta snow pillow sites now omits the "new" adjective.
4	pg 5, et al	The reviewer questioned whether the first issue of the forecast was 1-November (as stated on page 5), or 1-October, as presented in other sections of the report	Noted and revised	All references to a 1-Oct issue have been removed. A 1-Oct issue date is not included in the Libby water supply forecast model.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
5	pg 7, Table 1	For completeness, you should put units designations on all data types, not just FLOW.	Noted and revised	A note was added at the bottom of Table 2 providing information on the unit designations.
6	pg 7, Table 1	Explain (in the text) why you did not use SWE in the Dec model.	Noted and revised	A statement on 1-Dec snow was added to Appendix C, page 41.
7	pg 7, Table 1	I think it would be good to explain (in the text) your rationale for the Jan model. That is, explain why you use little SWE data and why you chose to use 35 years instead of 25. This would be an obvious question for someone to ask.	Noted.	The suggested discussion is already presented in the *Executive Summary* (first bullet on page 3) and in Appendix C.
8	pg 7, Table 1	You use "prev" for QBO Jan-Mar time period but not for any other time periods. Seems inconsistent to me. For example, SOI time period is "prev" too -- but you don't use this designation. So where is the cutoff? Maybe you need to either drop the "prev" or use "prev" for all variables in the calendar year previous to the one being forecasted.	Noted and revised	All references in the report to "QBO PrevJanMar" were changed to "QBO JanMar". Note that the text in the original model input and output files will retain the original variable name used during the analysis ("QBO_PrevJanMar")
9	pg 7, Table 1	PNA could be used in March model too -- why not?	Noted.	The PNA variable did not add any information to improve the 1-Mar forecast.
10	pg 7, Table 1	Shouldn't you just put "O" in this column to be consistent with the one-letter month designations for the other precipitation months?	Noted.	A single-letter designation would be more consistent, however I choose to use a three-letter abbreviations for single months for clarity. Series of two or more months combine single-letter abbreviations, as a pattern is easily discernible. I elected to retain use of 3-letter abbreviations only for single months, as single-letter abbreviations are not unique (J for Jan, Jun or Jul?; M for Mar or May?)

