



**A GOAL PROGRAMMING
ALGORITHM TO
INCORPORATE THE
COLUMBIA RIVER NON-
POWER FLOW
REQUIREMENTS IN THE BC
HYDRO GENERALIZED
OPTIMIZATION MODEL**

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**BPA Reservoir System Modeling
Technologies Conference
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**UBC Civil
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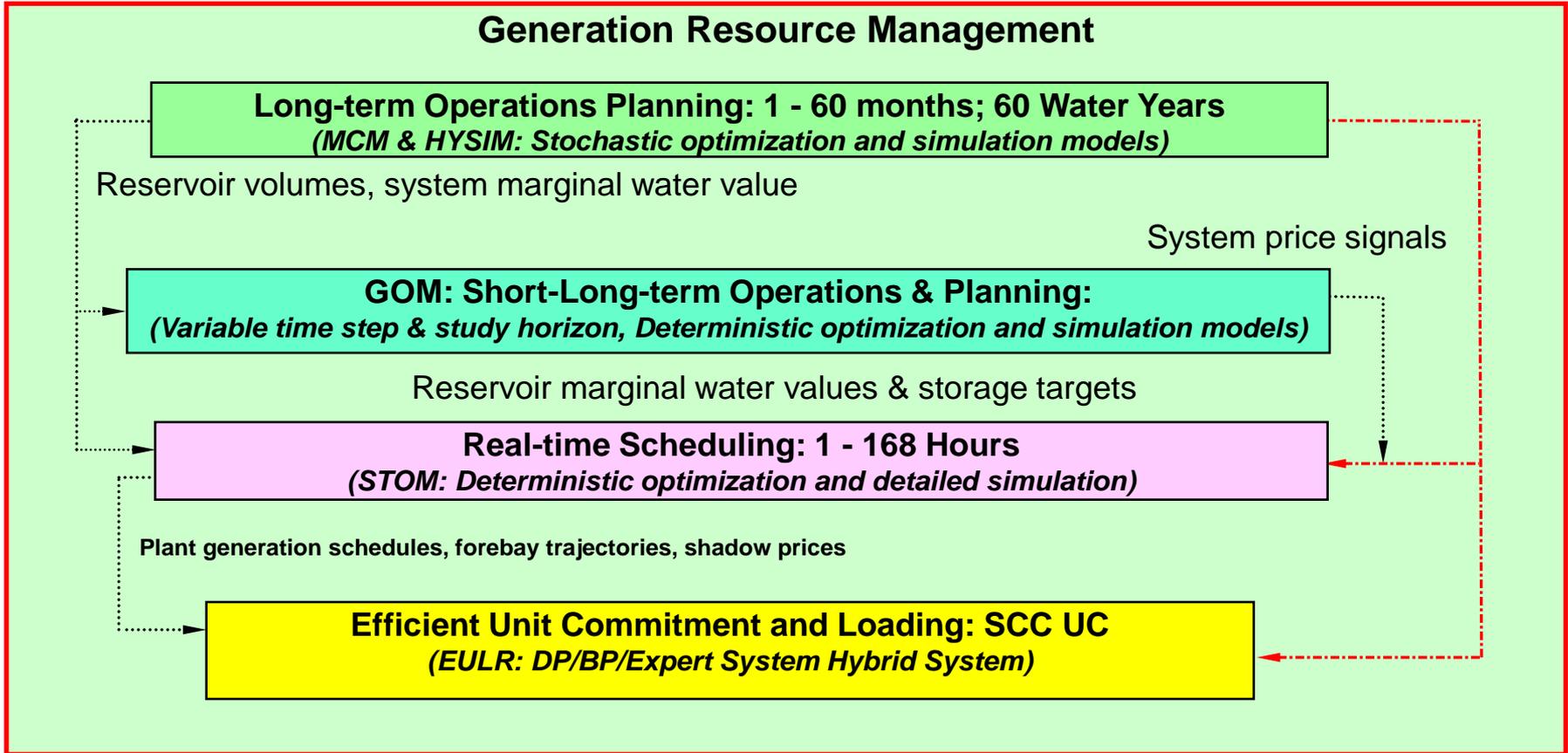


