Appendix 8
Water Supply Forecasts, Hedges, and Distributions

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1. Early Season Water Supply Forecasts:

The following December forecast procedures have been approved by the Columbia River Treaty Operating Committee (CRTOC) for some Treaty purposes:

Dworshak	April-July volume
Libby	April-August volume
Mica	January-September, January-July and April-August volumes
Arrow (total)	January-September, January-July and April-August volumes
Duncan	January-September, January-July and April-August volumes
The Dalles	January-July, April-July and April-August volumes

For all other forecasts required for early-season purposes or outside the water supply forecast season (July through November), the median volume from the most recently adopted modified flow dataset will be used unless otherwise agreed upon by the Columbia River Treaty Hydromet Committee (CRTHC) and the CRTOC. Early-season volume forecasts will not be used in developing monthly streamflows (as described in section 7 below) for the AER/TSR but will be used for all other treaty calculations that require seasonal volumes.

2. Hydrometeorological Adjustments:

From time to time, issues with computation of water supply forecasts or the forecasts for streamflow coordination for the TSR have arisen, e.g. missing data, questionable input values to forecasts, changes to the runoff distributions, or similar hydrometeorological issues. These issues have resulted in the need for in-season adjustments that are difficult to coordinate in real-time. At the 27 September 2019 CRTOC meeting, the CRTOC delegated responsibility to the CRT Hydromet committee to approve these adjustments and then provide documentation of the changes to the CRTOC.

3. Developing January-July Volumes from Statistical Forecast Volume Periods for VECCs:

Whether early-season or within season, calculating the January-July volume forecast period from a different statistical volume forecast period will be done by the following methodology:

3.1 For volume forecasts supplied by BCHydro, the Northwest River Forecast Center and the U.S. Bureau of Reclamation, the January-July volume forecast is provided so no additional computation is required.

3.2 For Libby, the forecast equations produce an April through August volume. To create a January-July volume forecast, the August volume must first be removed and then the January-March volume must be added using the following procedure:

3.2.1 Determine the percent of average the April-August volume forecast is based on the average from the most recently adopted modified flow data set for the same period

3.2.2 Multiply this percentage of the average August volume from the most recently adopted modified flow data set

3.2.3 Subtract this value from the April through August forecast to get an April through July forecast

To add January through March volumes this process should be followed:

a. If an observed streamflow volume is available for January, February, and/or March, then that observed streamflow volume is used for that month.
b. If a streamflow forecast is available for the month the AER/TSR is being produced, then the streamflow forecast is used for that month only.
c. If none-of-the-above are available, then the monthly average streamflow volume from the most recently adopted modified flow data set should be used for each missing month.

The CRTOC agreed at the March 2012 meeting that VECC's for Dworshak are no longer needed.

4. Error Statistics to Be Used for Treaty Purposes:

Under the recommendation of the CRTHC, the CRTOC endorsed using the Cross Validation Standard Error (CVSE), when available, for all Treaty purposes for the respective equations and volume forecast periods.

For volume periods where a forecast equation is available and a CVSE has been computed, the CVSE will be used. In those periods when a forecast procedure is not available, the median volume over the forecast period calculated from the most recently adopted Modified flow record will be used as the forecast. The Root Mean Squared Error (RMSE) around the median seasonal volume will be used as the error statistic.

The RMSE around the median is computed by using the forecast period median as the forecast for each of the years in the most recently adopted Modified flow record. For example, the RMSE around the January-July median is:

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum \quad Jan - Jul\ (Median\ Volume - Observed)^2},$$

where “Observed” is defined as each year’s January-July accumulated volume as published in the most recently adopted modified flow data set.

4.1 Mica, Arrow, and Duncan CVSEs are produced for all forecast periods as part of the Principal Components regression (REG) inflow forecast development (See Attachment 1).

4.2 Libby - For required forecast periods which are created from different forecast periods (i.e. January-July forecast from a April-August forecast), an equivalent CVSE for the Required period will be derived. Attachment 2 presents both the procedures to prepare the January-July and date-July forecasts used to populate Table 1 and the detailed equations used to compute the equivalent CVSEs.

5. Computation of Hedges:

Under the recommendation of the CRTHC, the CRTOC endorsed using the appropriate t-statistic based on the equation's historic sample size for computation of the hedges used to compute the 95% exceedance value. The t-statistic should vary depending on the sample size used to develop the CVSE or RMSE.

Based on the current equations, and their associated sample size, the t-statistics detailed in Table 1-a will be used (the number below each t-statistic is the historic sample size from which the CVSE was developed). For projects where the median volume is used absent an approved volume forecast procedure, the t-statistic for an 80-year record will be used. The hedges to be used to compute the one-sided 95% confidence limit, calculated using the errors and the appropriate t-statistic from above, can be found in Table 1.

6. Monthly Distribution Factors:

The monthly distribution factors will be calculated on most recently adopted modified flow data set for use in TSR streamflow forecast development and coordination and for AOP/DOP applications. Further explanation of the development of the monthly distribution factors can be found in Attachment 3. The monthly distribution factors can be found in Table 2.

7. Development of Streamflow Forecasts for TSR Purposes:

Treaty Storage Regulation (TSR) modeling is done twice a month. Monthly (semi-monthly for April and August) streamflow forecasts are developed through a coordinated process and then submitted by the U.S. Army Corps of Engineers (Corps) and Bonneville Power Administration (BPA) for implementation in TSR/AER modeling. Other parties submit forecasts for their own projects and these forecasts are not coordinated. In order to provide a common methodology and consistency when coordinating streamflows and to provide an opportunity to blend near-term knowledge with long term historic shaping, the following procedures were developed:

7.1 January through June Forecast Season:

7.1.1 First TSR of the Month:

a. The forecast for the current month is coordinated with appropriate organizations or agencies.

b. The residual volume (January-July volume less observed whole months and coordinated forecast for current month when in the January-July timeframe) is shaped using the monthly distribution factors to come up with the remaining monthly streamflow values.

