Assessing the Canadian Hydro Operation Post 2024 in the Absence of the Treaty

Bonneville Power Administration
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Photograph on front cover: Mica Dam (courtesy John Hyde)

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1.0 EXECUTIVE SUMMARY

The purpose of this project was to assess how the Canadian hydro system might be operated post 2024 in the absence of the Columbia River Treaty. The results of this assessment would then be used in the overarching assessment on the merits of terminating the Treaty, modifying the Treaty or continuing with the Treaty. There are many considerations in projecting the operations of the Canadian projects but the major assumptions include an assessment of:

- BC Hydro loads and resources post 2024
- Extent of non-power objectives (fishery, recreation, local flood control, etc.)
- Energy markets and transmission post 2024

To evaluate these uncertainties, a series of scenarios were developed to span a likely range of possibilities that attempted to incorporate these assumptions. The inputs were broken down into five main headings:

1. Post 2024 loads and resources (including possible new generation projects)
2. Level of non-power requirements including fishery and recreation concerns
3. Market conditions, namely what periods would energy be valued highest
4. Transmission limitations including tie-line transfer capability
5. Varying levels of water supply based on the 2000 level 70 year Modified Flow data set

Two models were used to evaluate the numerous scenarios, HydSim, which is a 14 period model and Columbia Vista (CV), which runs in weekly or near weekly time steps. The primary output of interest is the Columbia River flow out of Arrow which is the last Canadian project controlling the main-stem Columbia River flows and the period ending elevations at Mica and Arrow. The side flows from the Kootenay River system as well as the Pend Oreille River system were also included in the analysis to obtain the Canadian / U.S. border flow estimation, however the operations of the projects on these two river systems were essentially taken from prior Phase I Treaty studies and not subjected to sensitivity analysis. The exception to this was a sensitivity study focused on an alternative Duncan operation (Case 8) which had minimal overall effects. Projected end elevations at Mica and Arrow can be used for further study of flood control operations without the Treaty.

The general approach of the studies was to compare the total BC Hydro system load with total generation and evaluate resulting secondary sales and purchases subject to transmission limits and market conditions and also subject to non-power objectives for fisheries and recreation.

BC Hydro had submitted a study that they ran that was based on a no-Treaty operation from Phase I. This study was labeled as “Case 1” in the scenario listing and is often used as a reference case for comparison purposes against the studies included in this report. It appeared that the BC Hydro study did not fully subscribe to assumed white fish operations in all the water years.

The flexibility on the Canadian hydro system was used to shift generation into the periods assumed to be the highest energy value. Prices assumed were based on historical pricing at Mid-C for the period 1999-2011 excluding the high 2000-2001 period (Skyrocketed California prices combined with very low water). Energy prices were designated on three levels; high, medium and low, based on associated high, medium and low surplus amounts determined for the Federal system from prior HydSim studies. Generally speaking, the winter period was viewed as the highest value period, followed by late summer. The peak run-off period of May-June was determined to be the lowest energy value period. Consequently, the studies generally ran the system hardest during the winter then late summer to maximize revenue. Corresponding outflows from Mica reflected this generation profile with higher flows during the winter, especially December and lowest flows, often times at zero discharge, during the May-June period.

Key Findings: Arrow outflows were projected to operate near full turbine discharge of approximately 40 kcfs except when spill could not be avoided due to high Mica discharge during the winter and during the high natural runoff observed in the peak snow-melt period of May –July. Mica is projected to operate similar to current operations but with higher outflows and corresponding power production in the winter period. Mica draft is projected to be slightly deeper in the spring.

Overall, studies reflected a fairly narrow discharge range at Arrow, similar to the Arrow operation submitted by BC Hydro +/- 10 kcfs on an average basis. Sensitivity studies on pricing and changes to other reservoir objectives shifted the discharge during periods but not significantly. Figure 51 displays the 70 year average outflow at Arrow for 15 of the scenarios run including an historical average outflow profile for the current Treaty operations.

Further discussion on the recommended studies that the Project Team believes best represents the Canadian operations in the absence of the Treaty, can be found in Section 9.0.

Next Steps: Results of these studies will be modeled in subsequent studies to determine power, flood control and operational impacts to the U.S. should the Treaty be terminated.

2.0 INTRODUCTION

The Columbia River Treaty 2014/2024 Review (CRT 2014/24) requires multiple hydro-regulation studies to assess the decision to terminate the Treaty, continue the Treaty, or lastly, continue the Treaty but with contract changes. To evaluate these options, an assessment of how BC Hydro would operate without the Treaty, post 2024 is required. This assessment will facilitate further studies to determine possible impacts to the downstream U.S. system based on projected Canadian flow releases at the border by operating the Upper Columbia Canadian projects for domestic purposes without Treaty requirements.

3.0 PROJECT DESCRIPTION

3.1 Project Objective

Determine Canadian Operations without the Treaty for input to future studies that will estimate resultant impacts to U.S. power and non-power objectives, including flood control. Canadian operations are primarily defined as resulting outflows from Arrow over the 70 year period 1929-1998 along with period ending elevations for Mica and Arrow.

3.2 Project Resources

Project Sponsors

- Nancy Stephan – CRT Project Co-Manager (BPA)
- Matt Rea – CRT Project Co-Manager (Corps)
- Rick Pendergrass – Sovereign Review Team SRT alternate member (BPA)
- Jim Barton – SRT alternate member (Corps)

Project Management

Brian Kuepper – Project Manager

Project Team

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Project Resources
John Hyde – BPA
HDR (Contractor) – Canadian Water Use Plans Report
PowerEn (Contractor)– BC Hydro Operations (loads, markets, transmission inputs, etc)

3.3 BC Hydro System

There are six major considerations for modeling the Canadian hydro system:

1. Water Supply
    - Use Historical 70 year Modified flows 1928-1998
    - Use observed 1998 – 2008 (calibration & validation studies)

2. Loads & Resources
    - Estimate BC Hydro firm loads (High and medium scenarios)
    - Estimate total system resources (new/upgraded hydro, thermal, contracts, renewables)

3. Markets
    - Energy prices, buying and selling (historical or forecasted)
    - Energy customers & transmission limits (assume Alberta and U.S. market)

4. Constraints & Non-power Objectives
    - Elevation and flow constraints (flood control, fishery, recreation)
    - Assumptions for all BC Hydro non-power related operations
    - Power constraints (reserves, min. generation, etc)

5. Risk considerations
    - Refill objectives
    - Market risks
    - Load estimates
    - Operation constraints

6. Local flood control

3.3.1 System Configuration

The Canadian system configuration, post 2024 includes the following 15 projects:

- Peace River (3 ea): GM Shrum, Peace Canyon and Site C (assumed on-line post 2024)
- Upper Columbia (3 ea): Mica, Revelstoke and Arrow Lakes (Hugh Keenleyside Dam)
- Kootenay River (7 ea): Duncan (no generation), Corra Linn, Upper and Lower Bonnington, South Slocan, Kootenay Canal and Brilliant
- Pend Oreille River (2 ea.): Seven Mile, Waneta

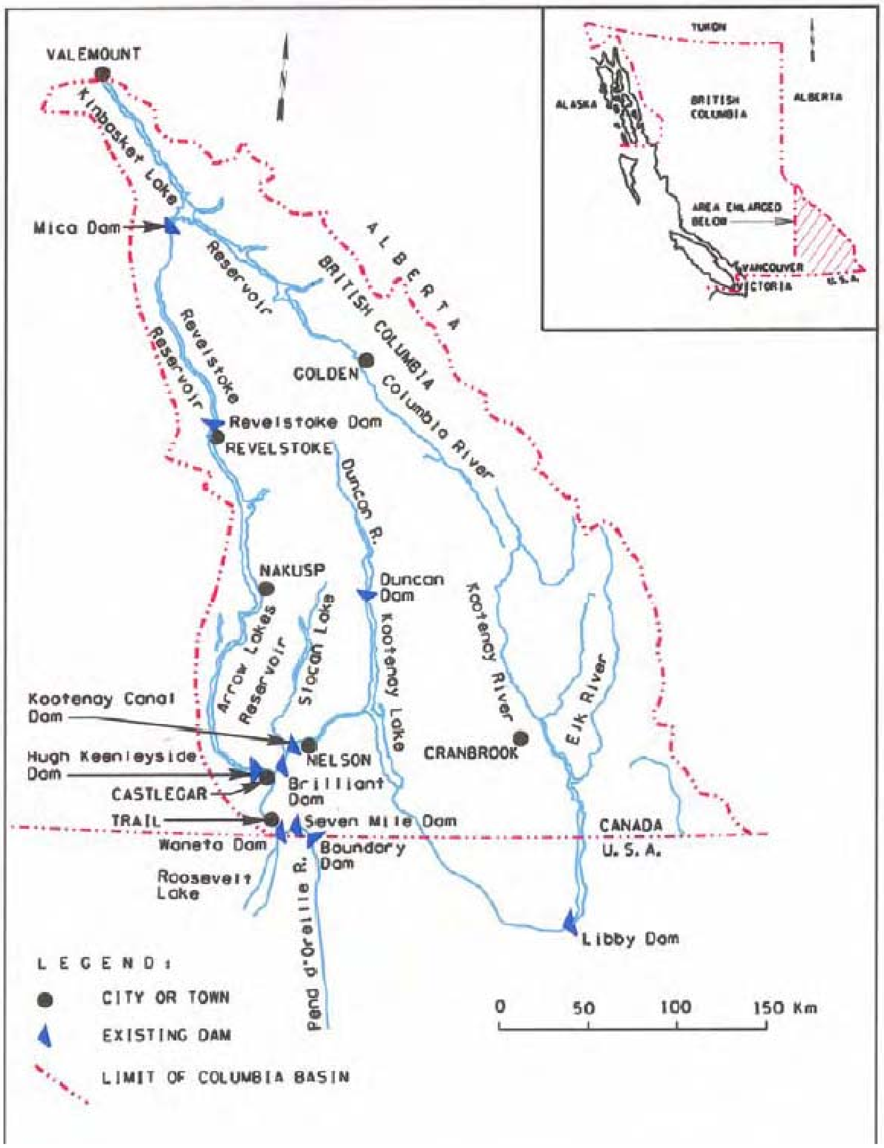


Figure 1: Lower Columbia Region

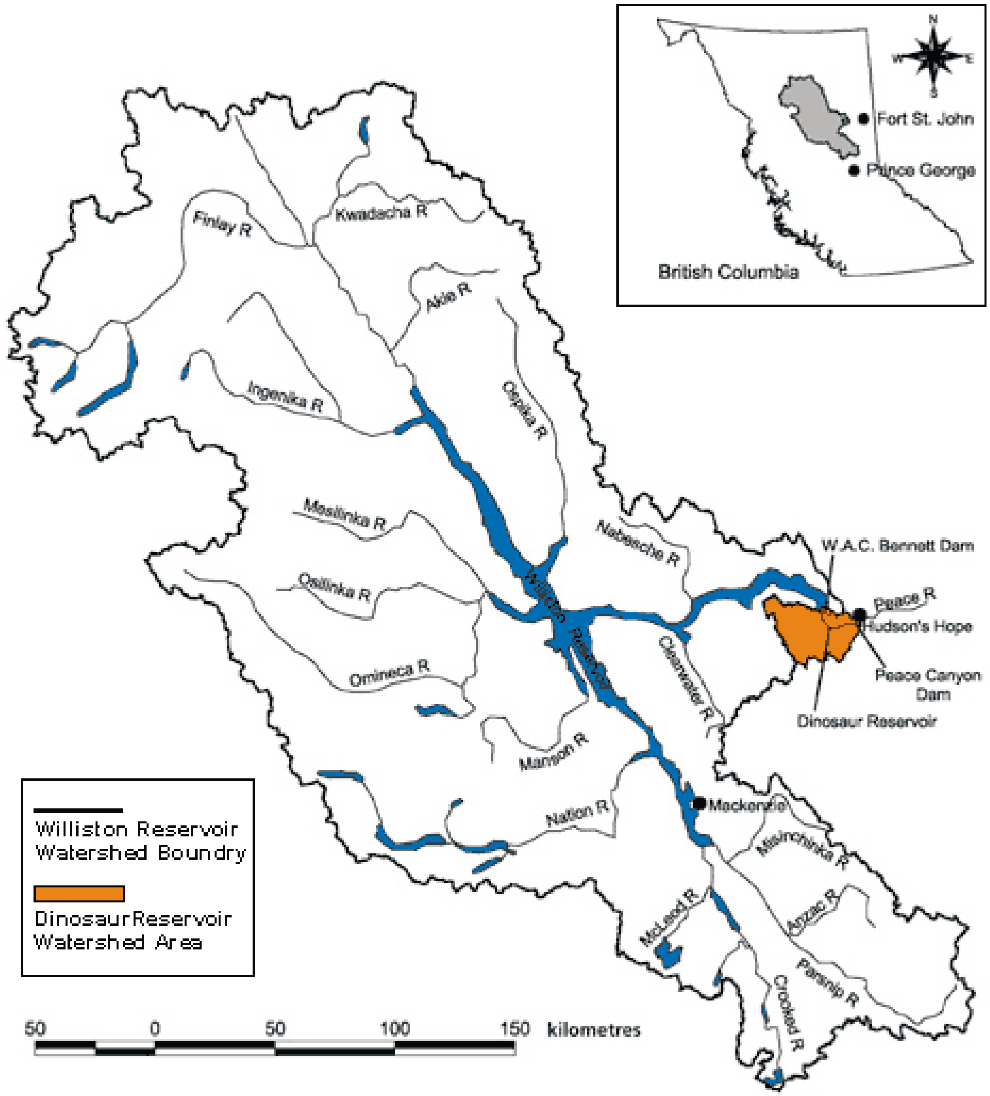


Figure 2: Williston Reservoir

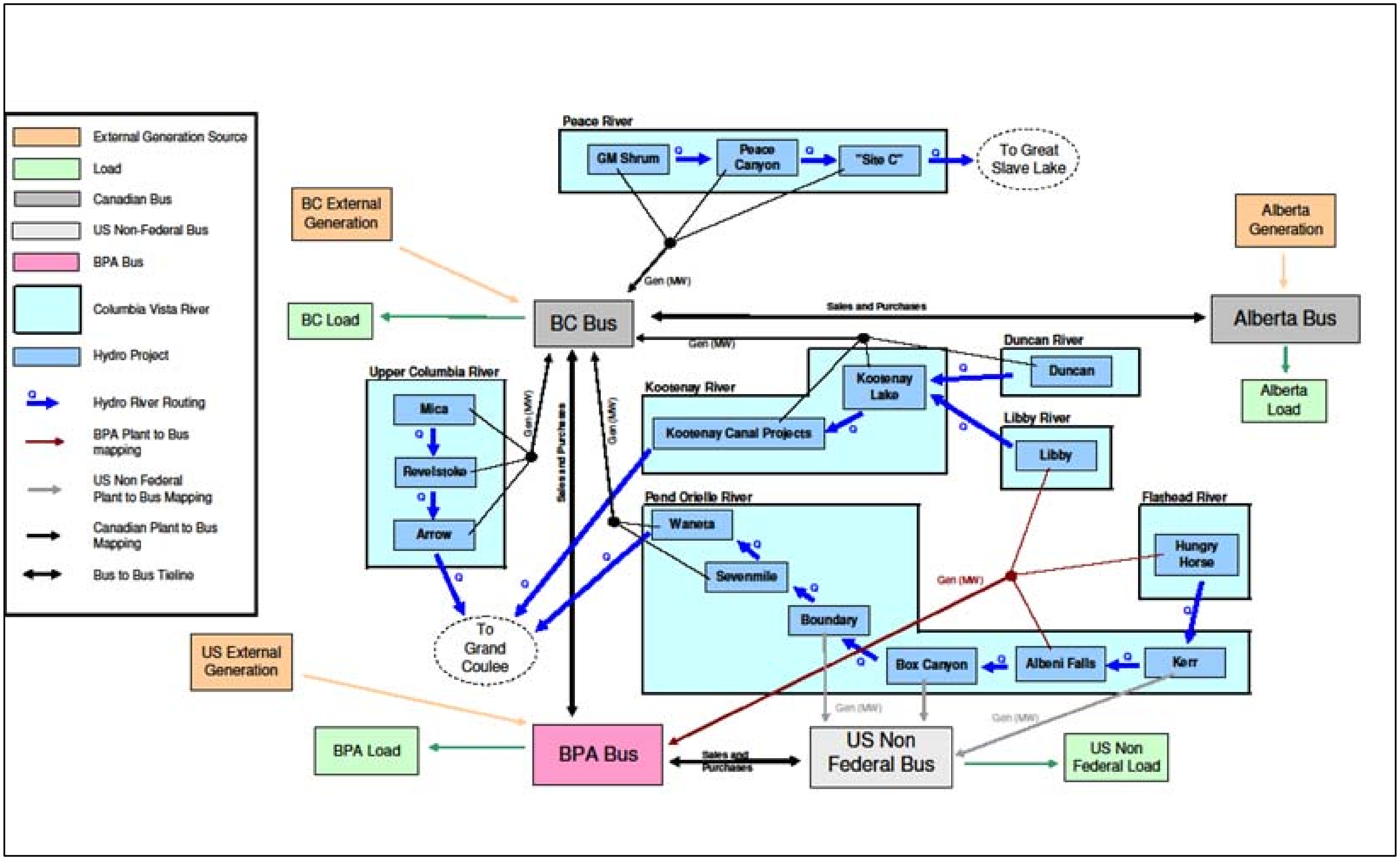


Figure 3: Canadian System Configuration used in the CV model

3.3.2 Generating Resources and Non-Power Objectives

BC Hydro's hydro generating plants are primarily located on four river basins; The Peace River, Columbia River, Kootenay River and the Pend Oreille River. Hydro generation currently contributes about 80% of the energy demand in the Canadian system. The Peace River Basin is located in the Northeast region of British Columbia Canada. This region is the home of Williston reservoir, a massive reservoir containing 33 MAF of storage, controlled by the GM Shrum generating plant. Downstream of GM Shrum is the Peace Canyon generating station. Currently, these two projects produce nearly 1/3 of BC Hydro's electricity requirements. The Mica and Revelstoke generating plants on the Columbia River Basin produce approximately 25% of the current system generation requirements. The remaining hydro projects, including small hydro in the Frasier Valley and on Vancouver Island, make up the 80% total hydro generating energy capability. The post 2024 resources assume an additional hydro project, "Site "C", which would be located downstream of Peace Canyon and two additional 500 MW units at Mica (assumed to be in service in 2015). "Site C" is currently in the planning cycle for a possible completion by 2021. See Table 14 for more project reference data.

The Peace River Basin must operate to minimize ice-jams and break-up of ice cover that can cause flooding below Peace Canyon. To alleviate this problem, discharge from Peace Canyon is kept at a steady high flow during the winter ice forming period (December-January) to allow for wider fluctuations after the ice bridging has been formed. The Columbia River non-power constraints assume a whitefish and trout fisheries protection flow level for both a spawning and emergence flow period. Arrow Lakes also has desirable recreational and ecological forebay level targets.

3.4 Modeling Methodology

Two regulating models were used in this project, HydSim and Columbia Vista (CV). HydSim is well known and accepted by the region but is limited to monthly time steps.

CV is used by BPA only and has not yet run production Regional studies. CV uses a more desirable weekly time step and is designed to perform global optimization that incorporates economics and energy markets. Configuring CV required more effort as it runs on a generating unit level rather than the project level used by HydSim.

The Modeling Methodology included the following steps:

A. HydSim and CV regulation models were configured to include the Peace River projects and future projected generating unit installations.

B. Validation studies (observed inputs) for both models were run and compared to observed outputs. Water Year 2006 was used in the validation runs. The resulting model output values for project outflows compared favorably with observed values. This validation added credence to the model configurations and their ability to capture the physical characteristics of the projects, particularly on the Peace River system.

C. BC Hydro operating objectives were identified and and translated into hydro constraints.

- HydSim – Operating rule curves that best captured BC Hydro (power and non-power) objectives were were developed
- CV – Established maximum and minimum parameters for each project and developed system market inputs (prices, market depth, tie-line limits)

D. Multiple Scenarios were established to best capture the uncertainities in inputs and assumptions. These scenarios were then run by the hydro regulation models.

E. Studies were evaluated and a final assessment process was established to arrive at a final reccomendation for BC Hydro operations without the Treaty. The assessment process culled out the studies that best met the criteria established by the Project Team.

3.4.1 Project Constraints

- Schedule The schedule required this project to be completed by January 31, 2011 to fit in with the overall CRT 2014/2024 schedule
- Resources. BPA staff as well as Corps and Mid-C participants needed to work around other commitments. Priorities were managed and workshops were planned to accommodate full schedules.
- Project plan had limited time for sensitivity studies. The plan required some flexibility to accommodate yet-to-be-determined sensitivity studies but still maintain a level of discipline to avoid undo scope creep.
- Assumptions and stream-lining efforts were defined and communicated to the Project Sponsors.

- Some tasks that were viewed as worthwhile were noted as outside the scope of this project but worth while as followup work. Examples of this would be an assessment of spill versus total dissolved gas (TDG) levels throughout the system as well as an assessment of possible "worst case" scenarios of BC Hydro operations.

3.4.2 HydSim

HydSim is a monthly hydro-regulation model that simulates the operation of seventy or so hydro-projects (depending on particular studies) in the Pacific Northwest under specific stream flow conditions and operating requirements. However in this study only the Canadian projects listed in Section 3.3 are included in the simulation. The model is used to determine the hydro-system's energy capability, along with each project's outflow and ending storage contents. HydSim is a deterministic model, not an optimizer (e.g. of power generation).

The HydSim model simulates one period (month) at a time, not using any forwarding-looking process. April and August are split into two half-periods since these months have significant natural flow differences between their first and second halves.

As mentioned previously in Section 3.3, HydSim uses as input the historic unregulated stream flow for water year sequences 1929 through 1998. The model is run in a continuous mode where at the beginning of each Fiscal Year (October), each project's initial storage contents match its ending storage contents of the previous water year (previous September).

For each period, the model reads input files containing unregulated stream flow, power load forecasts, hydro-independent power resources such as wind, thermal plants and other hydro-projects not regulated in HydSim, operating rule curves and operating requirements (more details in subsequent sections). Subtracting the hydro-independent resources from the total load yields the Residual Hydro Load which is one of the objectives HydSim operates the hydro system to meet.

Starting in October with a set of prescribed initial storage contents, HydSim regulates each storage project to fill, or draft to the ECC or draft proportionally to meet the residual hydro load beginning with upstream projects and working downstream while simultaneously checking that outflow and content requirements are met. If there are conflicting requirements while attempting to meet load and operating objectives, the model follows a priority list of constraints to determine the final operation for each project.

The next few sections provide descriptive details on HydSim modeling and operating rule curves usually derived from statistical analysis of snowpack and flow volume data over various periods for current Treaty studies. The lengthy mathematical details of the rule curves are available in the HydSim Manual. First the Upper Rule Curve (URC) at a storage project is designed for flood control and hence determines the maximum elevation (or maximum content) at the project for each period. Next the Energy Content Curve (ECC) represents the default project operation - drafting to meet load while also aiming to achieve a high probability of refill. High priority requirements such as minimum or maximum outflow limits will at times override the ECC operation.

If the hydro system drafting each project to its ECC generates enough or more power to meet (the Residual Hydro) load then the excess power could potentially become surplus and sold to produce revenue. Otherwise, each project must be drafted deeper than its ECC level according to a set of Critical Rule Curves (CRC's) that have their origins in (Pacific Northwest Coordination Agreement (PNCA) critical year planning and operation under the Columbia River Treaty with Canada. Mathematical details of the CRC's are similarly available in the HydSim manual. Each project in the hydro system is then proportionally drafted between these CRC's to meet load, if possible. However if drafting all projects to their lowest CRC still could not meet load, then the system is in a power deficit.

For this study, the 70-year URC's (1929 – 1998) for the Canadian storage projects beside Shrum were obtained from a Phase I Without-Treaty Base Case, "B2F600" study and based on local flood control with a maximum flow of 225 kcfs at Birchbank, Canada. URC's for GM Shrum was approximated by assessing maximum historical elevation for each period from available data from 1976 to 2009. It is not clear if GM Shrum does in fact operate to any URC's other then to regulate flows to minimize flooding due to ice build-up and break-up. The use of URC's is an integral part of running HydSim, hence the need to develop some sort of proxy.

The ECC and CRC's used in this study were developed specifically for this project, instead of being derived from statistical analysis of snowpack and flow volume data, and critical year planning and operations as is done under the current Treaty processes and regulations. The ECC and CRC's, were shaped to maximize generation (potentially leading to surplus and revenue) during high-priced periods and still aim to refill in most water years. These rule curves were developed to approximate draft rates in achieving favorable energy markets while balancing the refill objective. This is a subjective method but one viewed as reasonable in an era without Treaty planning. Note that the current Treaty studies make use of rule curves developed in a more rigorous and statistical manner. Below is an example plot of Mica's ECC and CRC's and their relation with an assumed price curve.

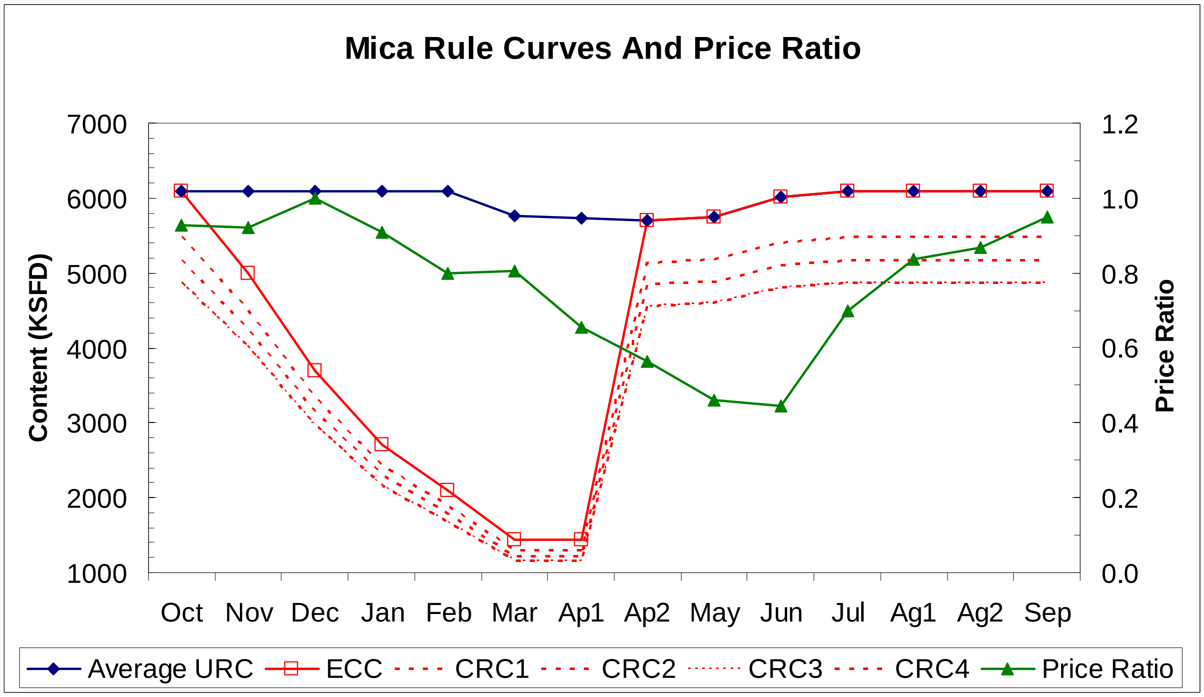


Figure 4: Mica Rule Curves and price ratio curve

In Fig. 4 the solid blue curve is Mica's 70-year averaged URC, and the green solid curve is the energy price ratio where the maximum price occurs in Dec at ratio 1 while the minimum occurs in Jun at ratio 0.45. Since the price is assumed to remain relatively high from October to March, Mica is drafted during those periods with the steepest draft during the highest priced months, October to January, and a gentler draft from January to March. Since prices are low from spring to midsummer, Mica remains at a stable content for the first period in April and begins refill quickly from the second period of April onward until September. As the price climbs higher in late summer, snowpack runoff should provide enough water to both refill the reservoir and discharge for generation. These operational objectives become the ECC, the solid red curve in the plot above.

The dotted red curves in Fig. 4 are the CRC's which would draft Mica deeper if drafting to the ECC could not meet load. The CRC's have been set as fractions of the ECC, and for simplicity, CRC4 was been set equal to CRC3. It is possible to draft Mica even deeper than suggested by the ECC since the minimum ECC still has about 1000 KSFD content. However, doing so would have prevented Mica from refilling for a majority of the 70 years and hence for subsequent years, Mica would not have as much content to draft for generation.

The ECC and the CRC's in Fig. 4 have been constructed relative to the 70-year averaged URC. The ratios of these curves relative to the 70-year averaged URC are shown in the table below.

Ratio to URC	Oct	Nov	Dec	Jan	Feb	Mar	1-Apr	2-Apr	May	Jun	Jul	1-Aug	2-Aug	Sep
ECC	1.000	0.821	0.608	0.444	0.345	0.249	0.249	1.000	1.000	1.000	1.000	1.000	1.000	1.000
CRC1	0.900	0.739	0.547	0.399	0.310	0.224	0.224	0.900	0.900	0.900	0.900	0.900	0.900	0.900
CRC2	0.850	0.698	0.517	0.377	0.293	0.212	0.212	0.850	0.850	0.850	0.850	0.850	0.850	0.850
CRC3	0.800	0.657	0.486	0.355	0.276	0.199	0.199	0.800	0.800	0.800	0.800	0.800	0.800	0.800
CRC4	0.800	0.657	0.486	0.355	0.276	0.199	0.199	0.800	0.800	0.800	0.800	0.800	0.800	0.800

Table 1. Ratio of the ECC and CRC's relative to the 70-year averaged URC from Fig. 1

For HydSim to run appropriately, a separate set of ECC and CRC's are needed for each of the 70 historical years in the simulation. Hence the ratios in Table 1 are applied to Mica's actual URC's for the 70 historical years to yield Mica's ECC's and CRC's for the 70 years.

Operating rule curves for other Canadian storage projects are similarly constructed, more details of which are discussed in Section 6.2.

3.4.3 Columbia Vista (CV)

CV is a hydro-regulation model that runs a C-plex linear program to optimize the revenue associated with secondary energy markets. BC Hydro firm system loads, natural inflows, reservoir and river flow constraints and price assumptions are inputs into CV. The model then shapes the generation into the higher value periods subject to constraints specified on the reservoirs river reaches. CV will incorporate buy / sell opportunities and transmission tie-line limits along with the hydro plant generation to meet firm load and to maximize revenue subject to the buying and selling of energy transactions. CV runs in a more desirable weekly time step (or near weekly) as compared to the 14 period HydSim studies. The ability to let CV shape energy generation (within constraints) automatically is a benefit over the pure simulation mode used by HydSim. When the studies must rely more on predetermined rule curves, HydSim runs very well and has advantages over the CV model.

3.5 Deliverables

The deliverables included a final report that included the following:

1. Validation results – a comparison of projected outflows against observed outflows.
2. A listing of operational constraints or guidelines for each of the BC Hydro projects that best reflects the Team's assessment of post 2024 operations
3. A single set of Canadian project operations (elevations, power and spill flows and generation values (70yrs * 14 periods) deemed to be the most "likely" operation without the Treaty. Note that the Arrow end contents & outflows are the main deliverables, to be used as input into subsequent studies.
4. Alternative operations for BC Hydro projects based on alternative study assumptions.

5. Assessment of key input variables e.g., an order of relative significance to the resulting outputs
6. Comparison of BC Hydro submitted operations (Case 1; without Treaty) against project study results
7. Summary Report

3.6 Issues / Risks

1. Difficulties in obtaining BC Hydro project data, especially Peace River data
2. Uncertainties around post 2024 loads and resources for BC Hydro.
3. Effective utilization of Team (BPA, Corps and Mid-C participants). Site visits or “workshops” were used to better communicate and discuss project issues. A Sharepoint site was developed by Chelan County PUD for the project and allowed for team members to review large quantities of data and study results. This provided to be very useful.
4. Scenarios were not fully defined in the beginning and it was not known how many scenarios would be required or how long it would take to run the studies.
5. Schedule – expected target date of Jan. 31 left little room for task slippage
6. Resource availability – competing priorities with Team members

4.0 VALIDATION STUDY

Neither HydSim nor Columbia Vista included the Peace River system in their configurations prior to these studies. In order to model the entire BC Hydro system resources and loads, the generation on the Peace River needed to be included. This also would better allow the joint operation of the Peace River and Columbia River to be modeled in conjunction with each other. BC Hydro planning specifically targets the joint operation of G.M. Shrum and Mica to find the optimal blend of working together in meeting generation requirements as well as refilling the projects. The Peace River projects include G. M. Shrum, Peace Canyon and the assumed in-service of Site C. The facility data for these projects were added to both HydSim and CV. To verify the facility data as being accurate and functional, a validation study was setup. The study objective was to input observed system loads, inflows and end of period elevations at the storage projects and compare the modeled outflows against the observed. It would have been useful to compare generation values as well but the observed hourly or daily generation values for the Canadian projects was not available. If the modeled outflows compared favorably with the observed outflows, the models would be considered to be accurate in capturing the physical parameters of the projects such as the storage-content tables and local incremental inflow control points.

The results of the CV weekly run for flow at the Canadian/U.S. border is shown in Figure 5 below. The observed flows are described in two different ways. There is a USGS gauge located on the border that gives the best indication of border flows. The local incremental flows between Arrow and the border were not available so a proxy flow for the border was calculated by summing up the project outflows for Arrow (Columbia River), Brilliant (Kootenay River) and Waneta (last project on the Pend Oreille River). The observed outflows from these three projects are labeled “Observed / theoretical” on the graph. The overall comparisons were favorable. Some differences would be expected in daily peak flow events that are approximated in weekly time steps of the CV model.

Both Hungry Horse and Libby were evaluated with 2006 observed flows, see Figure 9 and Figure 10. Modeled outflows and elevations track closely with the observed values for these U.S. projects.

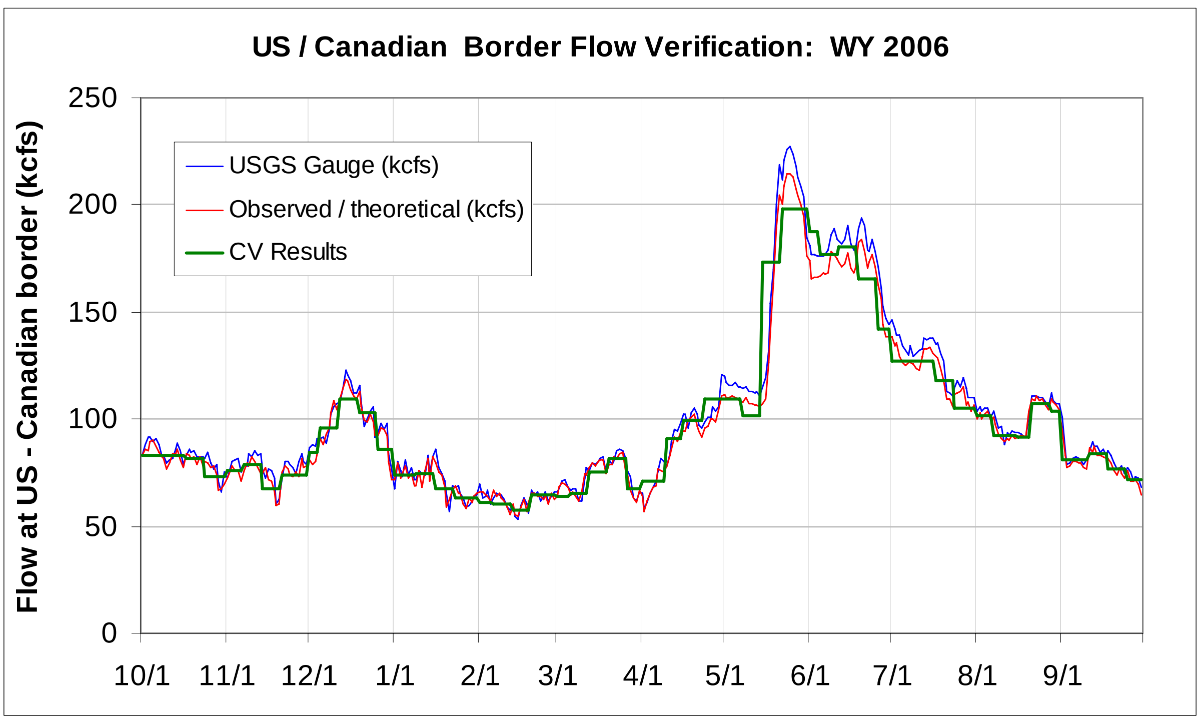


Figure 5: CV modeled and observed flow at the Canadian border for 2006 (weekly)

There are differences evident in the peak flow June period in Figure 6. This can be partially explained in the way the incremental flows were distributed in the models in the Kootenay and Pend Oreille basins. Some levels of incremental flows were modeled as inflows into Grand Coulee rather than the Kootenay or Pend Oreille Rivers. The models also do not reflect local inflows between Arrow and the Canadian border. For these reasons, a direct comparison is not possible at the border and the graphs should be viewed as informational only.

