COLUMBIA RIVER TREATY
HYDROMETEOROLOGICAL COMMITTEE

SUPPLEMENTAL REPORT

2015

Wildcat Creek Climate Station and Snow Pillow, Mica Basin, 2122m
Installed September 15, 2014

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Summary

The Canadian and United States Entities of the Columbia River Treaty established the Hydrometeorological Committee in 1968. The mandate of the Committee is primarily to be responsible for ensuring that hydrometeorological data necessary for the planning and operation of Treaty project facilities are collected and communicated to the Entities. The "Introduction to the terms of reference for the CRTHC, shown in Appendix A of this Supplemental Report gives a brief history of the Committee. Committee terms of reference are included in Appendix B of the Supplemental Report.

The Committee began issuing regular Annual Reports in 2001. General background information on Committee activities contained in the 2001 and 2002 annual reports is now presented in this separate supplemental document. The supplement contains general information that does not typically change from year to year.

Appendices in this document include:

Appendix A – Introduction to the Committee terms of reference
Appendix B – Terms of reference for the CRTHC
Appendix C – Process for reviewing hydrometeorological data networks
Appendix D – List of contributors of hydrometeorological data
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Acronyms

ABEnv - Alberta Ministry of Environment
AEC - Actual Energy Capability
AER - Actual Energy Regulation
AOP - Assured Operating Plan
BCH - British Columbia Hydro and Power Authority
BPA - Bonneville Power Administration
CBT - Columbia Basin Telecommunications
CHPS - Community Hydrologic Prediction System
CROHMS - Columbia River Operational Hydrometeorological Management System
CRT - Columbia River Treaty
CRTHC - Columbia River Treaty Hydrometeorological Committee
CRTOC - Columbia River Treaty Operating Committee
CWMS - Corps Water Management System
DOP - Detailed Operating Plan
EC - Environment Canada
ESP - Ensemble Streamflow Prediction
FCOP - Flood Control Operating Plan
SFTP - Secure File Transfer Protocol
HYDSIM - Hydrologic Simulation model
MOE - BC Ministry of Environment
MSC - Meteorological Service of Canada, Environment Canada
NRCS - Natural Resources Conservation Service

NWPP - Northwest Power Pool

NWRFC - Northwest River Forecast Center, US National Weather Service

NWSRFS - National Weather Service River Forecast System

Operating Year - August 1 to July 31 (CRTOC)

PEBCOM - Permanent Engineering Board Engineering Committee

PNCA - Pacific Northwest Coordination Agreement

POP - CRT Principles and Procedures Document

QPF - Quantitative Precipitation Forecast

RCS - Regional Climate Station

RFS - BCHydro River Forecast System

THOR - BPA's The Hydro Operations Resource

RWCDS - Regional Water Control Data System (USACE)

SNOTEL - SNOwpack TELemetry, NRCS snow pillow and climate data network

TSR - Treaty Storage Regulation study

UBCWM - University of British Columbia Watershed Model

USACE - US Army Corps of Engineers

USBR - US Bureau of Reclamation

USGS US Geological Survey

Water Year - October 1 to September 30 (CRTHC)

WSC - Water Survey of Canada, Environment Canada

WSF - Water Supply Forecast

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Appendix A Introduction to the Committee terms of reference[1]

The Columbia Treaty between Canada and the United States of America relating to cooperative development of water resources of the Columbia River Basin was jointly signed by the heads of the respective Governments on January 17, 1961. Final ratification of the Treaty occurred when Canada Ratified the Treaty on September 16, 1964.

Article XIV, Arrangements for Implementation contains:

2. In addition to the powers and duties dealt with specifically elsewhere in the Treaty, the powers and duties of the entities include:
    e. The establishment and operation of a hydrometeorological system as required by Annex A,

Annex A, Principles of Operation states:

2. A hydrometeorological system, including snow courses, precipitation stations and streamflow gauges will be established and operated, as mutually agreed by the entities and in consultation with the Permanent Engineering Board, for use in establishing data for detailed programming of flood control and power operations. Hydrometeorological information will be made

[1] *The text of this appendix is copied from the original 1967 document.*

available to the entities in both countries for immediate and continuing use in flood control and power operations.

In March of 1965, an International Task Force on Hydrometeorological Network, Columbia River Treaty was appointed to recommend establishment and operation of the Hydrometeorological Network and procedures for exchange of information between the two Entities. Each of the Entities was guided by the following instructions:

A. In collaboration with the respective Section of the task force, participate in the following activities:
    1. Recommend additions to the present hydrometeorological network to provide information essential to the operation of the Treaty storage to achieve the benefits contemplated by the Treaty which will:
        a. Provide current data on reservoir and streamflow conditions.
        b. Provide sufficient information for forecasting streamflow on a long-range (seasonal), medium range (10 days to a month or two), and short-range (up to 10 days) basis to meet the operational criteria of each project.
    2. Recommend establishment and operation of a communication system for timely reporting of all hydrometeorological factors to meet operational and forecasting requirements.

This system should utilize existing facilities where possible and new facilities should be recommended where needed.

3. Review the network from time to time and recommend additions to or deletions from facilities to ensure peak network efficiency.
4. Prepare reports and recommendations to the entities from time to time as appropriate.