7.1.2 Second TSR of the Month:

a. The forecasts for the remainder of the current month <u>and</u> the following month are coordinated with the appropriate organizations or agencies.

b. The residual volume (January-July volume less observed whole months and coordinated forecasts for current month and subsequent month) is shaped using the monthly distribution factors to come up with the remaining monthly streamflow values.

c. In the month of June, the TSR extends beyond the January-July period and includes the two halves of August. The July monthly values and the August bi-monthly values are based on forecast values that are coordinated between the appropriate organizations and agencies.

7.2 July through December Forecast Season:

7.2.1 First and second TSR of the month:

a. For all months and all projects, the monthly streamflow values are based on the streamflow forecast for the current month and the following month median streamflows that are coordinated between the appropriate organizations and agencies and median streamflows for subsequent months.

Table 1 - Summary of Errors and Hedges

Adopted January 2018	TABLE 1 (ksfd)										
	Summary of Errors and Hedges										
	*During the pre-season period, t(95%) = 1.664 and is applied to the 80-year median standard error for the single-tail 95% exceedance, August - November										
	During the seasonal forecast period, t(95%)=1.696 for Canadian Projects and 1.699 for Libby, and is dependent on the project and the forecast development period										
	80-year record refers to the 2010 Level Modified Flow Study										
	Hedge = Forecast SE x single-tail 95% exceedance t-statistic for Grand Coulee and Hungry Horse,										
	Hedge = Forecast CVSE x single-tail 95% exceedance t-statistic for Mica, Arrow , Duncan, and Libby										
ksfd											
Mica	**Statistic**	**Aug-Nov**	***1-Dec***	***1-Jan***	***1-Feb***	***1-Mar***	***1-Apr***	***1-May***	***1-Jun***	***1-Jul***	***1-Aug***
Jan-Jul 80-yr Volume	80-year Median	4937.4									
Jan-Jul 80-yr Volume	RMSE around the Median	563.4									
Jan-Jul Forecast	CVSE		556.7	509.3							
Date-Jul Forecast	CVSE				442.7	417.0	330.2	292.9	219.0	145.6	
Apr-Aug Forecast	CVSE		569.4	503.2	412.9	371.2	289.1				
Date-Aug Forecast	CVSE							242.4	208.9	191.8	156.8
Hedge (Jan-Jul or date-Jul)	t(95%) x CVSE	**937.5**	**944.1**	**863.8**	**750.8**	**707.2**	**560.0**	**496.7**	**371.5**	**246.9**	
Arrow Total	**Statistic**	**Aug-Nov**	***1-Dec***	***1-Jan***	***1-Feb***	***1-Mar***	***1-Apr***	***1-May***	***1-Jun***	***1-Jul***	***1-Aug***
Jan-Jul 80-yr Volume	80-year Median	10389.9									
Jan-Jul 80-yr Volume	RMSE around the Median	1240.9									
Jan-Jul Forecast	CVSE		1108.5	976.5							
Date-Jul Forecast	CVSE				841.8	801.2	619.1	493.7	382.6	203.1	
Apr-Aug Forecast	CVSE		1207.8	1010.9	868.4	770.9	588.9				
Date-Aug Forecast	CVSE							450.8	381.1	302.2	249.9
Hedge (Jan-Jul or date-Jul)	t(95%) x CVSE	**2064.9**	**1880.0**	**1656.2**	**1427.7**	**1358.8**	**1049.9**	**837.4**	**648.9**	**344.5**	

Adopted January 2018

ksfd

Duncan	Statistic	Aug-Nov	*1-Dec*	*1-Jan*	*1-Feb*	*1-Mar*	*1-Apr*	*1-May*	*1-Jun*	*1-Jul*	*1-Aug*
Jan-Jul 80-yr Volume	80-year Median	936.4									
Jan-Jul 80-yr Volume	RMSE around the Median	124.4									
Jan-Jul Forecast	CVSE		112.2	104.6							
Date-Jul Forecast	CVSE				90.6	86.7	68.9	58.7	50.0	30.4	
Apr-Aug Forecast	CVSE		121.5	107.0	92.6	82.6	59.1				
Date-Aug Forecast	CVSE							49.8	45.6	39.8	29.8
Hedge (Jan-Jul or date-Jul)	t(95%) x CVSE	**207.1**	**190.3**	**177.4**	**153.6**	**147.1**	**116.9**	**99.5**	**84.8**	**51.5**	

Libby	Statistic	Aug-Nov	*1-Dec*	*1-Jan*	*1-Feb*	*1-Mar*	*1-Apr*	*1-May*	*1-Jun*
Jan-Jul 80-yr Volume	80-year Median	3219.3							
Jan-Jul 80-yr Volume	RMSE around the Median	713.8							
Jan-Jul Forecast	Equivalent CVSE		524.4	540.4					
Date-July Forecast	Equivalent CVSE				436.2	414.1	301.0	292.7	285.6
Apr-Aug Forecast	CVSE		542.8	547.8	441.2	421.4	312.6	308.2	311.7
Hedge (Jan-Jul) revised 2011	t(95%) x CVSE	**1187.8**	**891.0**	**918.1**	**741.1**	**703.6**	**511.4**	**497.4**	**485.2**

Dworshak

The CRTOC agreed at the March 2012 meeting that VECC's for Dworshak are no longer needed, therefore Hedges are no longer provided.

For information on April-July forecast errors as used in Flood Control Refill Curves, see the AER/TSR flood control SOP.