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
11	pg 8, Table 3	This switch to 2 PCs and switch back to 1 is probably okay, given the variables in the equations. However, this is something worth watching in operational use to make sure there isn't some kind of funky discontinuity introduced here.	Noted.	No action required. The significance of each principal component variable (which determines the inclusion/exclusion of the PC) was included in the development of the final model equations. This t-test factor was included in the files containing the REG model output.
12	pg 11	This shift [in the historic streamflow data] is due to well-known shifts in the PDO. However, as we discussed on the phone, you don't need to mention this, especially if you feel uncomfortable doing so.	Noted and revised	I would agree that the shift is highly correlated with the PDO regime, but would be reluctant to characterize it as "due to" the PDO. Text substantially revised to acknowledge and discuss the relationship to PDO.
13	pg 11	Not necessarily. The only concern is whether this streamflow regime shift would somehow alter the basic input-output relationships. I suspect it doesn't. That is, the streamflow was high in those years because there was high snowpack. It would work the same now if we got similarly high snow packs. The only way the statistical relationships would be different would be if the future weather after forecast issuance was different between the two regimes -- however, I think this is unlikely. So -- bottom line -- I think you are probably overstating the case here.	Noted and revised	Text revised to remove statement of concern.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
14	pg 11	While I don't disagree with your choice of analysis period, there is another implied assumption here. That is, it is being assumed that the post-1975 regime is what we are still in, and it will continue. There is evidence that PDO has switched back to cool, or at least neutral -- although there isn't much evidence yet that this has caused a big step change in streamflow. It is possible that we could cycle back to a cool-wet period like the mid-40s to mid-70s, in which case, the older data would once again become representative. However -- now we have the big unknown influence of a warming climate, which could change all of this. At least we can reasonably relax somewhat about all of this because these various climate swings and changes won't show dramatic effects in the next 5-10 years, which would be the expected lifetime of these forecast models.	Noted and revised	Text substantially revised to acknowledge and discuss the relationship to PDO, addressing reviewer's concern.
15	pg 11	I could add Kennedy et al. (2009) -- I have added this citation to the Bibliography, in case you want to include it. If you want to see it, it is on the NWCC professional publications web page.	Noted and revised	Noted reference reviewed and added to bibliography
16	pg 11	What happened to the formatting here?	Noted and revised	Formatted corrected.
17	pg 12, Table 5	Wouldn’t the October index value not be available for use in November?	Noted.	Klauss Wolter is excellent at updating his MEI index during the first week of the month, usually by the 5th day. Klauss is also accessible via email and phone to discuss issues.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
18	pg 12, Table 5	Similarly, wouldn't the September index value not be available in October?	Noted.	Klauss Wolter is excellent at updating his MEI index during the first week of the month, usually by the 5th day. Klauss is also accessible via email and phone to discuss issues.
19	pg 12, Table 5	Why use "prev" here but not for all the others? There is no distinction between this one and the other indices except it is a few months earlier. Maybe the best solution is to say that all monthly periods for the climate indices begin in the calendar year prior to the forecast year.	Noted and revised	Revised to delete all references to "prev".
20	pg 12, Table 5	Use single letter here too.	Noted	I elected to use 3-letter abbreviations for single months, as single-letter abbreviations are not unique (J for Jan, Jun or Jul?; M for Mar or May?)
21	pg 12, Table 5	Why are there two periods listed for each forecast issuance date? Same for PNA, PDO, SOI. Clarify.	Noted and revised	Text added after Table 5 to provide clarification
22	pg 13	Same name. [2C09->2C09A] Was this a station move?	Noted.	Yes.
23	pg 13	Since this also has to do with Morrissey Ridge, place right after the previous one, or combine the two.	Noted.	The arrangement of the station changes is chronological, so the Morrissey Ridge entries should remain as presented, with the two Morrissey Ridge entries separated by Red Mountain.
24	pg 13	Marble Canyon, BC (snow course)	Noted and revised	Revised to specify station as a snow course.
25	pg 13	Vermillion River #3 (snow course)	Noted and revised	Revised to specify station as a snow course.
26	pg 13	Change "common data points between the two sites." to "concurrent observations"	Noted and revised	Revised.
27	pg 14	Does this [WSO] need to be spelled out, or would any potential reader know what WSO is?	Noted.	Choose to leave as is.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
28	pg 14	Change "is" to "are"	Noted and revised	Revised.
29	pg 14	Change "site" to "sites"	Noted and revised	Revised
30	pg 14	Also slightly to the east of the watershed boundary -- worth mentioning?	Noted and revised	Text added as suggested.
31	pg 14	Change "Tables 6" to "Table 6"	Noted and revised	Revised
32	pg 15	Are the May and June correlations with the May-Aug and Jun-Aug streamflow, respectively? If so, better say this in the caption. If not, that is not entirely the most pertinent, but you wouldn't have time to re-do these correlations, so don't worry about it.	Noted.	The caption is correct as presented - all the correlations are with Apr-Aug runoff, rather than using the slightly more relevant May-Aug and Jun-Aug runoff for the May and June issue dates.
33	pg 16 - Table 7	Delete this column. They are all the same, and you say "active" stations in the caption anyway.	Noted and revised	Column deleted.
34	pg 16 - Table 7	Why are these values in italics?	Noted and revised	Revised.
35	pg 18	Valid comment, but out of place here. Is this point related to item #4? That is, if a quality-assured database were developed, it would save much of the time-consuming effort you spent just in getting the data in shape for the statistical analyses.	Noted and revised	Text revised and recast as part of item #4.
36	pg 18 - #3	State why you feel this is necessary and what these data would be used for.	Noted and revised	Text added as suggested.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
37	pg 18 - #6	I took a stab at this [a standard statistic to measure consistency] in my 1992 paper, but no one has systematically looked at this issue.	Noted.	No action required.
38	pg 19 - #7	I would add that the Corps obtain direct access to NWS Coop data and obtain these data on their own. The NWCC has direct access through the ACIS network -- which is the best source I know of for real-time access to Coop data. It should be possible for the Corps to obtain access to this system.	Noted and revised	Text added as suggested.
39	pg 19 - #9	This is unclearly worded.	Noted and revised	Text revised to clarify.
40	pg 20			Added Kennedy, Garen and Koch referrence as previously recommended.
41	pg 25	If you cut off the months at February, then the Beginning Month Sum plots should have a staggered end point. For example, you couldn't have a point plotted at December for a 4, 5, or 6 month sum, because this would extend past an ending point of February for the period.	Noted and revised	Text revised to clarify.
42	pg 41	Revise reference date	Noted and revised	Changed "2003" to "2002"
43	pg 42- Table 11	Remove this column -- not needed, and they are all the same.	Noted and revised	Column removed.
44	pg 45	But you extended this to 25 years, right? Is the 20 years a left-over from your previous analysis before extending back 5 more years, or is there an error here?	Noted and revised	Text revised to clarify that 22 to 26 years of data was used in the calibration of winter forecast equations.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
NOAA/Domingue				
1	General comment	In part, these revisions were forced by the discontinuation of data collection at several stations in the previous model (2004 model). Given that it is costly to construct new models each time an entity discontinues operation of a hydro-meteorological station, the Corps should make efforts to ensure continuity of data collection at each of the stations included in each monthly model. At a minimum, this effort should include alerting the agencies that operate each site of the importance of the continued operation of the facility to populate the models. The author (Randal Wortman) did a laudable job of collecting available data.	Noted.	No action required.
2	General comment	In general, the 2010 model-generated estimates conform more closely with actual runoff than the 2004 model-generated estimates, improving confidence in the runoff estimates.	Noted and discussed.	The model development and calibration process did not include 2010 data. The 2010 forecast was generated late in 2010 after the equations had been finalized.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
3	General comment	The author also identified a significant difference in runoff means between the periods 1929-1947, 1948-1974, and 1975-2009, with the mean of the 1948-1974 period being significantly higher than the other two periods. As there are no significant developments in the upper Kootenai River watershed to explain this disparity, the cause is unknown. I agree with the authors, this observation is quite interesting and adds an element of uncertainty to runoff prediction (e.g. would a model developed on data exclusively from one of these periods be skillful in predicting runoff in another?). As clearly stated by the author, further investigation of this phenomenon is beyond the scope of the issue at hand, but the observation should be shared with the academic community to encourage further investigation.	Noted.	No action required.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
4	General comment	There is evidence that the models are slightly biased to the high side, particularly for November and December. For example, in Appendix G, the Corps presents graphics comparing the model results for the 2004 model, the 2010 model, and actual measured runoff for the 35 years between 1975 and 2010. For the month of November (the first monthly prediction) the 2010 model prediction was lower than the actual runoff in 13 of 35 years and at or above actual runoff in 22 of 35 years. This is likely due to the fact that a broad range of residuals are possible on the upside, but are limited by base flow on the low side and a single high residual can drive the regression fit upward. To thoroughly investigate this tendency, we recommend that the Corps conduct a residual analysis. One would not expect the residuals to be normally distributed, due to the bounds issue discussed above, but a severe skew would suggest that one or two large, positive residuals are overly influencing the model.(e.g. high Cook's distance) and culling such outliers may be in order to achieve a better fit. This bias is most notable in the November and December models where the prediction errors are greatest.	Noted and investigated further, revised Table 3.	Note that the equations and coefficients have been revised between the draft equations reviewed and the final equations and the resulting forecasts have changed slightly. The author disagrees with the reviewers analysis on several points: 1) the ordinary-least-squares regression analysis used in this study is designed to produced unbiased estimates, 2) 1-November forecasts are of minor importance and are thus a poor choice for review, 3) the reviewer bundled counts of forecasts "at" (i.e. near observed) in with "above actual runoff" (this biased the resulting counts!), and 4) the sample set is not large enought to derive any conclusions about the distribution ("normal", "skewed") of the residuals. A reanalysis of the 1-Nov forecasts using the final equations shows 15 forecasts below observed flows, 6 about the same, and 15 above observed flows. The concern with statistical bias appears unfounded. A statistical analysis of the 1-Nov residuals shows a skewness of -0.07 (basically 0.0), and for 1-Dec residuals a skewness of -0.11, thus the concern with the distribution of residuals appears unfounded for these issue dates. Additional residual analysis performed by the author shows the largest residual value skews to all be approximately -1.0, for the issue dates of 1-Apr, 1-May, and 1-Jun. The negative skews (representing cases of forecasting runoff less than observed) are the opposite of the reviewers stated concern. **Skewness values were added to Table 3, page 9.**The author would be wary about culling the data unless statistically justified.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
CRITFC/Heinith, Dittmer				
1	General comment	The work has been detailed and thoroughly sorted. The improvement in the performance for the pre-season period (Nov.-Dec.) is most promising and we hope the Corps proceeds to test the new procedures for this upcoming water year.	Noted	No action required.
2	General comment	We offer one comment. Although the summary of the average model performance is good, it would be highly desirable to break-out the performance according to ENSO-year classification. More water managers are modifying their operations based upon an El Niño, La Niña, or ENSO-Neutral year determination. One could go to the CIG website to see the differing ENSO years:http://cses.washington.edu/cig/pnwc/compensopdo.shtml#pdoensoyears . It would be very interesting to see how the performance would be in these categories.	Noted and revised.	The author agrees with the reviewers' comment, in general. The author agrees that there is potential for additional insights to be derived from a classification analysis based on ENSO years, but is hesitant to recommend operational decisions be based on the suggested analysis due to the extremely small sample sizes involved. The reviewers recommendation has been added to the list of recommendations for future work efforts.
3	General comment	Also, it is not clear what historic years were used - that information should be stated in the final report.	Noted and discussed.	The years used for each issue date calibration are already provided in in Appendix E - Principal Component Regression Models.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
USACE/NWS-Reese, Giovando, Fenolio				
1	General comment	Jeremy has many Alberta data sets going back to the mid-80s - please get with him to confirm you have all the data possible for these sites. Also, have you verified with Alberta there are no other sites in SW AB? If needed, Jeremy can contact a colleague for Alberta Environment to verify.	Noted and extensively revised.	The follow-up with Alberta Environment resulted in their sending me all the data for the 8 pillow sites. Several weeks additional work was required to fill in the missing data and work on new forecast models. A new set of forecast equations was developed and included in the 2nd report draft, but these equations were eventually abandoned during/after the technical review determined that too much attention was being paid to micromanaging the stations to be included and not enough to maintaining station consistency. New equations were fit after giving up on using S. Racehorse Creek, AB. Utilizing the additional Alberta snow data allowed the record in the resulting models to be extended 2 to 5 years.
2	General comment	What is the incremental correlation improvement having a climatic variable in the April-June forecast?	Noted and discussed.	First, the incremental correlation improvement would be entirely dependent on which climate variable is added to which forecast equation. Note that we don't have an April-June forecast as a dependent variable; does the reviewer mean a forecast during the April-June issue dates? The models presented for review included two climate variables (QBO and PNA) during each of the 1-Apr, 1-May and 1-Jun issue dates, so it is not clear on what the reviewer is addressing. Second, an incremental improvement in correlation is not the desired statistical metric for determining whether or not a variable should be included in pool of predictor variables. The NRCS REG software used in this study provides a statistically sound method for pursuing and evaluating predictor variables. An analysis of the "worth" of the PNA variable, using the RMSE statistic as the metric, in units of KAF, provides the following results for the 1-Apr, 1-May and 1-Jun equations, with and without the PNA variable: RMSE WithPNA w/o PNA 1-Apr 502 532 (diff. of 30 KAF) 1-May 468 514 (diff of 46 KAF) 1-Jun 380 440 (diff of 60 KAF) Not a huge change/improvement; but using PNA shows a consistent improvement.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
3	General comment	Please discuss why Snotel sites are dropped from the May equation? Many of those sites usually still have snow 01 May.	Noted and discussed.	It is correct that if a snow station predominately containing zeros (no snow) it is not particularly useful as a predictor variable (this eliminates several snow sites from consideration on 1-June). For all the other issue dates, including 1-Jun, the presence of snow is not a factor in variable selection. Predictor variables are primarily determined using the near-optimal branch-and-bound procedures of the NRCS REG program. This is where one can benefit from taking a step back and pondering how the statistical regression model works... The regression model makes use of the *variation* in the input data (if the input variable is a constant, it is useless; if it varies quite closely with the dependent variable then the input variable is quite useful; if multiple input variables show approximately the same variation, several are redundant and should be discarded!) For statistical parsimony (a $10 word!) we want to include variables that contribute to improving the prediction (and discard those that don't). Part of the process will involve some statistical tests on whether to keep a variable or not. In our modeling we are using principal components analysis to provide weighted combinations of observed variables to capture the all the variability in one or two PC variables.In summary "stations 1-Apr equations are dropped from the 1-May equations because their data show a variability that does follow the dependent variable data".
4	General comment	Is there a way to know more about the details of each data site used in the forecast? Many times understanding geographic location, canopy conditions, aspect, etc. can help when choosing the best sites (especially a good diversity in sites).	Noted and discussed.	The maps in Figures 3, 4, and 5 provide the geographic locations of the precipitation and snow stations. Table 7 provides significant metadata (latitude, longitud, elevation) for the significantly correlated snow stations. The statistical modeling methods don't care about these metadata. Variables selection occurs through a rigorous statistical process based on trying to find a correspondence in variation between the predictor variables and the dependent variable (i.e. when the value of X increases a given amount, the dependent variable increases a proportionate amount).