B. In addition, the Entities shall be responsible for the following:

1. Prepare such interim or supplemental reports as may be needed to adequately inform the Entities on significant developments, alternative considerations, and progress.
2. Coordinate activities as needed with the other task forces.
3. In developing the required network facilities, seek technical advice and obtain technical assistance, as necessary, from Canadian and other United States Agencies such as the Geological Survey, Soil Conservation Service[2], and the National Weather Service as well as within your own agencies, B.C. Hydro and Power Authority, the Bonneville Power Administration, and the Corps of Engineers.
4. Provide the Entities with copies of all correspondence, reports and drafts of reports, minutes of meetings, and distribution of all material.

[2] *Now the Natural Resource Conservation Service*

The International Task Force was in operation from 1965 through September 19, 1968. During this period, recommendations were prepared and subsequently adopted by the Entities with the concurrence of the Permanent Engineering Board. These recommendations established the basic hydrometeorological network of stations required by the Entities under the Treaty to provide data necessary for the operation of the Treaty projects. These were termed “Treaty facilities.”

The Entities agreed on October 23, 1967, to a definition for other hydrometeorological stations and communications not considered elements of the Treaty hydromet system but necessary for operational forecasting for the Columbia River. These were termed “supporting facilities.”

On September 19, 1968, the United States and Canadian Entities agreed to abolish the Task Force. The Hydrometeorological Committee was established at the same time. The terms of reference that follow outline the responsibilities given to the Committee at that time.

This document will be updated from time to time as changes occur in hydrometeorological requirements or facilities listings.

Appendix B Terms of reference for the CRTHC

May 20, 1968

1 - GENERAL

The Columbia River Treaty Hydrometeorological Committee will be composed of representatives of each Entity. The Committee will recommend the establishment of the Columbia River Treaty Hydrometeorological System. This system (hereinafter called "Treaty facilities") and the supporting facilities thereto are defined in an agreement between the Canadian and United States Entities dated October 23, 1967, as follows:

a. Treaty facilities

1. The Columbia River Treaty Hydrometeorological System shall consist of new and existing streamflow and reservoir gauges, snow courses, meteorological stations, and other related hydrometeorological data-collecting facilities a plan for methods and frequency of reporting, and a communication system to provide information for the operation of Duncan, Arrow, Mica and Libby reservoirs. It shall include hydrometeorological stations which provide

operational and forecasting data relevant to the flow of the Columbia River at Birchbank, British Columbia, or at an equivalent streamflow gauge, and in addition, certain key streamflow and reservoir gauges on the Columbia River downstream from Birchbank and [certain key streamflow and reservoir gauges] on the Clark Fork - Pend Oreille tributary.

2. All stations included in the System will be as agreed from time to time by the Entities in consultation with the Permanent Engineering Board.

3. Additions to or deletions from the System will be subject to mutual agreement by the Entities with the objective of assuring continued operation of the system.

b. Supporting facilities

1. It is desirable to identify other hydrometeorological stations and communications, not considered as elements of the system, which provide information for operational forecasting for the Columbia River.

2. A list of the hydromet stations and communications referred to in (1) above will be maintained by the Entities and all elements included in the list will be identified as “supporting facilities.”

3. Each Entity will make reasonable effort to assure the continued operation of supporting facilities located in its own country.

c. Supplemental data

Available hydrometeorological data from any part of the Basin required by either Entity from time to time will be provided by the other Entity on request.

2 – COMPOSITION OF THE COMMITTEE

The Committee will be composed of a United States Section and a Canadian Section. The members of each Section will be designated by their respective Entity. One member of each Section will be formally designated as chairperson of the Section.

3 – DUTIES OF THE COMMITTEE

The duties of the Committee will include the following, subject to modification and addition as may be deemed appropriate by the Entities from time to time.

i. Governing Treaty facilities:

a. Review existing hydrometeorological facilities and where necessary recommend additions and improvements in order to develop a hydrometeorological system which will:

1. Provide current data on reservoir streamflow conditions.
2. Provide sufficient information for forecasting streamflow to determine operation of the Treaty projects.

b. Recommend establishment of communication for timely reporting of hydrometeorological information to meet operation and forecasting requirements. Existing communication facilities

should be used where adequate and new facilities should be recommended where needed.

c. Recommend a plan for methods and frequency of reporting.

d. Review the system from time to time and recommend additions or deletions of Treaty facilities and to insure peak network efficiency.

ii. Governing supporting facilities:

Recommend other existing hydrometeorological stations and communications not considered as Treaty facilities for inclusion by the Entities in a list of "supporting facilities."

iii Prepare annual reports reviewing the Committee's activities for the preceding year and such other reports and recommendations to the entities from time to time as appropriate.

iv In the event of any substantial disagreement between the United States Section, the Chairmen of the Canadian and United States Sections will immediately refer the matter to the respective Entities through the Manager, Canadian Entity Services and the Staff Coordinators for instructions.

v Consult, and coordinate its work, with the Columbia River Treaty Operating Committee.