Adopted January 2018

ksfd

Hungry Horse	Statistic	Aug-Dec	*1-Jan*	*1-Feb*	*1-Mar*	*1-Apr*	*1-May*	*1-Jun*
Jan-Jul 80-yr Volume	80-year Median	1069.0						
Jan-Jul 80-yr Volume	RMSE around the Median	259.3						
Hedge	t(95%) x RMSE	**431.4**	**312.7**	**229.4**	**173.3**	**148.7**	**129.1**	**107.2**

Grand Coulee	Statistic	Aug-Dec	*1-Jan*	*1-Feb*	*1-Mar*	*1-Apr*	*1-May*	*1-Jun*
Jan-Jul 80-yr Volume	80-year Median	31587.4						
Jan-Jul 80-yr Volume	RMSE around the Median	5937.4						
Hedge	t(95%) x RMSE	**9879.8**	**7688.1**	**5656.2**	**4912.2**	**4055.5**	**3288.4**	**2926.1**

Adopted January 2018

TABLE 1 (kaf)

Summary of Errors and Hedges

*During the pre-season period, t(95%) = 1.664 and is applied to the 80-year median standard error for the single-tail 95% exceedance, August - November
During the seasonal forecast period, t(95%)=1.696 for Canadian Projects and 1.699 for Libby, and is dependent on the project and the forecast development period
80-year record refers to the 2010 Level Modified Flow Study
Hedge = Forecast SE x single-tail 95% exceedance t-statistic for Grand Coulee and Hungry Horse,
Hedge = Forecast CVSE x single-tail 95% exceedance t-statistic for Mica, Arrow, Duncan, and Libby

kaf

Mica	**Statistic**	**Aug-Nov**	***1-Dec***	***1-Jan***	***1-Feb***	***1-Mar***	***1-Apr***	***1-May***	***1-Jun***	***1-Jul***	***1-Aug***
Jan-Jul 80-yr Volume	80-year Median	9793.1									
Jan-Jul 80-yr Volume	RMSE around the Median	1117.4									
Jan-Jul Forecast	CVSE		1104.1	1010.2							
Date-Jul Forecast	CVSE				878.0	827.1	654.9	580.9	434.5	288.7	
Apr-Aug Forecast	CVSE		1129.5	998.1	818.9	736.4	573.4				
Date-Aug Forecast	CVSE							480.8	414.3	380.3	311.1
Hedge (Jan-Jul or date-Jul)	t(95%) x CVSE	**1859.4**	**1872.6**	**1713.3**	**1489.1**	**1402.7**	**1110.8**	**985.2**	**736.9**	**489.6**	

Arrow Total	**Statistic**	**Aug-Nov**	***1-Dec***	***1-Jan***	***1-Feb***	***1-Mar***	***1-Apr***	***1-May***	***1-Jun***	***1-Jul***	***1-Aug***
Jan-Jul 80-yr Volume	80-year Median	20608.1									
Jan-Jul 80-yr Volume	RMSE around the Median	2461.3									
Jan-Jul Forecast	CVSE		2198.6	1936.9							
Date-Jul Forecast	CVSE				1669.7	1589.2	1227.9	979.3	758.9	402.9	
Apr-Aug Forecast	CVSE		2395.6	2005.1	1722.5	1529.1	1168.0				
Date-Aug Forecast	CVSE							894.1	755.9	599.3	495.6
Hedge (Jan-Jul or date-Jul)	t(95%) x CVSE	**4095.7**	**3728.9**	**3285.0**	**2831.8**	**2695.2**	**2082.5**	**1660.9**	**1287.1**	**683.3**	

Adopted January 2018

kaf

Duncan	Statistic	Aug-Nov	*1-Dec*	*1-Jan*	*1-Feb*	*1-Mar*	*1-Apr*	*1-May*	*1-Jun*	*1-Jul*	*1-Aug*
Jan-Jul 80-yr Volume	80-year Median	1857.3									
Jan-Jul 80-yr Volume	RMSE around the Median	246.8									
Jan-Jul Forecast	CVSE		222.6	207.5							
Date-Jul Forecast	CVSE				179.7	172.1	136.7	116.4	99.2	60.2	
Apr-Aug Forecast	CVSE		241.0	212.2	183.6	163.8	117.3				
Date-Aug Forecast	CVSE							98.8	90.4	79.0	59.1
Hedge (Jan-Jul or date-Jul)	t(95%) x CVSE	**410.7**	**377.5**	**351.9**	**304.8**	**291.8**	**231.9**	**197.4**	**168.2**	**102.2**	

Libby	Statistic	Aug-Nov	*1-Dec*	*1-Jan*	*1-Feb*	*1-Mar*	*1-Apr*	*1-May*	*1-Jun*
Jan-Jul 80-yr Volume	80-year Median	6385.5							
Jan-Jul 80-yr Volume	RMSE around the Median	1415.8							
Jan-Jul Forecast	Equivalent CVSE		1040.2	1071.9					
Date-July Forecast	Equivalent CVSE				865.2	821.4	597.0	580.7	566.4
Apr-Aug Forecast	CVSE		1076.7	1086.5	875.1	835.7	619.9	611.3	618.2
Hedge (Jan-Jul) revised 2011	t(95%) x CVSE	**2355.9**	**1767.2**	**1821.1**	**1469.9**	**1395.6**	**1014.3**	**986.5**	**962.3**

Dworshak	Statistic	Aug-Oct	*1-Dec*	*1-Jan*	*1-Feb*	*1-Mar*	*1-Apr*	*1-May*	*1-Jun*

The CRTOC agreed at the March 2012 meeting that VECC's for Dworshak are no longer needed, therefore Hedges are no longer provided.

For information on April-July forecast errors as used in Flood Control Refill Curves, see the AER/TSR flood control SOP.

