Non-Treaty Storage Utilization – System Modeling Summary

1.0 Operational Modeling

1.1 Introduction

BC Hydro is currently examining four scenarios for utilization of Mica Non-Treaty Storage. BC Hydro simulated these operating scenarios using several interrelated computer models of the Columbia River hydroelectric facilities. The Water Licence Requirements group in BC Hydro is then able to use the modelling results and develop performance measures to compare how well each scenario performs in satisfying the Columbia River Water Use Plan objectives, and other system operating objectives.

1.2 Modelling Operating Scenarios

BC Hydro uses several Power Operations Models to simulate operations of the Columbia River hydroelectric facilities according to the criteria developed for each Non-Treaty Storage scenario. These simulation programs are the same models (or updated versions) that were utilized in the Columbia Water Use Planning process, and are commonly utilized in BC Hydro long range planning studies.

For each operating scenario, the Power Operations Models provide statistics for reservoir elevations, dam discharges, river flows and value of power generation for the years of simulated flow operation. These outputs serve as inputs to environmental models to calculate performance measures for each scenario.

Figure 1.1 illustrates the modelling process for Non-Treaty Storage studies, which is generally consistent with that used in the Columbia Water Use Plan.

1.3 Columbia River Treaty

Discussion on the integration of the Columbia River Treaty into system modeling is provided in Section 6.2.1 of the Columbia Water Use Plan Consultative Committee Report (July 2005).

Over a number of years, BC Hydro has annually negotiated non-power agreements with the US, including flow management agreements for:

- Rainbow trout spawning in the Canadian Columbia River to maintain river levels at Norns Creek Fan between 1 April and 30 June.
- Whitefish spawning, which allows storage at Kinbasket and Arrow Lakes reservoirs during January to reduce Arrow outflow by about 20 kcfs for enhancement of whitefish spawning.

These agreements are considered by both BC Hydro and their US counterparts to be critical operating agreements, that are required to meet environmental obligations on both sides of the border. As such, operational adjustments to projected Treaty operations were made for all Non-Treaty Storage scenarios that would reflect a continued presence of these agreements in future years.

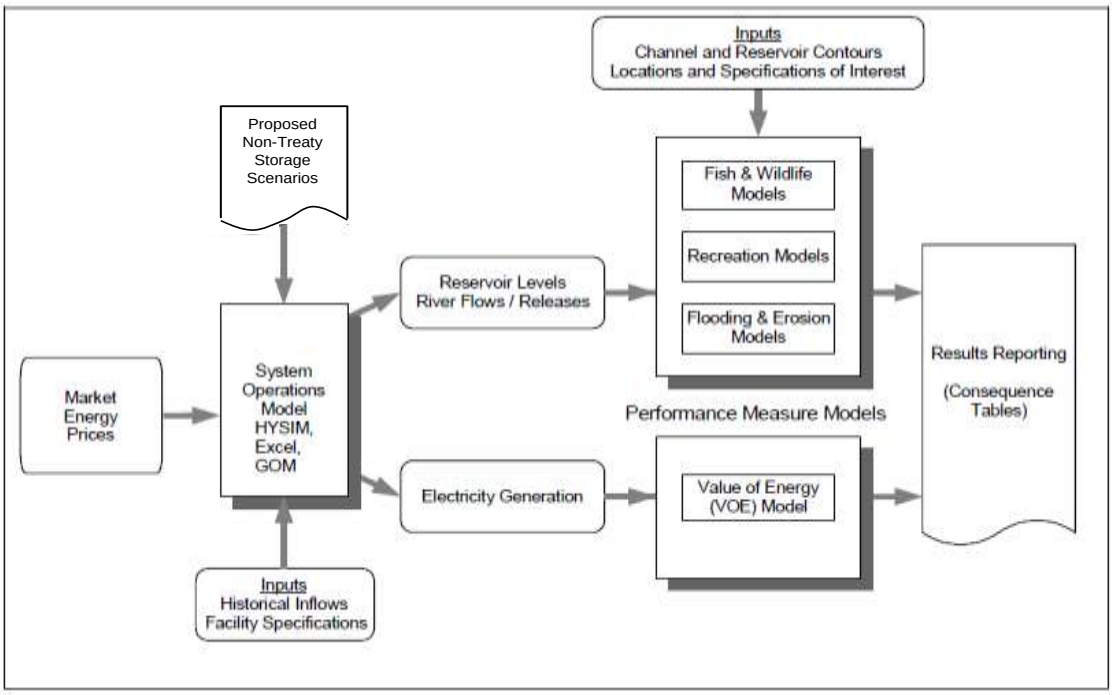

Figure 1.1: Non-Treaty Storage scenario modelling process

1.4 Power Operations Models

As in the Columbia Water Use Plan, the analyses of operating scenarios were carried out by three different but interrelated models of the Columbia River system. These models included:

1. HYSIM, which models the overall operations of the BC Hydro system system, including all reservoir elevations, dam releases and river flows on the Columbia River.
2. GOM, which is used to provide detailed modeling of flows immediately below Revelstoke Dam.
3. Excel Spreadsheet models that model:
    - Non-Treaty Storage operational scenarios.
    - Flow adjustments below Hugh Keenleyside Dam, which considered changes to Columbia River Treaty flows, driven by non-power agreements.

Principle requirements or inputs for the models included:

- Hydroelectric facility constraints based on physical limits (e.g., turbine capacity, reservoir capacity, spillway rating), licensing, integrated electrical system requirements, and Treaty obligations.
- Long standing critical operating agreements to manage BC Hydro and US environmental obligations. These agreements have been signed annually since

the mid-1990's, and have a very high likelihood of continuing to be signed in future years.

- Likely operations at Arrow under the Libby Coordination Agreement which is an evergreen agreement that provides the US with flexibility to meet EPA obligations at Libby, and provides a mechanism for BC Hydro to recoup power losses associated with this operation.
- Modifications to operations that would be reflective of the NTSA scenario that is being considered.

Variation in snowpack levels, freshet timing and precipitation events result in different reservoir elevations and facility discharges between years. These variations are reflected in different discharge regimes within a given scenario as the Operations Models attempted to optimize the value of power generation. In the case of Kinbasket, reservoir storage capacity is sufficient to influence next year operations by supplementing or withholding actual inflows using storage. This characteristic is unique to a multi-year storage reservoir, in that actual discharge is tied to both annual inflow and previous year storage and discharge decisions. For example, two successive drought years may have large implications on how the hydroelectric project behaves in the third year.

The primary output of the power operations models is a set of data describing reservoir elevations and flow releases through time for each facility. These outputs were then used as inputs to generate performance measures based on flow and/or reservoir elevations and to estimate power generation.

2 NTSA SCENARIO MODELING

BC Hydro is considering four scenarios for the utilization of Non-Treaty Storage at Mica. In all scenarios, monthly usage of the storage (storage and release) has been restricted to ensure that the modeled operations do not impact long standing BC Hydro or US fisheries objectives. Within the residual flexibility available, each scenario is then assumed to be operated to maximize the downstream power benefits based on forecasted energy market prices. While the residual flexibility is considered to be available within the modeling, it is noteworthy that any agreement signed with the US will likely be structured as an enabling agreement. Thus, the flexibility to operate Non-Treaty Storage will not be unilateral by either party, but rather will only be usable by mutual agreement.

In the Base Case – High Volume Utilization scenario (Scenario A), it is assumed that BC Hydro would not apply any volume restrictions on the operation of Non-Treaty Storage. This would allow for transactions that could potentially draft up to 4.5 MAF from Non-Treaty Storage. This scenario is considered to approximate the operation that would be expected in the 1990 Non-Treaty Storage Agreement. As well, the level of flexibility and operational outcomes are considered to be generally consistent with operational alternatives that were contemplated during the Columbia Water Use Plan.

An alternative Low Volume Utilization scenario (Scenario C) is also considered. Under this scenario, it is assumed that the operation of Non-Treaty Storage would be limited to an overall volume of about 2 MAF of net draft. The limitation in utilization of storage may be achieved either; explicitly through an Agreement with the US that has limitations in storage account volumes, or; through restrictions in the use of storage that would be applied by BC Hydro.

An alternative No Utilization scenario (Scenario D) is also considered. Under this scenario, it is assumed that the operation of Kinbasket and Arrow storage is operated exclusively under Treaty rules, and applicable supplemental agreements. The absence of Non-Treaty Storage activity would be the outcome of not negotiating an Agreement with the US on the operation of Mica Non-Treaty Storage.