In addition, each Section will be responsible to its respective Entity for the following:

a. Prepare such interim or supplemental reports as may be needed to keep the appropriate Entity informed on significant

developments, alternative considerations, progress, and operation of the Treaty facilities and supporting facilities.

b. Coordinate activities as needed with the appropriate Section of other Columbia River Treaty committees.

c. In determining and reviewing the required Treaty facilities and supporting facilities, seek technical assistance as necessary from other agencies in the appropriate country.

d. Provide the appropriate Entity with copies of all correspondence, reports, and drafts or reports, minutes of meetings, and the distribution of all material.

Appendix C Process for reviewing hydrometeorological data networks

The CRTHC ensures that the integrity of hydrometeorological stations that are required to monitor, plan, and operate Treaty facilities is maintained by following a prescribed process. The process involves several steps, as described below.

STEP 1 COMMUNICATE WITH DATA COLLECTION AGENCIES

Each year, the Committee formally reminds each contributing data collection agency or utility to inform the Committee of any impending changes in its operation of hydrometeorological stations near or within the Columbia River basin. Most hydrometeorological data required for the operation of the Columbia River Treaty are collected by Canadian federal and provincial state agencies. Data collection agencies and electrical utilities contacted are included in Appendix D.

STEP 2 DETERMINE TREATY STATUS OF STATIONS SUBJECT TO OPERATIONAL CHANGES

If informed of a proposed change to the operation of any hydrometeorological station, the Canadian and United States Sections of the Committee both determine if the change affects the ability to monitor, plan, or operate a Treaty facility. Specifically, the Committee will designate a station as Treaty or support if data from it are required:

as input to TSR studies
as input to HYDSIM
as input to CHPS or UBCWM models for Columbia River sub-basins
as input to seasonal water supply forecasting procedures required by the FCOP to monitor or operate Treaty facilities, including daily and additional seasonal forecasts for Treaty facilities

Brief descriptions of Treaty planning processes and models are included in Appendix E.

STEP 3 RESPOND TO DATA AGENCIES WHEN A CHANGE IN STATION OPERATION AFFECTS TREATY OPERATIONS

Where a change in the operation of a designated Treaty or support station is proposed, the Canadian and United States Sections of the CRTHC will explore several options:

If the change in station operation compromises monitoring, planning for, or operating a Treaty facility, the appropriate Section of the Committee will urge data collection

agencies on its respective side of the border to continue the current operation of the station.

Where data collection agencies are unable to continue the current operation of a Treaty or support station, the Committee will examine the impact that the proposed station change has on monitoring or operating a Treaty project. The Committee will also examine the practicality of modifying planning models to accept the proposed station change. The impact of the change in operation of the station should not, in the view of the Committee, deteriorate the accuracy of model results significantly. If the change does not significantly affect the ability to monitor, plan, or operate a Treaty facility, the Committee will not object to the proposed change.

Where changes to a Treaty or support station are detrimental to Treaty monitoring, planning, or operations, the CRTHC will attempt to fund and arrange other resources required to continue the operation of the station. Alternatively, a suitable replacement station may be investigated.

STEP 4 DETERMINE OVERALL ADEQUACY OF STATION NETWORK

The Committee is tasked with determining the adequacy of the station network for Treaty purposes. That review occurs each year and consists of a number of activities.

Those include:

- Forecast post-mortems each year provide indications of network and station reliability. Were there insufficient high elevation stations? Was a station not reliably reporting? Is the station network not dense enough to adequately represent the conditions?

- Overall trends in station data quality and reporting availability. For manual stations, is the observer network reporting reliably and is the data available in a timely fashion?
- A station may be specifically identified for discontinuation which would trigger a review
- Any time a forecast procedure is reviewed or updated, the entire reporting network is reviewed both historically and in real-time.

STEP 5 DOCUMENT COMMITTEE WORK

The Committee will document the following:

- Committee activity during the previous year, which usually includes October 1 through September 30
- Changes to the operation of Treaty or support stations proposed within the Committee's reporting period
- The Committee's response to the proposed changes
- Resolution of proposed changes to the hydrometeorological network
- Processes to communicate and exchange hydrometeorological data.

STEP 6 REGULARLY REVIEW HYDROMETEOROLOGICAL DATA REQUIREMENTS FOR TREATY MODELS

As required, the Committee will review existing and proposed models used for CRT planning studies and operations to assess hydrometeorological data requirements.

The Committee will recommend preferred daily and seasonal forecasting models to be used in CRT operations to the CRTOC.

Appendix D List of contributors of hydrometeorological data

The Canadian Section of the CRTHC typically writes letters to selected agencies at the beginning of each operating year requesting notification of changes to station networks. Data collection agencies contacted include:

Alberta Ministry of Environment
BC Ministry of Environment
Environment Canada - Meteorological Service of Canada
Environment Canada - Water Survey of Canada

The US Section of the CRTHC contacts selected agencies at the beginning of each operating year requesting notification of changes to station networks. Data collection agencies contacted include:

US Army Corps of Engineers
US Bureau of Reclamation
US Geological Survey
NOAA National Weather Service
US Natural Resources Conservation Service

Other agencies and electrical utilities contributing data for Treaty purposes include:

Avista

Fortis BC

BC Hydro

Bonneville Power Administration

Chelan PUD

Confederated Salish and Kootenai Tribes (Energykeepers, Inc.)