Adopted January 2018

kaf

Hungry Horse	Statistic	Aug-Dec	*1-Jan*	*1-Feb*	*1-Mar*	*1-Apr*	*1-May*	*1-Jun*
Jan-Jul 80-yr Volume	80-year Median	2120.3						
Jan-Jul 80-yr Volume	RMSE around the Median	514.2						
Hedge (Jan-Jul)	t(95%) x RMSE	**855.7**	**620.2**	**455.0**	**343.7**	**294.9**	**256.1**	**212.6**

Grand Coulee	Statistic	Aug-Dec	*1-Jan*	*1-Feb*	*1-Mar*	*1-Apr*	*1-May*	*1-Jun*
Jan-Jul 80-yr Volume	80-year Median	62652.7						
Jan-Jul 80-yr Volume	RMSE around the Median	11776.6						
Hedge (Jan-Jul)	t(95%) x RMSE	**19596.3**	**15249.1**	**11218.9**	**9743.2**	**8044.0**	**6522.4**	**5803.8**

Table 1-a: Summary of t-statistics and number of years in sample set

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Mica		1.696 (32)	1.696 (32)	1.696 (32)	1.696 (32)	1.696 (32)	1.696 (32)	1.696 (32)	1.696 (32)
Arrow Total		1.696 (32)	1.696 (32)	1.696 (32)	1.696 (32)	1.696 (32)	1.696 (32)	1.696 (32)	1.696 (32)
Duncan		1.696 (32)	1.696 (32)	1.696 (32)	1.696 (32)	1.696 (32)	1.696 (32)	1.696 (32)	1.696 (32)
Libby		1.699 (30)	1.699 (30)	1.699 (30)	1.699 (30)	1.699 (30)	1.699 (30)	1.699 (30)	
All other projects (based on 80-year record)	1.664 (80)	1.664 (80)							

Table 1-a: Summary of t-statistics

Table 2: 80-year Mean Monthly Distribution Factors

The numbers in these tables were rounded to the third decimal place. As a check, the numbers in the rows were summed to make sure the distributions equaled 1.000. When they didn't because of rounding, the July values were increased or decreased by .001 or .002 so that the sum would equal 1.000. The numbers shown in red are the adjusted values.

TABLE 2

80-Year Mean Monthly Distribution Factors

		Jan	Feb	Mar	Ap1	Ap2	May	Jun	Jul
MCD	Jan-Jul	0.024	0.020	0.024	0.017	0.032	0.184	0.345	0.354
	Feb-Jul		0.021	0.024	0.018	0.032	0.189	0.354	0.362
	Mar-Jul			0.025	0.018	0.033	0.193	0.361	0.370
	1Apr-Jul				0.018	0.034	0.197	0.371	0.380
	16Apr-Jul					0.035	0.201	0.378	0.386
	May-Jul						0.208	0.391	0.401
	Jun-Jul							0.494	0.506
	Jul-Jul								1.000
ARD	Jan-Jul	0.033	0.029	0.039	0.035	0.064	0.267	0.317	0.216
LOCAL	Feb-Jul		0.030	0.040	0.036	0.067	0.276	0.328	0.223
	Mar-Jul			0.042	0.037	0.069	0.285	0.338	0.229
	1Apr-Jul				0.039	0.072	0.297	0.352	0.240
	16Apr-Jul					0.075	0.309	0.367	0.249
	May-Jul						0.334	0.396	0.270
	Jun-Jul							0.595	0.405
	Jul-Jul								1.000
ARD	Jan-Jul	0.027	0.023	0.029	0.023	0.044	0.221	0.337	0.296
	Feb-Jul		0.024	0.030	0.024	0.045	0.227	0.347	0.303
	Mar-Jul			0.030	0.025	0.047	0.232	0.355	0.311
	1Apr-Jul				0.026	0.048	0.239	0.366	0.321
	16Apr-Jul					0.049	0.246	0.376	0.329
	May-Jul						0.258	0.395	0.347
	Jun-Jul							0.533	0.467
	Jul-Jul								1.000
DCD	Jan-Jul	0.026	0.019	0.023	0.020	0.039	0.218	0.340	0.315
	Feb-Jul		0.020	0.024	0.020	0.040	0.223	0.349	0.324
	Mar-Jul			0.024	0.020	0.041	0.228	0.356	0.331
	1Apr-Jul				0.021	0.042	0.234	0.365	0.338
	16Apr-Jul					0.043	0.239	0.372	0.346
	May-Jul						0.249	0.389	0.362
	Jun-Jul							0.519	0.481
	Jul-Jul								1.000
KOT	Jan-Jul	0.032	0.030	0.041	0.035	0.064	0.282	0.330	0.186
	Feb-Jul		0.031	0.042	0.036	0.067	0.292	0.341	0.191
	Mar-Jul			0.044	0.037	0.069	0.301	0.352	0.197
	1Apr-Jul				0.039	0.072	0.315	0.368	0.206
	16Apr-Jul					0.075	0.327	0.383	0.215
	May-Jul						0.354	0.414	0.232
	Jun-Jul							0.641	0.359
	Jul-Jul								1.000
HGH	Jan-Jul	0.028	0.026	0.037	0.042	0.087	0.350	0.324	0.106
	Feb-Jul		0.027	0.038	0.044	0.090	0.361	0.334	0.106
	Mar-Jul			0.040	0.045	0.092	0.371	0.343	0.109
	1Apr-Jul				0.047	0.096	0.386	0.357	0.114
	16Apr-Jul					0.101	0.405	0.374	0.120
	May-Jul						0.450	0.417	0.133
	Jun-Jul							0.757	0.243
	Jul-Jul								1.000