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
5		What is the correlation of precipitation sums used in the equation to the water supply forecast? It seems that precipitation is a heavy factor for this forecast equation, and it seems, especially, that the fall precipitation component in the previous one gave us trouble. I believe the methodology in the proposed equation, having the fall precipitation values drop off as you march through the year, is better than the equation we have been using.	Noted.	The author can compute the correlations if you want. I generally calculate several precipitation sums of various durations and combinations and then let the statistical models advise me as to which variables are generally most useful.
6	General comment	Because so much of refill at Libby depends on accurate forecasts, we would like to have as much flexibility as possible to review and coordinate the forecast, especially the May water supply forecast which determines the volume of water that must be provided for sturgeon. What flexibility does this equation have? What if one of the values is missing, can we recompute the coefficients? The NRCS has their VIPER spreadsheet model to compute the best correlations for a given month on the fly. They probably would be willing to give us a copy.	Noted and discussed.	The author totally agrees and concurs that we need to coordinate more closely with the NRCS and look at their VIPER model. We do not have any flexibility in our current approach. The reviewers desire is already included as item #5, page 19, in the list of recommended future work efforts. Additional text added to clarify that the procedures used in this study closely follow the guidelines in the NRCW water supply forecasting program.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
7	General comment	For the same reason, would it be worth the effort to have several forecast equations that can be used when climatic/SNOTEL sites are at a given level or percent of average (for example one set of equations for low snow pack, another for high snowpack). Given that in dry years the current equation has a tendency to over-forecast by more than one MAF, this type of procedure could be considered as an alternative.	Noted and revised.	The author agrees. It would be of definite benefit to look at "classification" modeling (low elev snow, El Nino, PDO, etc), but are quite hampered by limited years of data. There are some approaches that we could look at - we can discuss. Future work items #8, #9 and (new) #10 attempt to address this issue.
8	General comment	NWW uses simple linear regression for just SNOTEL sites in the Clearwater basin. The testing of sensitivity has shown during median inflow years the PCA and LR are very close. The main difference is in the high or low years. The advantage of the LR is we can run it on a daily basis, which for a year like this one proved valuable. The LR showed the volume forecast increase 2 wks before the PCA forecast could be used.	Noted and discussed.	The author disagrees. Given the same set of predictor variables, the LR and PCA have the same capability to produce a forecast on any given schedule (the NRCS runs their PCA VIPER model daily!). The PCA and LR models may very well produce similar results, sometimes, but, if the predictor variables are bringing similar information into the regression model (i.e. multiple snow variables) then standard statistical tests will demonstrate that the LR model is using variables that don't belong in the model. The LR model can have unreliable goodness-of-fit statistics and over-sensitive regression coefficients. I'll be glad to discuss, or look over and compare various models.
9	pg 3	Add text: ", set minimum Spring and Summer flow for bull trout, and determine the volume to be provided for sturgeon pulse, up to 1.6 million acre-feet each Spring. "	Noted and revised.	Text was revised.
10	pg 6	Please add from which months [for precipitation variables and snow variables]	Noted and discussed.	"Which months" are discussed in detail in the appropriate section for each variable type.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
11	pg 8 - Table 1	What was the reason for not using inflow sooner?	Noted and discussed.	Jan, Feb and Mar inflows are quite small and the variation in the monthly flow value has very little correlation to the seasonal volume. In the final equations, the observed flows are not used as predictor variables, but only to complement the "Date-to-August" value to enable computation of an April-August volume.
12	pg 8 - Table 3	Any thoughts on why this [CVSE value] increases?	Noted and discussed.	The equations and coefficients have been revised between the draft equations reviewed and the final equations, with the resulting CVSE statistics differing from those reviewed. The final models have similar issues as the reviewer noted. The Standard Error (RMSE) and CVSE are quite flat from the 1-Feb forecast forward. It is quite difficult to find a model that uses mostly the same variable pool ("consistency") and also shows improvement in these statistics. You can usually show an improvement if you start adding or deleting variables, but then you lose the "consistency". These concerns of consistency and accuracy received considerable discussion during the independent technical review, with the consensus of the reviewers that variable and forecast consistency should receive priority consideration over forecast accuracy (CVSE and SE statistics). The technical reviewers concurred that the temporary increase in CVSE and/or SE was within the "noise" range of the data and models and was acceptable.
13	pg 9	Add bullet for "Performance of the equation in real-time operations" (?)	Noted and discussed.	the author didn't address performance in real-time operations, except in relation to the availability of climatic variables (as there is frequently a lag of a month or more before their value is published). Related to comment by Amy, page 13.
14	pg 13	Is there a header missing here?	Noted and discussed.	No - just an abrupt introduction.
15	pg 15	We are hoping we can incorporate more flexibility into our forecast to adjust for this sad fact…	Noted.	
16	pg 15	The data I have from Alberta goes back to the mid-80s for most of the sites.	Noted and revised.	Addressed in comment #1 of this section.
17	pg 17	It would be good to have some graphs indicating how the new equation did compared to observed.	Noted and revised.	Added as Appendix G - Comparison of Observed and Monthly Forecasts from 2004 and 2010 models.