Douglas PUD

Grant PUD

Idaho Power

Appendix E Data communication and storage systems

CROHMS, CBT and other communications systems administered by the CRTHC are described in the following sections.

CROHMS

CROHMS is an acronym for Columbia River Operational Hydromet Management System. CROHMS was developed in 1970 through an agreement between the major federal agencies: USACE, BPA, NWS, USGS, USBR, and the NRCS. The objective of the agreement was to centralize the location of all hydrometeorological data for the Columbia Basin, in order to avoid duplication, and to distribute the data back to the agencies as needed. The centralized location is operated and maintained by the USACE. CROHMS consists of several hardware platforms which combine in function to provide current (operational) information to Reservoir Control Center sufficient to perform water control regulation. CROHMS is a generic term that is software-independent and is used to include CBT, the RCWDS (see below) and all other hardware and software components. It is the mission of USACE to provide data in a timely manner to the Treaty Entities for use in execution of the terms and conditions of the Treaty, including support and maintenance of an adequate hydrometeorological network. Higher Army authority sometimes places obstacles in the way of the timely delivery of said data and its supporting IT network

infrastructure. Therefore USACE must be diligent in assessing and addressing IT security requirements in order to continue to provide adequacy.

Data collection is the first process in the CROHMS system. This includes the CBT Messenger Network routed within the Intranet and some communication via the Internet. Data are collected via microwave, GOES (Geostationary Operational Environmental Satellite), and other methods . The data comes from all the agencies in the CROHMS agreement and BC Hydro. Each agency or utility is responsible for their data and their reservoirs in the Columbia Basin.

All these agencies together contribute data for an adequate complete picture of weather and streamflow in the entire Columbia Basin, including the Canadian portion of the basin.

COLUMBIA RIVER BASIN REGIONAL WATER CONTROL DATA SYSTEM

The Corps of Engineers Northwestern Division's Columbia Basin Water Management Division (CBWM) is home to a Regional Water Control Data System (RWCDS). The RWCDS's design is a three node system that are synchronized with replicated databases in Corps Portland, Seattle and Walla Walla Districts. The RWCDS is comprises of all hardware and software necessary to acquire, perform quality control, store, process, and disseminate all data related to planning and operations for all reservoir projects in the Columbia Basin. The RWCDS does not correct data received from the USGS or from non-Corps projects; but those data providers are contacted by RWCDS staff whenever erroneous data is received. Other non-Columbia Basin projects use the RWCDS as their real-time data warehouse. In addition to the data service of the RWCDS, the system simulation models are also executed on the RWCDS computers. The system is operated and maintained 24/7 by a combination of Corps of Engineers contract IT assets and regional Corps of Engineers support staff. All hardware and software are in compliance with Army policies and procedures and reflect corporately-developed

enterprise architecture and software. The Corps standard water management software suite is the Corps Water Management System (CWMS); and the database component (Oracle®) of CWMS houses the data.

CBT

The USACE operates the CBT system. CBT is one of several major subsystems of CROHMS and is the primary communications system between the hydropower projects and the operating agencies. The CBT system receives data directly from the United States Columbia Basin hydropower projects, primarily the USACE and the USBR but including other public and private utilities. There are approximately 40 CBT participants. Project data collection agencies transmit hourly data (or only daily data in some instances) from their respective systems to the CBT system in one of two ways. Data are transmitted via either the secure CBT web page (HTTPS protocol) or secure file transfer (SFTP protocol). A direct private circuits runs between the USACE in Portland and the NWRFC for enhanced reliability and security. Operating instructions to Projects are issued via CBT and are logged in the USACE email system. Hard copies are printed and archived for future reference

The CBT system operates much like an e-mail server. Each arriving message is coded with a list of addressees targeted to receive the message. The content of the message is a text field containing the data coded in “CBT Format”, a convention adapted and used by the operating agencies across the Pacific Northwest since 1957. The CBT server in Portland re-posts each message to the appropriate CBT web page of each agency. It simultaneously forwards the data to CROHMS and to BPA’s THOR system.

Information posted to the CBT web pages for retrieval by the CBT community is accessible only through secure, encrypted transmissions. Public access to the CBT system is not permitted.

Appendix F Data exchange reports

The following contains a summary of CRT hydrometeorological hourly, daily, monthly, and other reports:

HOURLY PROJECT DATA REPORTS

These reports include hourly data for the following hydropower projects:

ALF Albeni Falls	JDA John Day
BCL Big Cliff	LGS Little Goose
BON Bonneville	LIB Libby
CGR Cougar	LMN Lower Monumental
CHJ Chief Joseph	LOP Lookout Point
CHL Chelan	LOS Lost Creek
DET Detroit	LWG Lower Granite
DEX Dexter	MCN McNary
DWR Dworshak	PRD Priest Rapids
FOS Foster	RIS Rock Island
GCL Grand Coulee	RRH Rocky Reach
GPR Green Peter	TDA The Dalles
HCR Hills Creek	WAN Wanapum
HGH Hungry Horse	WEL Wells