BC Hydro 

Hydro System Modelling Hierarchy at BC Hydro

(Operations & Planning Models)

Generation Resource Management



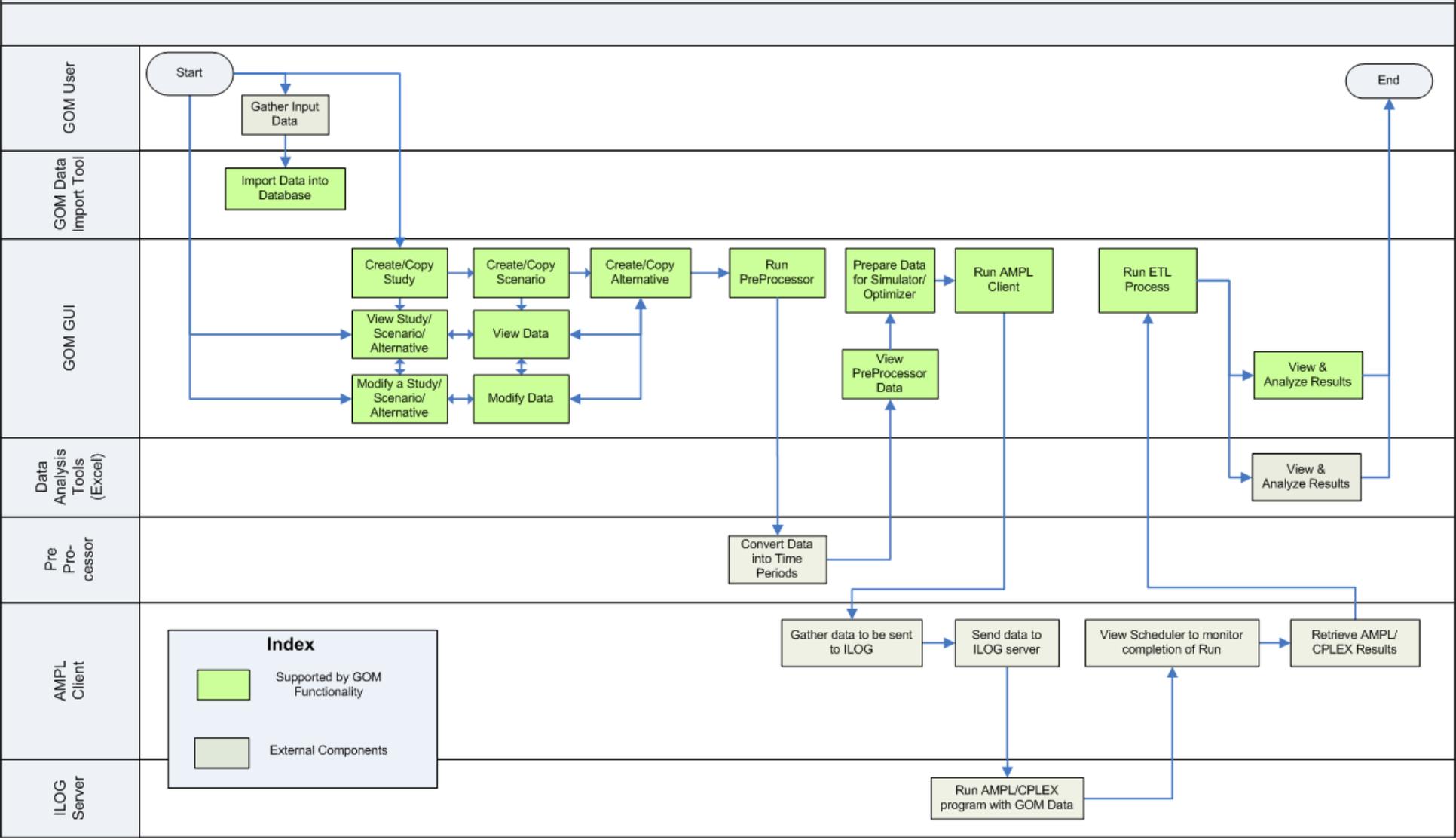
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Introduction to BC Hydro GOM