Comm ent #	Location	Reviewer's Comment	Disposition	Author's Response
18	pg 17	Should at least provide a summary of the difference in RMSE improvement or comparison to the 2004 equation.	Noted and discussed.	Appendix D provides this comparison.
19	pg 18	Can we start with what you've developed?	Noted and discussed.	This could easily be funded as a work item.
USACE/NWS				
1	pg 2	When we start using this forecast in the near future – I (Joel) will need to answer stakeholder questions on the forecasts so I want to make sure I understand this... Could you give me the detail to understand: How this forecast is improved with the inclusion of this variable relative to not including it?	Noted and discussed.	The forecast error (as measured by the RMSE) is consistently smaller when the QBO is used. See response to comment #2 (discussing PNA) in the previous section.
2	pg 7 - Table 1	Please document the precip correlations (as you did the SNOTEL correlations)	Noted and discussed.	The precipitation correlations were more complicated as there were multiple durations of "accumulated" precipitation over several possible durations to consider. The author did not calculate the correlations for all of the accumulated precipitation variables (as was done with the first-of-month SWE data); I instead let the NRCS REG program examine the correlation and performance statistic for each precipitation variable to determine which ones were most useful to the forecast model.
3	pg 25	I don't consider this a good correlation for late winter-spring forecasts.	Noted and discussed.	Although when considered by itself, a correlation value less than 0.4 would be of dubious interest, in comparison with any of the 720 candidate climate variables, any value over .35 appeared significant (independent work has confirmed that these are statistically significant correlation values). Of more importance than strict "correlation" is the question of whether the values tracked by these variables bring any "variation" information not represented by the other moisture input variables.
4	pg 36	I want to see correlation statistics associated with the precip stations and months chosen for each forecast.	Noted and discussed.	Please refer to response provided to comment #2, above.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
BPA/McManamon, along with Frank Weber, BC Hydro				
1	pg 1	Add basic parameters of the watershed to the introduction such as drainage are and elevation range	Noted and revised	These parameters have been added.
2	pg 1	Please provide rationale for using April-Aug rather than some other period.	Noted and discussed.	The Corps of Engineers is the operating agency for this project and they have chosen to use April-August as their runoff period on which to base operations. This period captures the very significant snowmelt driven runoff from the project that drives decisions on fishery releases, refill, and flood control space.
3	pg 2	This is most likely correlated with the PDO.	Noted and revised.	Agreed. Text substantially revised to acknowledge and discuss the relationship to PDO.
4	pg 3	I'm also concerned about changing the POR for these equations and the consistency from month to month.	Noted and revised.	The author shares the reviewers concern about the period of record (POR) and the month to month forecast consistency. The POR changes with every update, usually by adding on the most recent years of data, and occasionally by extending the record for earlier years by being able to fill in missing data. After discussion with Seattle District and others it was agreed to focus on the POR from 1974 forward for reasons detailed in the section *Non-Stationarity of the Libby Dam inflow series* (pages 10 and 11) and in Appendix F. In the development of the final equations (performed after this review) extra effort was been directed toward maximizing month-to-month consistency, which necessitated sacrificing forecast performance in some springtime months. These priorities were a consensus among the author and the technical review team members.
5	pg 4	Antecedent flow was also used as a predictor variable	Noted and discussed.	The reviewer is correct, per the draft report provided. The final equations developed subsequent to that draft report do not use antecedent flow as a predictor variable.
6	pg 5	Replace "1-November" with "1-October"	Noted and discussed.	The reviewer is correct, per the draft report provided. The equations and coefficients have been revised between the draft equations reviewed and the final equations. All references to a 1-Oct issue have been removed. A 1-Oct issue date is not included in the Libby water supply forecast model.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
7	pg 5	Clearly list the criteria used for forecast model development: including but not limited to minimizing CVSE, month-to-month consistency of models, conceptual design of the model structure, forecast period is April-August, early season forecasts stating in October and possibility of manual forecast updating	Noted and revised.	The criteria used for the forecast development is a combination of objective and subjective criteria, as discussed in the noted references (Garen,1992 and 2004; Wortman, 1990 and 2004). An additional reference to Garen, 2004 was added to the text. Conceptual design of the model structure is discussed in the introductory paragraph in *Statistical Forecast Equations* on page 4. Additional references to the NRCS Water Supply Forecasting Program and techniques (NRSC 2007 and 2010) were added. Forecast period of AprAug and October forecast issue date is address in responses #2 and #6, above. An additional page of material was added to page 6 to address this request.
8	pg 5	Since (i) the precipitation type in October is more variable than in the core winter months and (ii) October precipitation can be thought to be conceptually somewhat different from winter precipitation – it partially determines fall soil moisture levels - I found it useful to separate October precipitation from winter precipitation. This way, the forecaster can manually override the term if deemed necessary in a given year.	Noted and discussed.	The author agrees with the reviewer's concepts of fall and winter precipitation. In testing the statistical value of various ways to combine monthly precipitation values, or not, a variable retaining the accumulated precipitation from October through issue-date provided the best forecast up through the 1-March issue date. Dropping out the Fall precipitation data began improving the forecasts beginning with 1-April. Additional work could yet be performed to look more closely at handling October precipitation as a separate variable.The Corps operational concepts (which I believe tie in closely with Treaty requirements) do not permit us to consider "manually overriding" an equation or procedure which has been approved for operational use by the Treaty Operating Committee. Such an operation would invalidate any use of confidence intervals on the forecast.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
9	pg 5	In recent years, October precipitation has frequently been rain, while the Nov-Dec precip has been snow. Oct precip may add to the overall Apr-Aug volume by contributing to the antecedent conditions, but I'm concerned about lumping the two separate conceptual mechanisms together into a single value. Especially with the shortened period of record.	Noted	See response to comment #8, above. Additional work could be performed to look more closely at handling October precipitation as a separate variable.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
10	pg 6	Adam’s work (you have the report) showed that the runoff response to climate modes is generally non-linear (see one of his slides below). We concluded that PC Regression is therefore not the optimal tool to make use of climate indices-runoff relationships, specifically for early season ‘outlooks’. In fact, we have had very mixed results with our existing early season outlooks that are more heavily affected by climate information. Although we have not looked into this in detail, I have a feeling that it may partially be due to the linearity assumption in the PC Regression models. So, you may want to provide a review of statistical modeling techniques and justify the use of PC Regression in the context of other available techniques, such as non-linear modeling techniques (e.g., Neural Networks) or even consider using non-linear techniques.	Noted and discussed. Minor revision added.	The author has great respect for Dr. Gobena's work with climate variables and water supply, however the author does not believe that the referenced time series plots of runoff volume superimposed with ENSO categories should be interpreted to derive the conclusion that climate modes are generally non-linear and that linear models may be questionable for water supply forecasting. A scatter plot of each predictor variable against the dependent variable is more useful for subjective examination of the linearity relationship than the time series plot shown, and the scatter plots do suggest that the predictor variables are useful. In all of the linear modeling efforts in water supply forecasting (whether in standard variable space or principal component space) the predictor variables undergo a significance test at the 95% confidence level to verify that each and every predictor is statistically significant . All the predictor variables in all the PC regression models used in the Libby WSF as statistically significant (which is the underlying reason why the equations for several issue dates have 1 PC, and some have 2 PCs - only the statistically significant PCs are retained).Use of linear regression models, both standard and principal components, is well established in the peer-reviewed literature and supported by the other members of the independent technical review. Use of non-linear models, including neural net and other types, may offer improvements over linear modeling, but there has been no definitive work to date verifying their capabilities. An additional item has been added to the "recommended future work" section to include consideration for neural net and other non-linear models.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
11	pg 6	Is there a set of equations that use the same stations throughout the forecast cycle? Do they provide adequate statistical validation? There may be greater consistency in forecast from month to month if the same stations input is tracked during the entire cycle, rather than dropping out.	Noted, discussed, and revised.	There are several layers to the discussion regarding using the same stations for all issue dates throughout the forecast cycle. It should be obvious that there is a seasonality whereby stations have more or less significance (1-Nov and 1-Jun values at most snow stations are typically zeros and less than useful; climate variables are distinctly seasonal). Snow and precip variables also show some months are better than others for their variability to correspond to the runoff volume, and other months were the variability in the data from the same station adds noise. The use of a fixed set of stations throughout the forecast season results in degraded forecast performance due to this extra noise. The equations and coefficients have been revised between the draft equations reviewed and the final equations. In the development of the final equations (performed after this review) extra effort was been directed toward maximizing month-to-month consistency, which necessitated sacrificing forecast performance in some springtime months. These priorities were a consensus among the author and the technical review team members.
12	pg 7 - Table 1	1) Consistency? All the other snow sites use the June 1 value. Or is this a typo and should read June?	Noted, discussed, and revised.	No, the version of the equations provided for review found that the East Creek 1-May snow value had more significance to the forecast and provided increased forecast accuracy than using a 1-June value for this or any additional station. The equations and coefficients have been revised between the draft equations reviewed and the final equations. The issue noted is not part of the final equations.
13	pg 7 - Table 1	2) If it should read June, I have some concern that the June snow pack might not be indicative of the overall volume for Apr-Aug, and that perhaps you might have better luck with holding the May swe value instead of using the June 1 value.	Noted and discussed.	Please refer to response provided to comment #12, above.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
14	pg 7 - Table 2	provide a table of the contribution of individual predictor variables to the total water supply for normal conditions	Noted and discussed.	The author agrees that these "marginal" values for the original variables (rather than the PC predictor variables) provide useful information. The marginal values will be calculated and available on the forecast computation sheets on the Corps' web site (as they are now). The author does not understand the reviewer's reference to "for normal conditions" in this context.
15	pg 8 - Table 3	I find it problematic to use a different number of years for the development of water supply forecast models for the Oct to Dec and Jan to Jun forecast dates. This can introduce a jump in the forecast from the December to the January forecast date	Noted and discussed. Partially addressed.	It has always been an issue that there is not a consistent, continuous record for all data types of interest (climate, precipitation, snow and streamflow), and as discussed extensively throughout this report, there remain considerable gaps and challenges in the precipitation and snow records. This author has worked with the NRCS and other agencies to fill in the data record to the maximum extent possible while maintaining statistically sound methods in the estimation processes. The author believes it would be quite harmful to the forecasting performance to restrict the variables to the set with precisely concurrent years - the variable with the least years defines a window that forces truncation of a lot of potentially useful data. Although the equations and coefficients have been revised between the draft equations reviewed and the final equations, the reviewer's concerns can also apply to the final equations.
16	pg 8 - Table 3	Why aren't we just as well off to use the median value instead of the Oct and Nov equations? It doesn't appear that they provide much information. And it looks like there are 3 different periods of record…. Is 26 correct for the May1 and June1 forecast issue dates?	Noted and discussed.	As previously discussed, the 1-Oct issue data presented in the review draft has been abandoned. The author's understanding is that the median of the historic runoff volume (which years of record?) would be used in lieu of a 1-Oct forecast. The 1-November forecast adds an improvement over the median value. The RMSE using the Average and the Median for the 1-Nov forecast are 1295 and 1298, respectively (essentially identical). The RMSE of the 1-Nov PC regression forecast is 1085 (the same as the standard error presented in Table 3). This is a 16% reduction in the standard error, which, while not huge, is a distinct improvement over using the median value.Yes, the Alberta snow stations began recording late spring data (1-May and 1-Jun) in the year that they were installed, providing an extra "year" in the record when compared with the earlier spring issue dates.