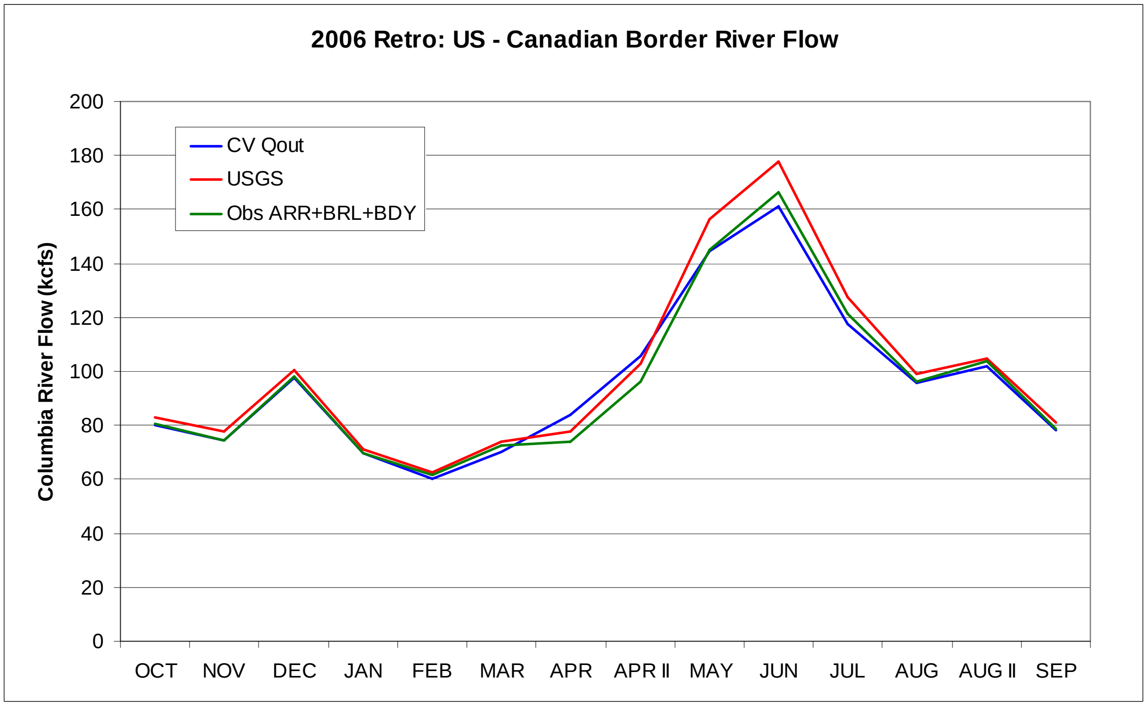


Figure 6: CV modeled and observed flow at the Canadian border for 2006 (14 periods)

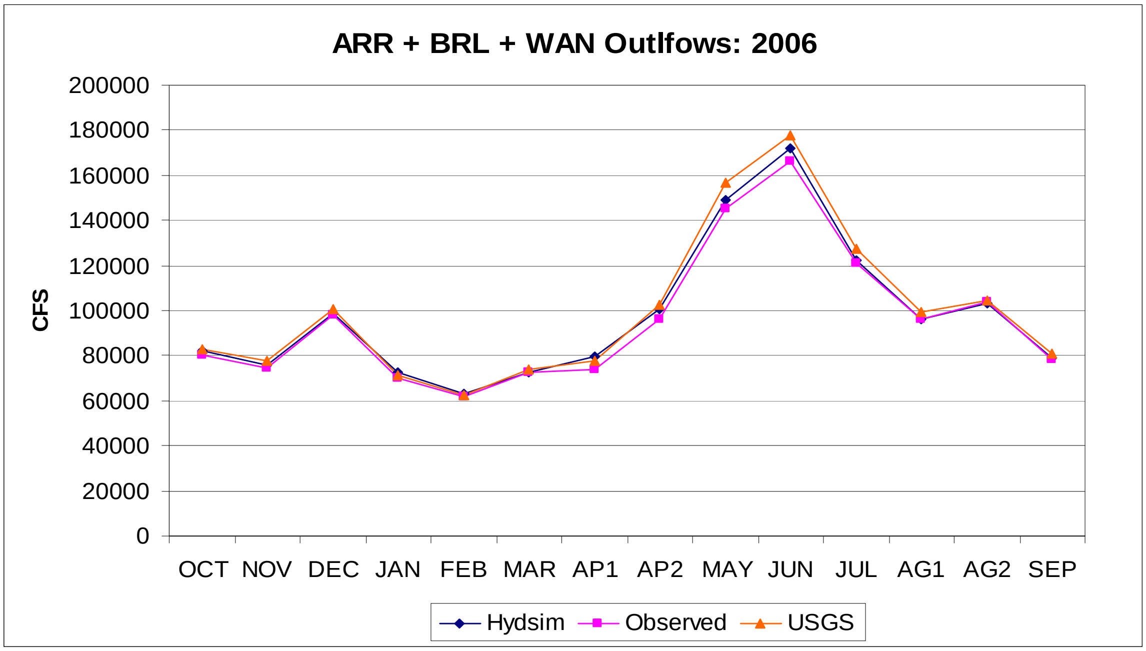


Figure 7: HydSim modeled and observed flow at the Canadian border for 2006 (14 periods)

There was a gap in obtaining historical data at the end of January and the end of July for GM Shrum, see the gap in the black line in Figure 8. For these weekly periods, comparisons cannot be made.

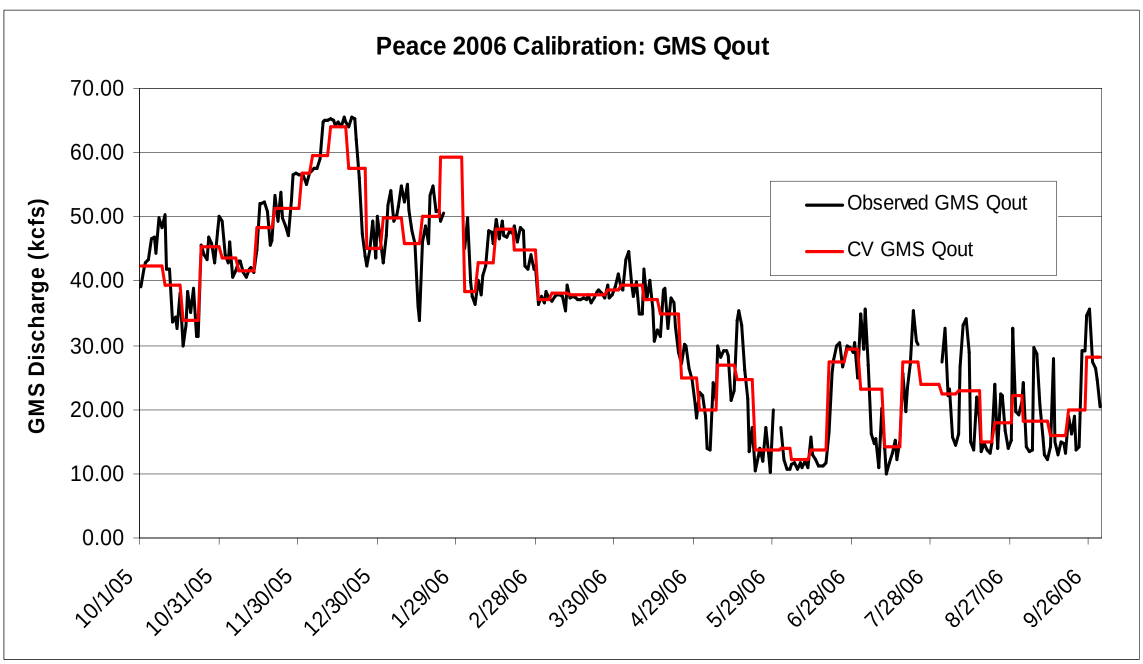


Figure 8: CV modeled and observed outflow at G.M. Shrum

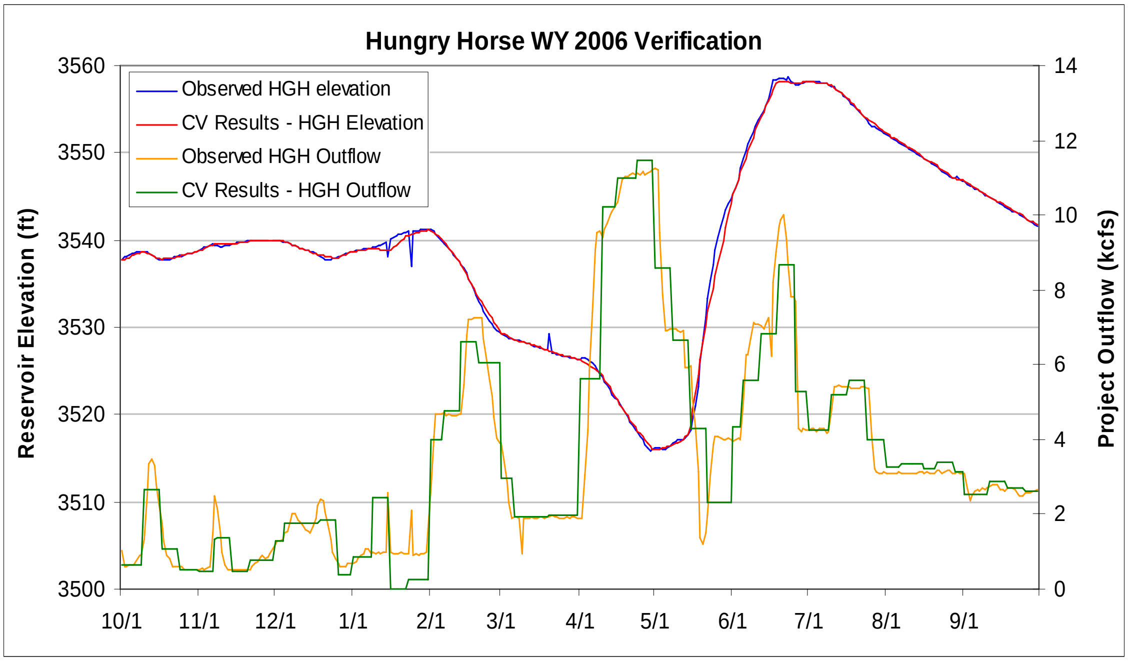


Figure 9: CV modeled and observed elevations and outflows at Hungry Horse

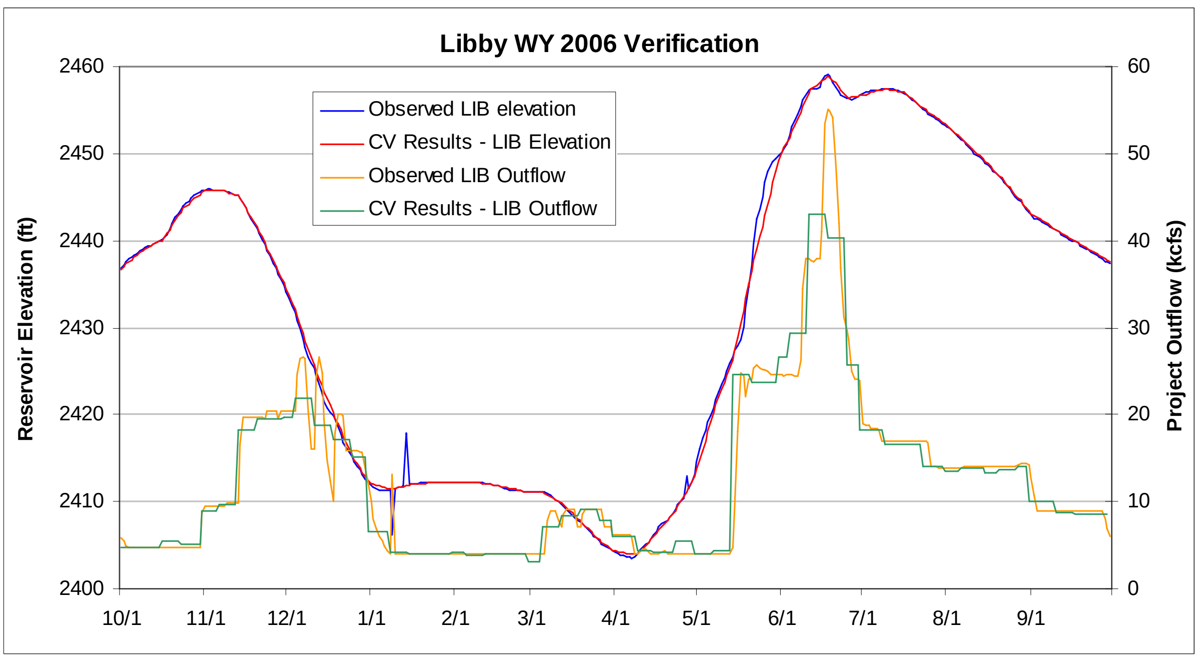


Figure 10: CV modeled and observed elevations and outflows at Libby

5.0 MODEL INPUTS AND ASSUMPTIONS

The model inputs can be described under the following seven headings:

- Streamflows
- Loads
- Other resources including small hydro, thermal and external contracts
- Energy Markets including customers, price assumptions, market depth
- Transmission limitations
- Local flood control
- Project operations including non-power objectives

Table 2 and Table 5 display the numerous scenarios that were modeled by CV and composed of varied assumptions from the listed seven input categories.

CV Studies		**Study Cases**													revised	#######		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
		BCH submitted	local flood control		mod. refill	low refill	rev. Arrow facility data	flat Qrtly. Prices	lower Arrow FB	high refill	70 yr. cont. (high refill)	high loads	alt. Duncan	alt. Arrow	revised price shape #1	price shape #2	new Arrow Facility Data and Seasonal prices	no Site C
# of Input Var.'s	**Input Variable**	**Case 1**	**Case 2-165**	**Case 2-225**	**Case 4**	**Case 4b**	**Case 4c**	**Case 4q**	**Case 4FB**	**Case 3**	**Case 3b**	**Case 7**	**Case 8**	**Case 9**	**Case 10**	**Case 15**	**Case 15b**	**Case 14**
1	Canadian Ops fixed to BCH submittal	X																
2	local flood control (165 kcfs at Birchbank)		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
3	local flood control (225 kcfs at Birchbank)			X														
4	high refill mode		X	X						X	X							
5	moderate refill mode				X		X	X	X			X	X	X	X	X	X	X
6	low refill mode					X												
7	Trout Spawning and Whitefish Ops.				X	X	X	X	X	X	X	X	X	X	X	X	X	X
8	medium load forecast		X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
9	high load forecast (no conservation)											X						
10	alternative Duncan Ops (market driven)												X					
11	alt. Arrow (natural lake)													X				
12	alt. Arrow Facility data (incr. Qt)						X	X	X								X	
13	alt. Arrow FB range (Lower)								X									
14	no Site C assumed																	X
15	Price assumption #1		X	X	X	X	X	X	X	X	X	X	X	X				X
16	Price assumption #2 (revised shaping)														X			
17	Price assumption #3 (revised shaping)															X	X	
18	Price assumption #4 (flat seasonal prices)							X	X									
19	70 yr. continuous mode (high opt. foresight)										X							

Table 2: CV Studies

5.1 Stream flows

The streamflows that were used in these studies for the Upper Columbia River, the Kootenay River Basin and Pend Oreille River basin were based on the 2000 Level Modified streamflow dataset that included the 70 year period 1929-1998. Inflows into the Peace Daily flows were based on the 1990 Level Modified flow dataset that included the 60 year historic record, 1929-1988. The 1990 Level Modified flow dataset was the last dataset to include the Peace River basin which included natural inflows into GM Shrum and Peace Canyon project. Observed gauge data and GM Shrum project data (elevations and outflows) was used to estimate Peace River natural streamflow data for the period 1989-1998. Daily streamflows were input into CV and the 14 period averages (Monthly except April and August split into two halves) were input in HydSim.

5.2 Loads

Two load estimates for BC Hydro’s total demand for 2024 were developed and modeled. The first load estimate of 67,400 GWh was derived from reported 2006 level loads and period shaping, projected into the 2024 future with a load increase factor of applied. This load projection was also compared to a load forecast generated by a contractor (PowerEn) and determined to be very similar. This load was considered as an “expected” or medium level scenario. For a demand sensitivity assessment, a high level load estimate of 77,400 annual GWh was included as an alternative load case. This value was determined by assuming that BC Hydro conservation estimates for the post 2024 era fell short. Figure 11 illustrates the total BC Hydro load estimates and the assumed monthly shaping that was modeled. The December – January period was assumed to be the highest load demand period. These two load estimates are consistent with BC Hydro’s Forecast Customer Demand Range shown in Figure 13 as the upper and lower boundary range for 2024, displayed in the yellow band. These estimates also are consistent with the projected load of 75,982 GWh for 2027 shown in Table 3 and the lower demand estimate of 62,231 GWh that included a Demand Side Management (DSM) plan, shown in Table 4.

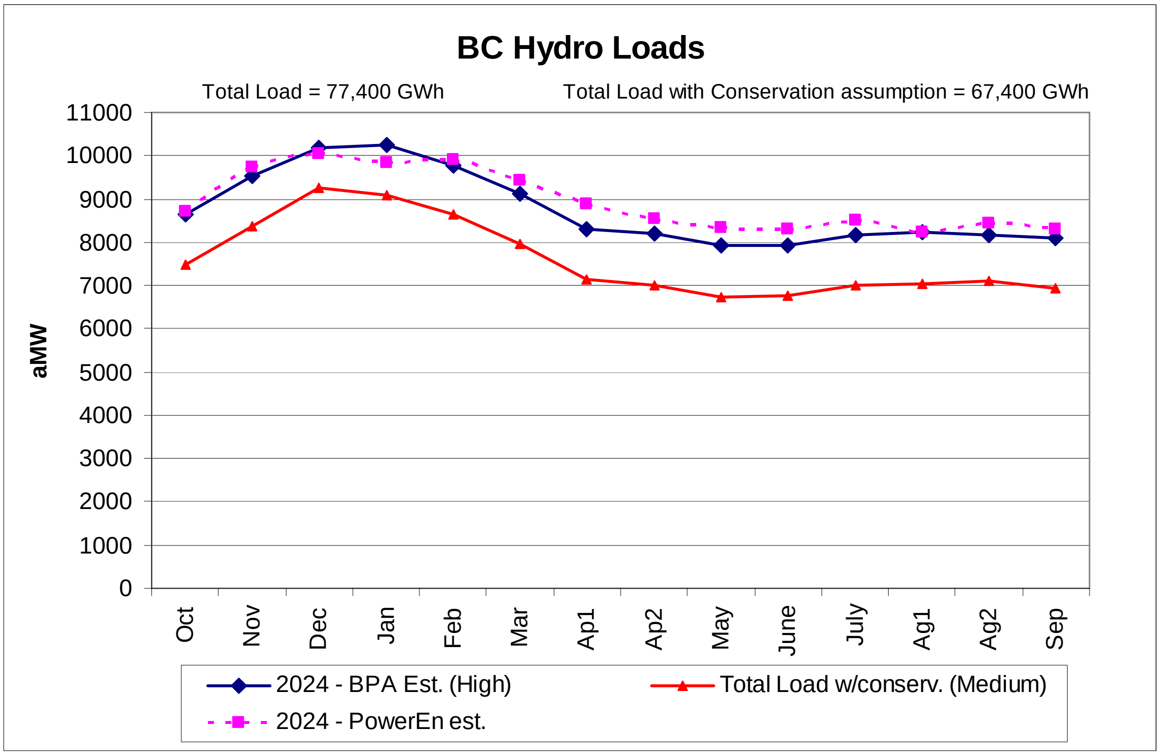


Figure 11: Modeled BC Hydro Load Estimates

ELECTRIC LOAD FORECAST 2010/11-2030/31

Table 1. Reference Energy and Peak Forecast Before DSM and With Rate Impacts for Selected Years (Excluding EVs and DSM/load integration)

Fiscal Year	BC Hydro Residential (GWh)	BC Hydro Commercial (GWh)	BC Hydro Industrial (GWh)	Total Firm Sales* (GWh)	Total Integrated System Requirements (GWh)	Total Integrated System Peak (MW)**
F2010	17,650	15,515	15,722	50,392	55,190	10,334
F2011	18,127	16,132	15,932	51,931	56,818	10,562
F2017	20,161	19,120	22,271	63,461	68,326	12,362
F2021	21,401	20,318	22,047	65,790	70,658	12,754
F2027	23,228	21,954	23,250	70,632	75,982	13,603
F2031	24,362	23,132	23,626	73,435	79,080	14,186
21 years: F2010 to F2031	1.5%	1.9%	2.0%	1.8%	1.7%	1.5%

Note:
* Total firm sales includes sales to all residential, commercial and industrial customers and sales to all other utilities including Seattle City Light, City of New Westminster and Fortis BC.
** Peak Demand for Fiscal 2010 is weather normalized.
***The Rate Impacts or natural conservation due to future rate increases on a total integrated basis reflected in the 2010 Forecast are 151 GWh for F2011, 1,354 GWh for F2017, 1,668 GWh for F2021, 2,005 GWh for F2027 and 2,234 GWh for F2031. The Rate Impacts reflected in the 2008 Forecast are 427 GWh for F2011, 1,269 GWh for F2017, 1,469 GWh for F2021, and 1,583 GWh for F2027.

Table 3: BC Hydro Load Estimates

Source: BC Hydro Electric Load Forecast 2010 Forecast Report before Demand Side Management activities (DSM); Table 1., pg. 14

Forecast Load/Resource Gap

GWh	F2012	F2017	F2022	F2027
Reference Load Forecast	61,362	66,172	69,318	73,847
DSM(1)	3,000	7,632	10,156	11,616
Electricity Supply Obligation	58,362	58,540	59,162	62,231
Existing and Committed Resources	55,406	55,608	54,786	54,748
Load/Resource Gap	2,956	2,932	4,376	7,483

(Source: Exhibit B-12, BCUC 3.269.1)

Table 4: BC Hydro Load Estimates from Long Term Acquisition Plan

Source: BC Hydro 2008 Long Term Acquisition Plan (July 27, 2009); pg. 118

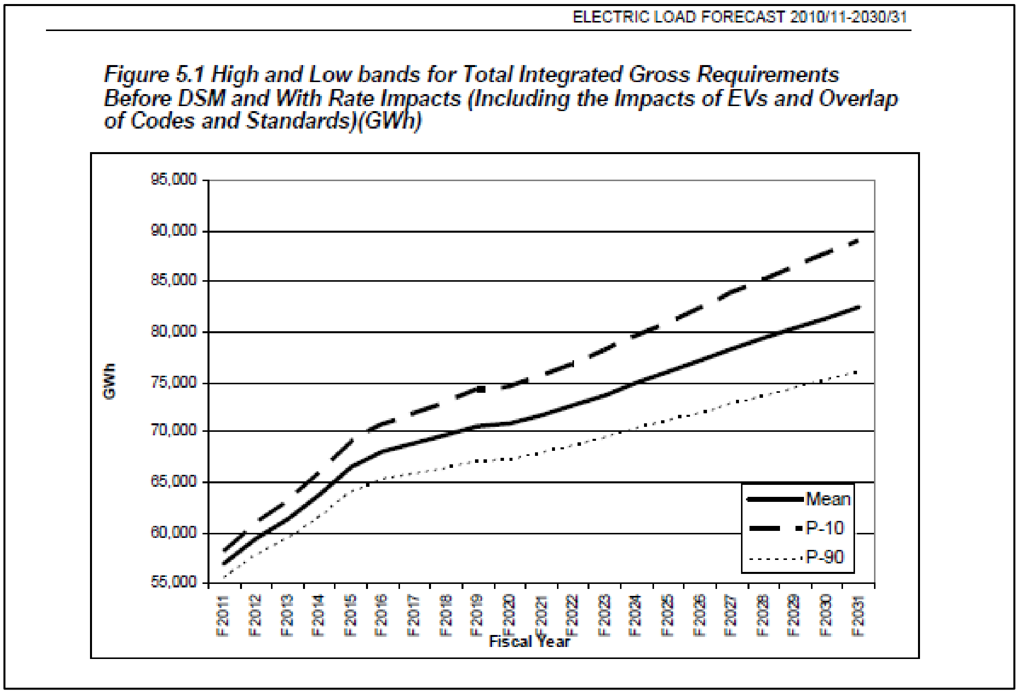


Figure 12: BC Hydro High and Low Load Bands

Source: BC Hydro Electric Load Forecast 2010 Forecast Report; Figure 5.1, pg. 28

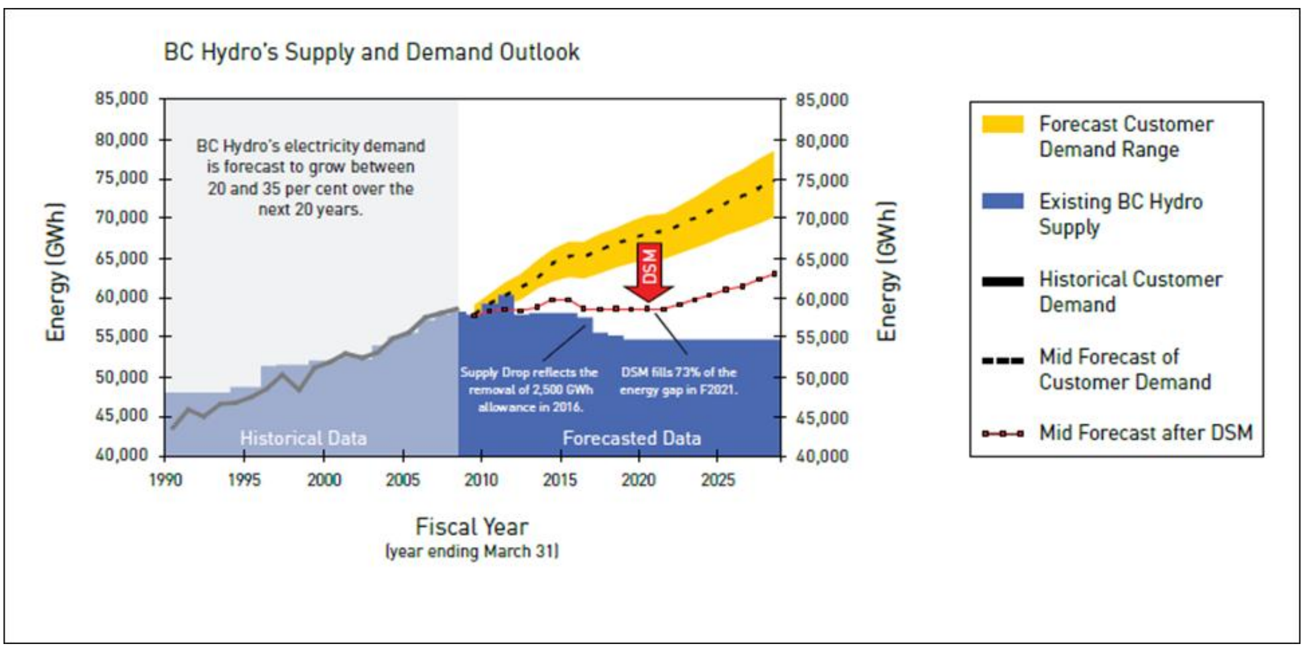


Figure 13: BC Hydro Supply and Demand Outlook

Source: BC Hydro's Electricity Conservation Report (2009)

5.3 Non-Hydro Resources

There are many resources located throughout British Columbia that were not explicitly defined in CV or Hydsim. These resources were aggregated and entered into each model as an "external resource". Using a variety of resources including the BC Hydro website an estimate of 2609.3 MW was made for the annual average external generation in the BC system. However, the capacity is much higher and as a result a shaped external resource profile was developed. Figure 14 shows the shape of the external resources used in both the CV and Hydsim modeling. This shape was estimated by dividing the total external resources into three categories; base load resources such as thermal plants, regulated hydro projects, and run of river hydro projects. Base load projects were assumed to have no shape across the year. Regulated hydro generation was assumed to have a shape similar to the regulated outflow from other modeled hydro projects. The shape of the run of river external generation was assumed to mimic the average annual natural hydrograph at Birchbank. Between May and July this shape resulted in generation above the turbine capacity of these run of river projects. This results in the flattened generation peak shown in Figure 14.

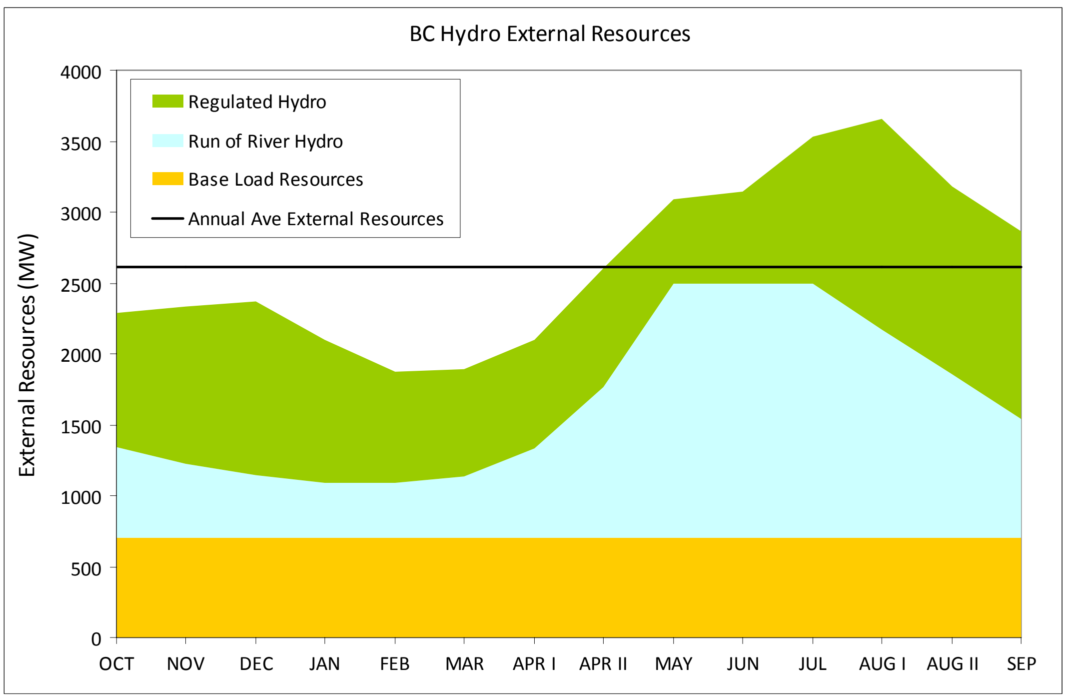


Figure 14: BC Hydro External Resource Estimates

5.4 Energy Markets

Price assumptions under three headings; high, medium and low were developed to represent BC Hydro's U.S. energy market. The price assumptions were based largely on the last decade of historical pricing at Mid-C. The high and low bands were developed to represent periods of low amounts of available surplus energy in the region and high surplus amounts respectively. The surplus levels were based on prior HydSim studies and reflected a U.S. system surplus. The December period, on average, ranked slightly highest followed by neighboring winter months and late summer months. May and June were historically the lowest values periods. The 70 water years were each designated under its high, medium or low pricing schedule.

U.S. Tiered Market Prices ($/MWh)

Fed. Surplus		Oct	Nov	Dec	Jan	Feb	Mar	Apr I	Apr II	May	June	July	Aug I	Aug II	Sep
Low	HLH	60	59	63	59	54	54	47	42	38	38	51	58	59	62
	LLH	49	49	52	47	42	42	34	28	21	20	32	39	39	48
Medium	HLH	50	49	53	49	44	44	37	32	28	28	41	48	49	52
	LLH	44	44	47	42	37	37	29	23	16	15	27	34	34	43
High	HLH	45	44	48	44	39	39	32	27	23	23	36	43	44	47
	LLH	34	34	37	32	27	27	19	13	6	5	17	24	24	33
Average	HLH	50	49	53	49	44	44	37	32	28	28	41	48	49	52
	LLH	44	44	47	42	37	37	29	23	16	15	27	34	34	43

Table 5: U.S. Market Prices

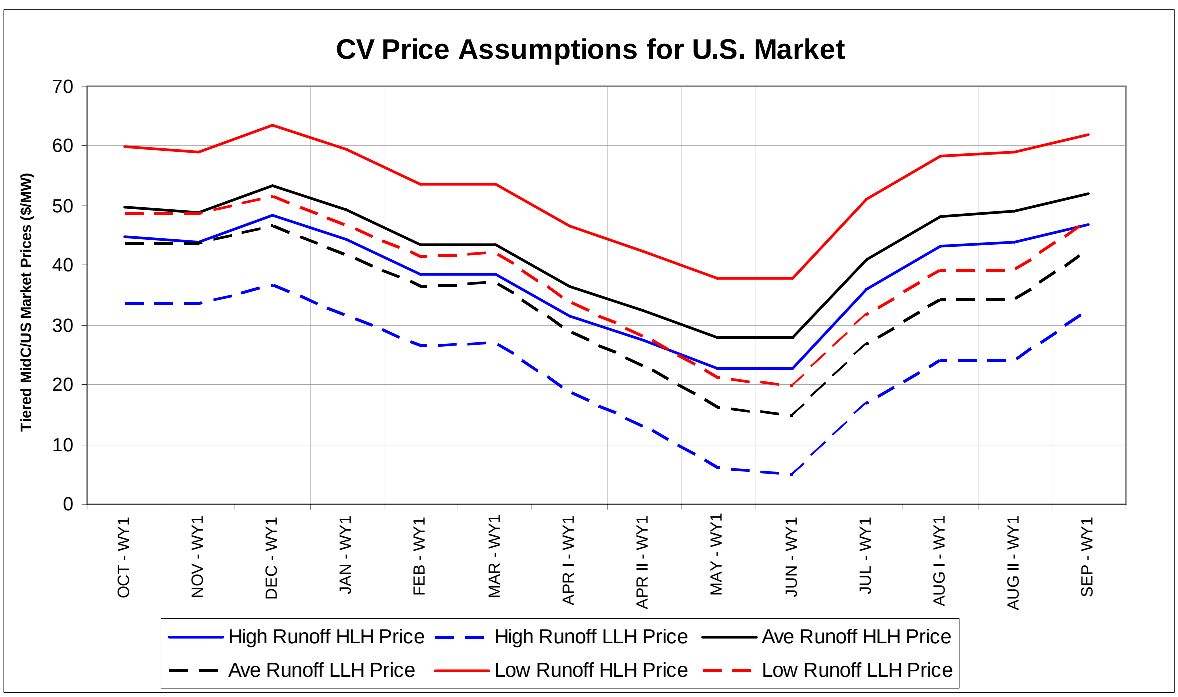


Figure 15: Assumed U.S. Market Prices

A market depth transaction assumption was used to limit the availability of energy on the market and attempt to reflect reasonable market conditions. In low water years for example, it would not be prudent to assume a limitless supply of energy available to purchase. Similarly, very high water supply conditions might lead to such a high surplus that the market would not support unlimited energy generation. It is worth noting however, that the energy market is more often limited by transmission availability than the assumed market depth assumptions. As an example, the market depth in May for 1943 water is assumed to be 4429 MW-mo, meaning that the U.S. market could export this amount to BC Hydro during this period. The transmission tie-line limit to import energy into BC Hydro is assumed to be 1950 MW, however. Therefore the maximum purchase amount for BC Hydro would be capped at 1950 MW during this period.

There were at least four pricing scenarios developed to assess the effects of market assumptions to reservoir operations. The output range was not significantly different as the general price curve shape did not deviate significantly from the historical averages.

	OCT	NOV	DEC	JAN	FEB	MAR	APR I	APR I	MAY	JUN	JUL	AUG I	AUG II	SEP
Very Low	2,002	1,949	1,600	1,013	1,323	1,318	1,653	2,065	2,473	2,518	2,974	1,462	435	1,075
Low	2,183	2,100	1,718	1,269	1,625	3,339	4,157	5,141	4,571	4,958	3,154	1,571	479	1,139
Medium	2,436	2,400	2,320	2,568	3,180	4,398	5,203	5,193	4,625	5,280	4,179	2,002	549	1,277
High	2,644	2,761	3,155	3,950	4,880	5,447	5,330	5,388	4,429	5,280	5,081	2,725	811	1,352
Very High	2,947	3,629	4,500	5,390	5,980	6,224	5,855	6,114	5,324	5,154	5,228	3,043	1,005	1,674
Average	2,442	2,568	2,659	2,838	3,397	4,145	4,440	4,780	4,284	4,638	4,123	2,161	656	1,303

Table 6: U.S. Market Depth

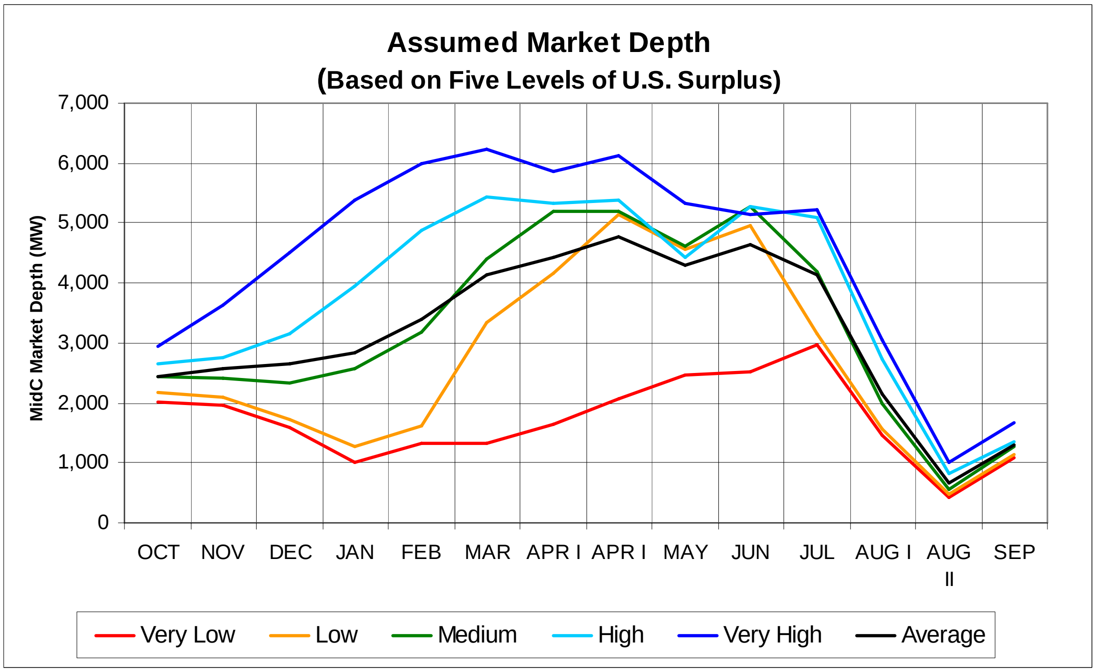


Figure 16: Assumed U.S. Market Depth

A single pricing assumption was made for the more limited Alberta market. These price assumptions were developed from historical market data.