A fourth scenario (Scenario B) has also been developed to examine the impact of a request by the US to consider modifications to spring and summer operations of Non-Treaty Storage under dry water conditions. Under this scenario, it is assumed that the operation of Non-Treaty Storage would be limited to an overall volume of about 3 MAF of net draft. In addition, the scenario models a release of water in the early summer to assist in the out-migration of salmon in the lower Columbia River. This additional flexibility is modeled as:

- Freshet release of 0.5 MAF in June on years that have flows that are less than 72 MAF at The Dalles (lower 15 percentile of HYSIM years).
- Return of storage in upcoming year, if greater than 92 MAF at Dalles (above average)

Market prices and US plant efficiencies were obtained from data inputs used in HYSIM, and are based on the BC Hydro 2008 Long Term Acquisition Plan (LTAP) electricity price forecast

3 HUGH KEENLEYSIDE DAM RELEASE MODELING

Treaty operations modeled in HYSIM used the 2012 Assured Operating Plan to define the Columbia River Treaty operation. Both the Non-Treaty Storage transaction, and the Treaty supplemental agreements were incorporated by adjusting the physical release from Arrow Reservoir, through an Excel spreadsheet analysis factoring three components, including:

- The Columbia Treaty operations as defined in the 2012 Assured Operating Plan.
- Critical environmental agreements with the US (i.e., rainbow trout flows, mountain whitefish flows, and LCA Provisional Draft).
- The NTSA scenario

While agreements with the United States vary from year to year, a “typical agreement profile” was constructed. These agreement profiles were applied to each year of the 60-year inflow data set, with the recognition that the change to river flows and reservoir storage may vary under each annual agreement depending on inflows and market conditions.

The resulting modified release from Arrow was delivered as an input to HYSIM.

Table 2.1: Non-Treaty Storage Usage Scenarios:

Scenario	Description	Constraints
A	Base Case – High Volume Utilization: This scenario allows for the operational usage of all available Non-Treaty storage. This scenario would approximate the operation that would be expected in the 1990 Non-Treaty Storage Agreement. As well, the level of flexibility and operational outcome is considered to be generally consistent with operational alternatives that were contemplated during the Columbia Water Use Plan.	Enabling agreement with maximum Non-Treaty draft of 4.5 MAF (full available Non-Treaty Storage at Mica).
B	Moderate Volume Utilization: This scenario allows for the operational usage of a moderate volume of Non-Treaty storage (1.5 MAF less than Scenario A). In addition, the scenario provides the US with flexibility to release additional water in summer to manage fisheries objectives. This additional flexibility is modeled as: o Freshet release of 0.5 MAF in June in years that have flows that are less than 72 MAF (78% of Normal) at The Dalles (lower 15 percentile of HYSIM years). o Return of storage in upcoming year, if greater than 92 MAF at Dalles (above average) o Requirement to store back, prior to next release.	Enabling agreement with either: – Non-Treaty active account limited to 3.0 MAF, or – BC Hydro constraining usage of Non-Treaty water. US with flexibility to release 0.5 MAF of water in spring/summer, under unusually dry conditions
C	Low Volume Utilization: This scenario allows for the operational usage of a limited volume of Non-Treaty storage (2.5 MAF less than Scenario A). This scenario can be achieved by either restricting the size of the Account via the Contract, or limitations being placed on the account draft through the enabling agreement format. This level of usage of Non-Treaty storage, is considered to be the minimum volume necessary to provide: - Fall/Winter draft for Kinbasket, to serve system load. - Key fisheries/power operations in the spring and summer. - Flexibility to manage Kinbasket reservoir operation in exceptionally high inflow years.	Enabling agreement with either: – Non-Treaty active account limited to 2.0 MAF, or – BC Hydro constraining usage of Non-Treaty water.
D	No Utilization: This scenario reflects an operation that is driven by the Columbia River Treaty only. The scenario can be achieved by either not signing an agreement with the US on the operation of Non-Treaty Storage, or by limiting the draft of account to zero, within an enabling agreement.	No Non-Treaty Storage Usage

4 HYDRO SIMULATION MODEL (HYSIM)

The BC Hydro project team used the Hydroelectric Simulation Model (HYSIM) to determine the operations of the BC Hydro system as a whole, including all reservoir levels, reservoir outflows and river flows on the Columbia River.

HYSIM is designed to model the entire BC Hydro system of electricity generation. This approach was needed to capture both the size and importance of the Columbia and Peace River systems within British Columbia and the fact that their operations are co-ordinated to optimize power generation. For a given load and resource portfolio, HYSIM will determine the most economic dispatch of the generating system, subject to operating constraints and objectives, under a range of streamflow sequences.

The HYSIM simulates operation of BC Hydro's integrated electric generation system on a monthly time-step. As such, it is able to provide end-of-month reservoir elevations, mean monthly flows, monthly generation and mean monthly operating costs. It does not reflect any variability of these outputs within the month (e.g., daily and/or hourly).