Comm ent #	Location	Reviewer's Comment	Disposition	Author's Response
17	pg 8 - Table 4	Can we make sure this data is going to be available before the equations get approved.	Noted and discussed.	The note at the bottom of Table 4 (where this comment was located) was provided in an attempt to address this very question. Stephanie Smith indicates that she does not foresee a problem with making the arrangements for BC Hydro to obtain the data from Alberta. Unfortunately, as is well known and discussed in several sections of this paper, unanticipated circumstances routinely alter the situation and expected data become unavailable. It would be expected that the Treaty Hydromet Data Committee could facilitate additional agreements to secure continuing availability of this and other forecast data in support of Treaty operations.
18	pg 9	Please note that the Libby Dam inflow data used are composed of estimated natural streamflow and inflow-available-for-outflow. If net evaporation changes since the construction of the reservoir are 'significant' this would result in an instationarity in the data record. Also see my comments below. One possible solution might be using the long-term Modified Flow record and work backwards by removing losses from lake evaporation from the entire record. You may want to explore that. Additionally, you may want to use this fact as another argument to use only flow data starting with the LBY operation, i.e., starting in 1970.	Noted and discussed.	The author provides a summary of the inflow calculations and measurements on the referenced page, with many more details provided in Appendix F - Libby Dam Inflow. The author concurs with the reviewer and similarly recommends that the Modified Flows be considered as the official flows of record for pre-project years (Appendix F - conclusion 4). There has been little or no previous discussion distinguishing inflow above the reservoir from inflow-available-for-outflow. Both evaporation (as noted by the reviewer) and bank storage (discussed in previous Libby WSF reports) could be factors effecting the inflow-available-for-outflow. The non-linearity in the post-project portion of the cumulative mass plot provided in Figure 2 suggests that either or both of the above factors (or others not yet identified) could be influencing the seasonal runoff volume. The magnitude of the effect appears to be within the noise range of the data, so it is difficult to determine whether this would be a worthwhile issue for further investigation.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
19	pg 9	This discussion suggests that some QC occurred. See comment in the Recommendations for Future work suggests that QC should be performed. Did you consider checking the seasonal values against the NWS runoff processor? For AER/TSR purposes, that's considered official 'truth' after the fact.	Noted and discussed.	As the reviewer surmised, QC was performed on the daily discharge data retrieved from CROHMS. The author believes that for all intents and purposes the (QC'd) project flows serve, or should serve, as the official outflows of record, and similarly for the inflow values calculated from the project outflow and pool elevations. The author is not familiar with the values in the NWS NWRFC seasonal runoff processor and has not heard that they are considered as the "official" historic values. Note that comment #18 recommends using Modified Flows and comment #19 recommends using Runoff Process flows, and the author recommends using project flows in CROHMS. This could be address as part of the *recommendations for future work efforts*, item #3.
20	pg 14	Punctuation issue	Noted and revised	Text was revised.
21	pg 17	But can this ever be a fair comparison. The 2004 equations were developed for 48-02 and you've just made the case that there has been regime shifts across that period. So the 2004 equations have to try to capture these shifts. By definition, should the equation developed for the more recent forecast period be better than an equation developed for a longer period of record with climate shifts in it?	Noted and discussed.	For clarification, the 2004 equations used various years in it's equations - a period of record from 29 years (1-Jan) to 55 years (1-Nov and 1-Dec), and 43 years for the remaining winter and spring issue dates. The analysis of forecast performance in Appendix D attempts to address the reviewer's question, but the issue remains open for further investigation.
22	pg 18	This suggests that no quality control of the data occurred?	Noted and discussed.	The author cannot state unequivocally that "no quality control of the occurred", rather that quality control was inadequate.
23	pg 18	What's the status of their QC on the historic period? I hear conflicting things.	Noted and discussed.	The reviewer is asking for insights into the status of QC at the NRCS NWCC. This author does not have insight into this issue and the question would be better directed to the NWCC staff.
24	pg 18	What about BC Hydro and the NWS. NRCS aren't the only ones in the water supply forecasting game.	Noted and revised.	Text added as suggested.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
25	pg 18	Typo- change "data" to "date"	Noted and revised	
26	pg 19	Typo - delete "be"	Noted and revised	
27	pg 18	Typo - change "insured" to "assured"	Noted and revised.	
28	pg 19	Recommend added "and QBO" to example	Noted and revised	
29	pg 23	Re-word. How about: What is the shortest aggregation period for climate indices that will result in a smooth transition in the strength of the correlation with seasonal inflow volume throughout the calendar year prior to the target period	Noted and revised	Text revised as suggested.
30	pg 24	Please elaborate why R=0.25 was chosen as cut-off between significant and not-significant	Noted and discussed	The author recognizes that a subjective value was used, rather than a specific statistical test at a standard level of significance. The author's subjective level of significance (0.33), summarized on Table 8, appears to be in close agreement with the 95% significance level for 29 years of data (0.367), as published by Gobena (from the reviewer's office) in a similar analysis. The author's value was merely used as a screening tool, with a lower value allowing for the possibility of including additional climate variables.
31	App. B	Consider renaming the title to Pre-screening of Precipitation Data	Noted and revised	
32	App. C	I suggest renaming the title to: Pre-screening of Snow Water Equivalent Data	Noted and revised	
33	pg 42	Revise Figure number	Noted.	Figure numbers have changed during revision and have been corrected.
34	pg 44	Which period of record does this statement suggest should be used? 20?	Noted and discussed.	This statement does not make a suggestion on a period of record to be used, but rather implies a consequence related to one's choice of POR.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
35	p g45	Is this actually due to the Alberta pillows, or to the change in climate regime?	Noted and discussed.	The author recommends against interpreting the relationship between the variables and the results as "causal". The analysis is based on statistical methods and criteria and is not a conceptual model.
36	App E.	The observed column shows decimal places which are not used in the tables following. I'd suggest for consistency sake to change these to whole numbers also.	Noted and discussed.	The author has limited control over the numbers produced by the statistical modeling software. The author would prefer that all seasonal volumes be rounded to units (as the observed flow data is presented); however, previous interactions with the Treaty Operating Committee and BPA have involved requests for three significant decimal figures. As such, and against better judgment, the author attempted to provide all figures involving either statistics and coefficients to 3 decimal places.
BC Hydro/Frank Weber				
1	General comment	Can you please explain in the report why you only used snow pillows? You mention mid-month forecast updates, for instance.	Noted and discussed.	The use of snow pillows allows for more expedient calculation of the forecast and also allows for the forecasters to be able to track the forecast throughout the month, which has some significant challenges if the forecast equations are working strictly with first-of-month SWE data. The author's desire was to see how far we could go (could we equal or exceed our existing model?), if we worked with snow pillow stations for the new equations.
2	Fig 7, 8 and 9	Slides 16, 17 & 18: also plot the RMSE of a naïve climatological forecast for reference, as that is what you want to beat.	Noted and discussed.	The referenced slides are from the ITR web-meeting presentation and are equivalent to Figures 7, 8 and 9 in the report.(This is similar to comment #16 from you or Ann in the BPA section)The RMSE using the Average and the Median (two alternatives for the naive forecast) forecast are 1295 and 1298, respectively (essentially identical) for the 35 years used in the 1-Nov and 1-Dec forecast. The RMSE of the recommended equations are the Model Std Error values from Table 3 (e.g. 1-Nov PC regression forecast is 1085).The author prefers to not present a uniform value representing the naive forecast on Figures 7, 8 and 9 and has provided the values to the reviewer for consideration.
3	General comment	Describe the motivation for the model redevelopment at the beginning of the document	Noted and revised	New study objectives text added at beginning of Executive Summary.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
4	pg 2	Replace ‘(e.g. May-Jul volume)’ with ‘(e.g., May-Aug volume)	Noted and revised	
5	pg 16 - Table 7	Table 7: In the header replace the term 'Snotel' with 'Observation Type' and then describe them as 'Snow Survey' or 'Snow Pillow'	Noted and revised.	Column header relabeled to "Snow-Course or Pillow"
6	pg 17	Change quality assured to quality controlled; QA are measures put in place before data are being collected to assure the data will be accurate & precise, while QC is the process of validating collected data.	Noted and revised.	Delete references to QA, retaining QC (quality control)
7	pg 18	I recommend listing the steps and techniques for quality control	Noted and revised.	The steps and techniques for quality control of the data are outside the scope of this water supply forecasting study, but would be essential as part of the recommended work effort #1 and #2.
8	Fig. 3 & 5	Please provide a legend and label the drainage basin	Noted and revised.	A label for the basin has been added. Legends were added.
9	Fig 6 & 7	Axis labels are not legible	Noted and revised.	Font size increased to 12 point.
10	pg 44	Revise: 'This suggests that the most recent 20 years represent a sample set with somewhat different characteristics than the calibration set sample, possibly showing a greater variability and/or changes in the central tendency compared to the calibration set sample.	Noted and revised	
11	pg 64	Remove 'all abbreviations are mine'	Noted and revised	