- GOM: Generalized Optimization Model developed in-house to model the BC Hydro system
- GOM used to develop detailed system generation, trade and reservoir operations schedules
- Variable time/ sub-time step (hourly, daily, weekly and monthly with sub-time-step (PLH, HLH, SLH, LLH, ...)).
- Fully integrated with other planning and operations models
- User-defined optimization problem: Reservoirs included in simulation/optimization run & optimization problem solved/ objectives

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GOM Components and Process



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GOM GUI

Easy to use **Study** interface

- o Define optimization problem
 - o Standard/ w/wo Wind, Regional (TX), CRT ...
- o Select plants optimized
 - o Hydro, Thermal, IPPs
- o Select study type
- o Select study sequence
 - o Flow, load or both
- o Select Run Option
 - o Simulate/ Optimize or both

The screenshot displays the GOM GUI interface for configuring a study. The main window is titled 'Study Explorer: Site C GOM study Case D7a'. The interface is divided into several sections:

- File Explorer (Left):** A tree view showing a list of study cases and sub-cases. 'Site C GOM study Case D7a' is selected and highlighted in blue.
- Main Configuration (Top Right):** Fields for 'Study Name' (Site C GOM study Case D7a), 'Problem' (MASTER_CURRENT), 'Requested By' (Joel Evans), and 'Description' (Data to be used with the Mica Pump model). There are also dropdown menus for 'Transmission Zone' (US/AB for Master Problem) and 'Type' (IRP study).
- Load Data Source (Middle Right):** A dropdown menu set to 'Site C Study: C6'.
- Sequence Configuration (Right Panel):**
 - Sequence:** Radio buttons for 'Load', 'Flow', and 'Both'. 'Flow' is selected.
 - Number Of Sequences:** A dropdown menu set to '1'.
 - Study Periods:** A table with columns 'Start Date' and 'End Date'. The values are '01-Oct-2023' and '30-Sep-2024' respectively.
 - Water Years:** A dropdown menu set to '1964-1973'.
 - Run Options:** A dropdown menu set to 'Optimize'.
- Tree View (Center):** A hierarchical tree view showing the study structure. It includes categories like 'Hydro', 'Columbia - Main Stem', 'Peace', 'IPP', 'Thermal', and 'USA Main'. Various plants and sub-cases are listed under these categories, with checkboxes for selection.
- Timesteps (Bottom Right):** A table with columns 'Timestep Type', 'Start Date', 'End Date', 'Number of Hours', 'Weekday Sub Times...', and 'Weekend Sub Timest...'. The values are 'Hourly', '01-Oct-2023', '30-Sep-2024', '1', and empty cells.

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Generation Resource Management

GOM GUI

Easy to use Scenario GUI

- o Define study input data used on: Load year, price year, sources of data
- o Define study scenarios:
 - o Energy (e.g., prices)
 - o Hydro limits (eg. outages)
 - o IPP plant limits
 - o Transmission limits
 - o Regional limits

The screenshot displays the GOM GUI for 'Transmission_cases'. The main configuration area shows the Scenario Name as 'Transmission_cases' and Price Years set to 2023 for both Load Year and Price Year. The HYSIM Source is 'Case 6: 2011 BRP 2011-01-11 Portfolio - 2023, with no Site-C, 3.0 MAF...' and the Price Data Source is '2011 IRP Study Price forecast ScrB for 2023 in \$2011 Canadian'.