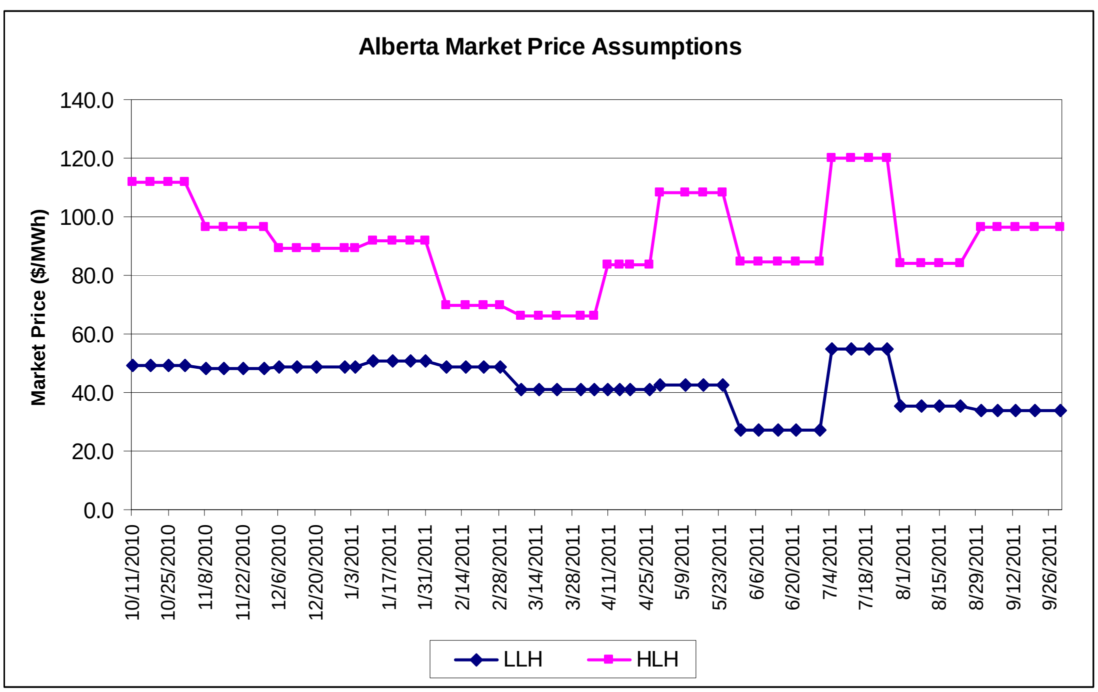


Figure 17: Assumed Alberta Market Prices

5.5 Transmission

Transmission tie-line limits were applied between the BC Hydro system and the two assumed market customers, the United States (Mid-C) market and Alberta. The following tie-line restrictions were assumed:

Assumed Transmission Capacity Limits:

BC Hydro to Alberta:	350 MW
BC Hydro from Alberta:	500 MW
BC Hydro to U.S.:	2350 MW
BC Hydro from U.S.:	1950 MW

Figure 18 and Figure 19 reflect the average 70 year transmission usage modeled in the Case 4C (recommended) study for the peak period 16 hour heavy load hours (HLH), the 8 hour light load hour (LLH) period and the average period. Note that the studies assumed on average, that BC Hydro exported HLH period energy year round to Alberta and both purchased and exported energy from Alberta.

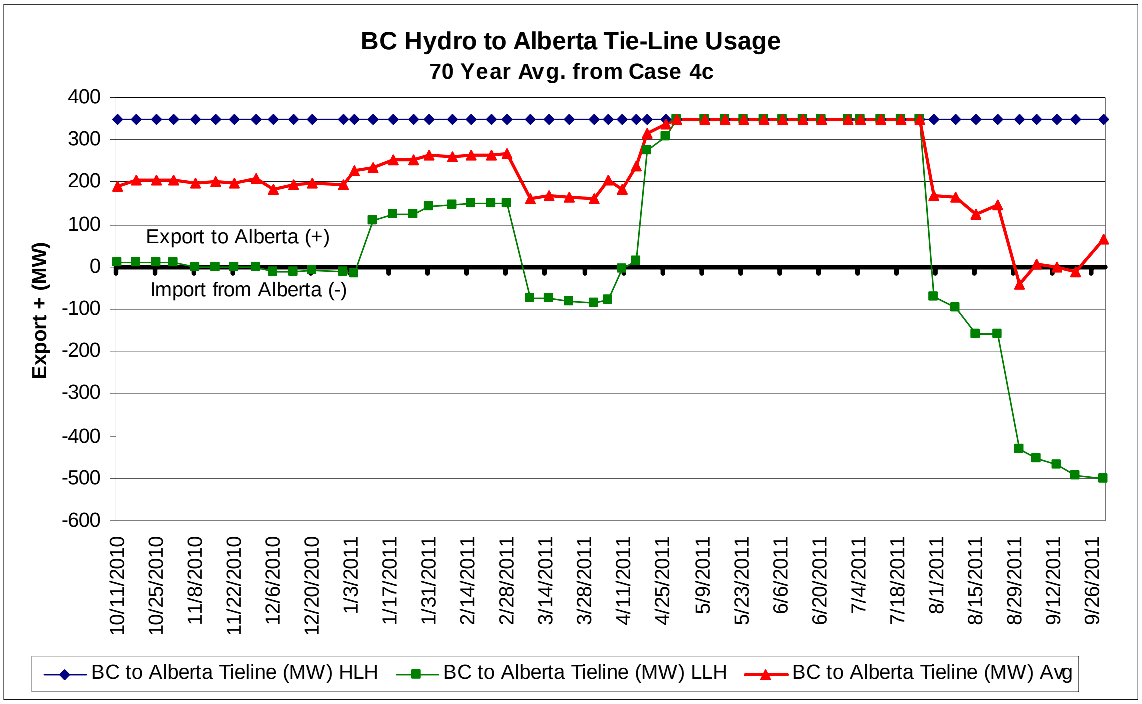


Figure 18: BC Hydro Transmission Usage with Alberta

On average, the studies assumed that BC Hydro was a heavy exporter of winter time energy to the U.S. and in the low valued May-June period, BC Hydro imported energy from the U.S., predominately to assist in refilling the storage projects of GM Shrum and Mica. Note that any particular water year would have it own profile of buying and selling energy in accordance to it unique water supply shape throughout the year.

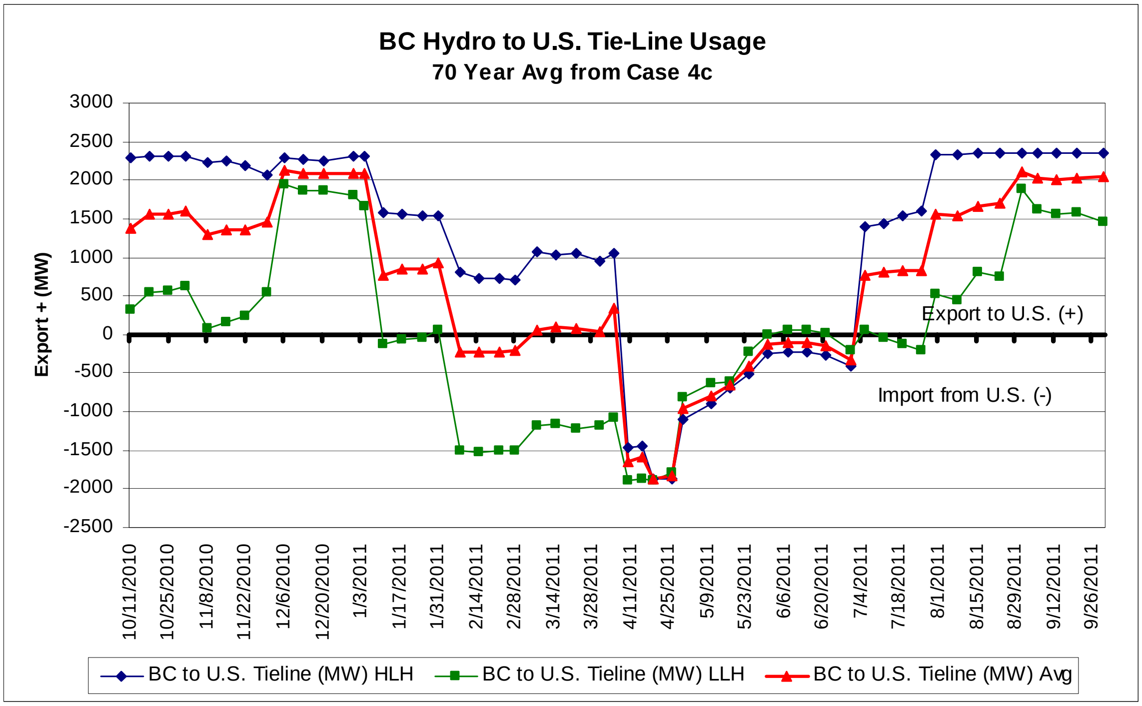


Figure 19: BC Hydro Transmission Usage with U.S.

5.6 Flood Control

Local flood control curves were used from the Phase I studies and are maximum reservoir elevations to which the projects may operate. The curves from the Phase I studies were developed such that flows at Birchbank would not exceed 225 kcfs at Birchbank, which is located on the Upper Columbia River downstream of the Kootenay River confluence. For these No-Treaty case studies, in addition to limiting the reservoir levels to the Phase I local flood control curves, the projects upstream of Birchbank, Arrow and Mica, would reduce outflows for an assumed local flood control flow of either 225 kcfs or 165 kcfs at Birchbank, depending on the scenario. The results of these studies will be used in subsequent studies performed by the Corps to evaluate flood operations in the U.S. in the absence of the Treaty. The subsequent studies will reregulate Mica or Arrow to incorporate the "called upon" operation that follows post 2024. The reregulation of these projects will determine which years would require additional flood storage space at Mica and Arrow in order to reduce flooding impacts for lower Columbia River flood events. The resulting end period elevations at Mica and Arrow in these No-Treaty studies will assist the Corp in evaluating where flood control space in Canada is available.

5.7 Project Operations

5.7.1 Peace River Projects

The three projects on the Peace River were assumed to be the least constrained in terms of optimizing power generation. Because of the more northerly location in British Columbia, ice bridging on the Peace River and the control of local flooding due to ice breakage is an operating consideration. The modeling attempted to control this process by establishing a relatively high flow in January as the ice formations develop in early winter, minimizing the chances this established outflow would be exceeded during the subsequent February-March periods. Ice breakage occurs when high flows overrun ice formations that were established under lower flow conditions.

5.7.2 Columbia River Projects

The Columbia River projects of Mica, Revelstoke and Arrow were generally operated to maximize power for firm load and for secondary revenues. The exception for this was to assume that Arrow would still be operated to enhance the whitefish and trout spawning operations during the January – June period.

5.7.3 Kootenay and Pend Oreille River Projects

The Kootenay and Pend Oreille (Canadian) projects were operated according to the prior Phase I “B2-Forecast” studies with the operation of Duncan provided by BC Hydro. Duncan outflows are in general not significant to the overall border flows as the average outflow runs approximately 4 kcfs with a range of approximately +/- 4 kcfs.

6.0 STUDY SCENARIOS

6.1 Columbia Vista (CV) Scenarios

The CV scenarios were developed to capture a range of input possibilities or "what if" conditions. The scenarios started with a "pure power" run (no system limitations) and then progressively added more constraints starting with local flood control and then adding the whitefish and trout spawning operations. The scenarios then multiplied as sensitivity studies were added to capture alternative refill, marketing and recreational considerations. The scenarios drew upon the HDR "Water Use Plans Report" that described possible alternative operations for each of the Canadian storage projects. The CV model ran 20 separate studies listed in Table 7 and the HydSim model ran 5 separate studies listed in Table 8. The schedule limits contributed to capping the number of sensitivity studies at this level.

	Study	Study Name	Comments
1	1	BCH fixed (14 period)	Mica, Rev., Arrow and Duncan Ops. Were fixed from their Phase 1 B2F600 Power Study
2	1a	BCH fixed (weekly)	Same as Study 1 but run in weekly mode
3	2-165 kcfs	Base Case 165 (14 period)	Local flood control (max flow of 165 kcfs @ Birchbank) and base operating constraints
4	2-165 wkly	Base Case 165 (weekly)	
5	2-225 kcfs	Base Case 225 (14 period)	Local flood control (max flow of 225 kcfs @ Birchbank) and base operating constraints
6	2-225 wkly	Base Case 165 (weekly)	
7	3	Case 3	Case 2-165, including trout spawning and whitefish
8	3b	Case 3b	Same as Case 3 but run in 70 yr. continuous mode
9	4	Case 4	same as Case 3 but relax refill / increased marketing (2nd yr. pricing at 90%)
10	4b	Case 4b	relax refill / market heavier (2nd yr. pricing at 80%)
11	4c	Case 4c	same as Case 4 but with updated Arrow Facility Data that better defines max turbine flow
12	4q	Case 4q	same as 4c but with flat quarterly prices
13	4FB	Case 4FB	same as 4q but with alt. lower Arrow FB elev. range
14	7	Case 7	Case 4 but remove conservation assumption (high loads)
15	8	Case 8	Case 4 but alternative Duncan Operation (HDR Report)
16	9	Case 9	Case 4 but alternative Arrow Operation (HDR Report)
17	10	Case 10	Case 4 w/ alternative pricing (revised monthly shaping)
18	14	Case 14	Case 4 but no Site C assumed
19	15	Case 15	Case 4 w/ alternative pricing (revised monthly shaping #2)
20	15b	Case 15b	same as Case #15 but with flat Qrtly. prices & updated Arrow facility data

Table 7: CV Studies

6.2 HydSim Scenarios

There are five scenarios simulated in HydSim. 1_1, 1_2, 2, 3_1 and 3_2. Except for the changes stated explicitly, all HydSim settings are the same as those in the Without Treaty Base Case (B2F600 Power study). The Appendix B contains a more detailed list.

	Study	Study Name	Comments
1	1_1	BCH fixed - Shrum Max Re	Mica, Rev., Arrow and Duncan Ops. Fixed from their Phase 1 B2F600 Power Study
2	1_2	BCH fixed - Shrum Power (	Mica, Rev., Arrow and Duncan Ops. Fixed from their Phase 1 B2F600 Power Study
3	2	Shrum Power Opt, Mica, Arrow Power Opt	Local flood control (165 kcfs), Shrum, Mica, Arrow Power Opt. Duncan Cora Fixed
4	3_1	Shrum Power Opt, Mica, Arrow Power Opt, Arrow NPR (WF & TS)	Same as Case 2, but with Arrow White Fish & Trout Spawning Op
5	3_2	Shrum Power Opt, Mica, Arrow Power Opt, Arrow NPR (WF & TS), and Arrow Pref Elev	Same as in Case 3_1, but Arrow operated to Alt. (lower) FB range

Table 8: Hydsim Studies

Hydsim Studies		Study Cases				
		1	2	3	4	5
		Col. Fixed, max. refill	Col. fixed, max. power	add 165 kcfs flood ctrl	shaped winter draft	shaped winter draft
	Effects	**Case 1_1**	**Case 1_2**	**Case 2**	**Case 3_1**	**Case 3_2**
1	Mica, Arrow, Dunc, Cora fixed to BCH submittal	X	X			
2	Peace River max. refill	X				
3	Peace River to power market		X	X	X	X
4	Mica, Arrow, for power (Cor & Dun fixed to BCH)			X	X	X
5	local FC (165 kcfs) and power market			X	X	X
6	Trout Spawning and Whitefish Ops.				X	X
7	Alt. Arrow FB range (lower)					X

Table 9: HydSim Study Case Setup Comparison

In all scenarios, all U.S. storage projects upstream from Canadian projects run on fix operations obtained from the Base Case. These U.S. projects are Libby, Hungry Horse, Kerr, Noxon, Priest Lake and Albeni Falls. Furthermore the three Peace River projects, G.M. Shrum, Peace Canyon and Site C, are added to the hydro-system. Due to winter ice-bridge and ice-jamming concerns, minimum outflow requirements at GM Shrum are: 10 kcfs in every period except for December which has a minimum of 40 kcfs, January with a minimum of 52 kcfs, and February- March with a minimum of 30 kcfs.

Below is a brief description of each scenario.

Case 1_1: The Columbia storage projects Mica, Duncan, Arrow and Corra Linn run on fixed operations from the Base Case while GM Shrum operates to maximize refill. A plot for G.M Shrum's rule curves is shown below in Figure 20.

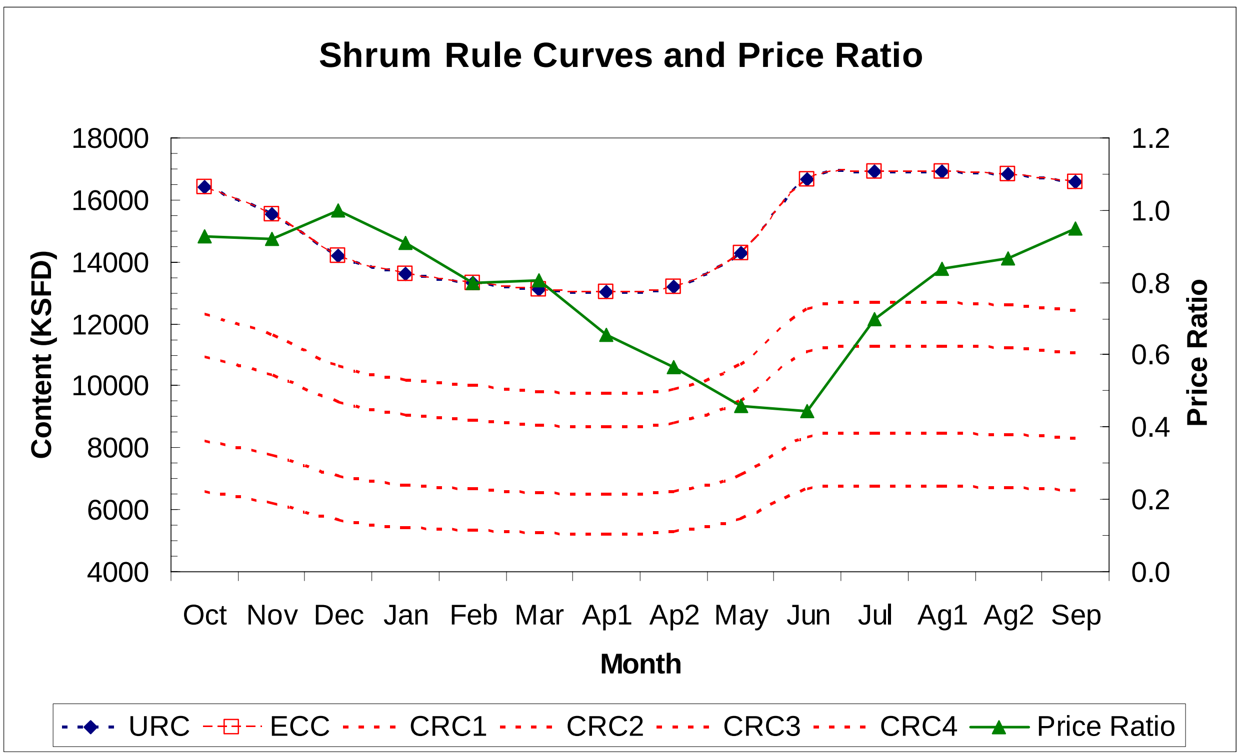


Figure 20. Shrum Rule Curves to maximize refill probability

It could be seen in Figure 20 that the ECC is set to operate to the URC and thus maximizing refill probability. For this operation G.M. Shrum could achieve an elevation of at least 2,204 ft (1 ft from the full elevation of 2,205 ft) about 83% of time in the 70-year simulation. Historically from 1976 to 2009, GM Shrum reached at least 2,204 ft about 22% of the time.

Case 1_2: Similar to case 1_1, the Columbia storage projects Mica, Duncan, Arrow and Corra Linn are again on fixed operations from the Base Case. However, motivated by the higher energy prices assumed during the period October-March, GM Shrum in this case operates to maximize generation drafting deeply during those periods. GM Shrum tries to achieve reasonable refill probability by filling from the second period in April to September. Figure 21 shows the rule curves developed for GM Shrum.

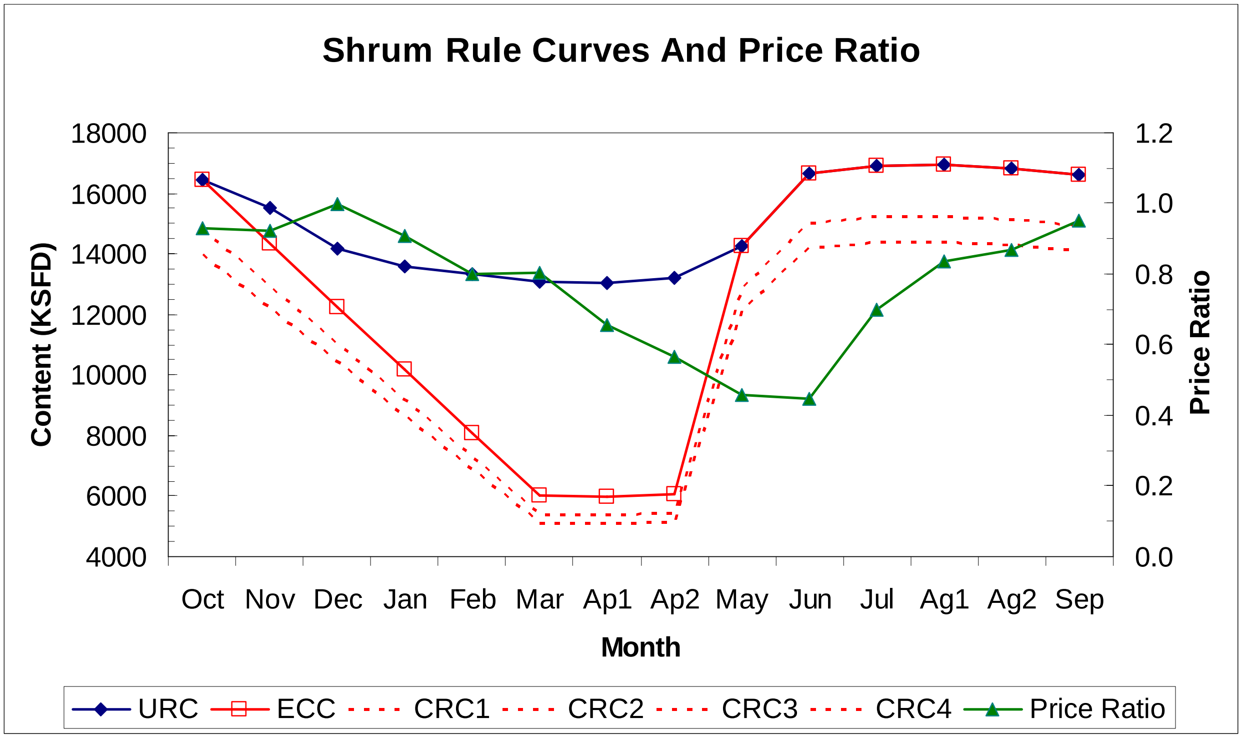


Figure 21. Shrum Rule Curves to optimize power generation

Since there is a preferred minimum elevation of 2140 ft (about 5,100 KSFD) at GM Shrum, and CRC2 is already near that minimum from March to the second period of April, for simplicity CRC3 and CRC4 have been set equal to CRC2 in Figure 21. For this case of maximizing generation, G.M. Shrum could refill to 2,204 ft about 26% of the 70-year simulation, quite comparable to the historic 22% refill probability.

Case 2: For this case, the G.M. Shrum project on the Peace River is set to operate for maximum generation and the rule curves are the same as those shown in Figure 21. The Columbia projects Duncan and Corra Linn, due to their limited operating flexibility, are once again fixed to those operations in the Base Case. Mica and Arrow are now free to be operated for maximum generation with a reasonable chance of refill. Mica's rule curves for this case were shown and discussed as an example previously in Figure 4. Mica could refill to within 1 ft of 2,475 ft about 89% of the times in the 70-year simulation. Arrow, on the other hand, is operated for maximum refill and hence the ECC is set to the URC in the following plot of Arrow's rule curves.

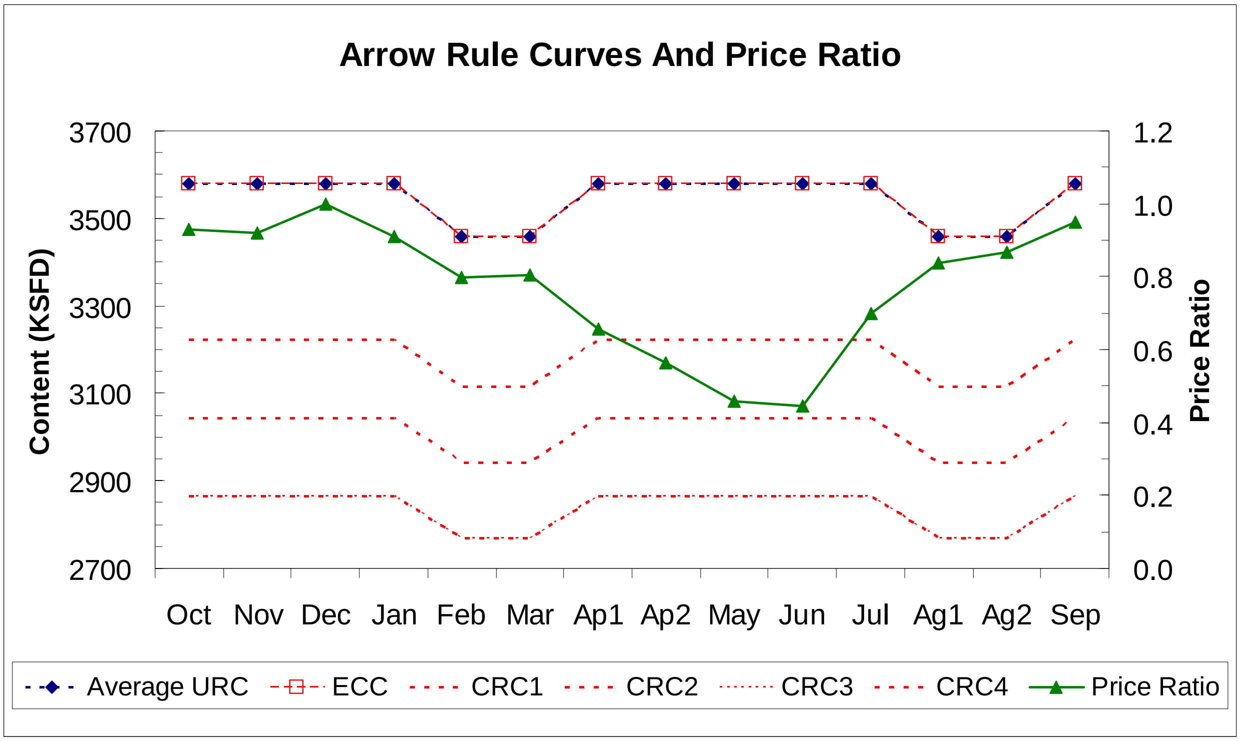


Figure 22. Arrow Rule Curves to maximize refill probability

Arrow refills to within 1 ft of 1,444 ft (3579.6 KSFD) about 89% of the time. In addition to the refill objective, flood control sets a preferred maximum flow of 165 KCFS, or a higher limit of 225 KCFS, at Birchbank. Out of 980 periods simulated, Birchbank only has 7 periods with flows around 175 KCFS and 1 period with flows about 238 KCFS. These high flows could be reduced with some fine-tunings of the Mica and Arrow rule curves around those periods.

Case 3_1: As in Case 2, G.M. Shrum and Mica both operate for maximum generation for this case and their rule curves are the same as those in Fig. 10 and Fig. 1 respectively. However, Mica has its maximum elevation increased by 5 ft to 2,475 ft. Meanwhile Arrow is set to satisfy both the white fish and trout spawning non-power requirements, and set to draft slightly from March to the second period of April corresponding to those spring periods when Mica has low outflow. Arrow begins to refill from May to September. The Arrow rule curves are shown in Figure 23 below.

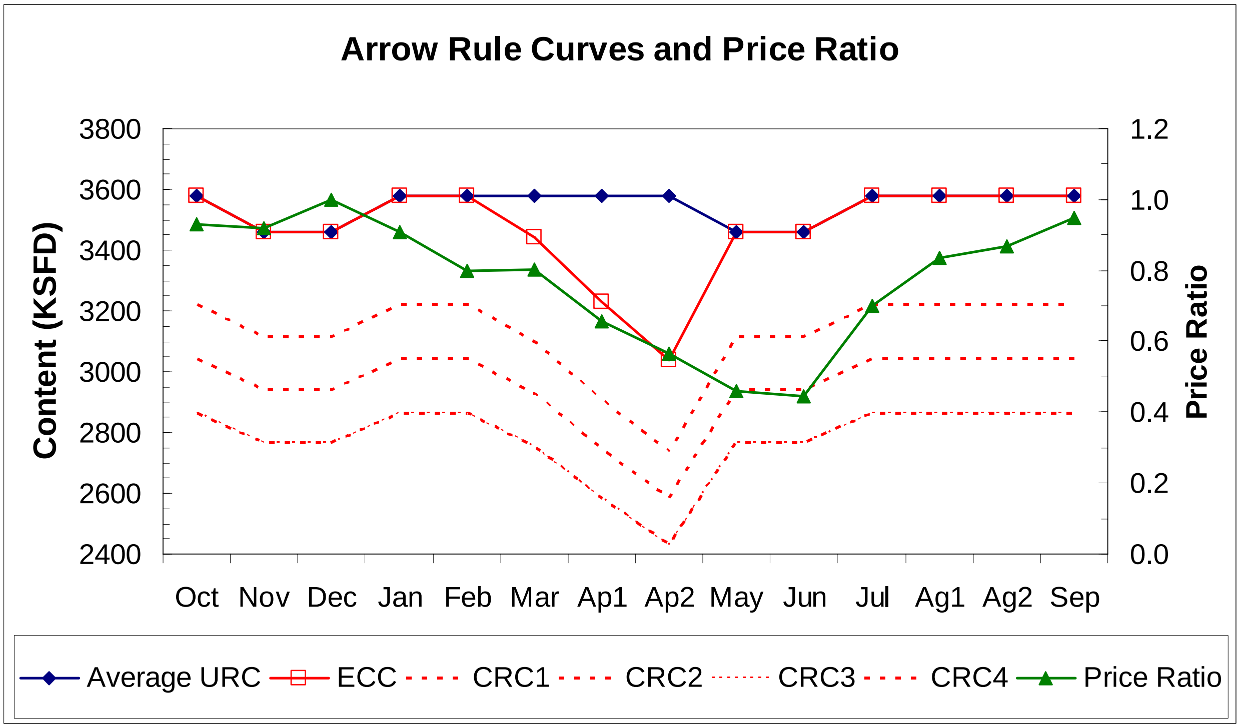


Figure 23. Arrow Rule Curves: Draft during periods with low Mica outflow

Arrow's refill percentage drops slightly to 83% for this case. Birchbank now has only 3 periods with flows around 170 KCFS and 1 period with flows about 234 KCFS. This case has the highest surplus power and revenue.

Case 3_2: This case is the same as Case 3_1 except that Arrow is to be operated at lower elevations for recreation in the summer months, and reach a maximum elevation of 1,442 ft (instead of 1,444 ft) for flexibility. The Arrow rule curves are shown in Figure 24.

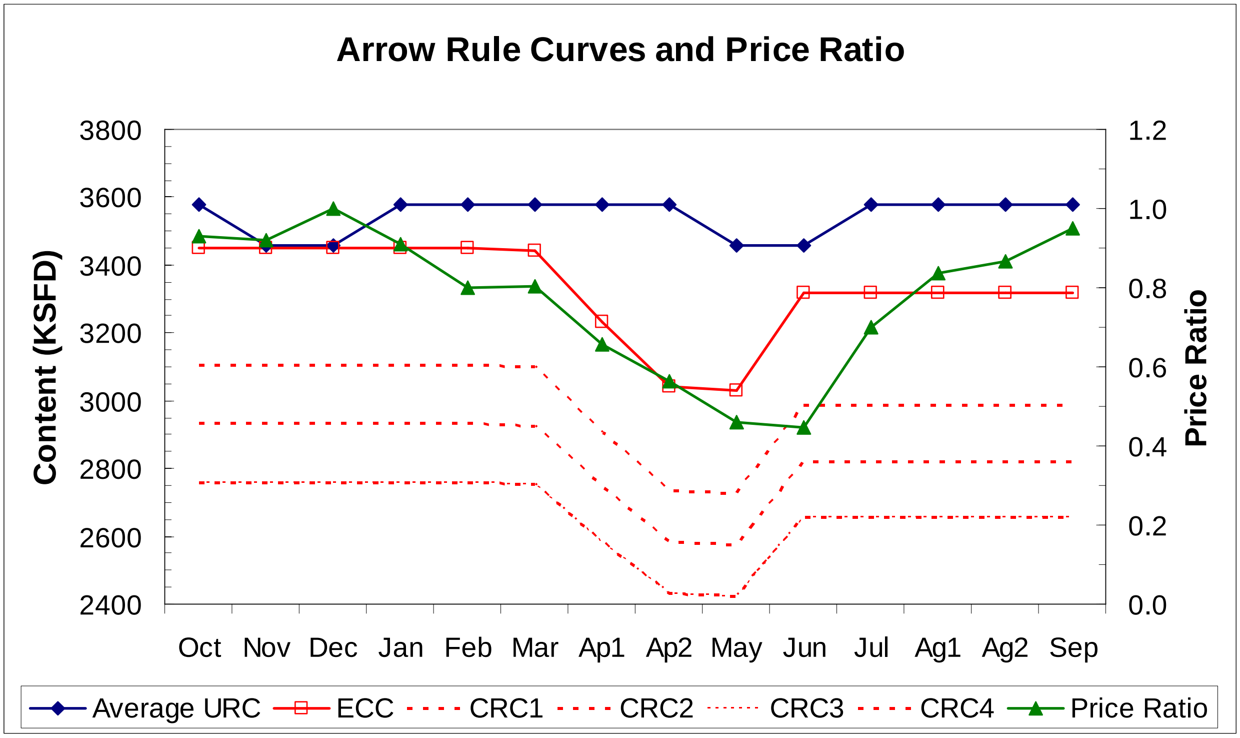


Figure 24. Rule curves for Arrow lower-elevation operations

For this case Arrow never refills to 1,444 ft of course but could reach 1,441 ft or higher in Oct about 43% of the time. Birchbank flow characteristics are similar to those in Case 3_1.

7.0 CV STUDY RESULTS

The CV results are shown under the following headings:

- Economics
- Generation
- Spill
- Refill
- Project Elevations and Outflows

7.1 Economics

A review of the various CV studies is shown in Table 10 below.

Case 1: BCH Fixed
Case 2-225: 225 kcfs Max flow at Birchbank
Case 2-165: 165 kcfs Max flow at Birchbank
Case 3: Includes Whitefish and Trout Spawning (w/ high refill)
Case 3B: 70yr Continuous
Case 4: Fish Ops with Moderate Refill
Case 4B: Fish Ops with Low Refill
Case 4C: Fish Ops with Moderate Refill and updated Arrow facility Data (max turbine flow)
Case 4Q: Fish Ops with Moderate Refill, updated Arrow facility Data, and quarterly prices
Case 4FB: Fish Ops with Mod. Refill, updated Arrow facility data, qrtly. prices, lower Arrow elev.'s
Case 7: High Loads (No Conservation)
Case 8: Duncan optimization
Case 9: Arrow "Natural Lake Operation"
Case 10: Alternative pricing 1
Case 14: No Site C
Case 15: Alternative Pricing 2
Case 15B: Alternative Pricing 2 with Updated Arrow Facility Data

Table 10: CV Study Case Descriptions

The net revenue results are a summation of the sales and purchases determined by the studies for the BC Hydro System. Note that sales and purchases are determined in coordination with the requirement to meet firm load at all times. Purchase can be made to meet firm load or to reduce project outflows and in effect store energy to be released at a later point in time. Figure 25illustrates the annual net revenue for each of the CV studies. Case 7 has reflects a reduced net revenue as this case reflects a high load assumption. Case 14 assumes that Site “C’ generating project is not in service in 2024 and therefore reflects a lower net revenue as well. Case 3B reflects the highest net revenue as might be expected since this study assumes the highest level of “perfect foresight” in operating the projects and also does not include a whitefish operation. Perfect foresight means that the reservoirs operate with full knowledge of the streamflow conditions the system will see in all future periods.

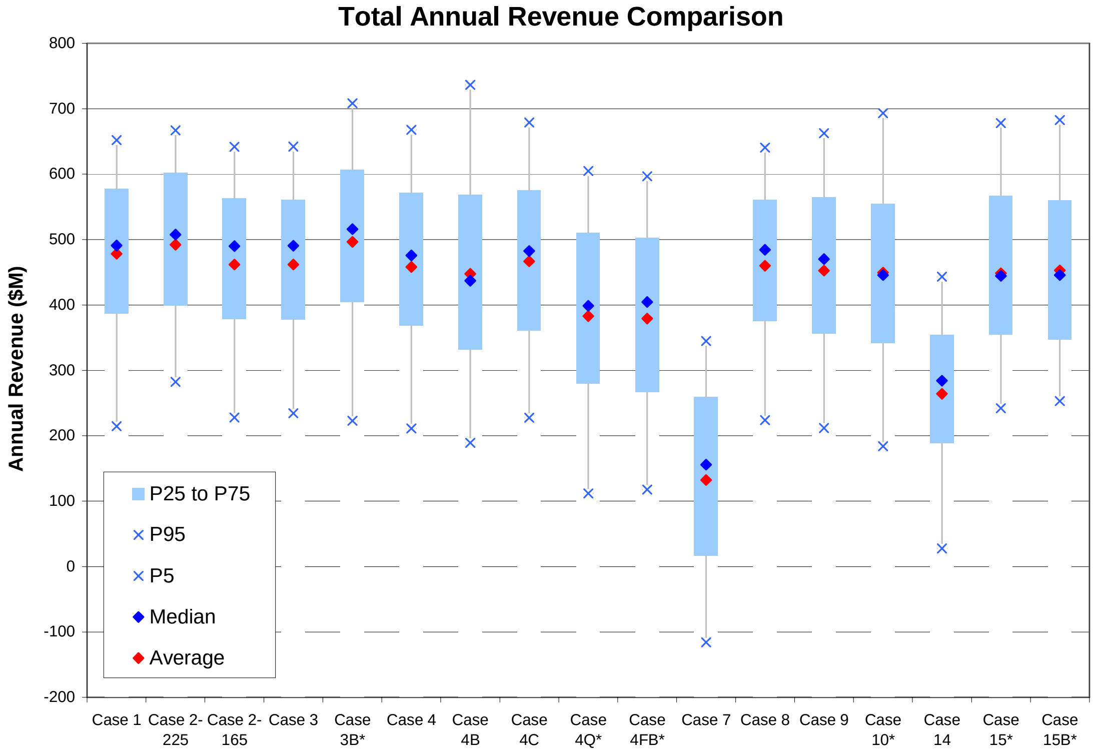


Figure 25. Annual Net Revenue Comparisons with Probability Values

Figure 26 displays the 70 year average net revenue for each study, ranked from lowest to highest. The statistical data pertaining to the entire 70 year result set from the study 4C is shown in Figure 27. Figure 28illustrates the accumulative net revenue for the 70 year results of Case 4C. There is a wide range in possible net revenue outcomes in accordance to the water supply of each year. The 5% to 95% range spans from approximately $220 million to $680 million with an average net revenue of approximately $470 million (U.S. dollars). A follow up study to assess the projected net revenue with the Treaty continuing would be of interest but outside the scope of this project.