HYSIM simulations were based on inflow data sets using the time series between 1940 and 2000 (60 years) with an annual load and resources as forecasted for the year 2016-17 (58,650 GWh/year). Modeling results reflect a single continuous sequence of reservoir inflows in which the initial conditions (e.g., Kinbasket Reservoir elevations) for each year were carried forward from the end of the previous year starting in 1940. 2008 LTAP electricity prices used in this study were based on then-current natural gas price forecasts, with variability that was dependant on water conditions in the Pacific Northwest.

Key assumptions used in HYSIM modeling is provided in the table below. Within the constraints that are placed on the operation, the model will seek to maximize the economic value of system operation. It is noteworthy that BC Hydro will not always however, operate the system to achieve the maximum economic value. Examples of conditions that would potentially result in adjustments to operations that deviate from the economic optimal include:

- Flood control events downstream of Arrow (in Canada or US) that may result in reductions in releases at Arrow, below Treaty specified flows.
- System generation adjustments to enhance Arrow soft constraints or other system objectives.
- System generation adjustments to manage non-power issues in other river basins. (eg: modifications to operation of Peace Projects, to facilitate Peace River winter ice cover formation).
- Discretionary Supplemental Agreements that may be negotiated with the US to enhance power and non-power benefits.

a. HYSIM: Assumptions and Methodology

Table 4-1 summarizes the assumptions built into the HYSIM.

Table 4-1: HYSIM Assumptions

- Forecast load 2016-17 (58,650 GWh/year)
- Streamflow sequence is from October 1940 to September 2000
- BCH gas and electricity price forecast as used in LTAP 2008
  - Market prices are based on average monthly prices for heavy load and light load periods
  - Energy limit is based on the estimated monthly transmission availability
  - The market prices are adjusted by water year to reflect the impact due to varying streamflow (at The Dalles)
- Resources
  - Existing BC Hydro resources and Independent Power Producers
    - Includes REV Unit 5, MCA Units 5 and 6.
  - Arrow Lakes Hydro generation (185 MW)
  - Additional Independent Power Producers
    - Vancouver Island Generation (265 MW)
- Columbia River Operations
  - Treaty operation based on 2012 Assured Operating Plan (AOP)
  - Flood control storage requirements based on 4.08/3.60 MAF flood control split at Kinbasket and Arrow Lakes reservoirs
  - BC Hydro and Bonneville Power Administration non-Treaty operation, varying by water year
  - Non-power operations based on 1 MAF flow augmentation storage (if possible) from January to February and released in July.
  - Libby Coordination Agreement operation (evergreen agreement with US) . Release in Aug/Sep, with return in October. Release in December with storage in March. Volume: 0.25 MAF
  - Non-power operations based on April through June flow shaping for trout protection
  - Minimum Arrow discharge of 10 kcfs year round
  - Revelstoke minimum flow of 5 kcfs.
  - Meet operating objectives to the extent possible through the use of Flex operation
- Peace River Water Use Plan Constraints
  - Williston Reservoir operating range as per water licence
  - Peace Canyon flows constraints
    - 51 kcfs from January to February for base case
    - Minimum 30 kcfs in March
    - Minimum 11 kcfs from April to November
    - Minimum 40 kcfs in December

b. HYSIM: BC Hydro Operations

The Peace and mainstem Columbia river systems account for approximately 70 per cent of BC Hydro's total generating capacity. Their large storage capacity provides BC Hydro with a significant amount of operating flexibility to co-ordinate their operations to meet the various demands on the system and to take advantage of market opportunities. Therefore, any constraints on either system will reduce this flexibility and may also have an impact on the other system.

The Columbia River system operation is modelled in accordance with the Columbia River Treaty coupled with critical non-power operations, and the anticipated usage of the Non-Treaty Storage Agreement scenarios considered. The Columbia River Treaty operation is computed based on the 2012 Assured Operating Plan. Downstream flood control requirements are based on the 4.08/3.60 MAF split at Kinbasket and Arrow Lakes reservoirs. Critical non-power operations that are considered to be long standing environmental obligations by BC Hydro and the US, are included in the operations. Non-Treaty Storage Operations are carried out to maximize downstream power benefits,

however limitations in these operations are set such that they do not compromise the well established non-power objectives on both sides of the border.

c. HYSIM: Streamflow Record

The 60-year streamflow sequence used in the HYSIM modelling was based on the October 1940 to September 2000 historical streamflow. This period includes a wide range of streamflow conditions and is considered to provide a sufficiently large sample to be representative of future streamflow.