TABLE 2

80-Year Mean Monthly Distribution Factors

		Jan	Feb	Mar	Ap1	Ap2	May	Jun	Jul
KER	Jan-Jul	0.032	0.030	0.040	0.040	0.081	0.329	0.325	0.123
	Feb-Jul		0.030	0.042	0.041	0.084	0.339	0.335	0.129
	Mar-Jul			0.043	0.043	0.086	0.350	0.346	0.132
	1Apr-Jul				0.044	0.090	0.366	0.361	0.139
	16Apr-Jul					0.094	0.383	0.378	0.145
	May-Jul						0.423	0.418	0.159
	Jun-Jul							0.723	0.277
	Jul-Jul								1.000
GCL	Jan-Jul	0.038	0.037	0.053	0.042	0.071	0.265	0.304	0.190
	Feb-Jul		0.039	0.055	0.043	0.074	0.276	0.316	0.197
	Mar-Jul			0.057	0.045	0.077	0.287	0.329	0.205
	1Apr-Jul				0.048	0.082	0.305	0.348	0.217
	16Apr-Jul					0.086	0.320	0.366	0.228
	May-Jul						0.350	0.400	0.250
	Jun-Jul							0.615	0.385
	Jul-Jul								1.000
BRN	Jan-Jul	0.125	0.125	0.161	0.084	0.084	0.174	0.166	0.081
	Feb-Jul		0.143	0.184	0.096	0.096	0.199	0.189	0.093
	Mar-Jul			0.215	0.113	0.113	0.232	0.221	0.106
	1Apr-Jul				0.143	0.143	0.296	0.282	0.136
	16Apr-Jul					0.167	0.345	0.329	0.159
	May-Jul						0.415	0.395	0.190
	Jun-Jul							0.675	0.325
	Jul-Jul								1.000
LIB	Jan-Jul	0.031	0.028	0.035	0.028	0.054	0.271	0.355	0.198
	Feb-Jul		0.029	0.036	0.029	0.056	0.280	0.367	0.203
	Mar-Jul			0.037	0.030	0.058	0.288	0.378	0.209
	1Apr-Jul				0.031	0.060	0.299	0.392	0.218
	16Apr-Jul					0.062	0.309	0.405	0.224
	May-Jul						0.329	0.432	0.239
	Jun-Jul							0.644	0.356
	Jul-Jul								1.000
ALF	Jan-Jul	0.044	0.044	0.063	0.052	0.087	0.306	0.291	0.113
	Feb-Jul		0.046	0.066	0.054	0.091	0.320	0.305	0.118
	Mar-Jul			0.069	0.057	0.095	0.335	0.320	0.124
	1Apr-Jul				0.061	0.102	0.360	0.344	0.133
	16Apr-Jul					0.109	0.384	0.366	0.141
	May-Jul						0.430	0.411	0.159
	Jun-Jul							0.721	0.279
	Jul-Jul								1.000
DWR	Jan-Jul	0.057	0.067	0.104	0.085	0.117	0.304	0.203	0.063
	Feb-Jul		0.071	0.111	0.090	0.124	0.322	0.215	0.067
	Mar-Jul			0.119	0.097	0.134	0.347	0.231	0.072
	1Apr-Jul				0.110	0.152	0.394	0.263	0.081
	16Apr-Jul					0.170	0.442	0.295	0.093
	May-Jul						0.533	0.356	0.111
	Jun-Jul							0.762	0.238
	Jul-Jul								1.000

TABLE 2

80-Year Mean Monthly Distribution Factors

		Jan	Feb	Mar	Ap1	Ap2	May	Jun	Jul
LWG	Jan-Jul	0.073	0.078	0.112	0.072	0.091	0.257	0.232	0.085
	Feb-Jul		0.084	0.120	0.078	0.098	0.278	0.250	0.092
	Mar-Jul			0.131	0.085	0.107	0.303	0.273	0.101
	1Apr-Jul				0.098	0.123	0.349	0.314	0.116
	16Apr-Jul					0.137	0.387	0.348	0.128
	May-Jul						0.448	0.404	0.148
	Jun-Jul							0.731	0.269
	Jul-Jul								1.000
MCN	Jan-Jul	0.053	0.054	0.074	0.051	0.076	0.257	0.280	0.155
	Feb-Jul		0.057	0.078	0.054	0.080	0.271	0.296	0.164
	Mar-Jul			0.083	0.057	0.085	0.288	0.313	0.174
	1Apr-Jul				0.062	0.092	0.314	0.342	0.190
	16Apr-Jul					0.098	0.334	0.364	0.204
	May-Jul						0.371	0.404	0.225
	Jun-Jul							0.642	0.358
	Jul-Jul								1.000
JDA	Jan-Jul	0.054	0.055	0.076	0.052	0.076	0.256	0.277	0.154
	Feb-Jul		0.058	0.080	0.054	0.080	0.271	0.293	0.164
	Mar-Jul			0.085	0.058	0.085	0.288	0.311	0.173
	1Apr-Jul				0.063	0.093	0.314	0.341	0.189
	16Apr-Jul					0.100	0.336	0.364	0.200
	May-Jul						0.373	0.404	0.223
	Jun-Jul							0.644	0.356
	Jul-Jul								1.000
TDA	Jan-Jul	0.056	0.058	0.078	0.052	0.076	0.253	0.274	0.153
	Feb-Jul		0.061	0.083	0.055	0.081	0.268	0.290	0.162
	Mar-Jul			0.088	0.059	0.086	0.286	0.309	0.172
	1Apr-Jul				0.065	0.094	0.313	0.339	0.189
	16Apr-Jul					0.101	0.335	0.362	0.202
	May-Jul						0.372	0.403	0.225
	Jun-Jul							0.642	0.358
	Jul-Jul								1.000
BON	Jan-Jul	0.059	0.060	0.080	0.053	0.076	0.250	0.269	0.153
	Feb-Jul		0.064	0.085	0.056	0.081	0.266	0.286	0.162
	Mar-Jul			0.091	0.060	0.087	0.284	0.306	0.172
	1Apr-Jul				0.066	0.095	0.312	0.337	0.190
	16Apr-Jul					0.102	0.335	0.361	0.202
	May-Jul						0.373	0.401	0.226
	Jun-Jul							0.640	0.360
	Jul-Jul								1.000

Attachment 1

Mica, Arrow, and Duncan
Cross-Validation Standard Error Computation Procedure

Columbia River Treaty Hydromet Committee
July 22, 2015

In 2006, BC Hydro produced new Principal Components regression (REG) forecasts for the Canadian Treaty projects, Mica, Arrow, and Duncan. The procedures produce monthly forecasts that are aggregated into seasonal volumes of interest. A January forecast was not produced, and its CVSE is approximated by using the RMSE around the median.