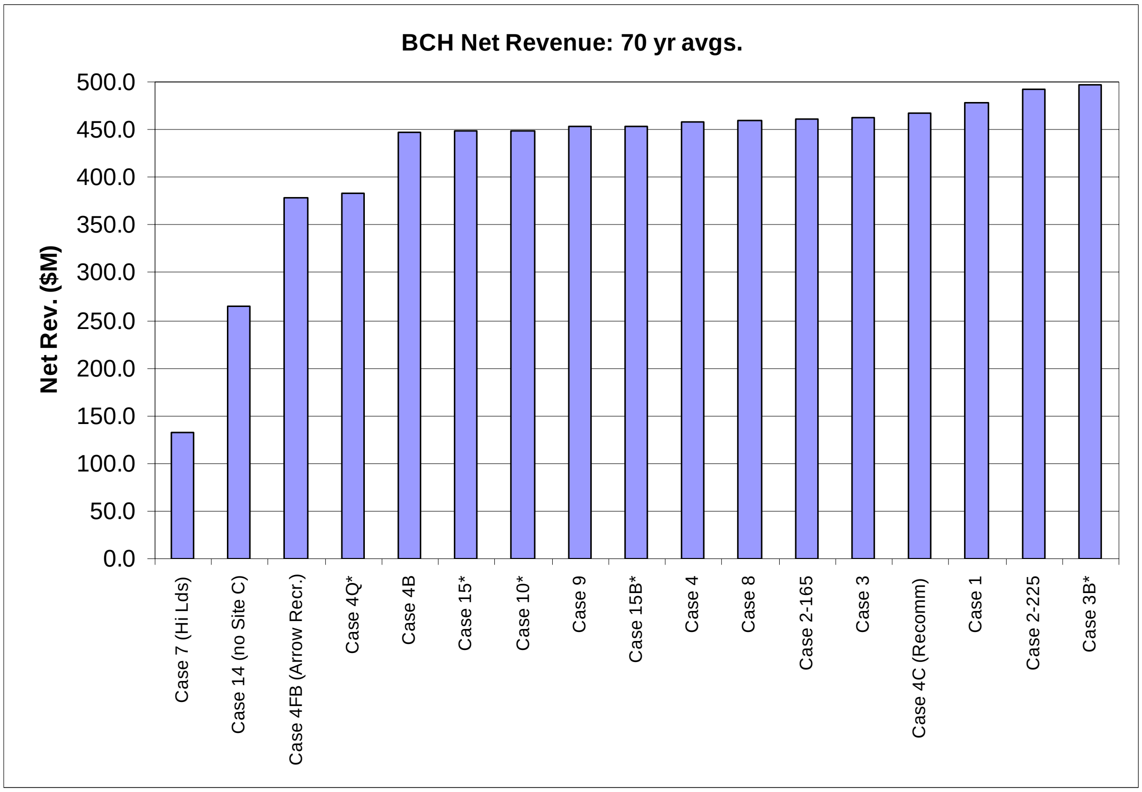


Figure 26. Annual Revenue Comparisons Ranked Low to High

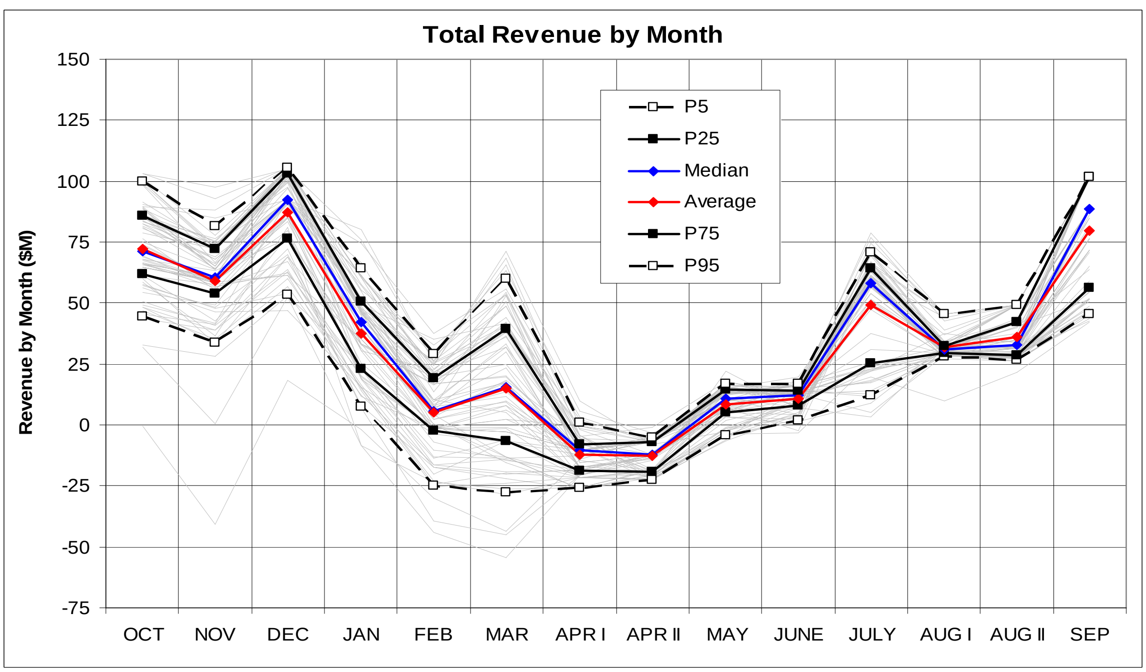


Figure 27. Case 4C (recommended) Annual Revenue by Month

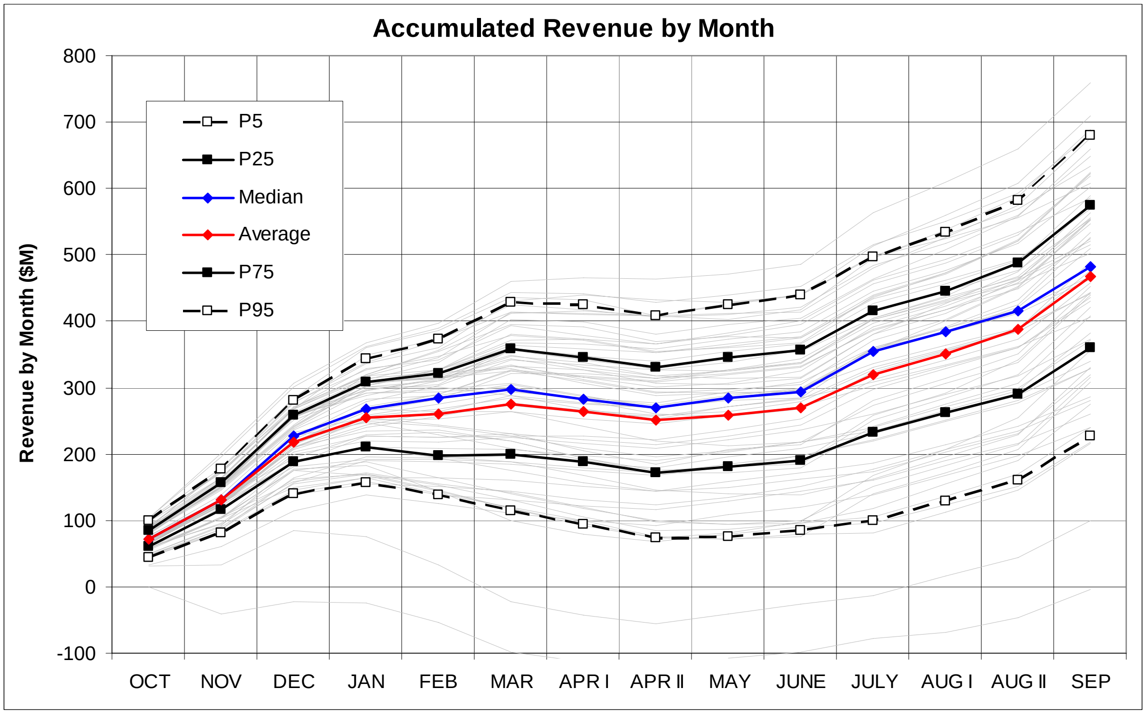


Figure 28. Case 4C (recommended) Accumulative Annual Revenue

7.2 Generation

The total generation for BC Hydro for Case 1 (BC Hydro submittal) and Cases 4C and 4FB are presented in Figure 29. The generation peaks in December as a reflection of the assumed higher value energy period and reaches the low in April which is the start of the trout spawning, the time when it is desirable to set low protection flows below Arrow. The 5% to 95% band is also plotted to reflect the 70 year range in outcomes. The spread averages around 1500 MW. Note that April also marks the deepest draft period as shown in Figure 30. Reservoirs begin their refill as the snow runoff begins.

An example of BC Hydro's hydro resource breakdown is shown in Figure 31. This example was based on Case Study 4C. Approximately 54% of the total hydro resources is comprised of the three large hydro plants; Mica, Revelstoke and GM Shrum.

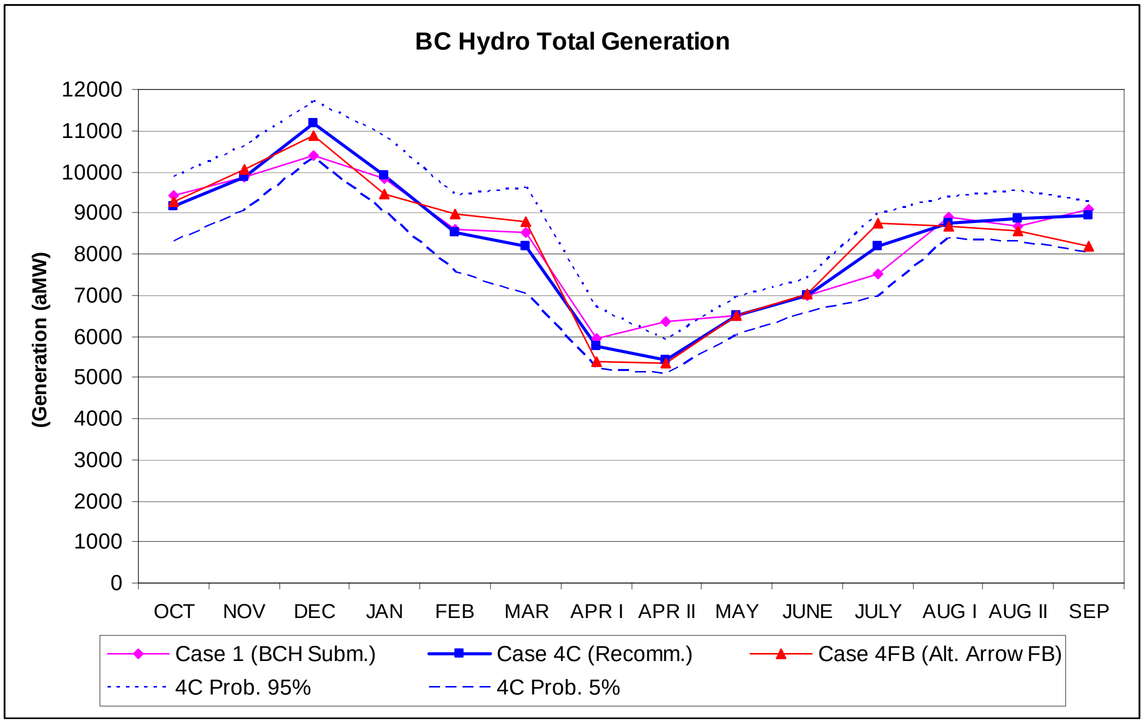


Figure 29. BC Hydro Generation

A comparison graph, Figure 30, was developed to plot a combined total draft for the three projects, Mica, Arrow and Duncan. The total Treaty storage of these projects is 15.5 MAF assuming Mica is Treaty full at elevation 2470.1 ft. With no Treaty, the studies assumed Mica would be operated up to elevation 2475.0 ft. by BC Hydro. Case 1 in this figure is based on Mica full at 2470.1 ft. while the other cases assume an additional 5 feet available at Mica. The studies in this report would therefore be based on a total available draft of 16.0 MAF. Case 1 was included for informational purposes only.

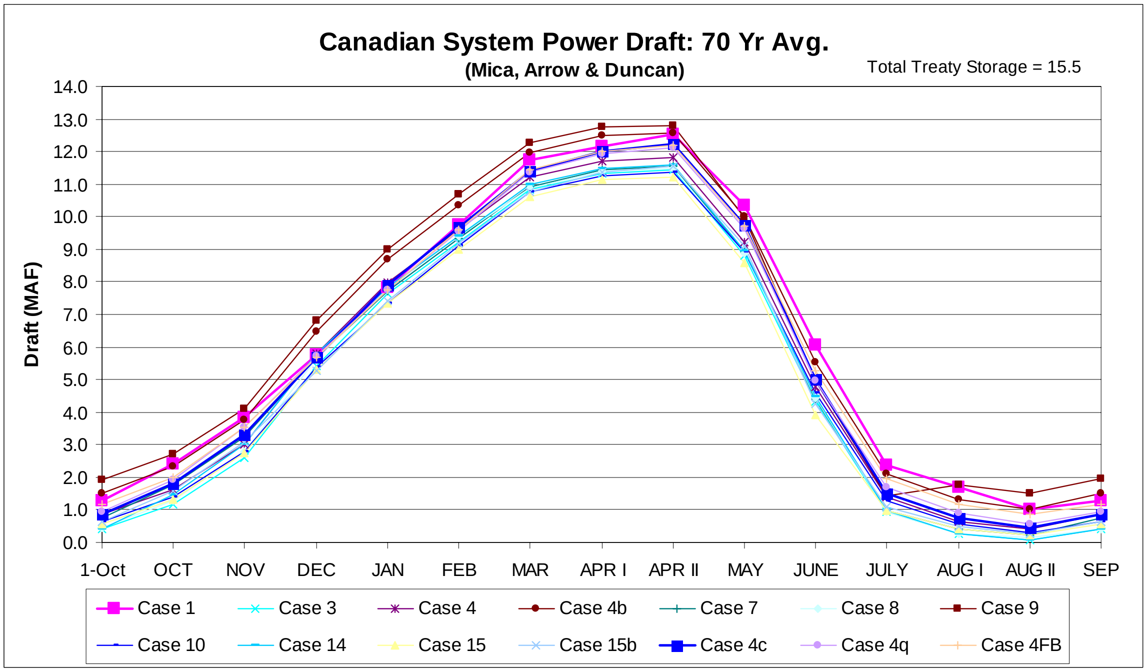


Figure 30. Canadian System Power Draft

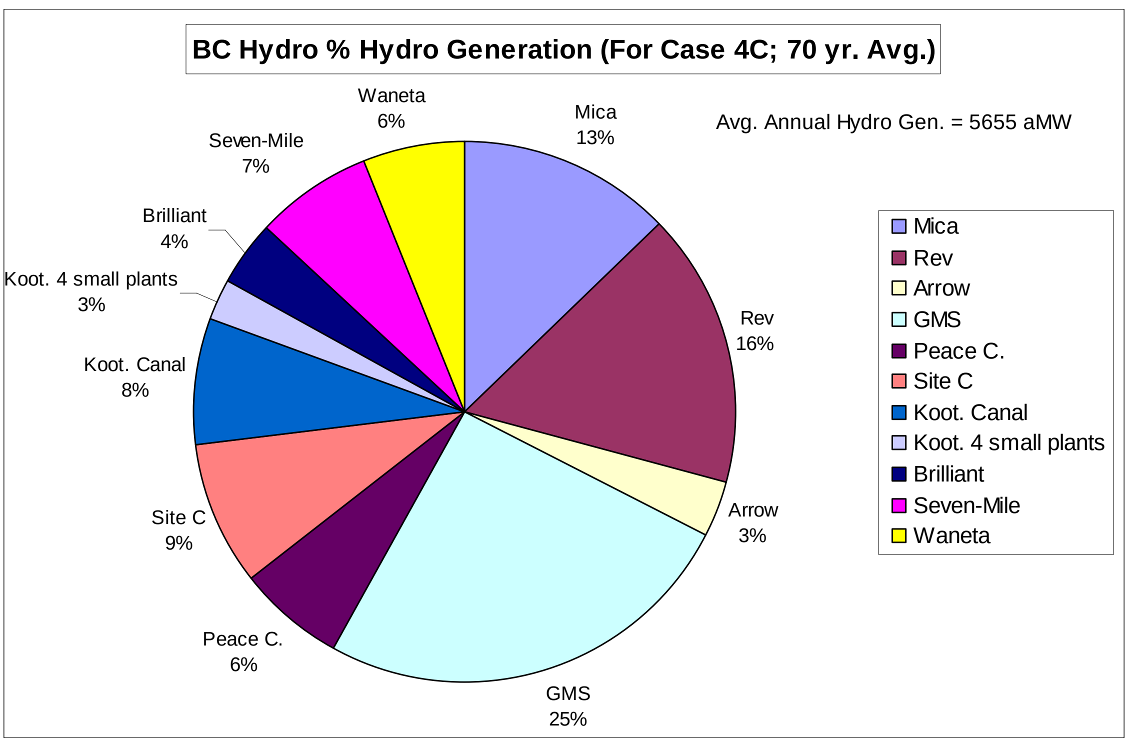


Figure 31. BC Hydro System Distribution of Hydro Generation

7.3 Spill

Spill at Arrow occurs when river flows are in excess of Arrow's turbine flow capacity of approximately 40 kcfs. The graph below shows the 70-year average spill for all the case studies at Arrow generally occurring during the month of December and again from May through September; during both time periods, the spill ranges from about 4 kcfs to 20 kcfs. The exception is Case 9 where Arrow elevation constraints were designed to mimic "natural lake" qualities and to draft quickly in August to enhance shoreline bird nesting areas. Spill volumes will contribute to gas supersatuation or Total Dissolved Gas (TDG) levels. The projected TDG levels at Arrow and downstream of Arrow are of key interest to fishery concerns. The scope of this project did not include projecting the dissolved gas levels or the resulting persistence downstream. These issues will likely be addressed in the Water Quality subgroup of the Treaty 2014/2024 process.

The three cases for further review and comparison – Case 1, Case 4C and Case 4FB are depicted in the legend in **bold.**

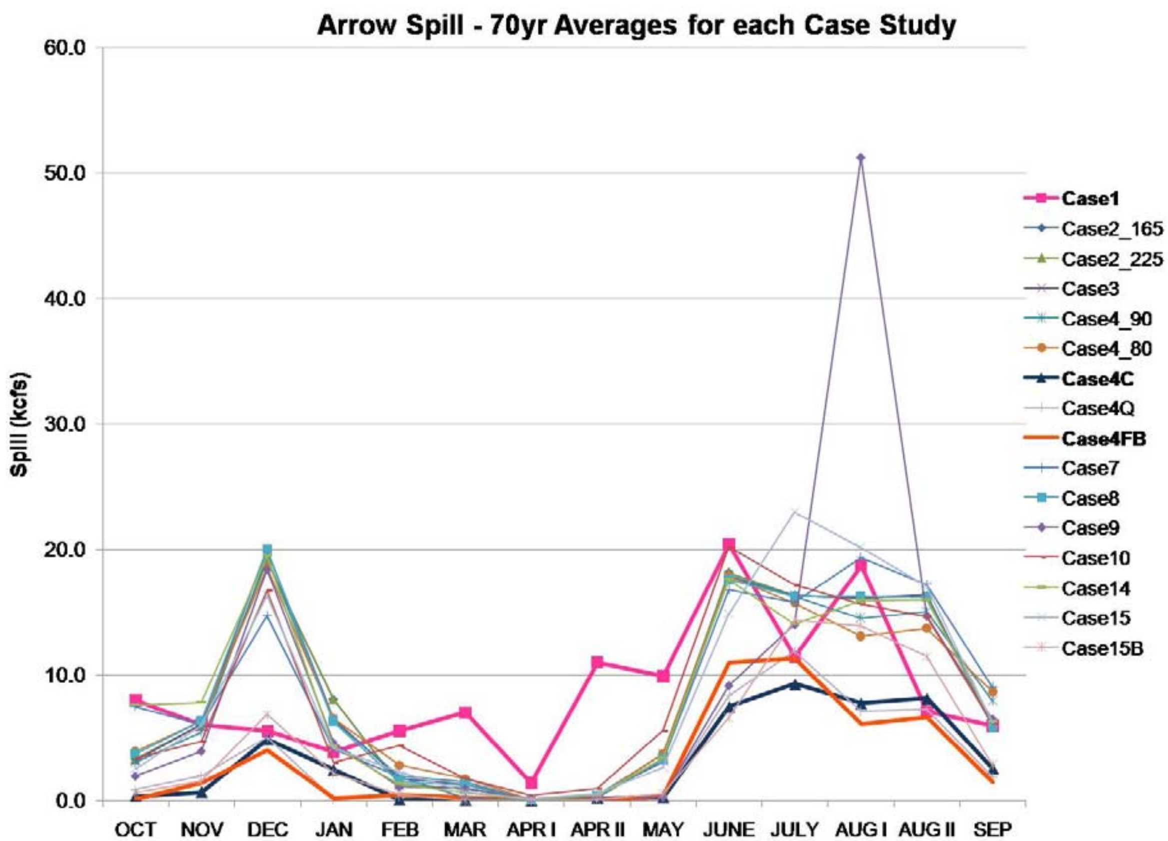


Figure 32. Arrow Spill Comparison

7.4 Refill

Williston Reservoir (GM Shrum) and Mica provide the highest level of storage for power draft purposes. It is desirable to refill these reservoirs each year to provide the maximum amount of flexibility and generation for the subsequent year. This is of high importance as the snow pack from year to year is highly volatile. Low water years or the need to produce adequate levels of generation may limit the ability to refill. Figure 33 reflects the % refill of Mica and Williston for the period 2005-2011. During this period, Mica filled to 90% or higher in all years. This would be expected as the Treaty planning regulations put a high priority in refilling Mica. In the absence of a Treaty, the requirement will be removed but the desire to refill Mica each year will likely remain. It is of interest to note that Williston refill declined during the 2009 – 2010 period. From a January-July runoff at The Dalles point-of-view, these years were declining in terms of water supply. The year 2011 was a very high water supply year and one in which Williston rebounded and filled completely. The storage at Williston is tremendous at 33 MAF. This reservoir can provide a high level of “generation insurance” in the event of poor water years. The modeling effort attempted to set reasonable probabilities for refill, consistent with historical observations. Figure 33 through Figure 43 display the level of refill in the studies alongside the refill level for recent history. It is important to note that the current Treaty regulations may often time “proportionally” draft the Canadian projects in the later summer period in order to meet firm load (FELCC). In the absence of a Treaty BC Hydro has much more flexibility to control the refill objective of their storage projects, subject to non-power requirements.