Each operating scenario was run continuously over the 60 years of streamflow data using initial conditions (at the beginning of October 1940) that match the conditions at the end of the streamflow period (September 2000). This ensured that the same amount of water was used in each scenario.

Some interests in the lower Columbia River are affected both by flows out of Arrow Lakes Reservoir and the Kootenay River system. To assess the impact of changing constraints on the lower Columbia River, the same time period of flows for the Kootenay River system were paired with each operating scenario on the Columbia River. Kootenay River flows were independently modeled on a daily time-step, using expected operations from Duncan and Libby dams. These results were coupled with the monthly time-step releases from Arrow, that were generated from the combination of Treaty and Non-Treaty operations (See Section 5).

d. HYSIM: Market Modelling

Import and export market transactions are modelled based the optimal system operation for the assume electricity market prices, and are limited by estimated monthly transmission availability. In the Pacific Northwest, electricity prices tend to vary depending on the runoff volumes in the Northwest. Therefore, the electricity price forecast is adjusted for each of the 60-year streamflow conditions used in the study based on the runoff volumes at The Dalles. The assumed price variations due to streamflow conditions ranged from about +45 per cent of the mean for a dry year to -25 per cent of the mean for a wet year.

Due to the flexibility of the hydroelectric system, BC Hydro is able to take advantage of market price variability by shaping the generation to enable market purchases during low price periods and sales during higher price periods. Any constraints on the system may reduce this flexibility, thereby increasing the cost of operating the system.

The price forecast used by HYSIM provides a single view of the market based on certain assumptions. In real time, there may be much more volatility due to a range of different factors, as the early years of this decade have shown. This volatility will tend to increase the value of the operating flexibility. It can also result in significantly more variability in the releases of certain dams within the Columbia basin.

5 Generalized Optimization Model (GOM)

Several environmental interests in the mid Columbia River were affected by fluctuating flows from Revelstoke Dam. Since HYSIM provides only monthly flow averages as output, a more refined approach was needed to explore Non-Treaty Storage scenarios that impacted these flow releases. The Generalized Optimization Model (GOM) simulated operations of Revelstoke Dam on a shorter (bi-hourly) time step, which allowed changes to these flow fluctuations to be studied in greater detail.

Electricity prices vary over the short term on a daily and weekly basis. BC Hydro uses its system's flexibility to maximize its hydroelectric revenues in response to these fluctuating electricity prices. Facilities on both the Columbia River and the Peace River system are used in co-ordination to achieve this flexibility.

a. GOM: Assumptions and Methodology

The General Optimization Model (GOM) was used to capture the way in which the entire BC Hydro system was co-ordinated to maximize revenues over the short term, guided by the monthly HYSIM results.

Table 5-1 summarizes the GOM assumptions.

Table 5-1: GOM Assumptions

- Water Years: uses 10 years of streamflow data from 1 October 1964 to 30 September 1973. Period considered to have a wide variation of market prices and stream flows.
- BC Hydro 2008 LTAP, 2016/17 load year, gas and electricity price forecast for Alberta and the United States.
    - Estimated hourly market prices and transmission availability. Interior to Lower Mainland transmission constraints are not considered. Current transmission access limitations to Alberta and United States markets.
    - The market prices adjusted by water year to reflect the impact due to varying streamflow conditions at British Columbia and Pacific Northwest.
- The initial forebay and ending elevations for each stream flow year in the GOM study, were set to match those derived by the HYSIM results for the corresponding water years.
- The monthly total energy production from the G.M. Shrum and the Mica generating plants were restricted to deviate by no more than a certain percentage from those derived by the HYSIM.
- The average monthly inflows for the studies were set to the inflows used in the HYSIM. Within each month, daily inflows are assumed to be constant for the Peace River system, while the Columbia River system used inflows that vary daily.
- The minimum plant outflows for the base case were assumed to be:
    - G.M. Shrum 1.5 kcfs
    - Peace Canyon:
        - January 52 kcfs
        - February to March 30 kcfs
        - April to November 10 kcfs
        - December 40 kcfs.
    - Mica 0 kcfs
    - Revelstoke 5 kcfs
    - Arrow 10 kcfs
    - Forebay limit:
        - Peace Canyon = 8.58 ft
        - Revelstoke = 4.59 ft

Note: Plant unit outages were scheduled primarily in the spring, but also in the fall, for each unit (20 unit-weeks per year of outage at MCA, 15 unit-weeks per year at REV). The unit outages for each plant in a river system were co-ordinated so that a unit outage at an upstream plant coincides with a unit outage at the downstream plant.