IHR Ice Harbor	

The CBT system is used to send the following data to CROHMS each hour:

Inflow (daily only)

Outflow

Spillway flow

Reservoir and tailwater elevations

Generation

DAILY PROJECT DATA REPORTS

Daily project data reports are sent to CROHMS just after midnight using the CBT system. The reports include project data for hydropower projects such as:

ALF Albeni Falls	JDA John Day
BCL Big Cliff	LGS Little Goose
BON Bonneville	LIB Libby
CGR Cougar	LMN Lower Monumental
CHJ Chief Joseph	LOP Lookout Point
CHL Chelan	LOS Lost Creek
DET Detroit	LWG Lower Granite
DEX Dexter	MCN McNary
DWR Dworshak	PRD Priest Rapids
FOS Foster	RIS Rock Island
GCL Grand Coulee	RRH Rocky Reach
GPR Green Peter	Salish-Kootenai Dam
HCR Hills Creek	TDA The Dalles
HGH Hungry Horse	WAN Wanapum
IHR Ice Harbor	WEL Wells

Reports include the following data:

Daily average inflow
Daily average outflow
Daily average spillway flow
Day-end reservoir elevations
Daily total generation data
Average head
Midnight storage

Streamflow data for the Canadian rivers: Similkameen River at Hedley, Okanagan River at Penticton, South Slocan River near Crescent Valley, and Columbia River at Birchbank are available from the Water Survey of Canada website URL www.wateroffice.ec.gc.ca. BC Hydro additionally makes the daily average streamflow data for all these stations available to CROHMS.

METEOROLOGICAL DATA REPORTS

Meteorological data reports, sent to CROHMS by mid-morning each day, typically include the following:

Maximum daily temperature
Minimum daily temperature
Instantaneous temperature
Incremental or accumulated precipitation

Weather data from hydropower projects and Canadian stations are sent to CROHMS. Weather data for other stations in the United States are collected by the NWRFC and transferred to the USACE using sFTP over a dedicated circuit.

SNOW DATA REPORTS

Daily SNOTEL data and monthly snow course data for United States stations are collected by the NRCS and transmitted to the NWS. The same information is placed on the NRCS anonymous ftp site.
The NWRFC acquires snow pillow data for Canadian sites from British Columbia's MOE web site. The USACE accesses snow data directly from NRCS and BC Hydro

RESERVOIR CONTROL CENTER MESSAGES

Operational messages and instructions for project operations are sent out to the projects from the USACE Reservoir Control Center throughout the day or night as needed. Daily flow forecasts submitted by the NWRFC are also included. These messages are distributed using the CBT system.

BPA MESSAGES

BPA sends in and fetches data via sftp application. The same data are viewed by BPA through the CBT Web Messenger. Messages include:

Operational messages
Generation schedules
Grand Coulee forecasts
PNCA Entitlements

WATER SUPPLY FORECASTS

Volume runoff forecasts are exchanged by e-mail and/or posted to the web sites of the originating agencies for review and coordination with other Treaty participants.

Appendix G Treaty studies, models, and forecast requirements

Several forecasting and operational models require the input of hydrometeorological data. These models are used to forecast seasonal water supply or daily inflows, or to plan the operation of Treaty facilities for power production or FRM. The following sections briefly describe these studies, models, and related forecasting requirements.

TREATY STORAGE REGULATION

The Columbia River Treaty was implemented in 1964 to coordinate the operation of Canadian Columbia basin reservoirs for optimum power and flood control benefits downstream in Canada and the United States. A Detailed Operating Plan (DOP) is prepared annually according to the Treaty for this purpose.

The DOP requires a TSR study as input to determine the monthly storage rights and obligations for the Canadian reservoirs Mica, Arrow, and Duncan. The TSR also provides mid-month storage rights and obligations for the months of April and August. The TSR uses the following input to determine basic operating requirements for Canadian Treaty reservoirs:

- DOP operating criteria for 76 coordinated system projects in the United States and Canada

- Current unregulated streamflow forecasts
- Flood risk management curves
- Refill curves

Only unregulated streamflow forecasts, hydro-independent generation, variable refill curves, and upper rule curves are changed. All other operating data in the TSR study, including firm and secondary loads, thermal and miscellaneous resources, non-power requirements, other plant and operating data, and other applicable rule curves, come from the applicable Assured Operating Plan, as modified by the Detailed Operating Plan or other agreement of the Operating Committee.

The USACE submits monthly streamflow forecasts for their projects to the NWPP and BPA provides all other Federal/Canadian project monthly streamflow forecasts. From January through July, all monthly shaping of the streamflow forecasts maintain the forecast seasonal volumes supplied by the project owners. The NWPP then combines the USACE and BPA forecast with other non-Federal project streamflow forecasts and makes the data available for use in the TSR model.

The TSR is normally run twice per month to provide the operation of Canadian reservoirs for the AER. Either of the Canadian or United States Entities may request that the TSR be run more often.

Actual operation of the Canadian Treaty storage projects is established by weekly Entity agreements that are based on the TSR end-of-month storage results, combined with supplemental operating agreements or FRM requirements. TSR operating information for Libby is provided at the weekly meeting for coordinating operations on the Kootenay, but is not used for Libby's actual operation.