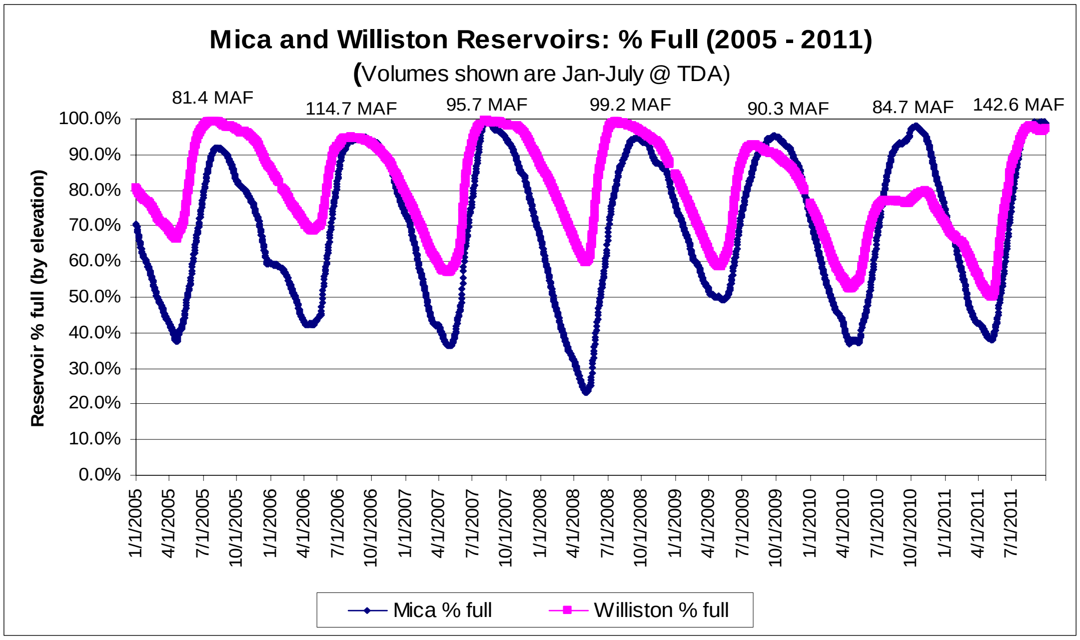


Figure 33. Mica and Williston 7 year historical refill percent

7.4.1 Williston Reservoir (G.M. Shrum)

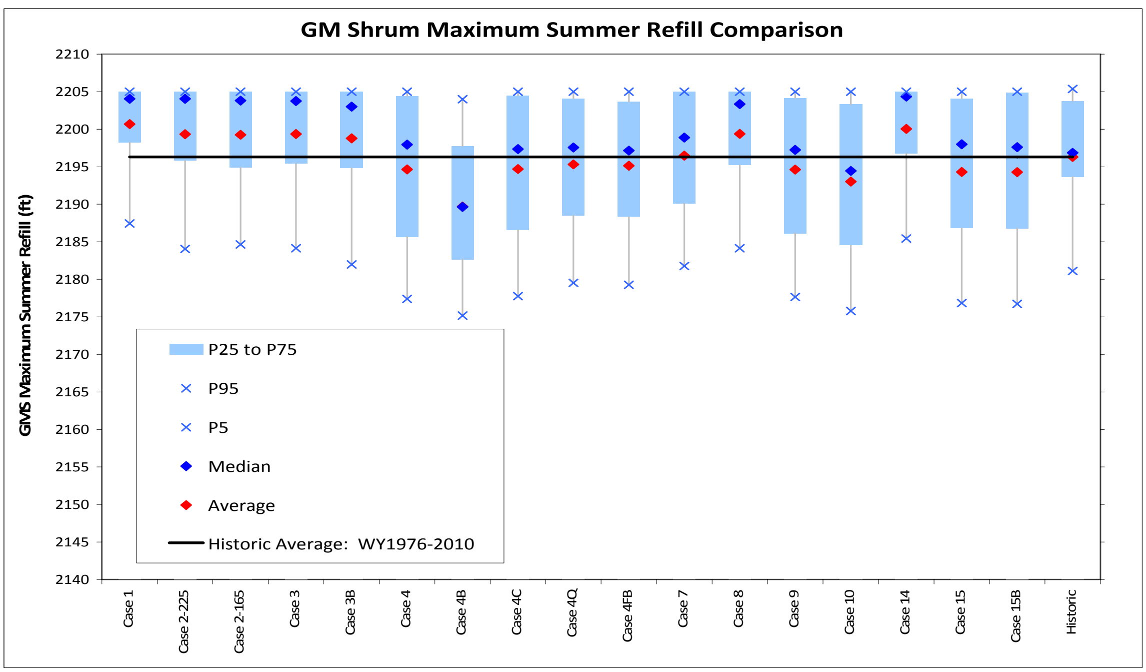


Figure 34. Williston Reservoir Maximum Summer Refill Comparison

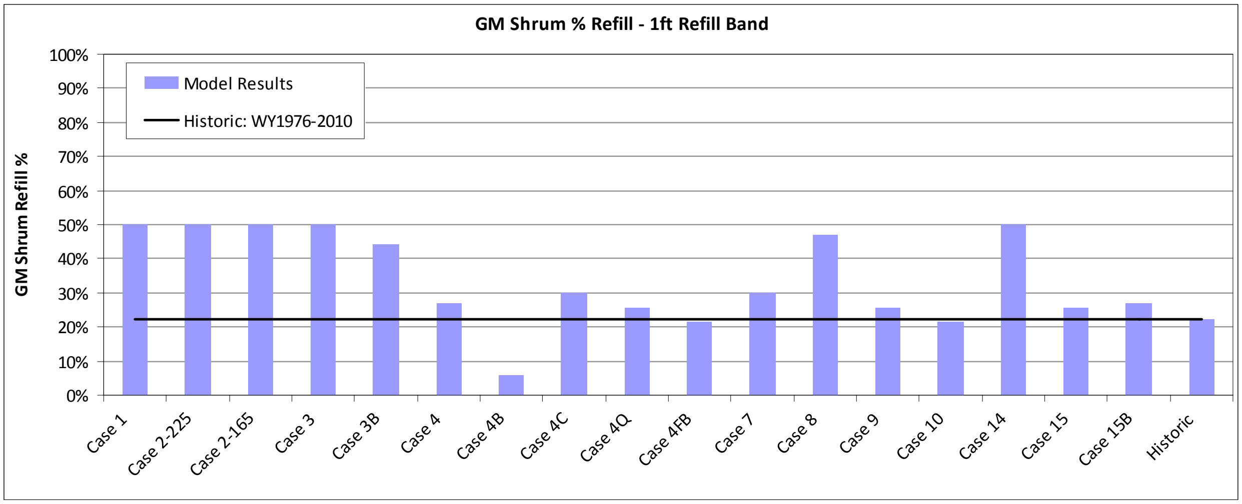


Figure 35. Williston Reservoir 1 ft. Refill Band

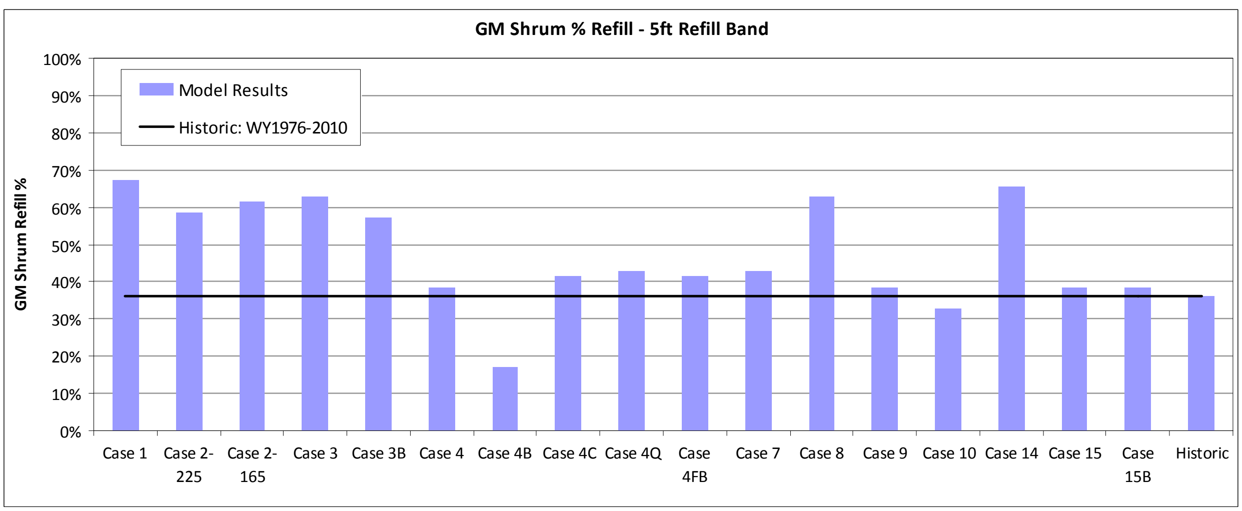


Figure 36. Williston Reservoir 5 ft. Refill Band

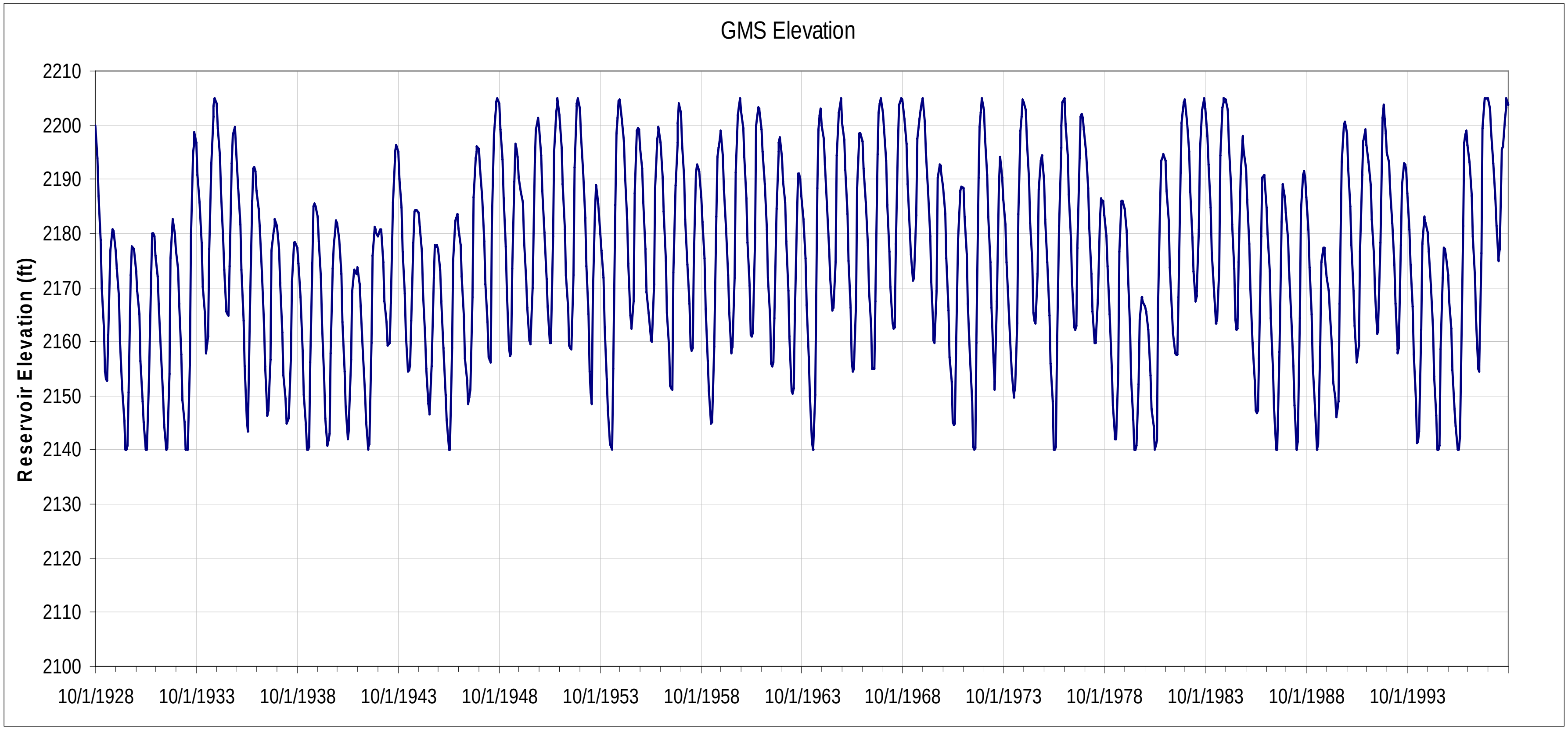


Figure 37. Williston Reservoir Refill 1929-1998, Case 4C

7.4.2 Mica Reservoir

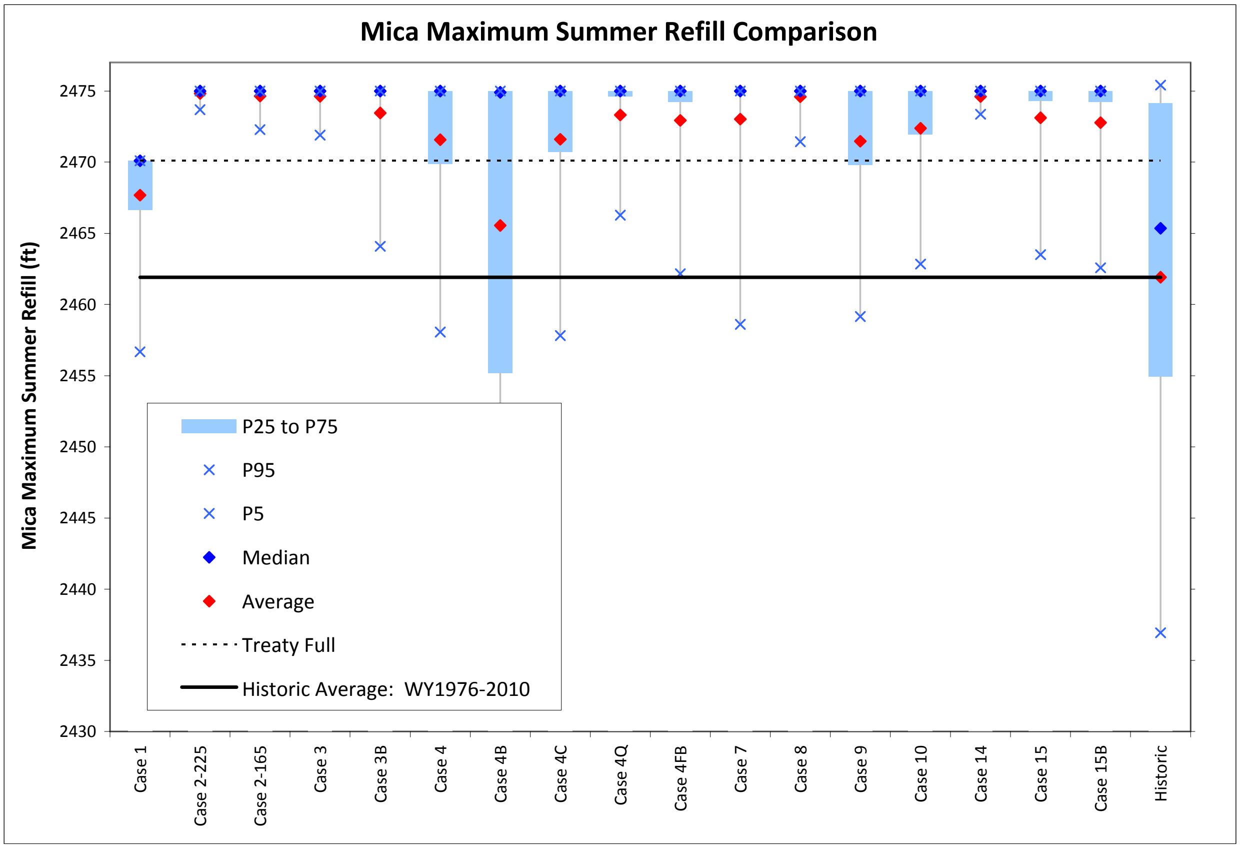


Figure 38. Mica Maximum Summer Refill Comparison

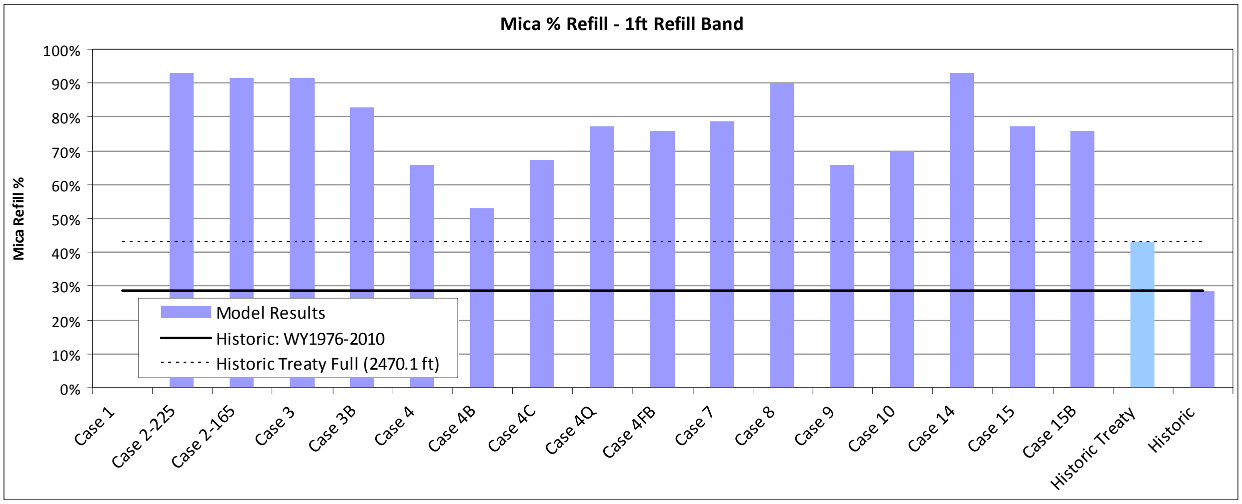


Figure 39. Mica Reservoir 1 ft. Refill Band

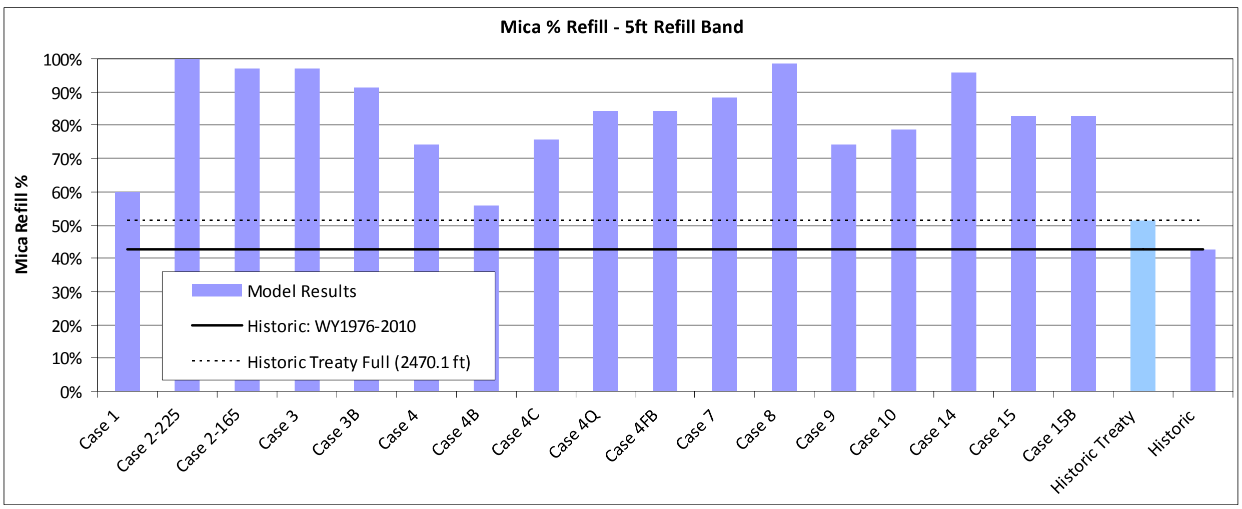


Figure 40. Mica Reservoir 5 ft. Refill Band

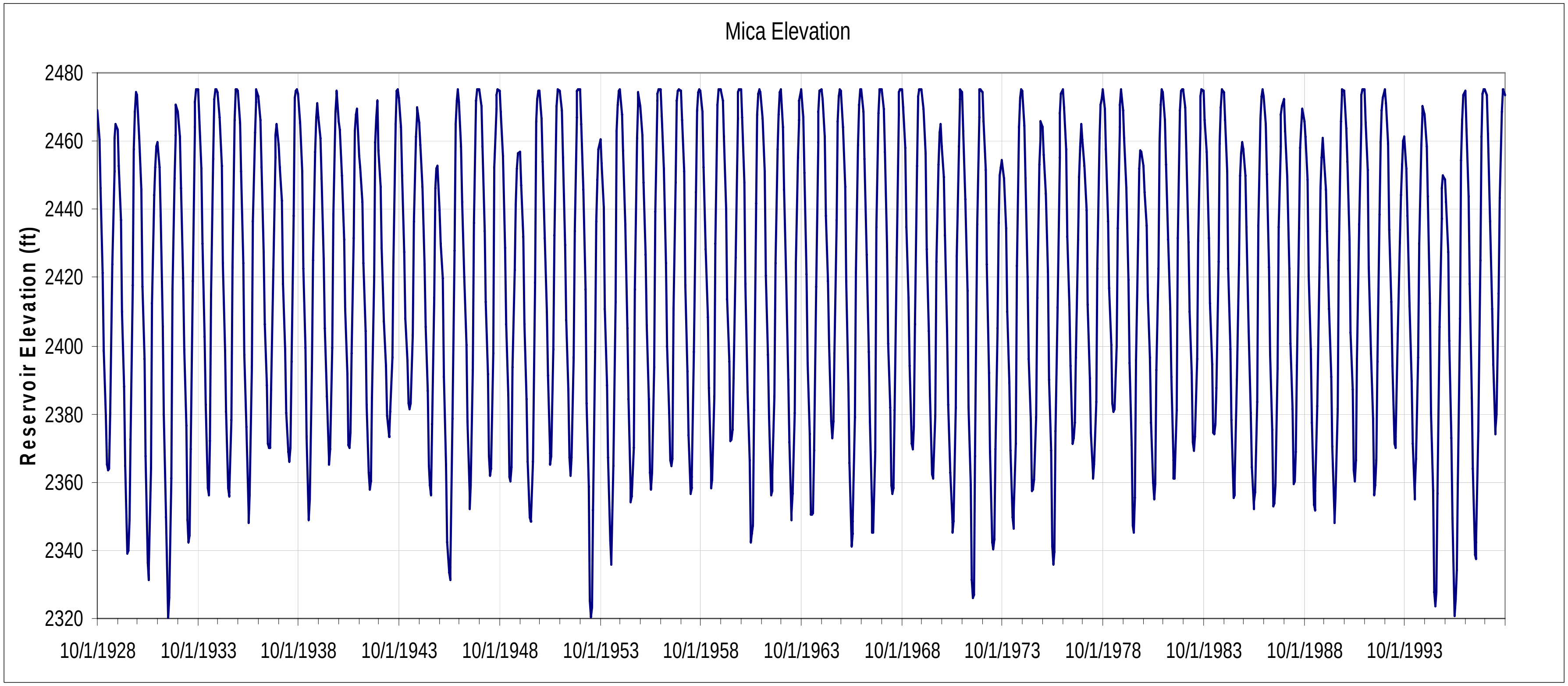


Figure 41. Mica Reservoir Refill 1929-1998, Case 4C

7.4.3 Arrow Reservoir

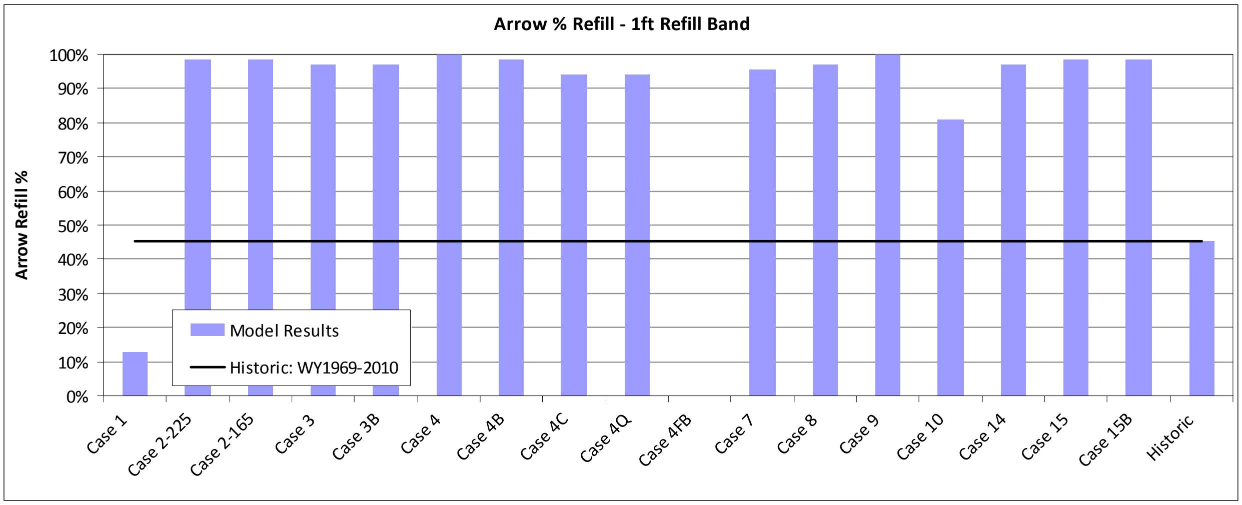


Figure 42. Arrow Reservoir 1 ft. Refill Band

7.4.4 Duncan Reservoir

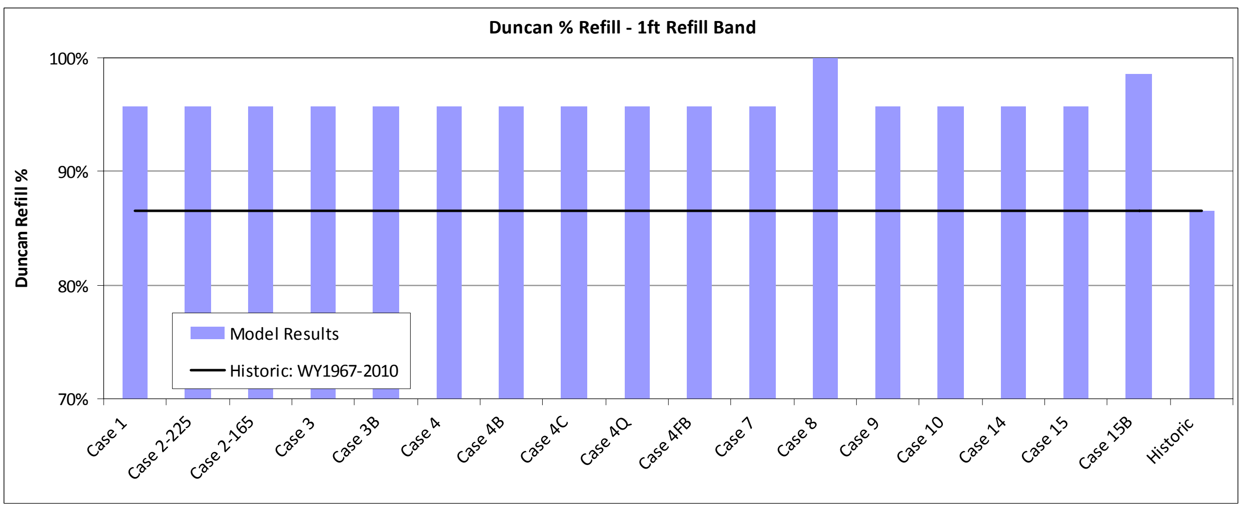


Figure 43. Duncan Reservoir 1 ft. Refill Band

7.5 Project Outflows and Elevations

The project outflows and end elevations are displayed in this section.

7.5.1 Williston (G.M. Shrum)

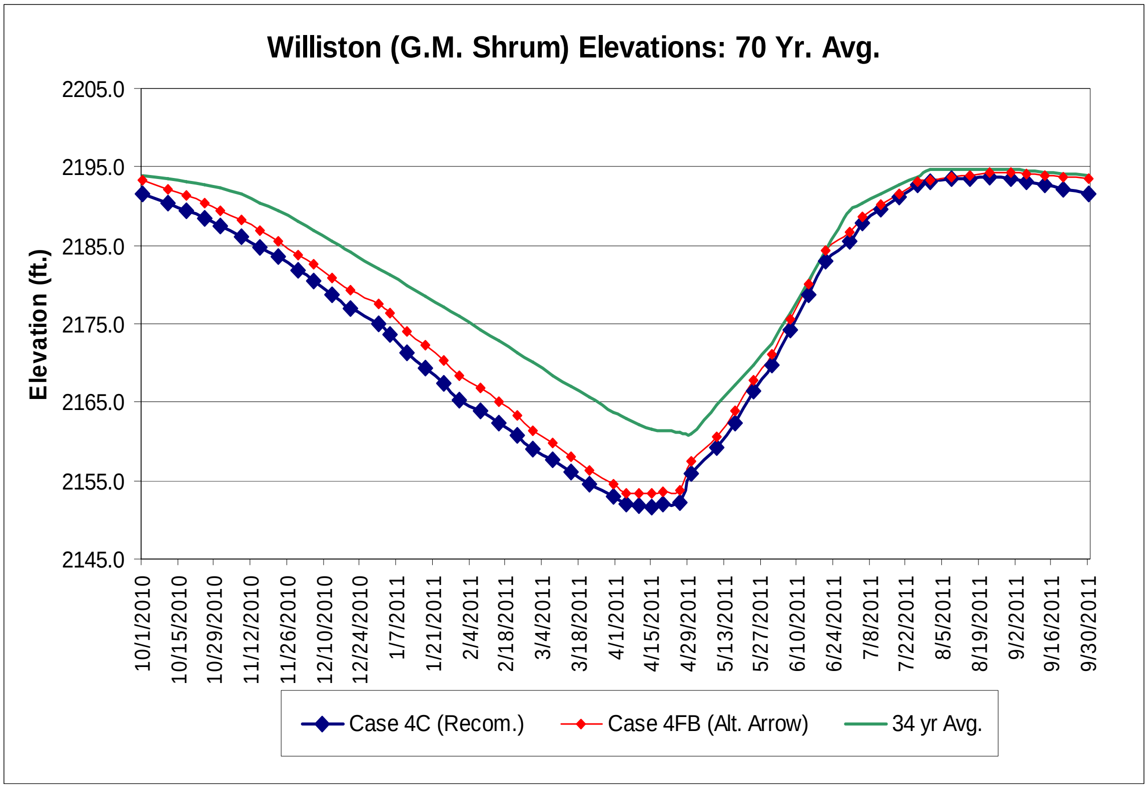


Figure 44. Williston (G.M. Shrum) Elevations

7.5.2 Peace River Site "C"

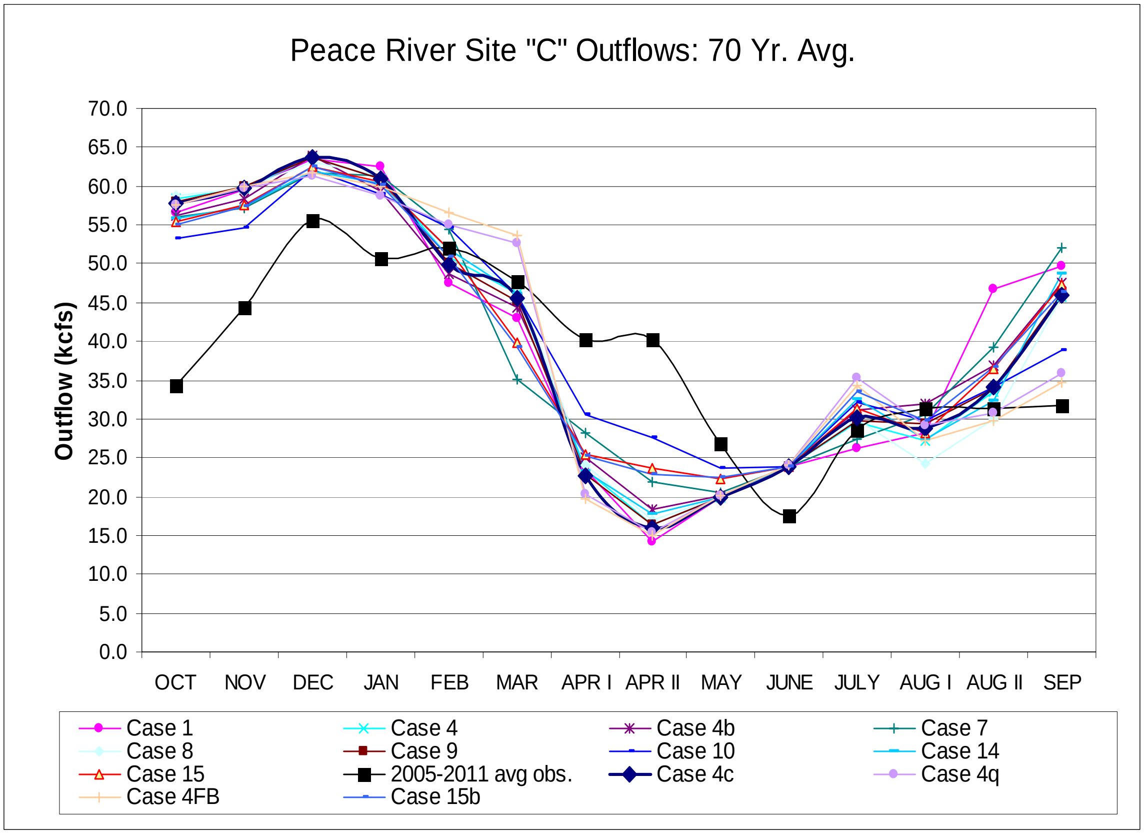


Figure 45. Peace River Site "C" Outflows

7.5.3 Mica

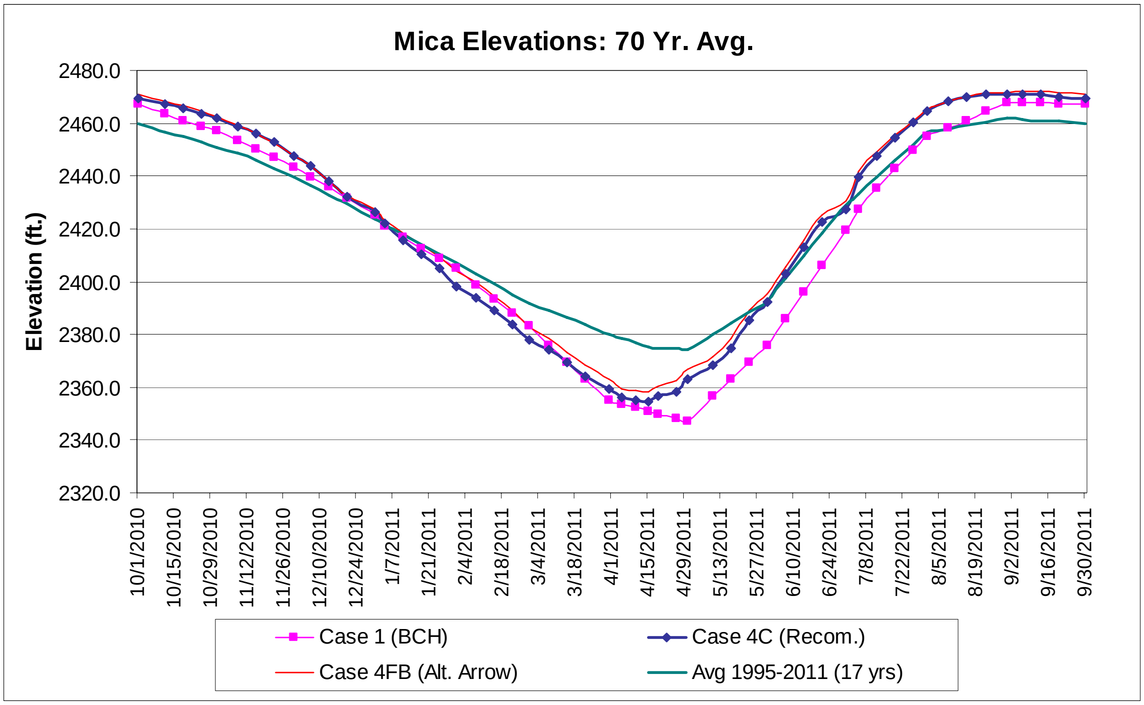


Figure 46. Mica Elevations

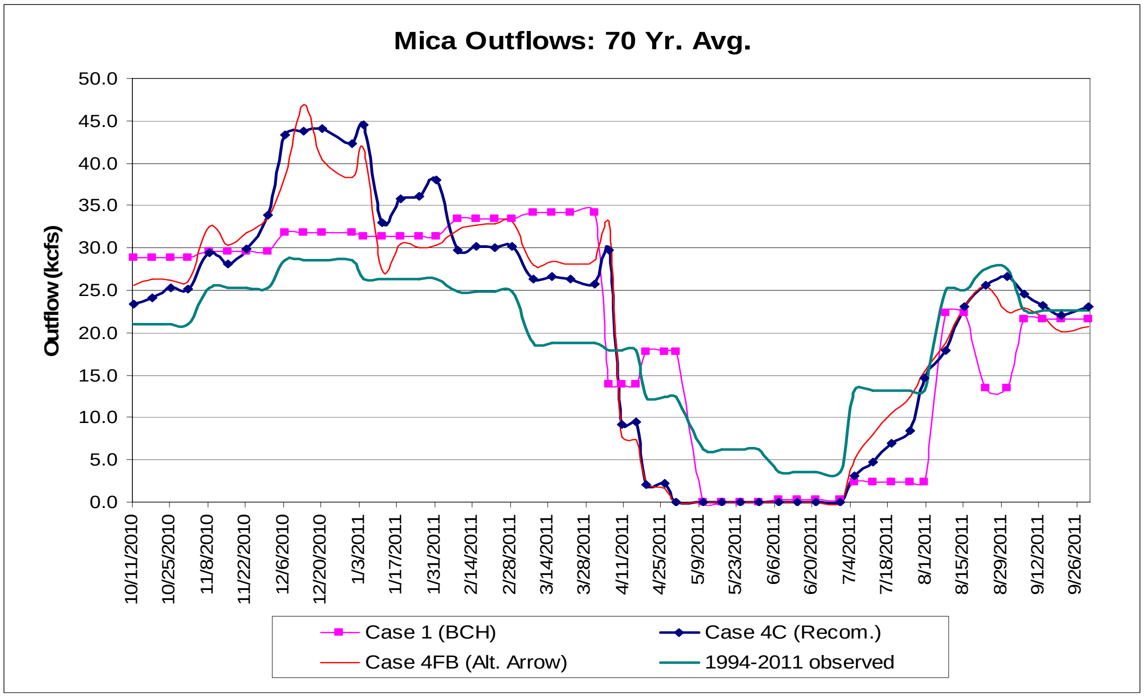


Figure 47. Mica Outflows

7.5.4 Arrow

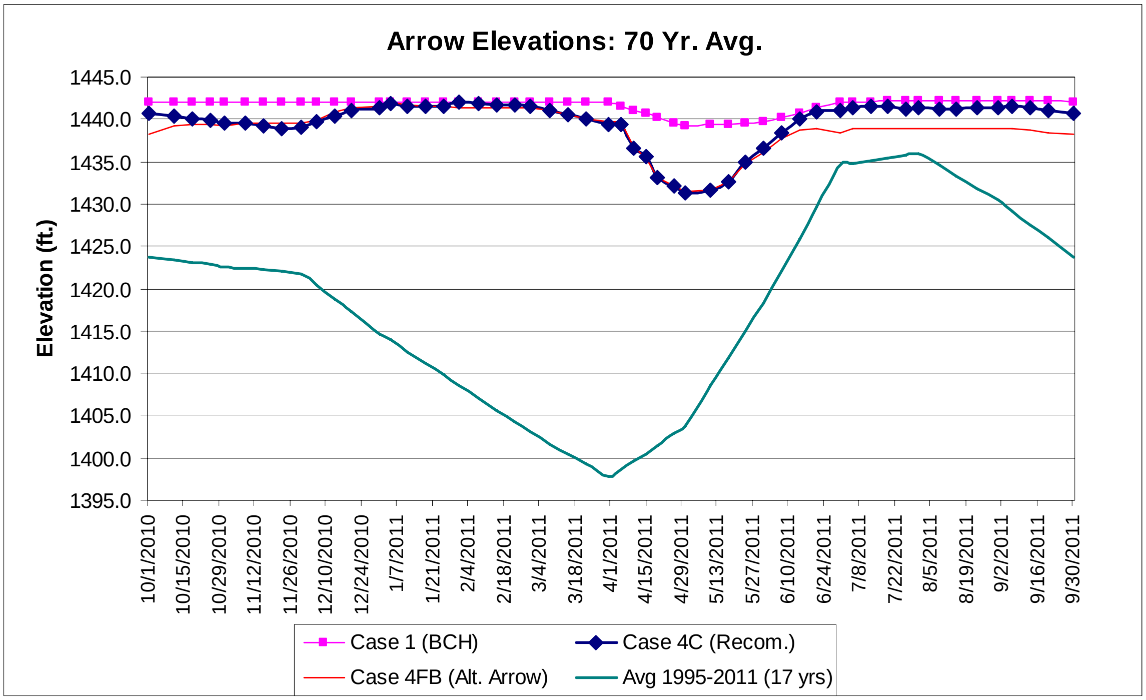


Figure 48. Arrow Elevations with Avg. Observed

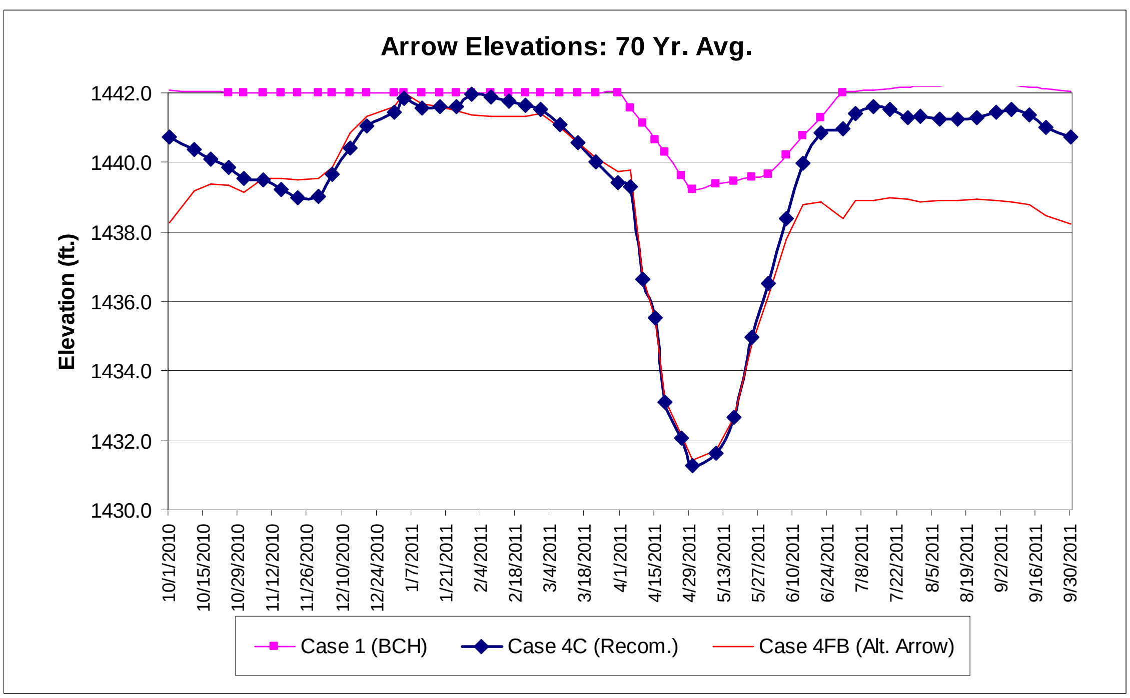


Figure 49. Arrow Elevations

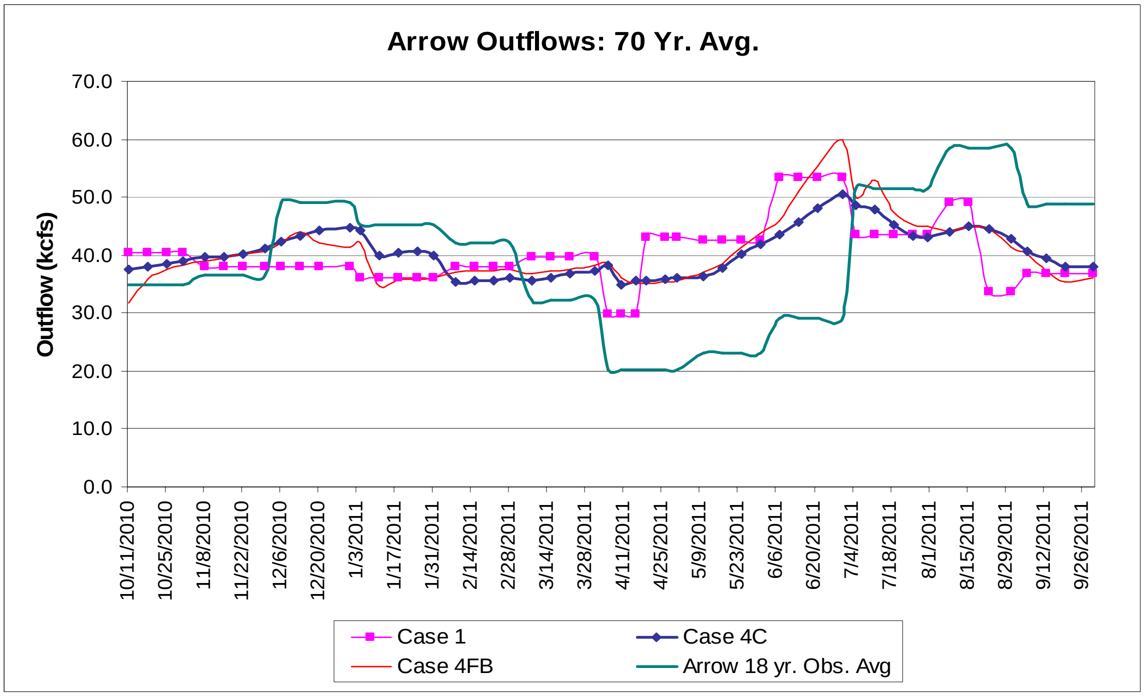


Figure 50. Arrow Outflows

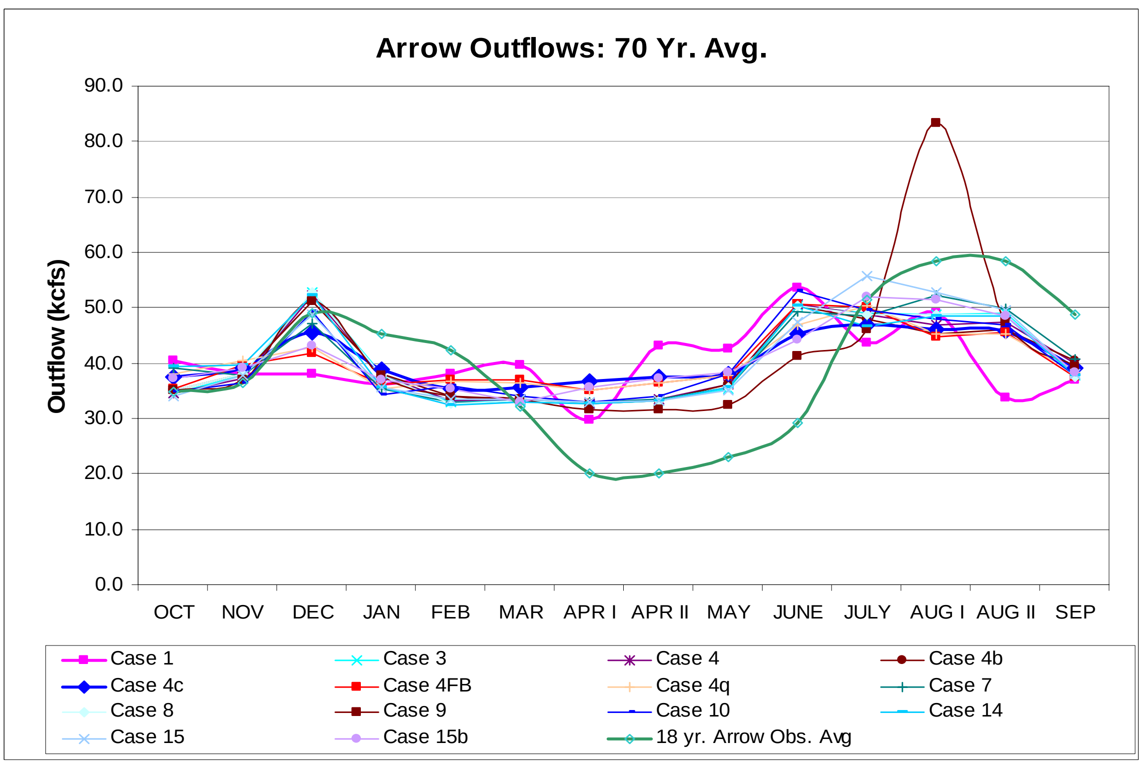


Figure 51. Arrow Outflows for all Case Studies

7.5.5 Duncan

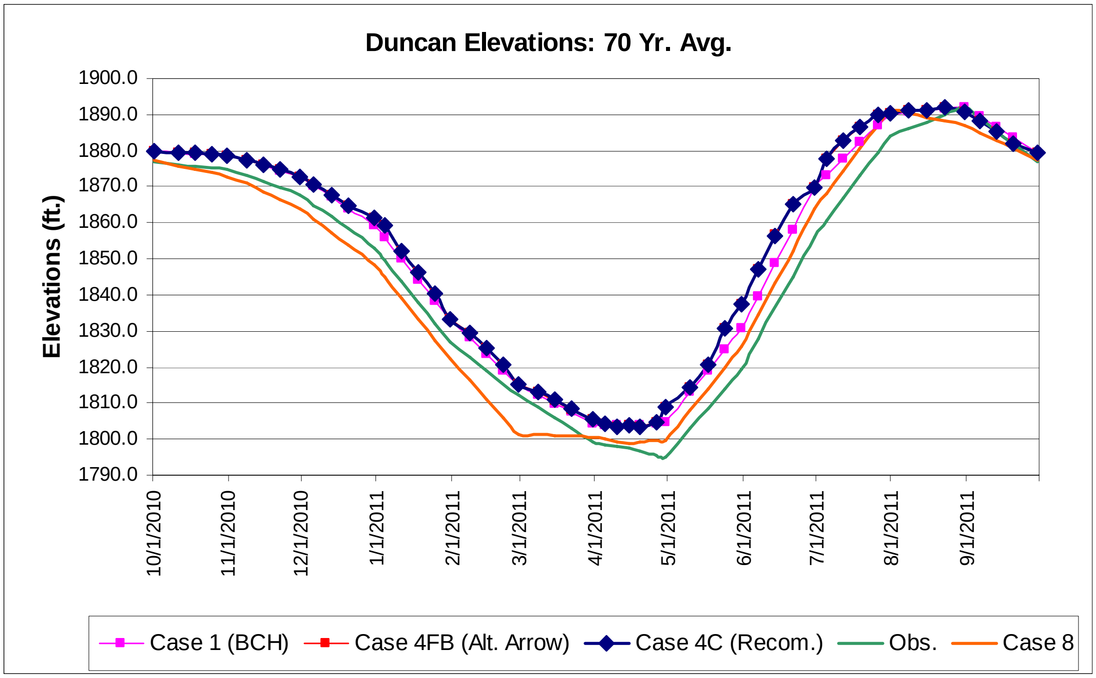


Figure 52. Duncan Elevations

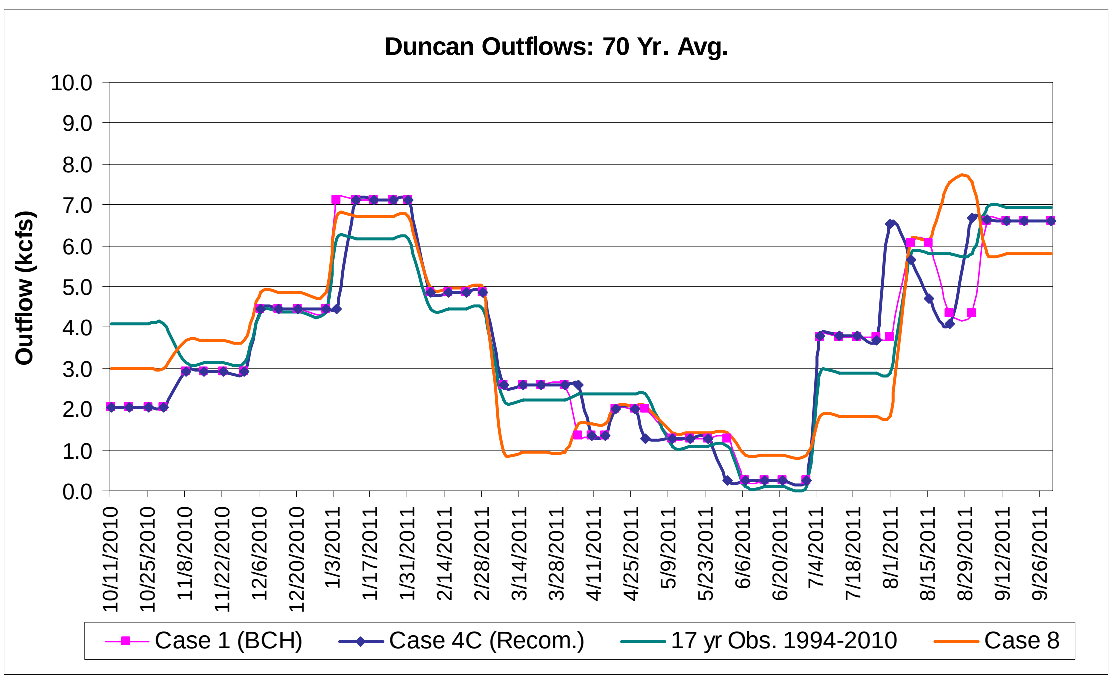


Figure 53. Duncan Outflows with Case 8 Power Optimization

7.5.6 Flow at the Border

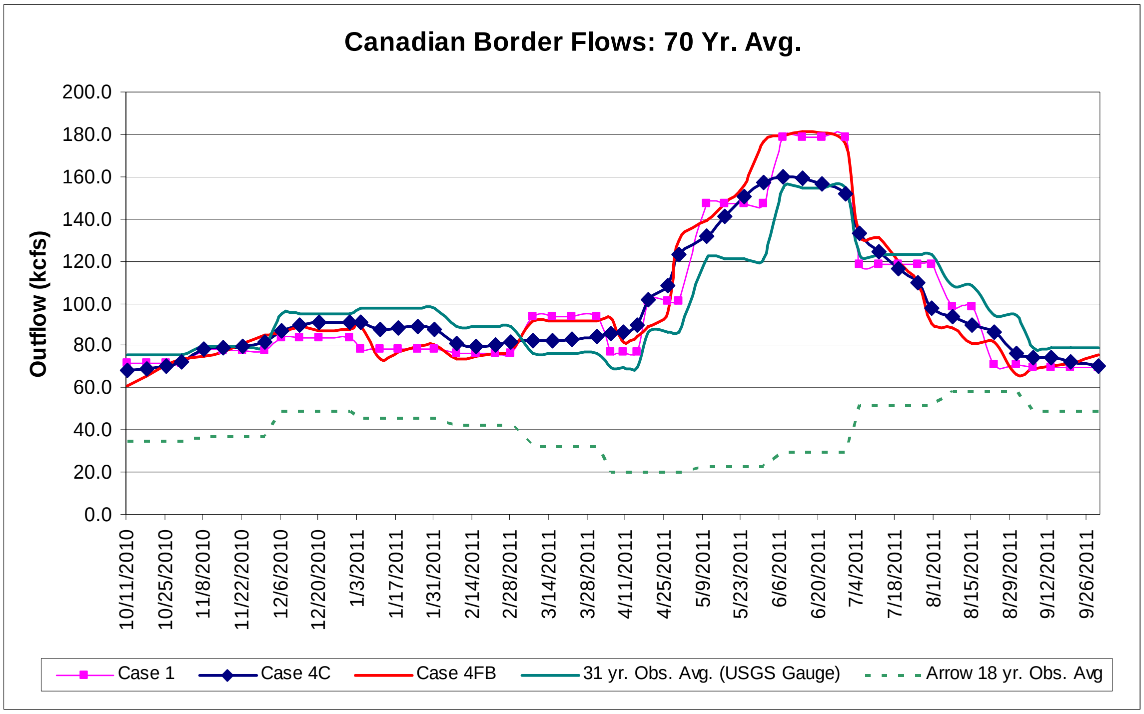


Figure 54. Border Flow Comparison with Observed flows

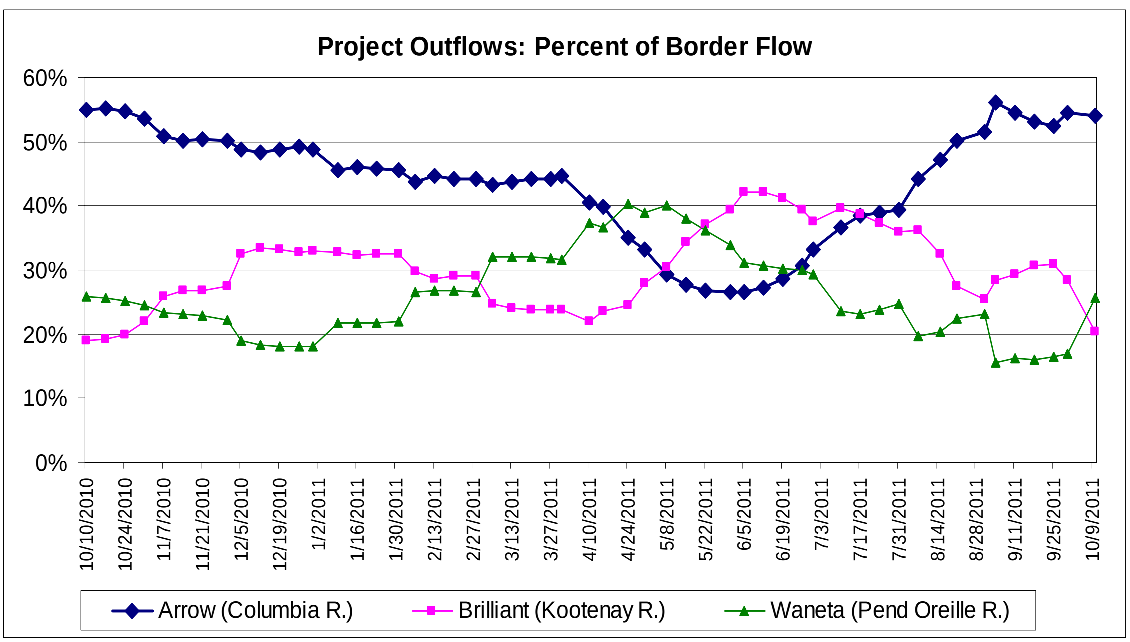


Figure 55. Border Flow as Percent of Three River Outflows (Case 4C)