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
12	pg 65	What is the uncertainty measure of +/-5% based on? Please elaborate and provide evidence.	Noted and discussed	The author believes the +/- 5% estimate to be quite generous. The author understands that estimates of discharge using standard streamflow rating curve techniques is considered accurate to +/- 5%, but up to 10% is still considered reasonable. The pre-project values previously used were based on upstream stream gage values being further extrapolated based on proportions of basin area (pg 64).
13	pg 65	Please elaborate on the impact of irrigation on Libby Modified Flows.	Noted and discussed	The author is aware that Modified Flow computations may include an irrigation adjustment; however, Modified Flows are not directly used in this Libby WSF study, except as one of several series reviewed for stationarity. The author is not familiar with the irrigation adjustment, if any, for the Libby Modified Flows, and will leave this to be addressed by those whose work involves this data.
BC Hydro/Adam Gobena				
1	App A	For those projects, the QBO is not statistically significantly correlated to F_S inflow volume.	Noted and discussed	Consolidated response to comments 1-3: Reviewer used a 3-month sum (or average, it doesn't make a difference to the correlations). I looked at 1-month to 6-month sums, with 1, 2, and 3-month sums starting in January being the best. For a given duration, the correlation plot for most of the climate variables is somewhat jagged, and usually improves in smoothness as the duration increases. In my analysis QBO and ONI are the exceptions, with every duration down to 1-month showing a smooth transition from one month to the next. This is quite unexpected. Mica, Arrow, and Duncan all show a somewhat similar response (somewhat parallel, differing in magnitude). Kootenay Local displays a different behavior than these other three (as do all the other projects in the plot). The East Kootenay (Libby) basin is not shown. As your plot shows, which basin is being looked at makes a remarkable difference. This is extremely significant!