Details for calculating seasonal CVSE from monthly equations are as follows:

Let S_e, $i = 1,,,n$, be standard errors for n monthly equations and Se_i be standard error for the seasonal volume forecast, then:

$$CVSE = \sqrt{\sum_{i=1}^{n} Se_i^2 + 2\sum_{i=1}^{n}\sum_{j=i+1}^{n} Cov(Se_i, Se_j)}\ ,$$

where $Cov\ (Se_i, Se_j)$ is the covariance between the monthly errors.

Adopted by CRTOC in January 2019

Attachment 2

Libby, Montana Water Supply Forecast
"Date-July" Forecast Development
And
CVSE Computations

Randal T. Wortman
Revised: February 2006
Updated: July 2015 by CRTHC

The statistical forecast equations developed for water supply forecasting by the Corps, were each developed for a fixed runoff season. Specifically, the Libby basin forecast equations were all fit to the same dependent variable, the April-to-August runoff volume. The standard error statistics all correspond to the regression equations for the April-to-August runoff season. Power planning studies, specifically, require consideration of other "seasons" than the specific season to which the forecast model was calibrated. The discussion that follows will first address various definitions of "standard error" for a statistical forecast, with the remainder of the paper presenting the author's perspective and recommendation on how to determine the "date-to-end-of-season" forecast for a variety of forecast dates, and the recommended procedure for calculating the standard error associated with this pseudo-forecast.

Standard Error For A Statistical Forecast Model

There exists a variety of statistics and methods that could potentially be referred to as the "standard error" for a calibrated statistical forecast model. The most familiar standard error statistics are the following:

1. Standard Error of the forecast equation (SE)
2. Standard Error of Prediction for an individual forecast (SE_{pred})
3. Cross-validation standard error (CVSE), sometimes called the Jackknife Standard Error (JSE) or the Leave-One-Out Standard Error (LOO SE).

Legitimate purposes exist for the use of each of the above standard error statistics and all of the above statistics include a degrees-of-freedom adjustment that compensates for the number of predictor variables used in the regression equation. The traditional Standard Error (SE) is the root-mean-squared-error of the predictions from the regression equation fit to the full set of observations. This standard error is a constant and has the smallest value of the three standard errors presented. It also represents the error corresponding to a forecast derived from all predictor variables simultaneously being at their average values. The Standard Error of Prediction (SE_{pred}) is the technically correct standard error statistic to use when calculating the error bounds on a new forecast calculated from a new set of observations of the predictor variables. The SE_{pred} statistic *is not a constant* and is calculated using the SE term adjusted by a

"leverage" factor derived from the current values of the predictor variables. Thus, the SE_{pred} varies, taking on a minimum value when the predictor variables simultaneously approach their mean value, and flaring to greater magnitudes as the predictor variables take on more extreme values. In a simple 1-variable regression analysis the confidence intervals for the SE plot as two lines parallel to the regression forecast line, and the confidence intervals for the SE_{pred} plot as mirror-image curves above and below the regression line.

The cross-validation standard error (CVSE) is the root-mean-squared-error of the leave-one-out predictions. The cross-validation predictions are calculated by iteratively dropping one observation from the data set and refitting the regression coefficients without that one observation in the model, then using the withheld observation with the leave-one-out calibration to generate a forecast. The leave-one-out forecast will always be slightly inferior to the full model forecast, and thus the CVSE will always be slightly larger than the SE and, unlike the SE_{pred}, take on a constant value.

All three of the above standard error statistics apply to a given statistical forecast equation fit to a set of specified predictor variables. Since it is not possible to incorporate non-existent observed values of the regression variables when working in a study scenario, the static CVSE provides a suitable alternative to the standard error of prediction SE_{pred}. The CVSE is believed to reflect the expected value of the error in a real-time forecasting environment more accurately than the SE, and unlike the SE_{pred}, the CVSE has a constant value independent of the values for the current set of predictor variables. The CVSE has been adopted by the NRCS and other forecasting agencies and is herein recommended as the preferred error statistic for use with developing confidence intervals on water supply forecasts for both real time operations and planning studies.

Derivation of Date-to-July Forecasts

A variety of computations could be devised to transform the April-August volume forecast into the "Date-to-July" pseudo forecast desired for various power and flood control studies. The following alternatives can be combined in eight different ways, providing eight different calculations to compute the date-to-July forecast series for each of the winter forecasts (1-Jan, 1-Feb, or 1-Mar):

1. April-August Volume from statistical model
    a. Use regression model (full dataset) forecast values
    b. Use cross-validation (leave-one-out) regression forecast values
2. Adjustment to change April-August volume into "Date-August" volume
    a. For any months prior to April add historic average volumes
    b. For any months prior to April add historic average volumes weighted by "percent of average" value for current April-August forecast
3. Adjustment to change forecast volume into "Date-July" volume
    a. Subtract average August volume
    b. Subtract average August volume, weighted by "percent of average" value for current April-August forecast

Comparison of Standard Error Statistics for Date-to-July Forecasts for the Libby Forecast

As an example, this information has been kept from the 2010 Libby Water Supply Forecast procedure. The information in the graphic below is not associated with the currently approved Libby forecast procedure.

Forecasts and forecast errors were calculated for five of the eight "date-to-July" combinations presented above, and the root-mean-squared-error (RMSE) of those "date-to-July" forecast errors were compared with the RMSE of the April-August cross-validation forecast error (i.e. the April-August forecasts CVSE). The following figure shows the RMSE value for each monthly forecast. The first three series utilize the cross-validation forecast, while the last three series utilize the standard regression forecast. Series 2, 3, 5, and 6 are from "date-to-July" forecasts developed using option 2a, above (average volumes used for winter months). Series 2 and 5 used option 3a, above (average August) and series 3 and 6 used option 3b, above (average August weight by the forecasts percent-of-normal).