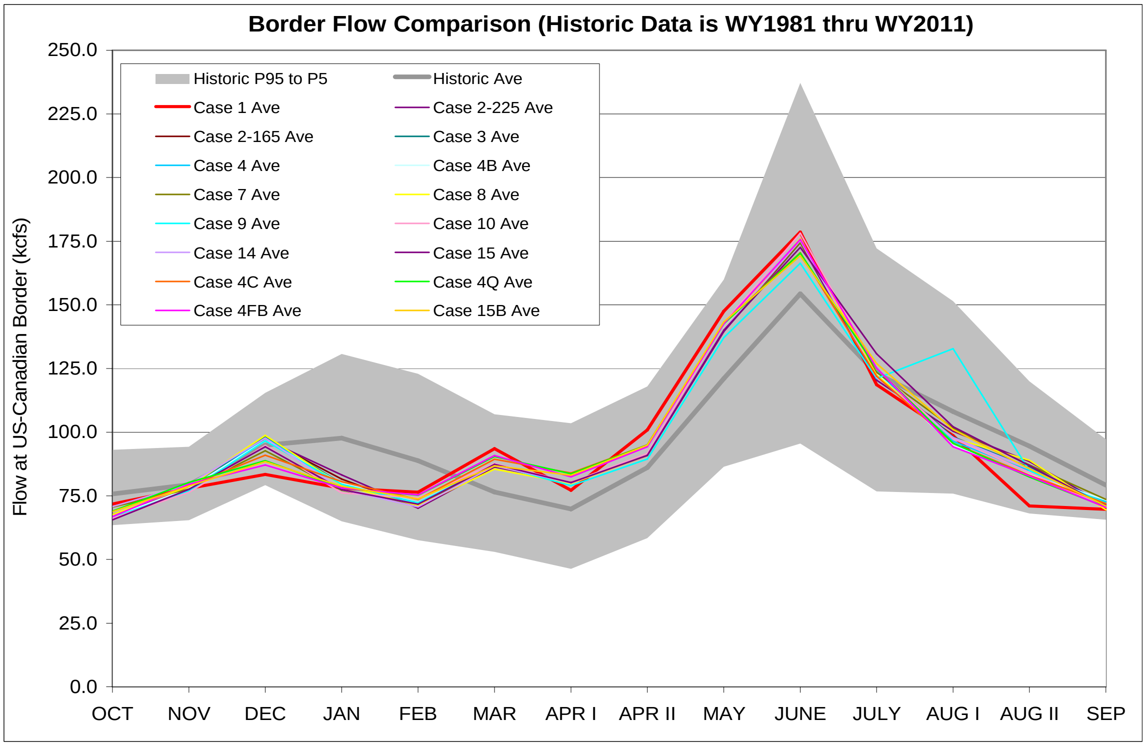


Figure 56. Border Flow Comparison for CV Studies

7.6 Synthetic Flow Analysis

7.6.1 Inflows

To better assess flood control operations during the peak of the snow melt runoff, the Corps developed a set of high synthetic flows at each for each inflow control point. These high flow scenarios included varying levels of probability ranging from a 1 in 100 year event up to a 1 in 1000 year event. The synthetic flows were developed using five water years; 1948, 1956, 1972, 1974 and 1997. Table 11 and Figure 57 below; illustrate the range of natural synthetic flows at Arrow for the summer time period. For comparison purposes, the average of the 70 year Modifed Flow set and the average of the aforementioned five water years, (non-synthetic) flows for Arrow is also shown.

Arrow Natural Inflow (kcfs)

		MAY				JUNE					JULY				AUGUST				Max
		5/8	**5/15**	**5/22**	**5/31**	**6/5**	**6/12**	**6/19**	**6/26**	**6/30**	**7/10**	**7/17**	**7/24**	**7/31**	**8/7**	**8/15**	**8/21**	**8/31**	
1	**WY48 100yr**	37.2	55.6	92.2	191.4	184.4	208.0	156.7	137.9	118.8	86.1	77.7	86.0	71.5	74.8	64.9	64.5	74.2	208.0
2	**WY48 200yr**	38.1	57.2	94.8	197.6	190.3	215.4	162.1	142.8	122.8	89.2	80.8	89.4	74.4	77.9	67.4	67.1	77.1	215.4
3	**WY48 500yr**	39.3	59.1	97.8	205.1	197.4	224.1	168.7	148.6	127.7	92.9	84.4	93.5	77.8	81.5	70.3	70.1	80.7	224.1
4	**WY48 MOD**	35.7	52.9	87.2	180.9	175.2	196.4	148.2	130.5	112.3	81.6	72.7	80.3	67.3	70.2	61.2	60.8	69.8	196.4
5	**WY56 100yr**	36.0	54.4	125.1	138.2	169.4	138.4	117.9	109.8	91.2	93.7	110.1	108.7	80.7	62.7	55.1	56.1	55.8	169.4
6	**WY56 MOD**	35.9	54.3	123.8	138.2	168.6	138.9	117.9	110.3	91.3	93.5	110.0	108.6	81.4	62.9	55.0	56.2	56.0	168.6
7	**WY71 100yr**	66.7	100.8	65.3	109.9	147.3	135.5	99.5	128.5	88.6	72.7	82.7	113.0	101.0	103.5	91.0	58.8	55.0	147.3
8	**WY71 MOD**	66.2	100.5	65.6	109.3	146.7	136.0	99.8	128.1	89.5	72.7	82.4	112.5	101.3	103.5	91.3	59.1	55.0	146.7
9	**WY72 1000yr**	33.3	87.4	133.3	178.4	241.7	283.9	198.3	178.8	180.8	162.8	166.7	140.2	130.6	115.7	111.0	87.9	83.8	283.9
10	**WY72 100yr**	29.1	76.4	116.6	156.0	211.4	248.3	173.5	156.3	158.1	142.4	145.9	122.7	114.3	101.2	97.1	76.9	73.3	248.3
11	**WY72 200yr**	30.5	80.0	122.1	163.4	221.3	260.0	181.7	163.7	165.6	149.1	152.7	128.4	119.6	106.0	101.7	80.5	76.8	260.0
12	**WY72 500yr**	32.1	84.3	128.6	172.2	233.3	274.0	191.4	172.5	174.5	157.1	160.9	135.3	126.1	111.7	107.1	84.8	80.9	274.0
13	**WY72 MOD**	27.2	71.0	108.3	144.0	196.5	229.0	162.3	144.7	146.8	132.2	135.5	114.5	107.2	94.8	91.5	72.2	69.0	229.0
14	**WY74 100yr**	62.6	57.8	46.6	88.3	97.2	95.4	210.7	250.1	164.5	140.7	138.3	149.9	132.1	123.5	78.1	72.7	68.0	250.1
15	**WY74 200yr**	64.4	59.4	47.9	90.7	99.9	98.1	216.6	257.0	169.0	144.6	142.1	154.0	135.8	126.9	80.3	74.7	69.9	257.0
16	**WY74 500yr**	67.4	62.2	50.1	94.9	104.5	102.6	226.6	269.0	176.9	151.3	148.7	161.1	142.1	132.8	84.0	78.2	73.2	269.0
17	**WY74 MOD**	54.8	51.1	40.4	76.6	84.3	82.7	181.6	217.1	143.9	122.4	120.1	130.3	114.6	107.9	68.6	63.1	59.3	217.1
18	**WY97 1000yr**	43.3	95.8	131.0	135.0	194.8	168.4	198.6	119.4	98.5	147.0	154.3	123.3	93.7	102.2	76.8	59.8	55.4	198.6
19	**WY97 100yr**	39.3	86.7	119.1	123.2	178.6	155.3	183.5	110.3	90.7	135.4	142.5	114.9	87.6	96.0	72.4	56.3	52.3	183.5
20	**WY97 200yr**	40.7	90.0	123.4	127.5	184.5	160.1	189.0	113.6	93.5	139.6	146.8	118.0	89.8	98.2	74.0	57.6	53.4	189.0
21	**WY97 500yr**	42.4	93.7	128.3	132.3	191.1	165.4	195.1	117.3	96.7	144.3	151.6	121.4	92.3	100.8	75.8	59.0	54.7	195.1
22	**WY97 MOD**	37.4	80.7	113.2	115.0	169.0	147.3	174.5	105.4	86.3	128.0	136.0	110.2	84.5	92.7	70.7	54.9	50.9	174.5
	Min	27.2	51.1	40.4	76.6	84.3	82.7	99.5	105.4	86.3	72.7	72.7	80.3	67.3	62.7	55.0	54.9	50.9	105.4
	P5	29.2	53.0	46.6	88.4	97.4	95.6	100.7	109.8	88.6	73.2	77.9	86.2	71.7	63.3	55.4	56.1	52.3	109.8
	P10	30.6	54.3	48.1	91.1	100.4	98.5	117.9	110.3	89.6	82.1	80.9	89.8	74.7	70.7	61.6	56.2	53.5	117.9
	P25	35.7	57.4	71.0	111.2	152.6	136.6	158.0	117.8	91.8	93.1	90.8	109.1	82.1	84.3	69.0	58.9	55.1	158.0
	Median	38.7	73.7	110.7	136.6	181.5	162.7	178.0	140.3	120.8	133.8	137.1	116.5	97.4	101.0	76.3	63.8	68.5	181.5
	Avg. All Synthetic	**43.6**	**73.3**	**98.2**	**139.5**	**172.2**	**175.6**	**170.6**	**155.1**	**126.7**	**121.8**	**124.7**	**118.9**	**101.2**	**97.6**	**79.3**	**66.9**	**65.7**	**175.6**
	P75	51.9	87.2	123.7	170.0	196.1	221.9	194.2	170.3	162.9	144.5	148.2	129.8	118.4	107.4	91.3	74.2	74.0	221.9
	P90	66.0	95.6	128.6	190.4	220.3	258.8	209.5	246.8	173.9	151.1	154.1	148.9	132.0	122.7	101.2	80.3	80.3	258.8
	P95	66.6	100.3	130.8	197.3	232.7	273.3	216.3	256.7	176.7	156.8	160.6	153.8	135.6	126.8	106.9	84.6	80.9	273.3
	Max	67.4	100.8	133.3	205.1	241.7	283.9	226.6	269.0	180.8	162.8	166.7	161.1	142.1	132.8	111.0	87.9	83.8	283.9
	6 yr avg Non-Synth	42.8	68.4	89.7	127.3	156.7	155.0	147.4	139.3	111.7	105.1	109.4	109.4	92.7	88.7	73.0	61.1	60.0	**156.7**
	70 Yr Mod. Avg	**47.3**	**64.3**	**78.5**	**98.6**	**113.2**	**117.0**	**119.1**	**114.5**	**110.9**	**107.0**	**104.3**	**93.0**	**84.4**	**75.4**	**67.5**	**59.4**	**51.6**	**119.1**

Table 11: Synthetic Natural Flows at Arrow

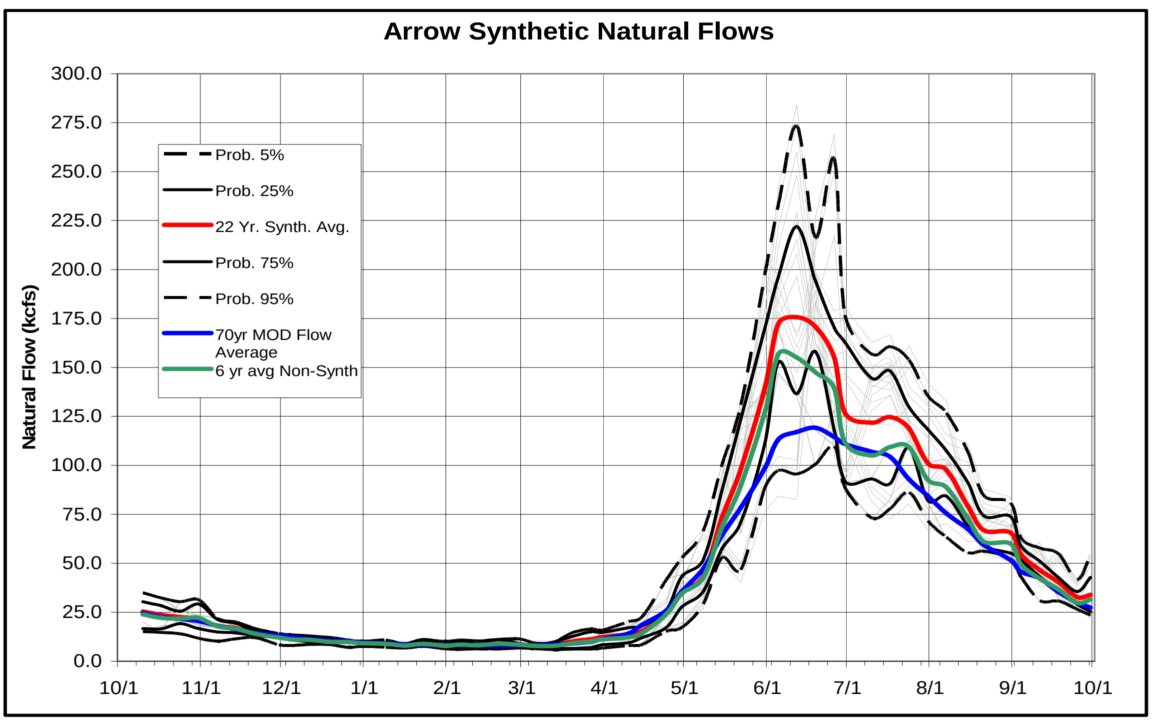


Figure 57. Synthetic Natural Flows at Arrow

7.6.2 Results

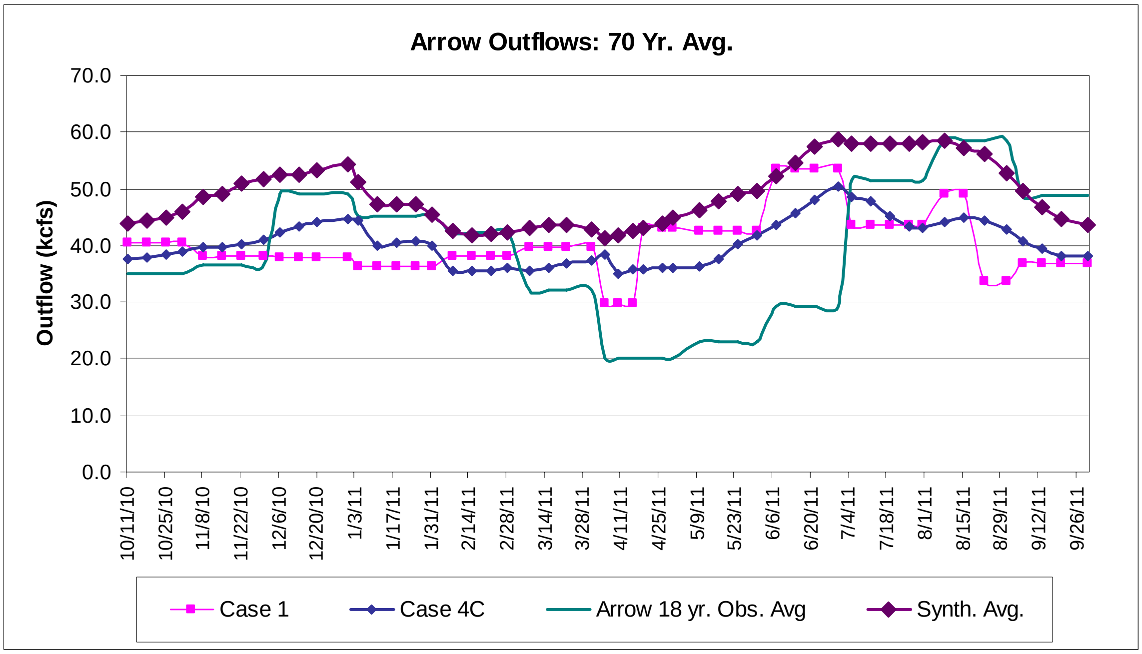


Figure 58. Arrow Outflows including Synthetic Average

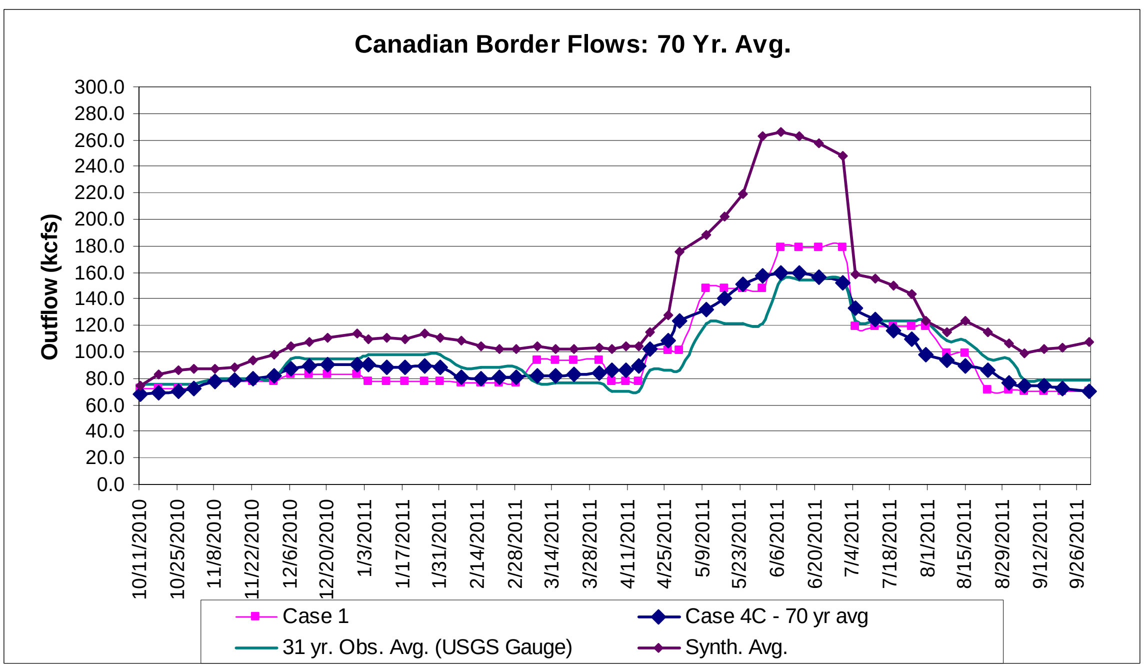


Figure 59. Canadian / U.S. Border Flows with Synthetic Average

8.0 SELECTION PROCESS

The selection process focused on culling the 25 different studies from both models into a small set of studies (or study) that the Project Team would recommend to be used in subsequent studies. This recommendation would attempt to project the set of 70 year operations that BC Hydro would follow in the absence of the Treaty.

There were two aspects worth noting in the selection process. The first was the objective to develop a selection process that best facilitated a collaborative process that made best use of the entire Team in culling the studies down. The nature of the studies required a degree of subjective inputs leading to an informed “best guess” at what BC Hydro would be doing under varying water supply years and a distant planning horizon. A Team approach in making such an assessment would provide a good balance in weighing alternatives. The second objective was to place an emphasis on evaluating the study inputs and assumptions rather than skipping straight to the outputs, as is often done. The overlaying theory was that the study or studies that best captured the expected operational inputs would in turn produce the projected Canadian operations with the highest Team confidence. The model inputs and assumptions broken down into 19 different variables and tabulated to produce a input survey for the Project Team. This table is shown in Table 12. The inputs covered the headings described in section 3.3 and included alternative case assumptions for local flood control, refill, non-power constraints, future resources and marketing. Ten Project Team participants than individually ranked each variable as to its robustness or likelihood of occurring. The ranking criteria incorporated a score of 1 to 5, with a 1 being a high likelihood and a 5 being a low likelihood. Following the individual ranking process, the Team met as a whole and discussed each input to clarify the inputs and address study questions. Each Team participant was than given the opportunity to revise their polling. The resulting input variable averages would therefore be considered the most robust or best assumptions to include. The last column of Table 12 captures the Team’s collective thinking as to the individual input variables relative weighting for robustness. This average score was then matched up with the individual studies to see which studies best aligned with the most robust assumptions, from a collective Team perspective. Table 13 is a result of this matching. Study 4C emerged as the study that best fit the inputs viewed as most likely.

Further group discussion led to an alternative sensitivity case that the Team viewed as worth passing on to the technical teams that will be using the recommended study or studies as input into their studies. The alternative Case 4FB was selected as this study presented a reasonable alternative operation at Arrow that put a stronger emphasis on operating this project for recreational and wildlife related benefits, as opposed to power production. While the outflows from Study 4FB were not significantly different from 4C on average, the elevations at Arrow were considered to be of notable difference. The Team will leave the decision as to what degree the subsequent modelers will want to include this alternative study as a consideration, to them.

	No-Treaty Modeling Input Poll	Please rank the modeling inputs using the following scale:										
		1 = High likelihood										
		2 = Good chance										
		3 = Moderate likelihood										
		4 = Somewhat likely										
		5 = Possible / Low likelihood										
		BPA Participants (6 ea)						**Chelan (2 ea)**		**Grant**	**Corps**	
	Input Variable	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	**Average**
1	Canadian Ops fixed to BCH submittal	2	4	3		2	2	3	4	2	2	**2.7**
2	local flood control (165 kcfs at Birchbank)	2	1	3	1	1	1	2	2	2	1	**1.6**
3	local flood control (225 kcfs at Birchbank)	3	3	3	1	2	1	2	4	3		**2.4**
4	high refill mode	4	3	4	3	4	3	3	3	1	3	**3.1**
5	moderate refill mode	2	2	2	2	2	2	2	3	2	2	**2.1**
6	low refill mode	5	5	4	3	4	2	4	4	3	4	**3.8**
7	Trout Spawning and Whitefish Ops.	1	1	3	1	1	1	2	1	1	1	**1.3**
8	medium load forecast	2	3	1		1	4	2	2	2	1	**2.0**
9	high load forecast (no conservation)	3	5	2		5	4	4	4	3	2	**3.6**
10	alternative Duncan Ops (market driven)	3	4	3	5	2	3	2	4	3	3	**3.2**
11	alt. Arrow (HDR natural lake)	5	5	5	4	5		5	4	4	4	**4.6**
12	alt. Arrow Facility data (incr. Qt)	1	1	1	1	*4*	3	3	2	2	1	**1.9**
13	alt. (lower) Arrow FB range for recreation, etc.	4	3	5	2	3	2	4	3	3	3	**3.2**
14	no Site C assumed	3	5	3	3	3	3	3	3	4		**3.3**
15	Price assumption #1	3	3	3		3		3	2	2		**2.7**
16	Price assumption #2 (revised mo. shaping)	4	3	3		3		3	3	3		**3.1**
17	Price assumption #3 (revised mo. shaping)	4	3	3		3		3	4	3		**3.3**
18	Price assumption #4 (flat quarterly prices)	2	2	3		4		3	4	3		**3.0**
19	70 yr. continuous mode (high optimal foresight)	4	5	2	5	2	5	4	3	2	5	**3.7**

Table 12. Case Study Input Poll

CV Studies				1st Choice		sensitivity											
		4	5	6	7	8	9	10	11	12	13	14	15	16	17		
		mod. refill	low refill	updated Arrow Qt	flat Qrtly. Prices	lower Arrow FB	high refill	70 yr. cont. (high refill)	high loads	alt. Duncan	alt. Arrow	revised price shape #1	price shape #2	new Arrow Facility Data and Seasonal prices	no Site C	"X" indicates 2.4 or less poll avg	
# of Input Var.'s	**Input Variable**	**Case 4**	**Case 4b**	**Case 4c**	**Case 4q**	**Case 4FB**	**Case 3**	**Case 3b**	**Case 7**	**Case 8**	**Case 9**	**Case 10**	**Case 15**	**Case 15b**	**Case 14**	**Poll Inputs**	**poll Avg.**
1	Canadian Ops fixed to BCH submittal																2.7
2	local flood control (165 kcfs at Birchbank)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	1.6
3	local flood control (225 kcfs at Birchbank)																2.4
4	high refill mode						X	X									3.1
5	moderate refill mode	X		X	X	X			X	X	X	X	X	X	X	X	2.1
6	low refill mode		X														3.8
7	Trout Spawning and Whitefish Ops.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	1.3
8	medium load forecast	X	X	X	X	X	X	X		X	X	X	X	X	X	X	2.0
9	high load forecast (no conservation)								X								3.6
10	alternative Duncan Ops (market driven)									X							3.2
11	alt. Arrow (natural lake)										X						4.6
12	alt. Arrow Facility data (incr. Qt)			X	X	X								X		X	1.9
13	alt. Arrow FB range (Lower)					X											3.2
14	no Site C assumed														X		3.3
15	Price assumption #1	X	X	X			X	X	X	X	X				X		2.7
16	Price assumption #2 (revised shaping)											X					3.1
17	Price assumption #3 (revised shaping)												X	X			3.3
18	Price assumption #4 (flat seasonal prices)				X	X											3.0
19	70 yr. continuous mode (high opt. foresight)							X									3.7

Table 13. Case Study Selections from Input Poll Results

9.0 RECOMMENDED CANADIAN OPERATIONS

The recommended study for BC Hydro operations without the Treaty is Study 4C. This study assumes the whitefish and trout spawning operation will continue post 2024.

Mica is operated to maximize revenue and attempt to refill. Mica outflows are highest in the winter period averaging 40-45 kcfs in the month of December. Mica reduces outflows to zero flows in the May-June period to refill the reservoir and to shift generation production into higher value periods. Mica increases outflows to near 25 kcfs in July as the project refills. In general, late summer flows average 20-25 kcfs as the project passes inflow and waits for the winter draft that starts in November.

Arrow is operated in general to full turbine outflow except for the winter and late summer period when inflows into Arrow exceed turbine flow. Arrow elevations on average run near full throughout the year except for an assumed slight draft prior to the peak runoff that serves to minimize spill.

Duncan operation was fixed to the operation modeled in the B2F600 Phase I Treaty studies. Duncan was not expected to modify its operations significantly in the absence of the Treaty. The studies did assume that the IJC operation at Kootenay Lake would continue post 2024. The average annual outflow of Duncan is approximately 4 kcfs with a range of outflows running from 0.1 kcfs to a maximum of 10 kcfs. Because of the low flows out of Duncan and the large re-regulation occurring at Kootenay Lake, the operation of Duncan was not considered significant to the overall flows at the Canadian border.

The primary product of this project was to estimate outflows and elevations for Arrow and Mica that could be plugged into subsequent studies that model the entire U.S. system to assess No-Treaty operational and power impacts to the U.S.

A second sensitivity study, Case 4FB was also considered noteworthy for subsequent studies. This study assumed that Arrow would operate to different forebay elevations reflecting a stronger emphasis on wildlife and recreation. Average 70 year Arrow elevations and outflows for Study 4C and Study 4FB are shown in Figure 49 and Figure 50. The 14 period monthly outflows for each of the 70 years is shown in Table 16. The weekly period average project operations (elevations and outflows) for Mica, Revelstoke and Arrow are available electronically and have been provided to the modeling staff at the Corps and BPA.

10.0 DISCUSSION

There were two major challenges in running these studies. The first was to attempt to project how another utility might operate their system with a reasonable balance between power/economics and non-power considerations such as recreation and fisheries. The second was to attempt to model the Canadian projects in a post 2024 planning horizon with so much uncertainty looming that far ahead in the future. Loads and resource planning for a period 15 years out should evoke a degree of vulnerability as future technologies, environmental concerns and regulations can be game changers and can creep up unexpectedly. On the modeling plus side, a large hydro-based resource system does translate into some simple rules, you can generate only to the extent the water is available - water supply plays the major role. The modeling objective then becomes an issue of shaping the generation to those periods of highest value, within the tolerance of non-power constraints. The large storage projects of Williston and Mica provide a high level of shaping capability and are a great benefit to BC Hydro. Some additional thoughts and comments on this project are as follows:

Two models: Both HydSim and CV were used to perform the studies. These studies were unique from several viewpoints; the addition of the Peace River projects, modeling a non-U.S. hydro system and operating primarily to meet load and maximize secondary revenues. HydSim is a long-standing reliable regulation model that works well for end of period rule curves, providing monthly or semi-monthly results. In the absence of the Treaty, the requirement to run to rule curves is removed. A procedure to develop operating rule curves was developed to allow HydSim to run the Canadian projects in a manner that would provide reasonable economic benefits and meet non-power constraints.

The CV model relied on an optimization engine that provided maximum economic benefits while also still meeting non-power constraints. The results of these studies were both in the 14 period mode as well as a weekly or near weekly output format. The weekly runs provided a higher resolution in operating to the natural inflows represented by the 70 water years. An effort was made to minimize weekly output fluctuations or variability that can occur in non-simulation runs; however some level of weekly variability may remain. Both models adapted well to the Canadian configurations and produced good study results.

Pricing: Price forecasting will always remain a key variable with large uncertainties. These studies relied to a large degree on how the historical markets over the last 10 years have behaved. Pricing was influenced by the water supply to some degree as has been observed, however there remains much volatility in energy markets and where the future might lead them. Sensitivity studies were run with alternative pricing schemes but the results remained consistent to some degree. Winter and late summer periods were assumed to be highest and high flow, peak runoff periods were assumed to be lowest.

GM Shrum (Williston Reservoir): GM Shrum provides nearly one third of BC Hydro generation requirements. The large storage capacity of the reservoir also allows for multiyear storage. The tradeoff between refilling the project and producing more generation is complex invoking a risk assessment of operations and financial objectives. The studies contained in this report had a tendency to draft Williston deeper than observed operations. It remains unclear just how Williston might operate in a non-Treaty environment in a future with higher load projections and added generation capacity on the Peace River with Site C constructed. Constraints could have been added to reduce the draft capability at Williston but there were no strong reasons to do so. Actual operations always present more uncertainties than the models reflect. The deeper draft may reflect the more "idealized" system planning environment inherent in the modeling effort.

Transmission: Transmission capability plays a key role in operating BC Hydro's system for meeting load and increasing revenue. The limits assumed in this modeling effort were on the high side assuming the full current levels of capacity. This might also be a form of "idealized" modeling. The economic drivers of the studies tended to purchase large amounts of energy from the U.S. market during the cheap energy periods of the peak runoff. While this makes sense conceptually and is consistent with observed practice, the extent of the energy purchases appeared to be higher than historical practice. Benchmarking historical operations under the Treaty requirements can be misleading, however. The ability to purchase was not curtailed in the models to limit this mode of operation but the extensive use may also be another form of "perfect foresight" or idealized modeling conditions.

Whitefish and Trout: The current Whitefish and trout spawning operations were assumed to continue indefinitely. This assumption, while reasonable, holds a level of uncertainty, particularly with the whitefish operations as indicated in the "Columbia River Project Water Use Plan – *Kinbasket Reservoir Fish and Wildlife Information Plan*", October 24, 2007.

Arrow Recreation and Wildlife: Arrow has many competing objectives. To maximize generation, Arrow would generally run near full pool elevation of 1442.0 ft +/- and run to full turbine flow throughout the year. To reduce outflows below full turbine, will generally result in increased spill during another period. The generating capacity at Arrow is relatively small however at 185 MW so the project can and will operate for other objectives. There are some levels of recreation in the surrounding area with a general desire to keep the lake in the range of 1435-1440 ft. elevation during the summer period. Arrow also provides nesting and foraging habitation for shorebirds. These interests and other fishery interests could result in lower reservoir elevations down to 1425 ft. or so. There is a potential for very large drafts from Arrow to provide high outflows in July to enhance the white sturgeon population. This operation might be similar to Study 9 that was run as an alternative scenario. All these possibilities could impact Arrow outflows. The general consensus of the Team was to lean more heavily in assuming that Arrow would operate more towards power benefits.

11.0 APPENDIX A: CANADIAN PROJECT INFORMATION

Canadian Hydro Project Information

	Canadian Projects Name	Abrev.	Service Date	Operator	# Units	Capacity (MW)	Max. Elev. (ft)	Min. Elev. (ft)	Stor. (ksfd)	Max H/K (MW/kcfs)	Dam Type	River, State
1	MICA	MCDB	1973	BCH	4	1792	2,475.0	2,320.0	3,529	42.5	STO	Columbia, British Columbia
	Mica units 5&6		*2015*	BCH	6	2800						
2	Revelstoke	REV	1983	BCH	4	1980	1,880.0	1,830.0	*630*	*33 (approx)*	STO/ROR	Columbia, British Columbia
	Rev. unit 5		*2011*		5	2480						
3	ARROW	ARDB	1968	BCH	2	185	1,444.0	1,377.9	3,580	5.0	STO	Columbia, British Columbia
4	DUNCAN	DCDB	1967	BCH	na	na	1,892.0	1,794.2	706	na	STO	Duncan, British Columbia
5	G.M Shrum	GMS	1967	BCH	10	2730	2,205.0	2,100.0	16,900	*46 (appr.)*	STO	Peace River, British Columbia
6	Peace Canyon	PCN	1980	BCH	4	694	1,650.0	1,640.0	*90*	*10.3 (appr.)*	ROR	Peace River, British Columbia
7	*Site "C"*	STC	*2021*	BCH	6	1100	1,515.0	1,509.0	*900*	*12.5 (appr.)*	ROR	Peace River, British Columbia

Table 14. Canadian Project Information

12.0 APPENDIX B: HYDSIM STUDY DETAILS

No Treaty HYDSIM Studies

Purpose of Studies:
Develop the Canadian system operation including the three Peace River projects, GM Shrum, Site C, and Peace Canyon, under the assumption of the Treaty terminated. The HYDSIM hydro regulation model was used to proportionally draft just the Canadian system to meet the Canadian load. All U.S. projects were on a fixed operation. Essential data to operate the Peace River had to be identified, developed and verified. Critical period rule curves (CRCs), and Variable energy content curves (VECCs) were developed by the modeler through an iterative process for optimal operation for power, refill and non-power requirements. The Upper rule curves (URCs) for the Peace projects were developed and fixed through out all the studies while the URCs for the Canadian Columbia projects were provided by BC Hydro. Plant data for Peace River projects was consistent in all cases, identified and verified through cross checking. HYDSIM results were analyzed to study refill, power and nonpower impacts on Canadian system.