FLOOD CONTROL OPERATING PLAN (FCOP)

The USACE is responsible for Columbia River Treaty flood risk management (FRM) operations. The FCOP was developed under provisions of the Columbia River Treaty. The FCOP prescribes criteria and procedures by which the Canadian Entity will operate Mica, Duncan, and Arrow Reservoirs. Libby Reservoir is included in the FCOP to meet the Treaty requirement to coordinate its operation for flood damage reduction in Canada. The operation of Treaty storage reservoirs is intended to reduce stages at all potential flood damage areas in Canada and the United States to non-damaging levels where possible. During large flood events where flood damage cannot be avoided, the plan aims to control levels to minimize damage. The FCOP addresses both local and system FRM requirements. Local FRM relates to areas immediately downstream of project reservoirs. System FRM relates to overall system storage operations that reduce flood potential in the Portland, Oregon / Vancouver, Washington river reach. Flows on the Columbia River at The Dalles are used to prescribe system FRM requirements.

The plan develops operations for the evacuation and refill phases through the winter and spring, respectively. The evacuation portion of the FCOP uses project-specific Storage Reservation Diagrams (SRD) to specify the amount of space to be evacuated from a reservoir based on the seasonal volume forecast. The flood mitigation/refill portion of reservoir operations is guided (via the FCOP) by short-term streamflow forecasts (provided by the NWRFC), reservoir space to be filled, and volume remaining to run off. Other water supply forecasts are provided as follows for the USACE to determine upper rule curves:

Libby and Dworshak, USACE
Mica, Arrow, and Duncan, BC Hydro
Hungry Horse, USBR

The NWRFC provides forecasts for all remaining points.

The FCOP was initially developed in 1965 and first published in 1972. Changes to the Libby evacuation flood control curve were made in 1989. The USACE, Northwestern Division, North Pacific Region published a revised plan in May 2003, entitled “Columbia River Treaty Flood Control Operating Plan”. Revisions were made in response to changes in flood control criteria and development of new evaluation procedures. Even though the title of the FCOP contains the phrase, “flood control”, USACE has adopted a more precise terminology, Flood Risk Management.

WATER SUPPLY FORECASTING

Columbia River Treaty seasonal water supply forecasts are required for two reasons. First, the forecasts are required to plan the evacuation of storage space from Treaty reservoirs for FRM purposes prior to the onset of the spring freshet. Second, they are required to plan reservoir operations to ensure a reasonable likelihood of refill following the spring freshet.

Seasonal water supply forecasts are generally made over a period of time when snowmelt runoff predominates. Common forecast periods for Treaty projects are from the forecast date to the end of July, August, or September. Seasonal water supply forecasts can be based on either statistical procedures or conceptual hydrological model simulations. Currently, many of the seasonal water supply forecasts used for calculating upper rule curves are based on statistical procedures. These statistical forecasts are made near the first of each month, usually starting 01 December. The last seasonal inflow forecasts are made on 01 July of each year for Canadian projects and 01 June for US projects. “Official” forecasts are used to determine storage space evacuation from Treaty reservoirs required for FRM and refill criteria, whether they are generated by statistical methods or conceptual hydrologic modeling methods.

STATISTICAL PROCEDURES

Statistical procedures are usually developed using multiple linear regression techniques, primarily Principal Components Regression. Forecast water supply to a reservoir over the coming spring and summer period is regressed against a variety of predictor variables. These variables typically include data from a number of hydrometeorological stations. Data are used to compute predictor variables, such as mountain snow water equivalent and accumulated valley-bottom precipitation. In addition, antecedent conditions, such as fall precipitation or winter base flow, are commonly used as predictor variables.

BC Hydro revised the statistical forecast methodology in 2007 and implemented early season forecasts in December (BC Hydro, 2007)[3]. The USACE recently revised its statistical forecast procedures for Libby Reservoir (USACE, 2014)[4].

ENSEMBLE STREAMFLOW PREDICTION

A conceptual hydrological model may be used to forecast water supply using a procedure known as Ensemble Streamflow Prediction, or ESP. Once initial watershed conditions, such as snowpack and groundwater storage, are determined on the forecast date, historical weather data are input to the conceptual model, one year at a time, initializing with the current basin-state conditions. A series of synthetic hydrographs is produced as shown in Figure 1. By assuming that each hydrograph simulation has an equal likelihood of occurring in the coming season, the

[3] *BC Hydro (Luo) 2007. BC Hydro VoDCA Statistical Volume Forecast Models for Canadian Columbia River Treaty Projects*

[4] *USACE 2014. Water Supply Forecasting Models for Libby, MT 2014 Revision*

synthetic series generated is analyzed to produce a probabilistic forecast of seasonal water supply over the coming season.

BC Hydro uses the UBC Watershed Model (UBCWM) to simulate flows required for the ESP procedure, whereas BPA and NWRFC use the Community Hydrologic Prediction System (CHPS). Forecasts produced using ESP techniques are generally used by downstream stakeholders as input to other models to determine probable outcomes of operations on hydro generation and fisheries operations. They also provide a valuable comparison to forecasts produced using statistical procedures.