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
2	App A	The MEI is overall superior in its predictive power to the QBO (both in the strength of the correlation as well as in the significance of the correlation).	Noted and discussed	Consolidated response to comments 1-3 (continued):On reviewer's plot, the best correlations for QBO for JFM (among the best) come from Duncan and Kootenay Local. The East Kootenay (Libby) basin is not shown.For any of the 9 basins shown, looking at the winter signals (JFM, FMA, MAM), QBO shows a greater correlation with Kootenay Local than with any other basin. Correlations for the East Kootenay (Libby) basin are not shown.Reviewer provides a 5% significance interval of +/- 0.367. My Feb (1-month) and JF (2-month) QBO correlation therefore both qualify as significant. My chosen JFM (3-month) correlation at -.356 barely misses the cutoff. I don't know if the extra 5 years of sample size would change the interval a smidgen as I didn't calculate the confidence intervals). It's very close for 3-month, and qualifies for 1 and 2 month sums.The author shows distinctly different results than the reviewer for the MEI correlations. For the East Kootenay (Libby) basin the MEI signal is very consistent and shows a poor correlation with Libby runoff (the largest correlation being a quite insignificant -0.237). MEI does not appear to be at all significant for the Libby basin. Author's conclusions: 1. Your Duncan and Kootenay Local plots for QBO are similar to my East Kootenay plot, however I am showing a stronger (and significant) correlation than in the basins you examined. 2. In my analysis, the MEI variable does not show any useful correlation with Libby Apr-Aug runoff. 3. Your analysis shows a very strong variety of responses from the different basins. I would be cautious about extrapolating the results of your analysis to draw any conclusion about the East Kootenay basin.