Case 0: A base 2006 study was performed to check the validity of data, and proper implementation of HYDSIM codes.

Case 1_1: Operate Mica, Duncan and Arrow, and Corra Linn to first codes provided by BC Hydro in the Phase 1 study base case while maximizing refill on the Peace river. Site C and Peace Canyon projects were operated as run of river projects. Refill was maximized by setting the ECC to the URC at GM Shrum (on Williston Lake). CRCs for proportional draft were developed based on the following portion of URC: CRC1 (0.75), CRC2 (0.667), CRC3 (0.5), and CRC4 (0.4).

Case 1_2: Operate Mica, Duncan and Arrow, and Corra Linn to first codes provided by BC Hydro in the Phase 1 Base Case study. Maximize revenue on the Peace River through monthly shaping (draft) of the ECC to reflect the pricing curves Oct through April. The ECC was set to URC from May through Sept for refill. CRCs for proportional draft were developed based on the following portion of ECC: CRC1 (0.9), CRC2 – CRC4 (0.85).

Case 2: Mica and Arrow were free to optimize subject to local flood control of 165 kcfs at Birtchbank (downstream from Arrow & Brilliant). Duncan and Corra Linn remained fixed as in Case 1_1 & 1_2. The ECCs & CRCs for the Peace projects were the same as in case 1_2.

Case 3: Same as Case 2 but subject to Whitefish and trout spawning non-power requirement at Arrow as described below:

Whitefish: Flow requirements January through March to protect eggs broadcast by White fish during Jan 1-21. February flows ideally would be equal to the January flows but can be as much as 19 kcfs lower (similar to current Treaty modeling). March flows should be equal or greater than the February flows to protect whitefish through the emergent fishery stage.

Trout spawning: Arrow outflow requirements April through June to avoid reductions for the purpose of protecting eggs deposited by trout during April and May. Set an initial low Arrow outflow (between 15 - 35 kcfs) in April and hold outflows through June at a level greater than or equal to that of the previous month.

Study Assumptions:

- Treaty is terminated.
- Continuous, 70-year of historic streamflows, 1929 -1998, Oct – Sept.
- The preferred minimum elevation at Lake Williston was set to 2140 ft.
- Minimum flow requirement at Shrum is 10 kcfs every period except: Dec 40 kcfs, Jan 52 kcfs, and Feb and Mar 30 kcfs for ice bridge/jamming.
- For Cases 1_1 & 1_2, the Canadian 70-year operation was fixed in HYDSIM via first codes to the results from the B2 Forecast Base case study referenced below. This data was previously provided by BC Hydro for use in that study. Projects fixed to this operation were: Mica, Revelstoke, Arrow, Duncan, and Corra Linn.
- In all studies, the U.S. 70-year operation was fixed in HYDSIM via first codes to the results from the B2 Forecast Base case study. Projects fixed were Libby, Horse, Kerr, Noxon, Priest Lake, and Albeni Falls.
- GM Shrum, Peace Canyon, and Site C were the Peace River projects that were modeled. The plant data was developed by Dan and Eric with initial source from BPA's current plant data included years ago. All Canadian projects on the Kootenay, Peace and Columbia rivers were included to meet Canadian generation. All U.S. projects generation was removed.
- A secondary Market limit of 2700 mw replaced an unlimited secondary market, resulting in over-generation spill.
- All Canadian projects were set to 100 percent availability.
- The Canadian monthly load was developed from the Canadian Integrated Resource Plan for 2004 and 2006 and projected to the 2024 level:

Jul	**Ag1**	**Ag2**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Ap1**	**Ap2**	**May**	**Jun**
7016	7086	6998	6927	7482	8369	9028	9101	8609	7957	7136	7051	6770	6774

  This load includes 1159 MW of conservation shaped flat across the year, and provided by Rob Diffley, BPA.

- Hydro Independent resources include hydro, and renewable such as small thermal and wind.

Jul	**Ag1**	**Ag2**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Ap1**	**Ap2**	**May**	**Jun**
352	3658	3178	2867	2287	2337	2366	2098	1877	1893	2102	2599	3091	3145

  This data was provided by Rob Diffley, BPA as an annual amount, but monthly shape provided by Eric.

- Upper Rule Curve (URC) for Shrum was set to the maximum storage elevation for each period over 30 years, (1976 – 2010) of data from Environment Canada website: http://www.wsc.ec.gc.ca/applications/H2O/graph-eng.cfm?station=07EF002&report=daily&year=2010
- Critical Rule Curves (CRC1 through CRC4) were used to proportionally draft projects to meet load not met by drafting to ECC levels.

Source Study:

Phase I study with the Treaty terminated, and the Canadian operation fixed to that provided by BC Hydro 2014/2024 Phase I study: B2 Forecast (base)

File location: Q:\TREATY\AOP25B2-Forecast\11_600base2\HSLT

Location of Studies: Q:\NoTreaty\HydsimRuns\ where Q is defined as Model on 'Bonfire

13.0 APPENDIX C: CV STUDY DETAILS

No Treaty Columbia Vista Study

Below is the base case table – Case 1 - with the defined river system and hydro constraints for the two case studies recommended for consideration in further studies. Differences from this base case are called out specifically for each case on subsequent pages.

Case 1 – BC Hydro Base Case

Operate Mica, Duncan, and Arrow according to BC Hydro operations as provided for the Phase 1 study base case. The Peace River projects are free to operate towards economic optimization. No "called-upon" adjustments are made.

River	Reservoir / System	Hydro Definition	Hydro Operation	Constraint
Peace River	GM Shrum Reservoir	Elevation	Minimum	2140
	GM Shrum Reservoir	Elevation	Stable Rising	May & June (1.0)
	GM Shrum Reservoir	Elevation	Stable Falling	Dec through Apr (3.0)
	Peace Canyon Reservoir	Elevation	Requested	1648
	Site C Reservoir	Elevation	Requested	1512
	GM Shrum to Peace Canyon	Discharge	Minimum	10.0 kcfs
	GM Shrum to Peace Canyon	Discharge	Maximum	69.5 kcfs
	GM Shrum to Peace Canyon	Discharge	Maximum Variation Flow	35.0 kcfs
	Peace Canyon to Site C	Discharge	Minimum	Icebridging ops
	Peace Canyon to Site C	Discharge	Maximum	70.0 kcfs
	Peace Canyon to Site C	Discharge	Maximum Variation Flow	35.0 kcfs
	Site C to Taylor	Discharge	Maximum Variation Flow	15.0 kcfs
Libby	Libby Reservoir	Elevation	Upper Rule Curve	from Phase 1
	Libby Reservoir	Elevation	Lower Rule Curve	from Phase 1
	Libby to Bonners	Discharge	Maximum Variation Flow	0.0 kcfs
	Libby to Bonners	Dynamic Discharge	Max-Min Absolute	Flat period flow
Duncan	Duncan Reservoir	Elevation	Upper Rule Curve	from Phase 1
	Duncan Reservoir	Elevation	Lower Rule Curve	from Phase 1
	Duncan Reservoir	Dynamic Discharge	Max-Min Absolute	Flat period flow
Kootenay	Kootenay Lake	Elevation	Upper Rule Curve	from Phase 1
	Kootenay Lake	Elevation	Lower Rule Curve	from Phase 1
	Kootenay Canal Power	Discharge	Maximum	29.0 kcfs
	Kootenay Canal Power	Discharge	Requested	29.0 kcfs
	Kootenay Canal Power	Discharge	Free Flow Maximum	1.0 kcfs
	Corra Linn to Up Bonnington	Discharge	Minimum	5.0 kcfs
	Corra Linn to Up Bonnington	Discharge	Free Flow Maximum	1.0 kcfs

River	Reservoir / System	Hydro Definition	Hydro Operation	Constraint
Upper Columbia	Revelstoke to Arrow	Discharge	Minimum	5.0 kcfs
	Revelstoke to Arrow	Discharge	Maximum	200.0 kcfs
	Revelstoke to Arrow	Discharge	Maximum Variation Flow	15.0 kcfs
	Arrow River Reach	Discharge	Maximum	55.0 kcfs in Jan
	Arrow River Reach	Discharge	Maximum Variation Flow	15.0 kcfs
	Arrow River Reach	Discharge	Ramp Down	0.0 kcfs (AprIl -Jun)
	Arrow River Reach	Fishery Dynamic Discharge	Fishery Max/Min Cap.	Jan - Mar (2011)
	Arrow River Reach	Fishery Dynamic Discharge	Fishery Max/Min Cap.	Jan - Mar (2012)
	Arrow River Reach	Discharge	Free Flow Maximum	1.0 kcfs
Flathead	Hungry Horse Reservoir	Elevation	Upper Rule Curve	from Phase 1
	Hungry Horse Reservoir	Elevation	Lower Rule Curve	from Phase 1
	Hungry Horse to Columbia Falls	Discharge	Maximum Variation Flow	0.0 kcfs
	Hungry Horse to Columbia Falls	Dynamic Discharge	Max-Min Absolute	Flat period flow
Border Reach	Norns Creek to Columbia	Discharge	Maximum	165.0 kcfs
Pend Oreille	Kerr Reservoir	Elevation	Upper Rule Curve	from Phase 1
	Kerr Reservoir	Elevation	Lower Rule Curve	from Phase 1
	Albeni Falls Reservoir	Elevation	Upper Rule Curve	from Phase 1
	Albeni Falls Reservoir	Elevation	Lower Rule Curve	from Phase 1
	Kerr to Thompson Falls	Discharge	Maximum Variation Flow	0.0 kcfs
	Kerr to Thompson Falls	Dynamic Discharge	Max-Min Absolute	Flat period flow
	Thompson Falls to Noxon Rapids	Discharge	Maximum Variation Flow	0.0 kcfs
	Noxon Rapids to Cabinet Gorge	Discharge	Maximum Variation Flow	0.0 kcfs
	Cabinet Gorge to Albeni Falls	Discharge	Maximum Variation Flow	0.0 kcfs
	Albeni Falls to Box Canyon	Discharge	Maximum Variation Flow	0.0 kcfs
	Albeni Falls to Box Canyon	Dynamic Discharge	Max-Min Absolute	Flat period flow
	Box Canyon to Boundary	Discharge	Maximum Variation Flow	0.0 kcfs
	Boundary to Seven Mile	Discharge	Maximum Variation Flow	0.0 kcfs
	Seven Mile to Waneta	Discharge	Maximum Variation Flow	0.0 kcfs
	Waneta to Columbia	Discharge	Maximum Variation Flow	0.0 kcfs

Case 4C – Updated Arrow Facility Data

Includes relaxed refill to drive more aggressive marketing, white fish and trout spawning operations and 165 max kcfs at Birchbank. First year prices follow water year, second year prices decrease 10% from average - effectively making first year prices relatively higher. Also includes new Arrow Facility Data. which changes max MW generation to 185 (from 160 MW); Max 39 kcfs through turbines (from 34 kcfs).

Only the hydro constraints for the Upper Columbia and Border Reach – which differ from the base case (Case 1) are provided below:

River	Reservoir / System	Hydro Definition	Hydro Operation	Constraint
Upper Columbia	Revelstoke to Arrow	Discharge	Minimum	5.0 kcfs
	Revelstoke to Arrow	Discharge	Maximum	200.0 kcfs
	Revelstoke to Arrow	Discharge	Maximum Variation Flow	15.0 kcfs
	Arrow River Reach	Discharge	Maximum	55.0 kcfs in Jan
	Arrow River Reach	Discharge	Maximum Variation Flow	15.0 kcfs
	Arrow River Reach	Discharge	Ramp Down	0.0 kcfs (AprIl -Jun)
	Arrow River Reach	Fishery Dynamic Discharge	Fishery Max/Min Cap.	Jan - Mar (2011)
	Arrow River Reach	Fishery Dynamic Discharge	Fishery Max/Min Cap.	Jan - Mar (2012)
	Arrow River Reach	Discharge	Free Flow Maximum	1.0 kcfs
Border Reach	Norns Creek to Columbia	Discharge	Maximum	165.0 kcfs

Case 4FB – Lower Arrow Forebay (with updated facility data)

Arrow forebay constraints added such that max elevation is at 1442' from Oct-May and 1439' from June-Sept; min elevation at 1430' from June-Sept. Uses average quarterly prices and updated Arrow facility data, where max MW generation to 185 (from 160 MW); Max 39 kcfs through turbines (from 34 kcfs). Also, includes whitefish and trout spawning operations with 165 kcfs at Birchbank.

Only the hydro constraints for the Upper Columbia and Border Reach – which differ from the base case (Case 1) are provided below:

River	Reservoir / System	Hydro Definition	Hydro Operation	Constraint
Upper Columbia	Arrow Reservoir	Elevation	Upper Rule Curve	1442' (Oct - May); 1439' (Jun - Sep)
	Arrow Reservoir	Elevation	Lower Rule Curve	1430' (Jun - Sep)
	Revelstoke to Arrow	Discharge	Minimum	5.0 kcfs
	Revelstoke to Arrow	Discharge	Maximum	200.0 kcfs
	Revelstoke to Arrow	Discharge	Maximum Variation Flow	15.0 kcfs
	Arrow River Reach	Discharge	Maximum	55.0 kcfs in Jan
	Arrow River Reach	Discharge	Maximum Variation Flow	15.0 kcfs
	Arrow River Reach	Discharge	Ramp Down	0.0 kcfs (AprIl - Jun)
	Arrow River Reach	Fishery Dynamic Discharge	Fishery Max/Min Cap.	Jan - Mar (2011)
	Arrow River Reach	Fishery Dynamic Discharge	Fishery Max/Min Cap.	Jan - Mar (2012)
	Arrow River Reach	Discharge	Free Flow Maximum	1.0 kcfs
Border Reach	Norns Creek to Columbia	Discharge	Maximum	165.0 kcfs

14.0 APPENDIX D: SUMMARY STATISTIC TABLES

Water Operations Summary Statistic Tables for CV Case Studies

The following graphs/tables offer descriptive statistics for select water operations for the three CV case studies recommended for further review. Specifically, minimum, maximum, average, median and percentile statistics regarding elevations and outflows at Mica, Arrow, and Duncan and flows at the U.S./Canada border are provided for the three cases. Elevation and outflows for Duncan are provided for only the base case and the Duncan Optimization case study to illustrate where water operations differ.

Mica Elevation

Case 1 – BCH Base Case

	OCT	*NOV*	*DEC*	*JAN*	*FEB*	*MAR*	*APR I*	*APR II*	*MAY*	*JUNE*	*JULY*	*AUG I*	*AUG II*	*SEP*
Min	2440.0	2428.2	2411.4	2391.7	2367.6	2342.2	2342.1	2341.7	2359.8	2399.3	2434.6	2444.5	2454.0	2456.6
P5	2447.7	2433.3	2417.0	2396.4	2372.9	2345.7	2345.5	2345.3	2365.2	2405.3	2437.5	2447.9	2456.7	2461.3
P10	2450.3	2436.4	2418.5	2397.9	2375.0	2348.1	2347.4	2346.9	2366.6	2408.0	2440.2	2452.1	2462.0	2463.9
P25	2456.5	2441.9	2423.3	2402.1	2378.2	2348.1	2347.6	2347.1	2369.4	2412.2	2449.0	2458.7	2466.7	2466.3
Median	2458.9	2443.7	2424.9	2404.9	2383.1	2353.8	2350.5	2347.3	2374.0	2418.2	2456.7	2463.1	2470.1	2468.0
Average	2456.9	2443.3	2425.2	2405.1	2383.2	2355.0	2351.0	2347.3	2375.7	2419.4	2455.0	2461.4	2467.7	2467.3
P75	2459.8	2446.5	2428.4	2409.2	2389.1	2361.2	2354.3	2347.6	2381.3	2425.4	2462.3	2466.1	2470.1	2469.4
P90	2460.4	2448.2	2431.1	2412.0	2391.2	2363.6	2355.8	2348.1	2386.1	2435.0	2463.4	2466.6	2470.1	2469.9
P95	2460.8	2448.9	2432.2	2412.4	2392.6	2365.6	2356.9	2348.3	2389.1	2438.6	2465.9	2468.0	2470.1	2470.1
Max	2462.8	2449.7	2436.2	2413.6	2393.5	2369.5	2358.7	2354.7	2399.0	2447.0	2470.1	2470.1	2470.1	2470.1

Case 4C – Recommended Study with update Arrow Facility Data

	OCT	*NOV*	*DEC*	*JAN*	*FEB*	*MAR*	*APR I*	*APR II*	*MAY*	*JUNE*	*JULY*	*AUG I*	*AUG II*	*SEP*
Min	2437.7	2423.7	2398.0	2375.8	2352.7	2322.7	2320.5	2326.7	2359.3	2403.8	2441.4	2451.1	2454.4	2444.4
P5	2445.9	2434.4	2406.5	2383.1	2361.7	2337.5	2332.9	2339.4	2367.1	2415.8	2445.2	2454.6	2457.3	2455.5
P10	2451.4	2436.6	2411.9	2385.7	2366.3	2348.2	2341.8	2344.4	2371.5	2416.8	2449.8	2458.3	2461.0	2458.6
P25	2459.2	2446.1	2417.8	2395.1	2375.8	2355.5	2352.7	2356.5	2382.0	2424.3	2457.5	2466.7	2470.7	2466.5
Median	2465.9	2452.3	2425.1	2401.7	2383.1	2361.2	2360.4	2364.1	2390.3	2429.7	2463.5	2471.9	2475.0	2475.0
Average	2463.1	2450.4	2423.2	2400.9	2381.9	2361.5	2359.0	2362.7	2389.2	2430.6	2461.9	2469.3	2471.6	2470.0
P75	2469.3	2457.0	2429.1	2408.5	2390.2	2370.5	2366.4	2371.9	2399.0	2437.7	2468.8	2475.0	2475.0	2475.0
P90	2470.1	2459.3	2432.5	2412.3	2394.7	2376.3	2374.7	2379.4	2402.1	2442.4	2471.0	2475.0	2475.0	2475.0
P95	2471.5	2461.6	2435.9	2415.3	2399.3	2380.5	2377.9	2381.4	2406.0	2447.1	2471.9	2475.0	2475.0	2475.0
Max	2475.0	2466.5	2440.9	2419.5	2402.7	2387.8	2384.9	2385.2	2419.7	2455.1	2473.3	2475.0	2475.0	2475.0

Case 4FB – Lower Arrow Forebay (with revised facility data)

	OCT	*NOV*	*DEC*	*JAN*	*FEB*	*MAR*	*APR I*	*APR II*	*MAY*	*JUNE*	*JULY*	*AUG I*	*AUG II*	*SEP*
Min	2431.4	2415.0	2395.6	2375.8	2354.2	2323.4	2323.1	2327.1	2364.9	2403.2	2445.9	2451.4	2451.6	2443.9
P5	2450.4	2434.3	2406.2	2384.3	2360.4	2330.2	2331.8	2337.7	2367.8	2413.7	2448.2	2457.9	2462.0	2460.4
P10	2453.2	2439.0	2412.2	2393.8	2369.3	2344.0	2342.9	2345.7	2369.5	2418.3	2453.3	2460.9	2464.2	2463.5
P25	2460.8	2444.6	2418.9	2399.6	2379.4	2355.4	2354.4	2357.3	2380.9	2424.1	2458.2	2466.6	2472.3	2470.0
Median	2464.4	2449.1	2426.0	2407.2	2386.8	2364.5	2363.5	2368.5	2394.4	2434.9	2463.5	2471.6	2475.0	2475.0
Average	2463.0	2448.4	2425.0	2406.3	2385.7	2363.0	2361.8	2365.6	2391.7	2432.7	2462.1	2469.6	2472.2	2471.7
P75	2467.0	2454.8	2433.7	2415.4	2395.8	2373.3	2372.3	2375.7	2402.2	2440.6	2467.0	2473.7	2475.0	2475.0
P90	2470.0	2458.0	2437.0	2418.9	2400.0	2378.5	2377.1	2381.5	2407.5	2445.6	2469.3	2475.0	2475.0	2475.0
P95	2470.3	2459.6	2437.7	2419.8	2401.6	2380.1	2381.2	2384.3	2410.8	2449.4	2471.4	2475.0	2475.0	2475.0
Max	2475.0	2463.2	2442.0	2425.7	2407.6	2390.7	2388.7	2390.2	2420.1	2457.3	2473.0	2475.0	2475.0	2475.0

Mica Outflows

Case 1 – BCH Base Case

	OCT	*NOV*	*DEC*	*JAN*	*FEB*	*MAR*	*APR I*	*APR II*	*MAY*	*JUNE*	*JULY*	*AUG I*	*AUG II*	*SEP*
Min	17.2	17.5	24.3	26.2	27.9	27.9	4.1	5.0	0.0	0.0	0.0	0.0	0.0	0.0
P5	21.6	22.5	26.5	27.7	29.4	30.5	5.2	6.9	0.0	0.0	0.0	3.8	0.0	10.3
P10	23.9	24.6	27.5	28.6	30.7	31.3	5.9	8.0	0.0	0.0	0.0	6.1	0.0	15.1
P25	26.0	27.5	30.5	29.4	32.1	33.2	7.7	12.2	0.0	0.0	0.1	10.5	0.0	19.2
Median	27.6	29.8	32.3	31.4	33.4	34.6	12.2	17.7	0.0	0.0	0.5	22.1	12.9	22.4
Average	28.9	29.5	31.8	31.4	33.4	34.2	13.9	17.8	0.0	0.2	2.4	22.3	13.5	21.6
P75	29.2	32.6	33.7	32.6	34.8	35.3	19.5	21.9	0.0	0.3	1.7	32.3	22.8	25.1
P90	38.8	33.8	34.6	34.3	36.2	36.1	23.0	27.1	0.0	1.1	6.3	37.9	31.8	28.3
P95	42.6	34.9	35.9	36.3	36.7	36.5	25.7	29.0	0.0	1.3	14.0	49.7	36.5	30.5
Max	43.0	39.4	38.1	38.8	37.7	38.3	29.3	39.9	2.5	1.5	24.2	55.2	46.3	35.5

Case 4C – Revised Arrow Facility Data

	OCT	*NOV*	*DEC*	*JAN*	*FEB*	*MAR*	*APR I*	*APR II*	*MAY*	*JUNE*	*JULY*	*AUG I*	*AUG II*	*SEP*
Min	16.9	23.2	28.5	26.9	21.2	9.1	0.3	0.0	0.0	0.0	0.0	3.9	9.9	14.1
P5	19.3	24.7	34.3	28.8	26.4	17.7	2.3	0.0	0.0	0.0	0.0	5.3	12.2	15.5
P10	20.0	25.0	37.5	29.5	27.1	18.5	3.9	0.0	0.0	0.0	0.0	8.7	13.4	17.5
P25	21.8	26.8	43.4	30.2	28.1	23.4	6.6	0.0	0.0	0.0	1.2	10.7	20.1	19.4
Median	22.6	28.1	47.6	31.7	29.1	27.9	11.5	1.6	0.0	0.0	7.0	19.2	29.3	22.6
Average	23.0	28.7	46.0	33.8	29.1	25.9	10.9	2.5	0.0	0.0	6.9	18.1	26.4	23.7
P75	24.2	29.8	50.3	37.5	29.9	28.5	15.1	4.2	0.0	0.0	9.9	24.2	32.4	26.6
P90	25.8	33.0	52.0	41.2	31.6	30.0	17.0	6.6	0.0	0.0	13.6	30.4	35.5	31.2
P95	28.4	36.1	52.8	43.2	33.0	30.1	18.6	7.7	0.0	0.0	17.3	31.3	40.5	35.9
Max	30.7	39.0	53.7	45.4	35.0	31.5	19.7	11.4	0.0	0.0	28.0	32.3	45.8	43.6

Case 4FB – Lower Arrow Forebay (with revised facility data)

	OCT	*NOV*	*DEC*	*JAN*	*FEB*	*MAR*	*APR I*	*APR II*	*MAY*	*JUNE*	*JULY*	*AUG I*	*AUG II*	*SEP*
Min	19.5	25.2	29.1	12.6	27.6	12.6	0.3	0.0	0.0	0.0	0.0	2.6	10.0	13.2
P5	20.2	26.7	30.5	21.5	28.4	19.8	1.2	0.0	0.0	0.0	0.0	8.6	12.9	15.0
P10	21.4	27.1	32.2	24.7	29.0	26.3	1.8	0.0	0.0	0.0	2.3	9.4	15.0	16.8
P25	22.7	28.5	34.7	29.4	30.1	28.5	3.0	0.0	0.0	0.0	4.7	13.2	20.0	19.3
Median	26.0	30.7	39.8	30.7	31.3	29.5	8.4	1.5	0.0	0.0	9.8	17.1	25.3	21.3
Average	26.2	31.6	40.2	29.4	31.8	28.8	8.3	2.0	0.0	0.0	9.8	17.5	25.3	21.9
P75	29.0	34.2	46.1	31.1	33.0	30.4	12.3	3.6	0.0	0.0	14.8	21.1	31.6	24.6
P90	31.6	37.2	47.8	32.1	35.7	31.2	14.9	5.0	0.0	0.0	17.6	26.3	33.7	26.4
P95	33.4	40.3	51.2	32.3	37.0	32.3	17.1	6.9	0.0	0.0	20.3	30.1	34.9	29.0
Max	36.3	43.6	52.7	34.8	40.2	38.5	19.8	9.0	0.0	0.0	29.2	31.7	38.7	34.6

Arrow Elevation

Case 1 – BCH Base Case

	OCT	NOV	DEC	JAN	FEB	MAR		APR II	MAY	JUNE	JULY	AUG I	AUG II	SEP
Min	1442.0	1441.8	1442.0	1442.0	1441.8	1442.0	1440.1	1438.0	1438.0	1442.0	1442.0	1442.0	1442.0	1442.0
P5	1442.0	1442.0	1442.0	1442.0	1442.0	1442.0	1440.1	1438.0	1438.2	1442.0	1442.0	1442.0	1442.0	1442.0
P10	1442.0	1442.0	1442.0	1442.0	1442.0	1442.0	1440.1	1438.0	1438.5	1442.0	1442.0	1442.0	1442.0	1442.0
P25	1442.0	1442.0	1442.0	1442.0	1442.0	1442.0	1440.1	1438.0	1439.3	1442.0	1442.0	1442.0	1442.0	1442.0
Median	1442.0	1442.0	1442.0	1442.0	1442.0	1442.0	1440.3	1438.6	1439.8	1442.0	1442.0	1442.0	1442.0	1442.0
Average	1442.0	1442.0	1442.0	1442.0	1442.0	1442.0	1440.7	1439.2	1439.7	1442.0	1442.2	1442.2	1442.3	1442.1
P75	1442.0	1442.0	1442.0	1442.0	1442.0	1442.0	1441.2	1440.3	1440.2	1442.0	1442.0	1442.0	1442.0	1442.0
P90	1442.0	1442.0	1442.0	1442.0	1442.0	1442.0	1442.0	1442.0	1440.4	1442.0	1442.4	1443.0	1444.0	1442.0
P95	1442.0	1442.0	1442.0	1442.0	1442.0	1442.0	1442.0	1442.0	1440.5	1442.0	1444.0	1444.0	1444.0	1442.0
Max	1442.4	1442.0	1442.0	1442.0	1442.0	1442.0	1442.0	1442.0	1441.5	1442.2	1444.0	1444.0	1444.0	1444.0

Case 4C – Revised Arrow Facility Data

	OCT	NOV	DEC	JAN	FEB	MAR	APR I	APR II	MAY	JUNE	JULY	AUG I	AUG II	SEP
Min	1434.9	1434.1	1442.6	1442.8	1441.4	1436.6	1432.8	1427.9	1425.9	1437.8	1439.5	1439.1	1438.9	1436.8
P5	1437.6	1435.3	1443.7	1443.3	1442.3	1437.8	1433.0	1429.3	1428.8	1439.3	1440.3	1440.3	1440.5	1440.1
P10	1438.6	1435.9	1443.8	1443.5	1442.5	1438.7	1434.7	1431.2	1431.9	1440.0	1442.0	1441.6	1442.4	1440.8
P25	1440.0	1438.3	1444.0	1443.8	1442.8	1440.1	1436.0	1432.3	1434.0	1441.6	1443.4	1443.0	1443.4	1443.1
Median	1442.4	1441.8	1444.0	1444.0	1443.3	1441.3	1437.6	1433.5	1436.6	1443.6	1444.0	1443.8	1444.0	1444.0
Average	1441.6	1440.7	1443.9	1443.9	1443.2	1441.2	1437.5	1433.8	1436.5	1442.7	1443.4	1443.2	1443.4	1443.1
P75	1443.4	1443.3	1444.0	1444.0	1443.7	1442.9	1438.9	1435.2	1439.1	1444.0	1444.0	1444.0	1444.0	1444.0
P90	1443.8	1444.0	1444.0	1444.0	1444.0	1443.6	1440.5	1437.1	1441.3	1444.0	1444.0	1444.0	1444.0	1444.0
P95	1444.0	1444.0	1444.0	1444.0	1444.0	1443.9	1440.9	1438.0	1443.0	1444.0	1444.0	1444.0	1444.0	1444.0
Max	1444.0	1444.0	1444.0	1444.0	1444.0	1444.0	1443.0	1443.6	1444.0	1444.0	1444.0	1444.0	1444.0	1444.0

Case 4FB – Lower Arrow Forebay (with revised facility data)

	OCT	NOV	DEC	JAN	FEB	MAR	APR I	APR II	MAY	JUNE	JULY	AUG I	AUG II	SEP
Min	1435.6	1434.4	1442.0	1438.6	1438.4	1434.8	1429.8	1425.5	1424.6	1435.7	1438.2	1436.8	1438.1	1433.9
P5	1436.4	1436.8	1442.0	1440.4	1440.3	1437.8	1433.3	1429.3	1429.0	1438.4	1439.0	1438.3	1438.9	1435.9
P10	1437.3	1437.2	1442.0	1440.8	1440.8	1438.3	1433.8	1430.1	1430.6	1439.0	1439.0	1438.7	1439.0	1436.9
P25	1438.2	1438.3	1442.0	1441.3	1441.1	1439.4	1435.3	1431.0	1432.4	1439.0	1439.0	1439.0	1439.0	1438.7
Median	1439.8	1440.2	1442.0	1441.7	1441.9	1440.4	1436.5	1432.6	1435.6	1439.0	1439.0	1439.0	1439.0	1439.0
Average	1439.6	1439.7	1442.0	1441.5	1441.5	1440.3	1436.2	1432.6	1435.3	1438.9	1439.0	1438.9	1439.0	1438.5
P75	1441.0	1442.0	1442.0	1442.0	1442.0	1441.7	1437.4	1433.7	1437.8	1439.0	1439.0	1439.0	1439.0	1439.0
P90	1442.0	1442.0	1442.0	1442.0	1442.0	1442.0	1438.5	1435.4	1440.7	1439.0	1439.0	1439.0	1439.0	1439.0
P95	1442.0	1442.0	1442.0	1442.0	1442.0	1442.0	1439.2	1436.7	1441.3	1439.0	1439.0	1439.0	1439.0	1439.0
Max	1442.0	1442.0	1442.0	1442.0	1442.0	1442.0	1439.9	1441.4	1442.0	1439.0	1439.0	1439.0	1439.0	1439.0

Arrow Outflows

Case 1 – BCH Base Case

	OCT	*NOV*	*DEC*	*JAN*	*FEB*	*MAR*	*APR I*	*APR II*	*MAY*	*JUNE*	*JULY*	*AUG I*	*AUG II*	*SEP*
Min	24.5	24.1	28.1	31.4	32.8	32.0	18.1	20.1	23.7	29.0	20.5	17.1	10.7	10.9
P5	30.1	27.5	31.5	32.3	34.1	34.4	19.4	25.6	28.1	35.2	27.2	22.5	13.4	22.3
P10	33.2	29.7	33.3	32.8	35.3	36.6	20.4	28.2	31.1	38.8	29.5	25.5	14.7	27.4
P25	35.5	36.3	36.3	34.3	36.7	38.2	24.8	36.1	35.7	44.8	34.4	33.9	19.9	32.1
Median	40.3	38.6	38.1	35.7	38.0	39.7	30.4	43.1	42.5	51.9	41.5	47.6	30.0	36.2
Average	40.4	38.1	37.9	36.2	38.1	39.7	29.8	43.1	42.7	53.5	43.6	49.1	33.7	36.8
P75	43.2	40.7	40.1	37.7	39.1	41.5	33.9	50.7	49.2	61.6	53.1	62.5	43.9	41.1
P90	50.4	44.1	41.9	39.9	40.8	43.2	38.5	57.7	54.7	70.8	58.8	72.9	53.8	49.3
P95	52.8	45.3	42.2	41.9	42.1	44.4	39.8	60.1	58.5	75.1	64.9	79.6	62.5	51.1
Max	60.3	49.2	43.6	46.9	43.0	46.2	46.3	93.6	66.8	87.3	80.9	107.8	90.4	68.9

Case 4C – Revised Arrow Facility Data

	OCT	*NOV*	*DEC*	*JAN*	*FEB*	*MAR*	*APR I*	*APR II*	*MAY*	*JUNE*	*JULY*	*AUG I*	*AUG II*	*SEP*
Min	28.2	35.0	34.8	30.0	24.2	22.0	22.9	22.9	22.9	31.7	33.6	22.7	25.4	25.4
P5	34.5	35.6	34.8	33.8	30.2	27.1	27.5	29.0	29.9	35.2	34.8	33.9	31.7	31.1
P10	35.1	35.9	34.8	34.5	32.3	28.3	30.9	31.9	32.7	37.5	35.0	35.4	34.8	33.4
P25	36.2	36.7	35.9	35.0	35.4	35.0	34.7	37.5	37.8	39.2	36.8	38.6	37.2	34.9
Median	37.3	39.5	45.3	36.2	36.0	36.4	38.6	39.1	39.3	40.3	42.9	43.3	43.3	37.0
Average	37.5	39.1	45.5	38.8	35.2	35.5	36.6	37.4	37.9	45.4	46.9	46.2	45.7	39.1
P75	39.2	40.0	53.9	42.2	36.0	37.9	39.3	39.4	39.6	49.3	53.8	54.0	53.2	40.0
P90	40.0	43.2	56.7	46.4	36.4	38.9	39.5	39.5	40.0	59.0	65.4	61.6	61.2	49.1
P95	40.3	45.8	58.5	49.3	36.8	40.0	39.5	39.7	40.9	68.5	73.1	64.6	67.0	52.0
Max	48.5	46.9	59.6	51.7	41.5	40.9	39.8	47.6	56.7	75.3	75.9	80.0	87.5	68.9

Case 4FB – Lower Arrow Forebay (with revised facility data)

	OCT	*NOV*	*DEC*	*JAN*	*FEB*	*MAR*	*APR I*	*APR II*	*MAY*	*JUNE*	*JULY*	*AUG I*	*AUG II*	*SEP*
Min	22.6	30.5	32.8	17.6	29.7	22.2	21.5	21.9	23.8	33.7	29.4	28.1	24.9	21.8
P5	25.9	35.6	35.8	26.7	32.0	32.9	26.5	27.8	32.3	39.9	35.8	31.9	28.9	26.5
P10	27.4	36.4	36.7	28.6	32.9	33.3	28.1	32.5	32.9	40.0	39.9	35.1	37.4	28.6
P25	32.2	37.8	36.9	36.0	36.0	36.0	33.3	35.4	37.4	40.1	41.5	40.0	40.0	34.6
Median	36.8	39.8	36.9	36.6	36.9	37.6	37.4	38.2	39.0	47.2	49.1	42.3	41.3	37.9
Average	35.3	39.8	41.7	35.2	36.5	36.8	35.5	36.6	37.9	50.9	51.2	44.8	45.3	37.7
P75	39.8	40.0	46.6	37.3	37.4	38.3	39.0	39.0	39.6	58.4	58.2	50.6	53.0	40.0
P90	40.0	44.1	54.4	38.5	38.3	39.5	39.5	39.5	39.9	70.6	68.8	56.5	58.4	45.3
P95	40.1	47.4	56.0	38.8	40.0	39.8	39.8	39.8	40.1	73.1	74.0	62.1	59.9	50.2
Max	43.7	53.3	60.0	40.4	46.6	44.1	40.1	42.5	56.3	79.6	78.8	71.5	75.8	68.0

Duncan Elevation

Case 1 – BCH Base Case

	OCT	NOV	DEC	JAN	FEB	MAR	APR I	APR II	MAY	JUNE	JULY	AUG I	AUG II	SEP
Min	1871.3	1862.6	1846.5	1820.8	1812.1	1797.4	1795.9	1794.2	1812.1	1848.6	1873.2	1881.8	1888.9	1875.3
P5	1873.9	1865.7	1850.2	1824.4	1812.1	1798.5	1797.3	1794.5	1816.9	1854.3	1881.3	1886.5	1892.0	1876.4
P10	1874.7	1867.8	1853.1	1826.9	1812.1	1799.2	1797.5	1795.0	1819.3	1856.1	1883.9	1887.8	1892.0	1877.0
P25	1875.8	1868.9	1855.2	1829.0	1812.5	1799.8	1797.9	1797.4	1822.4	1862.8	1892.0	1892.0	1892.0	1878.1
Median	1878.2	1872.1	1858.5	1831.7	1812.5	1800.3	1799.3	1800.5	1829.2	1870.3	1892.0	1892.0	1892.0	1879.2
Average	1878.7	1872.6	1859.3	1833.2	1815.3	1804.2	1803.7	1804.5	1830.6	1869.9	1890.1	1891.0	1891.9	1879.6
P75	1881.0	1875.2	1862.6	1836.1	1812.5	1800.7	1802.5	1805.7	1836.9	1878.0	1892.0	1892.0	1892.0	1880.9
P90	1883.0	1878.5	1866.6	1839.3	1814.1	1815.8	1809.4	1814.4	1842.9	1883.7	1892.0	1892.0	1892.0	1883.2
P95	1887.2	1882.0	1868.1	1841.5	1832.2	1831.7	1829.1	1825.0	1844.5	1884.8	1892.0	1892.0	1892.0	1884.1
Max	1889.7	1886.0	1888.1	1887.3	1889.8	1892.0	1892.0	1892.0	1875.7	1892.0	1892.0	1892.0	1892.0	1887.1