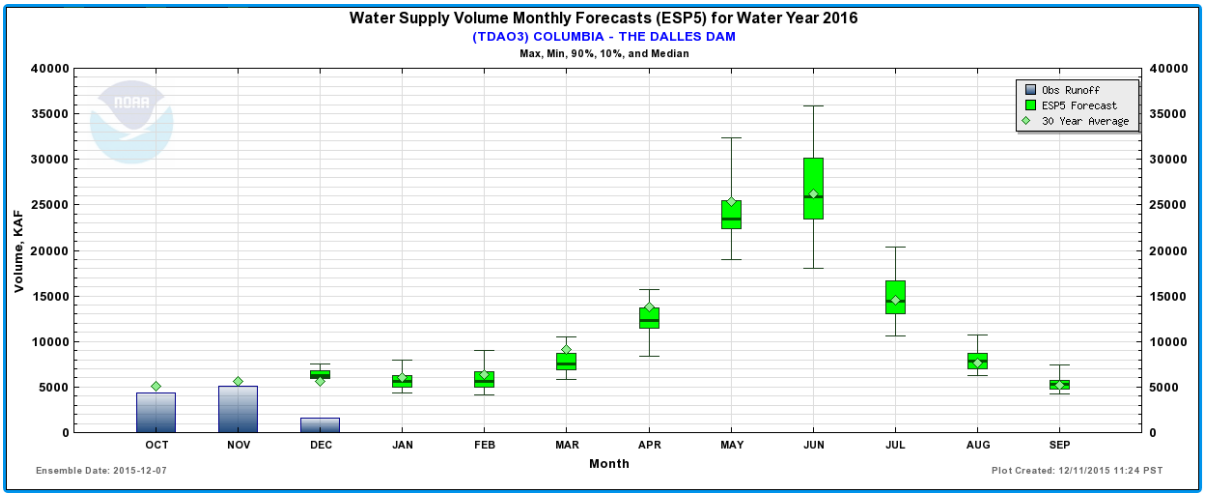

Figure 1 *Example of Ensemble Streamflow Prediction range of forecast monthly volumes for The Dalles. Taken from December 7, 2015 forecast from Northwest River Forecast Center website.*

The two forecasting methods have separate advantages and disadvantages. One advantage of statistical procedures is that they are relatively easy to develop. They are also entirely objective; that is, forecasts are deterministic and consistent, regardless who prepares them. ESP forecasts produced by conceptual models may be subjective. For example, individual forecasters may adjust a model's basin state conditions differently in order to get the model to "track" observed flows to the forecast date. The subjective adjustments to basin state conditions can lead to

different water supply forecasts. However, forecasts produced using conceptual models provide the best means available today for disaggregating seasonal runoff volumes into daily runoff distributions over the forecast period. These distributions are invaluable input to operational models required for Treaty projects.

The NWRFC now uses ESP exclusively for all of its forecasting products and uses a ten-day weather forecast to establish basin conditions as the foundation for the ESP forecasts. The NWRFC generates ESP forecasts for 10-day, 5-day, 0 day QPF. The CRTHC has adopted the 5-day QPF as the forecast used for operating the Columbia Basin. The 50% (representing the expected value) seasonal volume for any location is then published as the official forecast. An ESP seasonal volume forecast can be issued as often as several times per week, so each year prior to the January official forecast the CRTHC selects a day early in each month that shall be used as the official seasonal volume forecast. Criteria used to select each month's official forecast date are:

1) As close to the fifth working day as possible
2) Due dates for AER and TSR
3) Holidays that preclude staff from being available to produce forecasts.

INFLOW FORECASTS

DAILY AND WEEKLY

BC Hydro, BPA, and NWRFC independently produce daily inflow forecasts to assist in planning daily and weekly operations of Treaty facilities. The NWRFC provides the unregulated inflow forecasts to the USACE.

BC Hydro uses the UBC watershed model to produce daily reservoir inflow forecasts. The UBCWM is built into BC Hydro's River Forecast System (RFS) that was put into operation in 2002. Daily total precipitation, maximum and minimum temperature are the model's forcing variables. Observed forcing variables over the past seven days and quantitative precipitation and temperature forecasts (QPFs) over the coming five days are input to the model to forecast reservoir inflows over the combined twelve-day period. Basin-state conditions, such as snow water equivalent and groundwater, are simulated up to the day before the forecast date. The RFS offers the ability to update basin state conditions or modify forcing variables to match simulated and observed flows over the seven days leading to the forecast date. At BC Hydro, hydrologists produce five-day inflow forecasts for Mica, Arrow, and Duncan reservoirs by noon of each working day.