The table below shows the configuration for constraints and data:

Alternative	Data	BC-AB	BC-US
<input checked="" type="checkbox"/>	TLK-MAX	base-2011 update	base-2011 update
<input checked="" type="checkbox"/>	TLK-MIN	base-2011 update	base-2011 update

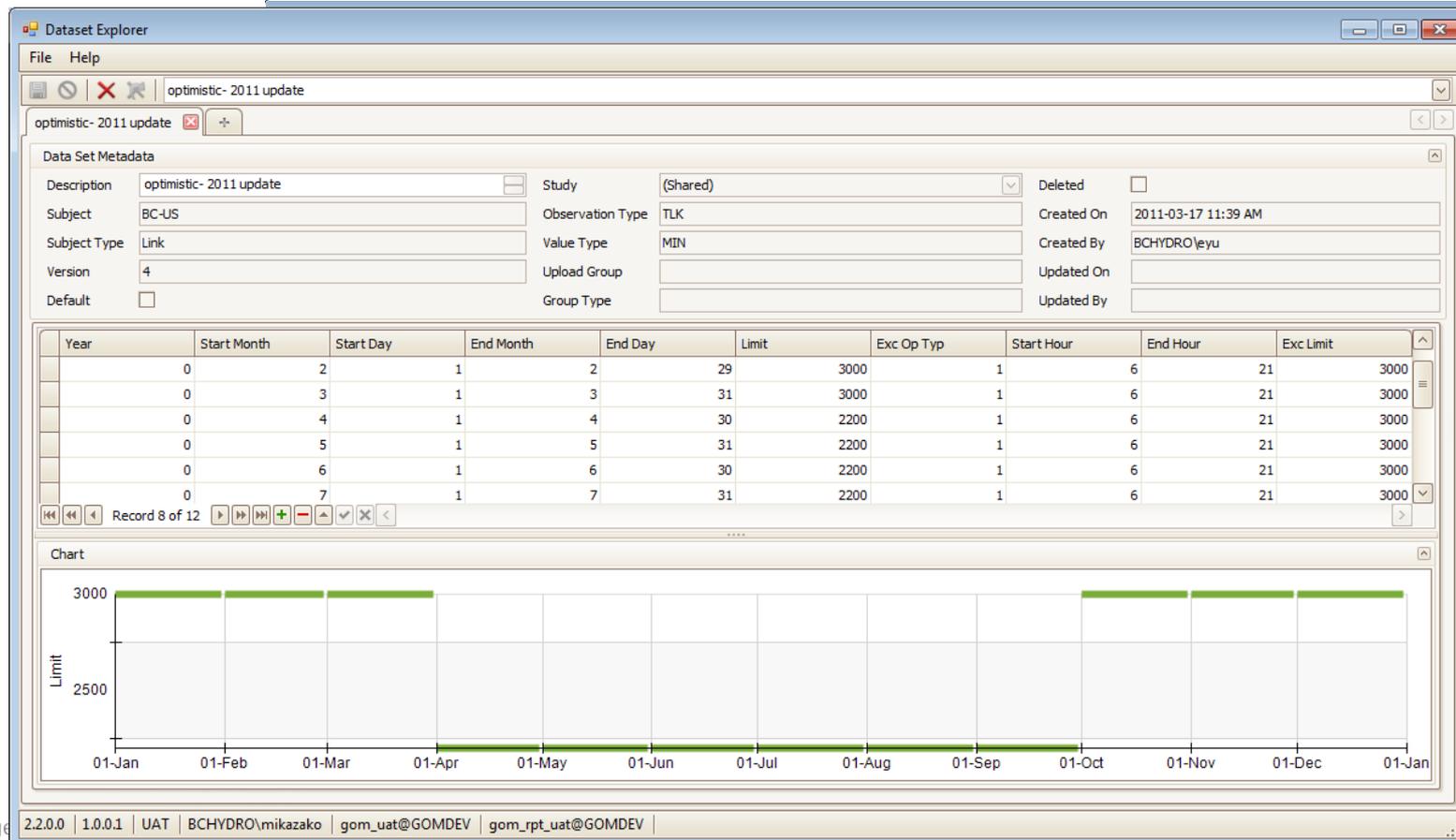
A tooltip is visible over the 'For STC study' row, showing details for 'For STC study' with Name, Version, Version Date/Time, Default, and Uploaded By columns.