Case 8 – Duncan Optimization

	OCT	NOV	DEC	JAN	FEB	MAR	APR I	APR II	MAY	JUNE	JULY	AUG I	AUG II	SEP
Min	1855.8	1847.0	1826.7	1794.2	1794.2	1794.2	1794.2	1794.2	1794.2	1838.0	1882.3	1892.0	1885.5	1864.0
P5	1859.8	1849.7	1830.1	1799.4	1794.2	1794.2	1794.2	1794.2	1804.0	1849.5	1889.2	1892.0	1885.5	1866.8
P10	1861.4	1851.9	1832.8	1804.2	1794.2	1794.2	1794.2	1794.2	1809.6	1851.1	1891.0	1892.0	1885.5	1867.0
P25	1863.2	1853.8	1838.9	1812.0	1794.2	1794.2	1794.2	1794.2	1816.7	1857.1	1891.0	1892.0	1886.6	1868.6
Median	1869.2	1860.6	1846.2	1824.4	1795.4	1799.2	1794.5	1796.5	1828.0	1863.9	1892.0	1892.0	1887.5	1872.2
Average	1872.9	1863.9	1848.4	1822.3	1801.4	1800.5	1798.9	1799.7	1825.6	1863.7	1891.3	1892.0	1887.0	1877.4
P75	1885.6	1875.3	1859.6	1830.9	1806.7	1803.6	1803.8	1807.6	1832.9	1870.4	1892.0	1892.0	1887.5	1891.4
P90	1887.8	1878.7	1863.6	1839.0	1814.6	1809.6	1806.9	1810.0	1841.3	1876.7	1892.0	1892.0	1887.5	1892.0
P95	1888.6	1879.8	1867.5	1842.8	1821.2	1811.2	1812.7	1810.0	1846.1	1879.3	1892.0	1892.0	1887.5	1892.0
Max	1892.0	1884.7	1870.7	1847.3	1836.4	1818.2	1814.2	1810.0	1848.3	1890.7	1892.0	1892.0	1887.5	1892.0

Duncan Outflows

Case 1 – BCH Base Case

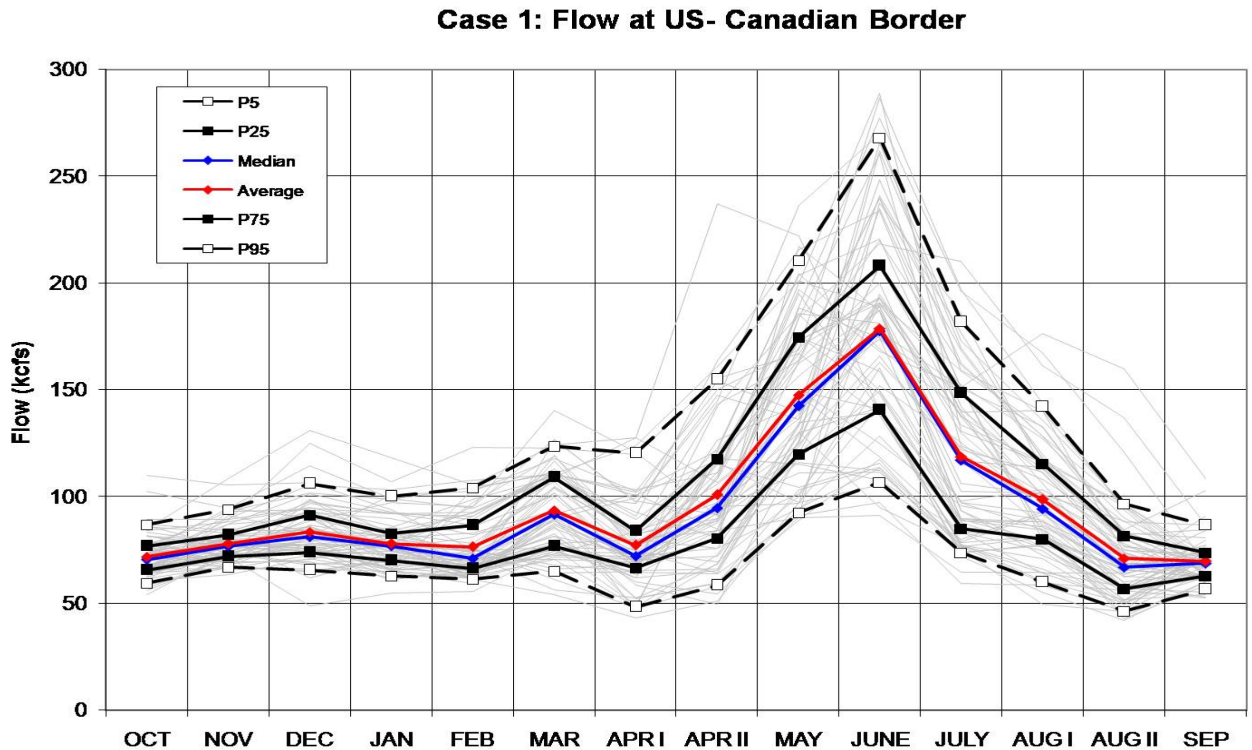
	OCT	NOV	DEC	JAN	FEB	MAR	APR I	APR II	MAY	JUNE	JULY	AUG I	AUG II	SEP
Min	1.9	2.8	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.9	0.1	6.0
P5	2.0	2.9	4.5	6.4	0.4	0.1	0.1	0.1	0.1	0.1	0.1	1.9	0.8	6.6
P10	2.0	2.9	4.5	6.7	2.9	0.9	0.1	0.1	0.1	0.1	0.1	3.0	1.7	6.6
P25	2.0	2.9	4.5	7.0	4.1	2.6	0.6	0.2	0.1	0.1	0.6	5.0	3.6	6.6
Median	2.0	2.9	4.5	7.2	5.0	2.8	1.4	2.4	0.3	0.1	3.5	6.2	4.6	6.6
Average	2.0	2.9	4.4	7.1	4.9	2.6	1.3	2.0	1.3	0.3	3.8	6.1	4.3	6.6
P75	2.0	2.9	4.6	7.5	6.2	3.0	1.7	3.0	1.5	0.1	5.4	7.3	5.3	6.6
P90	2.0	2.9	4.6	7.8	6.8	3.1	2.0	3.5	3.1	0.1	8.1	8.7	6.4	6.7
P95	2.0	2.9	4.6	7.8	7.3	3.3	2.4	3.9	5.2	0.2	8.7	9.4	6.8	6.7
Max	4.0	2.9	6.2	9.5	8.4	6.4	7.3	10.0	10.0	10.0	12.7	10.8	8.6	7.4

Case 8 – Duncan Optimization

	OCT	NOV	DEC	JAN	FEB	MAR	APR I	APR II	MAY	JUNE	JULY	AUG I	AUG II	SEP
Min	0.1	0.5	0.6	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	5.8	1.0
P5	3.1	2.3	2.8	0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	3.8	6.2	1.3
P10	3.1	2.9	3.4	2.7	0.5	0.1	0.1	0.1	0.1	0.1	0.1	4.5	6.4	1.8
P25	3.1	3.9	5.3	4.6	2.2	0.1	0.1	0.6	0.1	0.1	0.1	5.3	6.8	2.8
Median	3.1	3.9	5.3	8.3	5.7	0.3	1.3	2.0	0.1	0.1	0.1	6.2	7.4	7.5
Average	3.0	3.7	4.8	6.7	5.0	0.9	1.6	2.1	1.4	0.9	1.8	6.1	7.6	5.8
P75	3.1	3.9	5.3	8.8	7.9	0.9	2.2	3.8	2.6	0.4	2.9	7.0	8.1	8.1
P90	3.1	3.9	5.3	8.8	8.8	2.4	4.2	4.2	3.2	2.7	5.6	8.3	9.1	8.1
P95	3.1	3.9	5.5	8.8	8.8	4.9	4.8	4.2	4.3	5.4	8.1	8.8	9.7	8.1
Max	3.1	3.9	5.7	8.8	8.8	7.0	6.9	4.2	8.9	7.4	9.1	10.2	11.1	8.2

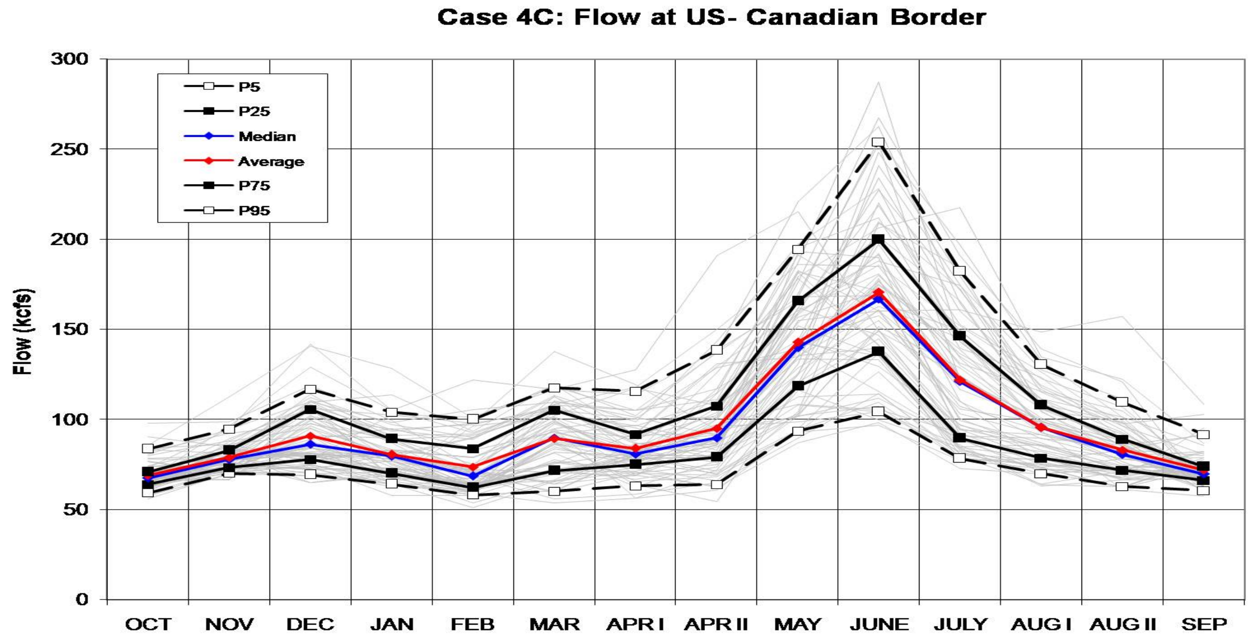
Border Flow

Case 1- BC Hydro Base Case



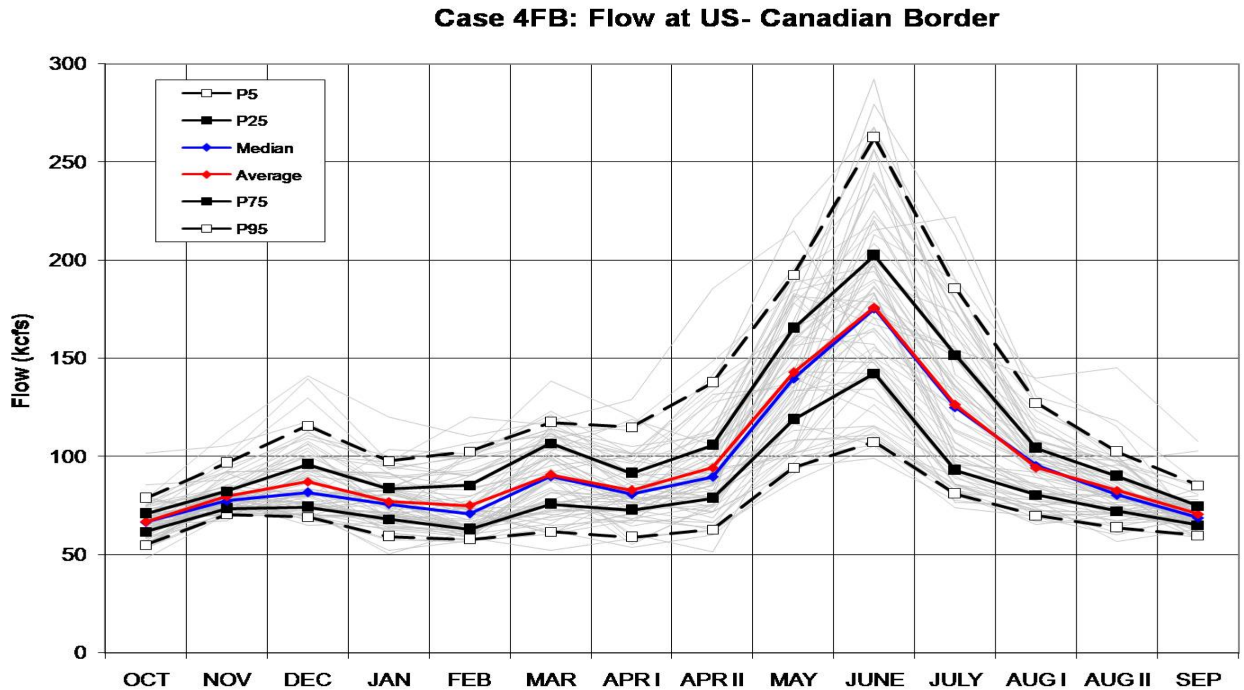
	OCT	*NOV*	*DEC*	*JAN*	*FEB*	*MAR*	*APR I*	*APR II*	*MAY*	*JUNE*	*JULY*	*AUG I*	*AUG II*	*SEP*
Min	53.8	63.3	48.8	54.9	55.4	54.1	43.3	49.6	89.0	91.1	59.2	49.7	41.9	52.6
P5	59.3	66.8	65.5	62.7	61.3	65.0	48.2	58.5	92.4	106.5	73.7	59.9	46.2	56.6
P10	62.2	67.4	69.2	64.9	62.1	70.7	52.6	64.1	96.9	113.3	76.7	64.7	50.1	60.1
P25	65.6	71.9	73.9	70.0	66.2	76.7	66.5	80.3	119.7	140.5	84.8	80.0	56.6	62.8
Median	70.5	76.6	81.2	76.8	70.9	91.6	72.1	94.6	142.4	177.5	116.9	94.2	66.9	68.7
Average	71.8	77.9	83.4	78.0	76.4	93.5	77.2	100.8	147.5	178.6	118.6	98.5	71.0	69.7
P75	76.8	82.1	91.2	82.6	86.5	109.1	83.9	117.5	174.4	208.0	148.4	115.2	81.6	73.6
P90	84.0	89.9	98.8	94.2	97.2	117.9	101.9	144.9	200.0	249.6	168.5	133.2	95.2	80.8
P95	86.7	93.8	106.1	100.1	104.0	123.5	120.3	154.7	210.5	267.8	181.7	142.0	96.5	86.6
Max	109.9	108.3	130.9	118.3	122.9	140.4	127.5	236.9	236.4	288.9	209.9	176.2	159.9	108.4

Case 4C – Updated Arrow Facility Data



	OCT	NOV	DEC	JAN	FEB	MAR	APR I	APR II	MAY	JUNE	JULY	AUG I	AUG II	SEP
Min	56.0	66.3	64.9	57.9	51.1	53.6	56.2	54.5	87.0	96.7	72.7	63.1	61.3	57.5
P5	59.1	70.0	69.3	64.1	58.0	60.0	63.1	63.8	93.5	104.2	78.3	69.8	62.7	60.5
P10	61.5	70.4	72.2	65.7	59.4	65.2	68.4	68.8	101.2	109.4	80.8	72.6	66.9	62.4
P25	63.9	73.2	77.7	70.1	62.2	71.6	75.0	79.0	118.5	137.5	89.6	78.5	71.7	66.2
Median	67.4	77.7	86.1	79.6	68.6	89.7	80.8	89.8	139.7	166.9	121.0	95.6	80.5	69.7
Average	68.9	78.9	90.9	80.5	73.6	89.3	83.9	95.0	142.7	170.5	121.9	95.6	83.1	71.9
P75	70.8	82.9	105.5	89.3	83.8	105.2	91.6	107.3	165.7	199.8	146.1	107.9	89.0	73.8
P90	79.8	88.2	110.1	98.3	97.1	113.0	104.9	129.5	186.2	234.5	172.6	122.8	101.2	82.4
P95	83.6	94.6	116.7	103.9	100.1	117.4	115.6	138.2	194.4	253.9	182.1	130.3	109.4	91.6
Max	98.0	112.5	141.6	128.1	121.7	137.5	127.5	190.9	220.7	287.3	217.4	148.5	157.0	108.4

Case 4FB – Lower Arrow Forebay



	OCT	*NOV*	*DEC*	*JAN*	*FEB*	*MAR*	*APR I*	*APR II*	*MAY*	*JUNE*	*JULY*	*AUG I*	*AUG II*	*SEP*
Min	48.2	67.2	64.8	50.4	56.3	52.2	53.5	51.5	87.4	99.0	73.8	65.3	56.8	58.0
P5	54.8	70.3	69.1	59.2	57.7	61.6	58.7	62.7	94.3	107.4	80.9	69.8	63.6	59.7
P10	56.1	70.8	70.2	63.2	59.0	65.5	65.7	66.2	101.3	111.9	83.0	72.4	67.0	62.0
P25	61.6	73.4	74.1	68.0	63.0	75.6	72.6	78.8	118.8	142.3	92.9	80.3	72.2	64.9
Median	66.5	77.4	81.7	75.7	70.8	89.7	80.7	89.6	139.5	175.3	124.9	95.4	80.3	68.8
Average	66.7	79.7	87.1	77.0	74.9	90.6	82.8	94.3	142.7	176.0	126.2	94.3	82.6	70.5
P75	70.8	82.3	95.9	83.5	85.3	106.5	91.4	105.6	165.2	202.5	151.7	104.2	89.9	74.8
P90	75.8	91.8	109.3	94.1	99.8	113.9	101.5	129.5	184.7	243.3	175.4	118.0	98.4	79.8
P95	78.7	96.8	115.6	97.6	102.5	117.4	114.8	137.6	192.5	262.5	185.7	127.3	102.2	85.3
Max	101.7	112.3	141.0	120.0	120.2	138.3	128.9	185.8	221.1	292.0	222.1	140.0	145.2	107.5

15.0 APPENDIX E: ARROW OUTFLOWS (70 YR DETAILS)

Case 1	Oct	Nov	Dec	Jan	Feb	Mar	Apr I	Apr II	May	Jun	Jul	Aug I	Aug II	Sep
1929	54.0	37.7	34.3	32.7	38.5	33.6	18.6	25.5	31.6	44.8	34.4	40.6	23.8	34.9
1930	51.0	27.9	31.5	32.6	33.1	35.9	30.8	57.6	36.6	39.9	36.0	66.0	46.1	41.3
1931	48.4	27.1	35.8	32.8	37.0	32.0	21.8	29.7	40.8	46.0	39.6	43.7	34.9	39.6
1932	39.3	44.4	30.8	36.7	39.2	44.4	34.0	51.1	49.6	68.4	44.5	60.7	58.7	38.5
1933	35.8	39.7	42.1	34.3	39.8	38.7	27.0	42.1	37.7	63.1	57.5	70.2	57.3	44.4
1934	44.0	42.6	39.7	38.7	41.5	46.2	38.6	93.6	63.4	47.7	46.7	62.6	52.5	35.0
1935	38.9	46.0	41.4	36.7	38.2	40.9	29.4	41.2	36.2	52.7	50.7	66.8	34.9	42.0
1936	37.7	37.2	36.4	35.2	36.5	38.2	18.8	60.2	55.9	49.3	34.6	54.3	40.9	35.7
1937	35.9	42.5	33.3	31.4	36.2	32.2	19.2	22.5	28.6	42.2	32.9	23.0	13.8	31.4
1938	33.9	43.4	39.3	37.1	38.4	39.0	27.5	44.5	39.1	56.5	34.8	27.2	23.7	47.8
1939	51.5	28.2	32.7	35.9	37.2	38.4	27.0	47.7	45.8	35.5	34.7	44.5	30.5	38.1
1940	49.3	37.3	37.8	40.4	41.9	42.2	30.0	41.8	42.8	42.1	32.6	49.2	36.9	51.1
1941	55.9	40.8	35.2	34.9	37.9	41.1	38.5	48.1	31.0	31.8	26.6	32.2	26.6	35.4
1942	42.7	43.4	40.9	35.1	39.8	38.5	24.3	35.2	31.2	37.7	36.2	37.7	25.2	34.8
1943	33.3	32.8	36.5	32.9	35.9	36.3	29.8	46.2	27.8	34.9	40.7	25.2	15.3	23.1
1944	50.8	34.4	35.3	31.8	37.9	33.0	20.4	28.3	31.1	32.0	20.5	28.7	13.2	37.6
1945	39.7	40.0	31.6	34.6	34.7	35.4	20.2	23.2	35.3	41.1	28.0	23.0	10.7	24.4
1946	33.3	29.8	28.1	34.8	36.8	38.0	27.3	45.6	53.5	60.6	53.7	51.7	40.1	36.9
1947	31.0	31.7	36.7	33.9	37.7	40.0	30.7	54.4	43.4	53.4	44.6	44.8	30.7	36.1
1948	44.6	36.9	39.5	33.0	36.0	39.0	26.4	42.6	52.5	70.5	39.4	55.0	55.9	37.4
1949	39.6	38.1	40.9	35.6	37.6	38.7	24.3	43.9	52.9	37.8	31.6	31.9	19.5	12.4
1950	24.5	36.8	37.5	33.6	32.8	38.7	30.6	36.3	31.9	70.5	56.1	57.2	52.7	39.9
1951	36.3	35.0	33.2	41.9	38.2	38.3	35.9	43.8	53.0	45.2	42.9	50.6	29.2	28.7
1952	37.8	37.2	36.2	34.5	35.0	37.1	25.3	55.6	46.9	49.7	38.9	47.5	19.3	31.6
1953	34.8	33.3	36.0	33.3	38.4	40.2	21.2	32.2	38.1	49.1	40.6	30.5	25.7	38.0
1954	40.8	38.7	38.3	37.8	38.5	40.0	31.7	36.3	43.7	56.4	66.6	84.7	76.1	49.0
1955	43.9	47.3	41.7	39.6	42.3	42.0	24.9	25.7	23.7	66.4	57.7	48.6	28.9	34.4
1956	35.4	37.1	37.6	31.6	35.2	38.6	31.4	59.6	57.8	58.6	43.5	46.7	43.9	35.2
1957	41.3	38.4	38.4	35.4	36.0	38.4	29.1	39.3	66.8	53.5	33.9	40.5	28.7	32.7
1958	36.1	39.1	38.2	36.8	39.0	41.8	30.8	37.1	60.5	63.4	35.6	47.2	43.1	41.0
1959	41.4	40.0	37.0	32.0	37.1	42.9	32.3	46.0	44.6	70.3	61.7	60.1	40.4	52.7
1960	48.2	42.5	39.9	39.9	37.9	42.6	46.3	38.4	38.4	61.8	54.6	45.5	17.2	37.4
1961	43.3	40.7	42.1	33.8	38.0	41.2	36.0	36.6	53.8	61.2	51.9	56.1	51.0	31.2
1962	41.3	40.0	38.0	36.4	40.8	39.5	24.7	46.8	36.2	57.4	47.6	47.8	29.6	37.8
1963	40.3	39.7	40.5	38.6	39.0	42.3	36.0	49.9	37.3	52.3	44.7	48.4	28.1	46.5
1964	38.2	37.5	38.6	35.9	40.6	39.1	26.3	28.6	33.5	77.1	63.5	62.1	36.9	43.5
1965	50.3	40.6	39.6	34.7	37.9	39.4	30.2	53.1	42.5	58.6	43.8	64.6	43.9	28.4
1966	40.3	45.5	39.4	37.3	40.1	37.6	39.0	36.9	46.9	62.7	55.8	70.8	39.2	40.9
1967	40.4	40.7	35.6	38.1	37.5	39.8	32.5	36.5	37.6	87.3	69.3	81.9	65.7	50.9
1968	42.7	41.3	37.6	38.6	37.4	45.4	32.9	34.3	45.8	75.3	65.7	67.4	50.2	49.2
1969	41.6	36.3	37.3	38.8	36.7	39.7	45.9	50.9	54.6	64.9	35.1	49.2	35.0	38.0
1970	41.3	44.5	42.9	36.3	38.8	39.4	19.7	20.1	26.4	46.6	28.9	25.5	14.7	29.5
1971	29.3	32.0	37.3	32.6	36.2	37.7	30.0	46.3	47.7	57.9	39.9	76.0	35.3	37.4
1972	37.8	36.4	36.8	34.3	33.6	39.1	40.5	36.0	53.8	85.0	80.9	93.1	70.2	41.1
1973	41.8	43.0	40.5	36.9	38.1	38.1	21.4	25.8	35.5	42.2	40.7	41.3	12.4	18.9
1974	26.6	35.3	38.8	33.3	37.2	39.9	36.5	52.2	39.7	74.7	58.4	72.6	46.2	34.9
1975	32.0	36.5	39.7	37.8	35.4	36.6	18.1	27.1	34.6	54.7	45.7	22.1	21.6	31.9
1976	43.3	44.1	38.0	44.6	37.9	40.2	37.8	39.6	53.8	47.2	64.1	107.8	90.4	68.9
1977	45.9	39.5	42.1	42.6	38.1	36.7	22.5	36.4	33.1	41.4	29.6	37.5	26.3	27.8
1978	28.1	25.6	35.0	36.1	36.5	40.7	31.9	43.5	30.7	50.1	45.9	41.4	27.4	61.9
1979	60.2	37.4	37.8	37.1	37.9	39.6	21.4	30.1	34.6	40.4	35.4	17.1	16.7	34.2
1980	34.9	28.1	41.9	34.9	38.7	38.2	19.7	68.0	52.3	41.1	30.4	26.7	16.9	36.2
1981	39.2	38.5	43.5	33.3	38.7	43.7	33.6	49.8	50.6	51.4	54.8	62.6	44.3	41.5
1982	40.5	45.1	42.3	36.7	33.6	37.5	30.8	36.8	40.4	73.3	50.2	75.6	46.5	51.2
1983	40.8	44.0	39.4	35.4	36.2	42.0	33.7	51.0	46.9	50.5	53.2	47.9	19.9	33.6
1984	36.8	39.4	43.6	37.9	39.8	39.9	31.7	43.5	26.3	57.7	48.1	39.9	21.0	23.4
1985	35.0	39.8	36.4	35.0	38.1	39.8	28.2	36.1	45.7	44.9	31.6	22.0	14.7	21.6
1986	32.8	38.4	37.7	35.7	36.6	42.9	34.0	39.4	36.7	60.4	39.3	52.9	31.0	30.5
1987	34.8	38.3	36.3	35.7	39.2	39.9	34.7	44.4	47.3	44.6	31.6	33.9	12.8	35.1
1988	41.0	34.6	35.0	33.5	38.1	36.6	26.2	60.6	42.5	46.9	35.3	30.6	24.0	29.4
1989	39.8	40.1	39.8	38.6	39.8	41.4	23.9	42.7	35.6	47.7	31.2	29.6	21.7	33.2
1990	35.0	36.1	41.0	34.5	42.9	45.1	35.7	58.5	36.4	55.9	46.4	58.2	40.6	33.2
1991	34.4	43.9	41.0	42.0	42.8	41.1	39.0	55.3	47.1	53.0	56.7	76.7	53.5	42.0
1992	34.2	37.4	40.2	37.4	43.0	42.8	31.0	54.0	42.5	46.8	26.2	29.8	13.6	29.1
1993	43.0	39.1	38.3	37.5	38.4	40.5	24.3	31.6	47.9	29.0	25.7	22.0	19.0	10.9
1994	48.4	25.6	31.2	35.1	38.4	40.0	33.4	60.1	46.5	45.4	42.3	41.9	18.6	32.9
1995	39.3	24.1	38.9	37.1	40.7	41.5	29.8	32.9	36.8	50.8	33.0	37.2	20.0	40.0
1996	40.6	38.9	39.7	46.9	40.0	43.9	45.5	56.1	40.5	64.1	53.4	64.4	40.6	40.3
1997	41.1	39.3	37.8	34.4	38.0	43.1	34.2	46.1	55.0	73.0	53.0	71.9	44.1	50.2
1998	60.3	49.2	40.2	40.1	40.9	44.3	33.1	46.2	59.1	38.9	28.7	34.1	18.3	32.7
Avg.	**40.4**	**38.1**	**37.9**	**36.2**	**38.1**	**39.7**	**29.8**	**43.1**	**42.7**	**53.5**	**43.6**	**49.1**	**33.7**	**36.8**

Table 15. Case 1, 70 yr results (BC Hydro submittal) Arrow Outflows

Case 4C	Oct	Nov	Dec	Jan	Feb	Mar	Apr I	Apr II	May	Jun	Jul	Aug I	Aug II	Sep
1929	37.6	39.9	36.9	36.0	29.0	25.3	24.2	32.0	32.0	39.9	39.0	38.0	40.1	37.3
1930	36.3	40.0	36.9	36.0	36.0	36.0	33.7	37.5	37.6	38.6	39.3	42.5	41.8	38.8
1931	38.3	40.1	36.9	39.8	37.3	36.9	39.1	39.1	39.2	40.0	40.0	38.0	41.1	39.6
1932	38.6	37.3	56.3	39.4	42.8	40.2	40.0	40.0	40.0	73.2	50.0	38.8	37.9	37.7
1933	39.9	40.0	45.5	37.8	36.9	38.8	39.3	39.3	39.3	51.3	51.6	63.1	60.4	42.6
1934	41.3	46.7	46.7	48.6	37.2	39.0	41.3	53.7	53.7	53.7	58.4	60.2	56.5	38.0
1935	40.0	40.0	50.2	44.4	36.6	36.0	32.1	37.1	37.1	37.3	55.5	54.4	49.1	38.2
1936	38.8	39.8	39.9	39.8	36.0	37.1	39.1	39.1	39.1	53.5	43.0	42.7	48.4	34.8
1937	32.2	38.4	36.9	32.0	25.7	24.6	27.7	27.7	27.7	40.1	37.4	38.8	38.8	37.0
1938	35.5	39.9	36.9	35.8	34.2	27.7	38.0	38.0	39.4	44.4	39.9	39.7	38.0	41.2
1939	38.1	40.0	43.3	36.9	36.9	36.0	35.8	39.5	39.8	39.8	39.3	40.9	40.7	37.0
1940	39.3	40.0	40.0	36.0	36.0	36.0	37.7	39.5	39.8	39.8	44.9	42.9	51.8	58.3
1941	37.4	38.6	36.9	36.0	36.0	36.0	33.4	33.4	33.4	35.5	40.0	39.9	39.3	51.9
1942	37.6	38.4	36.9	36.0	36.0	36.0	27.4	28.2	28.2	37.6	40.1	38.7	38.2	48.3
1943	33.6	34.8	36.9	30.0	31.8	21.3	23.1	23.1	23.1	32.2	37.0	40.1	36.9	30.0
1944	33.7	34.3	36.5	33.9	23.5	22.3	25.7	25.7	25.7	36.6	31.1	40.0	40.0	36.9
1945	35.7	38.3	36.9	34.3	31.9	34.2	32.9	32.9	32.9	36.9	38.9	40.0	40.1	36.9
1946	31.6	29.6	36.8	33.3	33.6	27.2	39.0	39.0	39.4	59.8	39.8	41.4	43.5	36.9
1947	35.1	38.1	36.9	37.2	36.8	38.5	39.4	39.4	39.9	42.0	41.4	51.3	42.9	39.5
1948	40.0	39.8	38.5	36.9	36.9	40.0	39.0	39.0	40.0	66.0	45.7	51.7	59.0	37.0
1949	40.1	39.8	40.9	38.7	36.7	36.9	34.1	39.1	40.0	40.0	36.9	35.5	30.1	32.4
1950	36.4	40.0	36.9	32.5	33.3	27.1	35.9	35.9	35.9	42.0	53.9	43.3	57.1	37.4
1951	40.1	39.7	37.1	37.1	37.0	36.0	38.8	38.8	38.8	38.9	56.2	50.3	41.8	29.6
1952	31.2	39.9	36.9	36.9	36.0	36.0	39.4	39.4	39.8	46.3	38.7	45.7	43.6	28.6
1953	39.2	42.1	46.8	48.6	36.9	38.3	30.5	35.6	36.7	38.7	36.9	32.7	38.1	37.4
1954	39.8	39.8	43.9	36.9	36.9	39.9	38.7	38.7	38.7	40.7	71.5	59.5	62.2	49.0
1955	39.5	37.4	49.7	51.9	37.2	38.2	35.7	35.7	35.7	37.3	58.1	38.2	46.1	37.1
1956	39.0	40.1	36.9	37.7	36.9	40.0	39.2	39.2	39.2	56.7	44.6	53.1	53.3	39.6
1957	39.5	40.0	44.4	40.7	36.0	36.0	37.3	37.3	37.3	56.4	39.4	41.2	37.8	31.6
1958	39.9	39.8	46.7	42.1	36.0	36.0	38.1	38.6	39.6	63.0	43.2	43.6	47.8	38.9
1959	40.1	37.8	46.3	36.9	37.1	38.4	39.3	39.3	39.7	61.9	63.8	59.7	53.4	52.7
1960	37.0	37.6	47.8	45.5	37.6	37.0	38.0	39.4	39.4	49.3	59.9	50.5	46.2	39.1
1961	39.7	45.6	56.4	44.9	36.8	38.2	37.4	38.7	39.4	51.6	47.0	49.9	62.8	34.8
1962	39.7	39.5	48.5	39.2	36.0	36.0	32.0	37.5	38.0	40.1	50.3	44.9	44.4	40.1
1963	38.6	46.4	52.5	42.8	36.6	37.4	34.8	36.1	36.1	36.9	51.5	38.2	39.1	43.7
1964	38.2	37.5	53.9	39.6	37.0	39.7	37.0	37.0	37.0	51.2	68.7	50.7	41.9	40.4
1965	37.3	37.1	48.7	38.4	38.5	39.9	38.8	38.8	38.8	38.8	57.6	66.5	68.1	39.7
1966	39.9	40.4	52.7	45.8	36.0	36.0	32.0	38.9	39.5	53.4	61.3	50.4	41.9	39.4
1967	38.6	40.1	50.6	45.5	36.6	37.6	38.4	38.4	38.4	73.8	75.8	63.1	64.3	46.5
1968	39.0	40.0	45.8	44.5	38.2	38.6	39.2	39.2	39.2	68.0	67.1	61.3	64.2	48.1
1969	38.2	40.0	42.6	37.1	36.9	40.1	39.7	39.7	40.0	60.1	49.4	55.8	48.0	38.7
1970	39.9	40.0	48.9	36.9	36.0	36.0	24.4	24.4	24.4	36.9	36.6	34.1	36.9	36.8
1971	36.4	39.9	36.9	36.1	36.0	36.0	33.7	36.4	36.4	41.6	42.8	44.0	50.4	38.6
1972	37.9	40.4	55.1	49.7	39.9	40.0	39.5	39.5	39.7	74.4	76.0	64.9	70.2	37.9
1973	39.4	39.8	47.2	43.1	36.0	36.4	29.8	32.5	33.2	39.2	36.9	36.0	29.7	23.6
1974	39.9	39.9	36.9	36.5	36.8	36.7	38.0	38.0	38.0	54.5	58.4	60.5	53.6	34.8
1975	40.1	39.7	41.3	42.8	36.0	36.0	26.1	29.5	29.5	40.1	39.1	39.0	40.0	39.9
1976	39.9	37.0	48.9	50.7	36.1	37.8	39.0	39.0	39.4	43.3	74.9	80.6	88.9	68.9
1977	39.0	39.7	36.9	36.9	36.0	36.0	24.4	33.0	33.0	39.0	36.9	36.9	36.9	36.9
1978	30.2	39.9	36.9	33.8	23.6	26.7	36.8	37.2	37.2	38.9	41.7	46.8	47.6	62.5
1979	39.9	39.2	37.4	36.9	36.0	36.0	29.2	34.2	34.2	40.0	36.9	40.1	40.1	36.9
1980	39.3	39.4	36.9	36.9	37.0	38.6	39.2	39.3	40.3	41.6	39.6	38.3	39.0	36.9
1981	37.1	39.4	36.9	36.0	36.2	36.0	38.9	38.9	40.0	47.7	54.4	57.6	60.9	39.4
1982	38.6	44.5	50.3	36.9	36.9	37.3	39.1	39.1	39.1	57.8	50.8	69.1	60.2	51.2
1983	40.0	40.0	41.3	36.8	37.4	37.0	39.6	39.6	39.6	44.4	52.6	53.2	51.6	38.2
1984	39.9	39.8	38.9	36.9	36.9	37.9	33.4	33.4	33.4	40.0	42.1	42.9	41.6	37.3
1985	39.9	39.8	40.2	36.9	36.0	36.0	34.7	37.6	38.5	38.5	37.4	28.9	29.8	31.3
1986	40.0	39.9	38.3	36.9	36.0	36.0	33.7	35.8	35.8	38.4	37.3	45.2	40.9	26.7
1987	39.2	39.5	37.2	36.9	36.9	38.7	39.2	39.2	39.8	41.2	38.3	32.5	28.5	30.7
1988	30.5	39.9	36.9	36.7	36.0	36.0	35.2	39.3	39.6	39.7	47.1	37.6	36.9	36.9
1989	39.9	39.8	42.8	36.9	36.9	37.4	37.3	37.3	37.4	37.6	42.3	37.0	37.0	36.9
1990	37.7	39.8	36.9	36.0	36.0	36.0	39.5	39.5	39.5	44.9	46.4	45.9	52.3	39.9
1991	39.8	39.9	42.8	45.4	37.0	36.9	39.9	39.9	40.0	48.9	72.9	64.3	69.3	36.5
1992	40.0	39.6	38.6	41.9	37.5	38.5	33.6	39.3	39.6	39.6	36.9	23.1	25.9	24.8
1993	40.0	39.7	38.7	36.9	36.0	37.6	24.7	30.9	34.9	34.9	34.1	25.0	29.8	24.2
1994	34.7	39.7	36.9	36.9	36.0	36.0	34.6	35.5	37.7	37.7	52.3	37.4	36.9	36.9
1995	37.9	40.0	45.9	44.5	36.9	37.0	39.1	39.1	39.1	40.7	37.8	39.6	38.9	40.5
1996	38.7	41.8	52.6	47.6	39.0	36.9	38.5	38.5	38.5	48.5	57.5	40.7	39.3	39.9
1997	40.4	41.4	55.0	50.3	36.9	38.1	38.4	38.4	39.9	64.0	59.1	38.8	50.0	46.0
1998	48.5	39.1	53.7	47.3	37.5	38.6	39.3	39.3	39.9	39.9	37.4	44.2	39.5	31.6
Avg.	**38.2**	**39.6**	**42.8**	**39.4**	**35.9**	**36.0**	**35.4**	**37.0**	**37.3**	**46.0**	**47.7**	**45.7**	**46.0**	**38.9**

Table 16. Case 4C (recommended case) 70 yr results Arrow Outflows