Comment #	Location	Reviewer's Comment	Disposition	Author's Response
3	App A	Correlations of opposite signs with QBO of the two winters preceding the runoff season could be indicative of the strongly periodic pattern of QBO. Note that the QBO cycle is ~ 28 months, so the existence of a plausible physical explanation for the ~ 14 month lead indicated in the Libby study other than the cyclic nature of the QBO is highly unlikely.	Noted and discussed	Consolidated response to comments 1-3: The author has no strong tie to using the QBO in the Libby WSF, except for the significance of the variable to the forecast. Earlier in the process I manually constructed alternate models with the “best” equations, but dropping out QBO, and every equation showed an consistent increase in the forecast standard error of about 5% (up to 9% as I recall). I can revise the equations to eliminate QBO, however QBO appears to bring something to the table to help with the forecast. **Subsequent analysis (Composite Analysis of Large-Scale Circulation Data) by reviewer has demonstrated sufficient evidence relating the QBO variable and the Libby inflow volume so that the reviewer recommends keeping the QBO variable in the equations.**
4	App A	The intent of [our] analysis was to check whether we had missed the QBO as an important climate index in his Teleconnections Analysis. Consequently, we only analyzed BC Hydro inflow data. The results were not intended to be transferrable to the Libby watershed, but complementary.Rather than deterring you from using the QBO for WSF models, I hope that this discussion can shed some more light on the relatively poorlyunderstood role of climate indices in WSF model development.	Noted.	

Appendix I. Details of the 2011 Update to the 2010 Revision

In January 2011, subsequent to the approval of the equations in the 2010 revision, the NOAA Climate Prediction Center announced that they were publishing new “historic” datasets for many of their climate variables. Included in the updates were new “historic” values for the MEI, SOI, PNA and WP indices calculated using new 30-year climate normals based on 1981-2010 weather. As the 2010 Libby water supply forecast equations were calibrated using SOI and PNA values from the earlier database (based on 1971-2000 climate) it was necessary to revalidate the climate variables and to recalibrate the model coefficients using the revised climate variables values.

Since the model recalibration for the climate variables was occurring during early 2011, the dataset for the calibration was extended one additional year to now include all the data from water year 2010. Forecasts were generated using the new equations (Table 2, page 8) and new forecast model statistics (Table 3, page 9) were calculated.

This new model and the related forecasts will be referenced as the “2011 Model” and “2011 Equations”.

The following tables and figures were updated to reflect the new climate data, the new equations, and the new forecasts:

Table 2 – Regression Coefficients for the Libby WSF model

Table 3 – Libby WSF model statistics

Table 5 – Best Climate Index Variables

Appendix A: Correlation Analysis of Climate Index Variables

Table 8 – Best correlations between climate variables and Libby inflow

Climate Index correlation charts (10 pages of charts)

Appendix D: Comparison of Model Performance Statistics

Figure 9 – Performance statistics of 2004, 2010, and 2011 Libby WSF models compared

Appendix E: Principal Components Regression Models

Entirely new equations and forecasts (16 pages)

Appendix G: Comparison of Observe and Monthly Forecasts from 2004 and 2011 Models

Entirely new charts comparing the 2004 forecasts and new 2011 model forecasts (36 charts)

Minor edits were made throughout the report in an attempt to reflect the additional year in the calibration dataset.