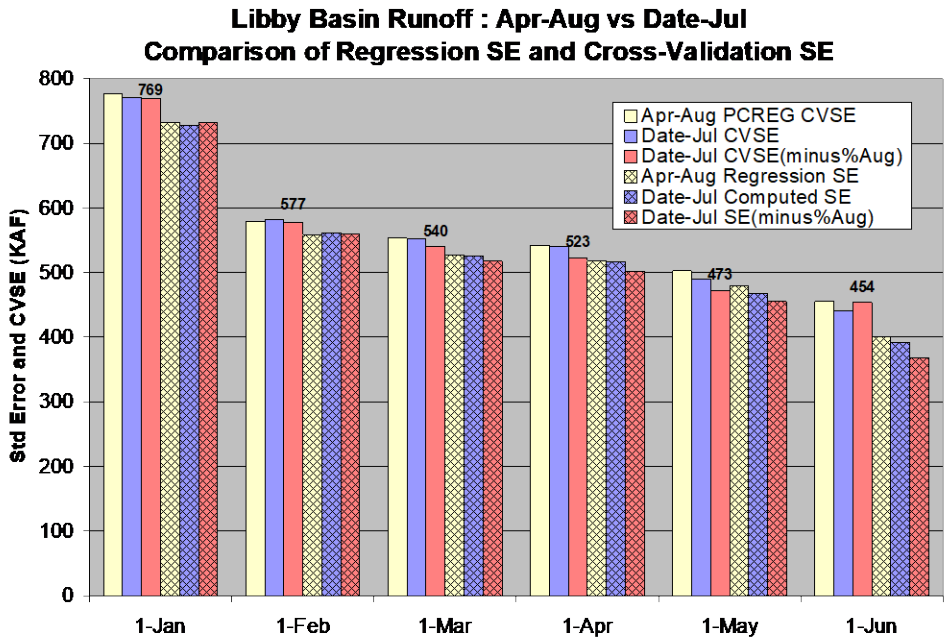

Figure 1: Libby Basin Runoff comparison of statistics

The above figure shows that from 1-January to 1-May it would be problematic to argue that there is a statistical significance in the results for a given forecast date or that any one method is superior to any other.

Recommended Libby Date-to-July Forecasts and Equivalent CVSE Computations

In order to provide the best consistency with the CVSE statistic used with the full April-August forecast model, it is recommended that the Date-to-July forecasts and errors be constructed using the methodology of the third series, whereby the Corps' Libby April-August first-of-month cross-validation forecasts are adjusted by adding in the historical average winter month volumes, then further adjusted by subtracting out the average August volume weighted by the April-August forecast percent-of-average factor.

The recommended equations for computation of the Date-to-July forecasts are as follows:

1December Jan-July Fcst = Jan Avg + Feb Avg + Mar Avg + 1-Dec Apr-Aug Cross-Validation Forecast – (JanFcstPct * AugAvg)

> Note: the above equation is an estimate of what the 1December Jan-Jul forecast is and therefore does not include an estimate of December volume.

1January Jan-July Fcst = Jan Avg + Feb Avg + Mar Avg + 1-Jan Apr-Aug Cross-Validation Forecast – (JanFcstPct * AugAvg)

1February Feb-Jul Fcst = Feb Avg + Mar Avg + 1-Feb Apr-Aug Cross-Validation Forecast – (FebFcstPct * AugAvg)

1March Mar-Jul Fcst = Mar Avg + 1-Mar Apr-Aug Cross-Validation Forecast – (MarFcstPct * AugAvg)

1April Apr-Jul Fcst = 1Apr Apr-Aug Cross-Validation Forecast – (AprFcstPct * AugAvg)

1May May-Jul Fcst = 1-May May-Aug Cross-Validation Forecast – (MayFcstPct * AugAvg)

1June Jun-Jul Forecast = 1-Jun Jun-Aug Cross-Validation Forecast – (JunFcstPct * AugAvg)

with

JanFcstPct = 1-Jan Apr-Aug Cross-Validation Forecast / Average Apr-Aug Forecast

FebFcstPct = 1-Feb Apr-Aug Cross-Validation Forecast / Average Apr-Aug Forecast

MarFcstPct = 1-Mar Apr-Aug Cross-Validation Forecast / Average Apr-Aug Forecast

AprFcstPct = 1-Apr Apr-Aug Cross-Validation Forecast / Average Apr-Aug Forecast

MayFcstPct = 1-May Apr-Aug Cross-Validation Forecast / Average May-Aug Forecast

JunFcstPct = 1-Jun Apr-Aug Cross-Validation Forecast / Average Jun-Aug Forecast

Adopted by CRTOC in January 2019

Computation of Equivalent CVSE for Libby Date-July Forecast Periods

Only April-August CVSEs are computed as part of Libby's (REG) process. Therefore for all of the date-July estimated forecasts an equivalent CVSE must be computed. Those equivalent CVSEs for the January-July estimated forecasts dated 1-Dec and 1-Jan and the date-July forecasts dated 1-Feb, 1-Mar, 1-Apr, 1-May, 1-Jun are determined as follows:

1-Dec equivalent CVSE (Kaf):

$$\sqrt{\sum_{1}^{n} \frac{1Dec\ Jan - Jul\ (Observed - Forecast)^2}{(n-2)}}$$

Where n = number of years in the sample size
n-2 = degrees of freedom = sample size reduced by one degree of freedom for the computation of the regression line slope and reduced again by one degree of freedom for the computation of the y-intercept for the same regression line.