The US Entities produce independent daily forecasts for Canadian and US projects from Mica to Bonneville Dam and on the Willamette River. BPA and NWRFC use the CHPS model to produce daily reservoir inflow forecasts. CHPS is a lumped physically-based model that uses mathematical equations to represent physical processes of the hydrologic cycle. The system consists of components that model snowpack, soil moisture, time of concentration of flow, reservoir operations, and river routing. CHPS has been calibrated for 178 sub-basins in the Columbia River basin above The Dalles. During calibration, as many as 55 years of mean areal precipitation and temperature data were used to develop model parameters.
In operational use, both the NWRFC and BPA use CHPS independently. Observed and forecast weather data are input to the model. Precipitation and temperature data up to the current date are input. Hydrologists may make adjustments to model states and inputs over the past five to ten days to improve the simulated streamflow to better match observed flows. BPA meteorologists forecast future precipitation and temperature that hydrologists input to the model to generate streamflow forecasts. BPA produces daily forecasts in 6-hour time steps out 14 days into the

future. The NWRFC produces forecasts in the same 6-hour time steps for the next 10 days. Hydrologists use model output as primary guidance when issuing an inflow forecast. However, forecasters often use other available information and data, as well as their own experience, to adjust model output before issuing a forecast. The USACE accepts streamflow forecasts from the NWRFC and regulates inflows to meet project objectives.

MONTHLY

Monthly inflow forecasts are required for the AER and TSR models. Currently, the USACE and BPA provide these forecasts to the AER and TSR modellers. During the January-to-July period, these monthly forecasts preserve the official water supply volume forecasts. In addition, the USACE and BPA submit the monthly hydrograph shape. The hydrograph shape is subject to coordination with the Entities. During the August-to-December period, the monthly shape and overall volume is provided by the submitting agency in coordination with the Entities. Preparing monthly inflow forecasts can be more subjective in many respects than preparing daily or water supply forecasts. The monthly shape is derived using various tools and models. The USACE uses a combination of the NWRFC's models and historic percentages. From January into the early spring, the USACE uses the unregulated inflows provided by the NWRFC for the current and next month, then enters the residual volume into a spreadsheet, which evenly applies the same percentage to the remaining months through the end of July to derive the correct overall volume. The NWRFC forecast is generated using CHPS for the short (10-day) and longer-term (45-day) forecasts. The short-term forecasts utilize current antecedent conditions throughout the basin combined with 10-day precipitation and temperature forecasts. The longer-term forecasts are generated using the Ensemble Streamflow Prediction (ESP) component of CHPS. With ESP, the current antecedent conditions are combined with historical meteorological data

(temperatures and precipitation from water year 1949 to 2009 to generate a suite of hydrographs. Statistics can then be applied to the hydrographs to look at potential water scenarios.

BPA also uses CHPS to arrive at a monthly hydrograph shape. Each week, BPA runs ESP, and reviews how the short-term and mid- to long-term ensemble blends with that short-term forecast. A single streamflow trace of daily average streamflow is created by blending from the short-term forecast into the mean, median or some combination of those two statistics of the ensemble streamflows. This single trace is summed into monthly time steps and provided as input to the AER spreadsheet. During the January-July period, those values are used as starting points for the current and next month, and then each remaining months' volume is adjusted to match the official volume forecast for each point and the shape in the 'out' months is dictated by the median shape of the most recent Modified Flow set. These initial monthly flow forecasts are coordinated with BCHydro for the Canadian project, with the Bureau of Reclamation for Hungry Horse, and with the Corps of Engineers for the Corps projects. During the August-to-December period, monthly shaping only needs to be extended about two to three months into the future.

During the coordination discussions differences in flows, volumes and percentages are resolved by splitting the difference or using professional judgment to provide monthly values at each project which make hydrologic sense. When monthly flows or percentages fail to make sense, either agency can approach the CRTHC to request an alteration to the agreed upon procedure. These requests and alterations might include adjustments to the forecast procedure inputs, to the weightings used in the distribution or to the way monthly volumes are distributed. Each case is dealt with separately depending upon the circumstances.

PURPOSE FOR WATER SUPPLY FORECAST PERIODS

Different water management decision processes require water supply forecasts for different periods for a given water year. The following is a table of which forecast periods are used for which decision process for given projects.

Project	Agency	Forecast Type	Jan-Jul	Apr-July	Apr-Aug	May-Jul	May-Sept
Mica	BCH	Regression	VECC TSR		FRM	FRM	
Arrow	BCH	Regression	VECC TSR	Refill	FRM		
Duncan	BCH	Regression	VECC TSR	Refill	FRM	FRM	
Libby	USACE	Regression	VECC TSR	Refill	FRM	FRM	
Hungry Horse	USBR	Regression	VECC TSR		FRM	FRM	FRM
Grand Coulee	NWS	Ensemble	VECC TSR		FRM		
Dworshak	USACE	Regression	VECC TSR	Refill		FRM	
Brownlee	NWS	Ensemble	TSR	Refill			
Lower Granite	NWS	Ensemble	Fish Issues TSR	Fish Issues			
McNary	NWS	Ensemble	Fish Issues TSR				
John Day	NWS	Ensemble	Fish Issues TSR				
The Dalles	NWS	Ensemble	VECC /Fish Issues TSR		FRM	FRM	
Bonneville	NWS	Ensemble	TSR				

BCH – BC Hydro
NWS – National Weather Service (Northwest River Forecast Center)
USACE – US Army Corps of Engineers
USBR – US Bureau of Reclamation

VECC – Variable Energy Content Curves
FRM – Flood Risk Management
TSR – Treaty Storage Regulation