1-Jan equivalent CVSE (Kaf):

$$\sqrt{\sum_{1}^{n} \frac{1Jan\ Jan - Jul\ (Observed - Forecast)^2}{(n-2)}}$$

1-Feb equivalent CVSE (Kaf):

$$\sqrt{\sum_{1}^{n} \frac{1Feb\ Feb - Jul\ (Observed - Forecast)^2}{(n-2)}}$$

1-Mar equivalent CVSE (Kaf):

$$\sqrt{\sum_{1}^{n} \frac{1Mar\ Mar - Jul\ (Observed - Forecast)^2}{(n-2)}}$$

1-Apr equivalent CVSE (Kaf):

$$\sqrt{\sum_{1}^{n} \frac{1Apr\ Apr - Jul\ (Observed - Forecast)^2}{(n-2)}}$$

1-May equivalent CVSE (Kaf):

$$\sqrt{\sum_{1}^{n} \frac{1May\ May - Jul\ (Observed - Forecast)^2}{(n-2)}}$$

1-Jun equivalent CVSE (Kaf):

$$\sqrt{\sum_{1}^{n} \frac{1Jun\ Jun - Jul\ (Observed - Forecast)^2}{(n-2)}}$$

t-Statistic Considerations when Forecast Procedures have varying Periods of Record

The 2010 Libby forecast procedure used four sets of historic years to develop its forecast equations. Transitioning from four different t-statistics for any given project could lead to confusion. The CRTHC evaluated the difference in t-statistics for the various data sets and determined that a fixed t-statistic value provided some consistency in methodology across the different forecast dates, with only a very small sacrifice of technical precision. Therefore, in the event that a future forecast procedure does not have a consistent training period length for all forecast months, a single t-statistic will be used based on the historic data set most frequently used for the development of the project's forecast equations.

Adopted by CRTOC in January 2019

Attachment 3

Monthly Distribution Factors
Used to Compute Monthly Streamflows for the TSR

Monthly distribution factors for runoff volumes of Date-July are computed for projects where monthly streamflows/volumes are submitted by BPA and the Corps for the TSR. The distribution factors are based on the most recently adopted Modified Flow data set mean volumes and represent the mean shape. A forecast volume for Date-July is multiplied by the appropriate monthly distribution factor to obtain a monthly volume.

As an example, the following shows the Libby monthly mean and Date-July mean volumes.

Libby 80-year mean monthly volumes (Kaf)

JAN	FEB	MAR	AP1	AP2	MAY	JUN	JUL
0.20	0.18	0.22	0.18	0.34	1.71	2.24	1.24

Example 1: Mean monthly volumes

Libby 80 year mean month-July volumes (Kaf)

JAN-JUL	FEB-JUL	MAR-JUL	AP1-JUL	AP2-JUL	MAY-JUL	JUN-JUL
6.32	6.12	5.94	5.72	5.54	5.20	3.49

Example 2: Mean residual volumes

To compute each month's distribution factor which will be applied to a Jan-Jul volume, each period mean is divided by the Jan-Jul mean. For example, January's distribution factor is 0.2/6.32=.031 and February's distribution factor is 0.18/6.32 = .028.

To compute each period's distribution factor that will be applied to a February-July volume, each monthly mean is divided by the February-July mean. For example, February's distribution factor is 0.18/6.12 = .029, and March's distribution factor is 0.22/6.12 = .036.

Calculations are likewise for applying to March-July, 1 April-July, 16 April-July, May-July, and June-July volumes. The following table shows all of the distribution factors for Libby.

Libby Distribution Factors

	Jan	Feb	Mar	Ap1	Apr	May	Jun	Jul
Jan-Jul	0.031	0.028	0.035	0.028	0.054	0.271	0.355	0.198
Feb-Jul		0.029	0.036	0.029	0.056	0.280	0.367	0.203
Mar-Jul			0.037	0.030	0.058	0.288	0.378	0.209
1 Ap1-Jul				0.031	0.060	0.299	0.392	0.218
16 Apr-Jul					0.062	0.309	0.405	0.224
May-Jul						0.329	0.432	0.239
Jun-Jul							0.644	0.356

Example 3: Distribution factors

Adopted by CRTOC in January 2019

Attachment 4

How Whatshan Dam impacts Arrow inflow forecasts for AER/TSR

Columbia River Treaty Hydromet Committee
September, 2017

Whatshan Dam was built by the B.C. Power Commission and completed in 1952. It is a concrete hydroelectric dam on the Whatshan River in the Canadian province of British Columbia. The Whatshan powerhouse has undergone three major transformations since 1951 when it was first built by the British Columbia Power Commission to provide electricity to the Okanagan and the Upper Arrow Lakes in 1951. In 1953 the powerhouse was destroyed after a rock and mud slide roared down the mountainside. The powerhouse was rebuilt soon after only to have to be rebuilt again a few meters higher to avoid being flooded after the completion of the Hugh Keenleyside Dam in 1968. The replacement 54MW powerhouse completed in 1972 is at the end of a 3.4 kilometer long tunnel and is located on the western side of Upper Arrow Lake in the Monashee Mountains. It is owned and operated by BC Hydro.[1]

Water supply volumes for Arrow Reservoir (Hugh Keenleyside Dam) are computed are different for the observed and forecasted periods. The forecasted inflows for Arrow produced by BCHydro do not include a regulated Whatshan forecast. BCHydro does not necessarily have a method for forecasting Whatshan's outflows and instead using Whatshan's inflows as a proxy for forecast months.

> The AER/TSR Arrow Total includes WGS observed OUTFLOWS to date, but since we don't have a forecast of WGS outflows, the inflow forecast can be used as a proxy. Over the summer months, WGS comprises less than 1% of the total Arrow inflow, which is well within the 5% standard error of forecast on the Arrow total predictions.[2]

However, the observed values for after the fact do include a regulated Whatshan outflow. These values are tracked in a Treaty spreadsheet and the values coordinated between BPA and BCH for Treaty accounting. That after the fact process is soon to be replaced with a Treaty/non Treaty accounting program, but the computations will remain comparable. For Treaty modeling (TSR), accounting, and tracking, the Arrow inflow needs to include a Whatshan regulated outflow. The inflow forecasts for Arrow submitted by BPA for the AER/TSR still continue to be from the Treaty spreadsheet which correctly contains a Whatshan regulated outflow in the observed Arrow value.

[1] http://www.virtualmuseum.ca/sgc-cms/expositions-exhibitions/hydro/en/dams/index.php?action=whatshan

[2] Note from BCH to BPA in January 2006 included in water supply forecast.