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GOM GUI

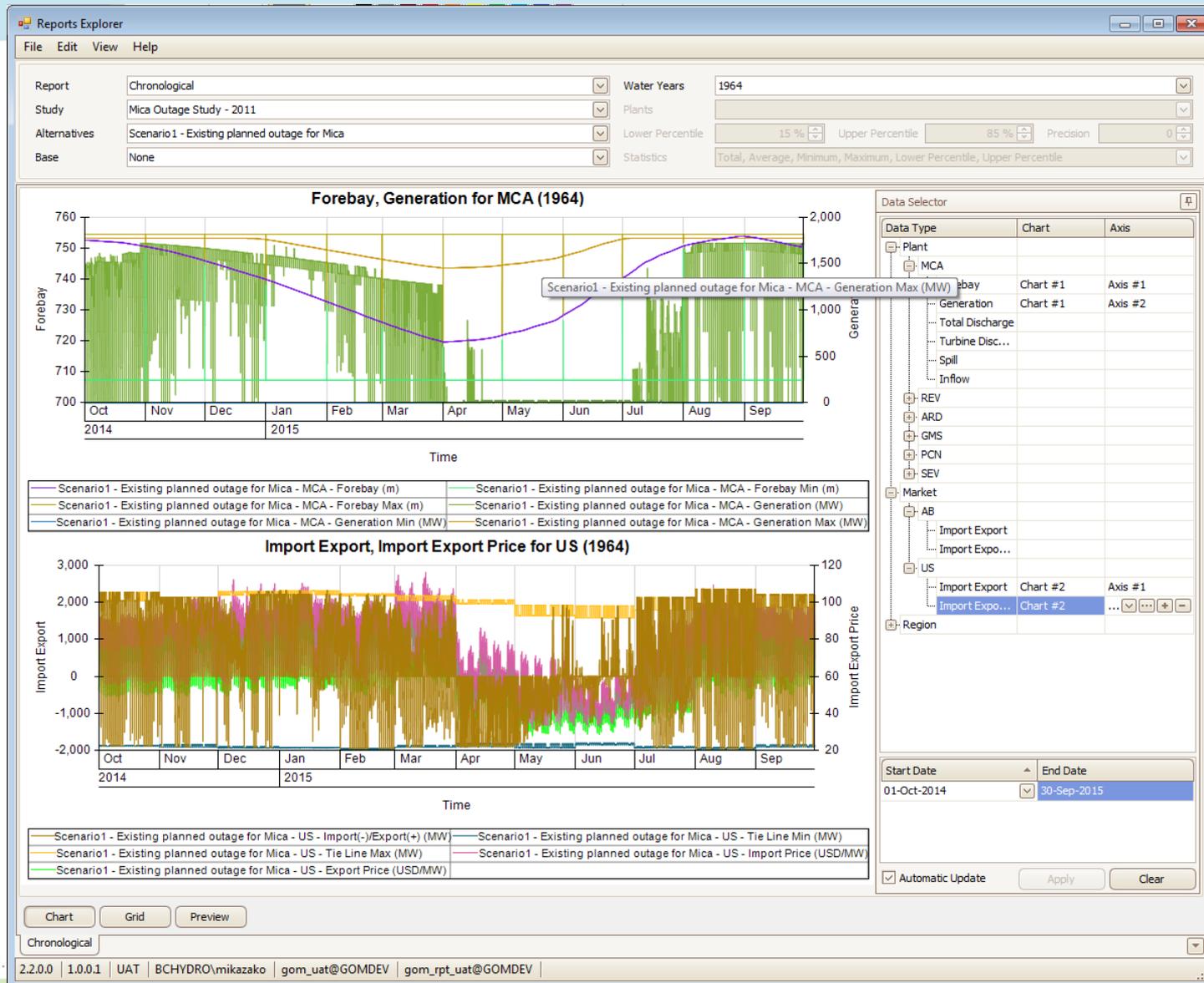
Easy to use **Alternative GUI**

- o Specify limits for selected scenarios
- o Example: US Transmission limits



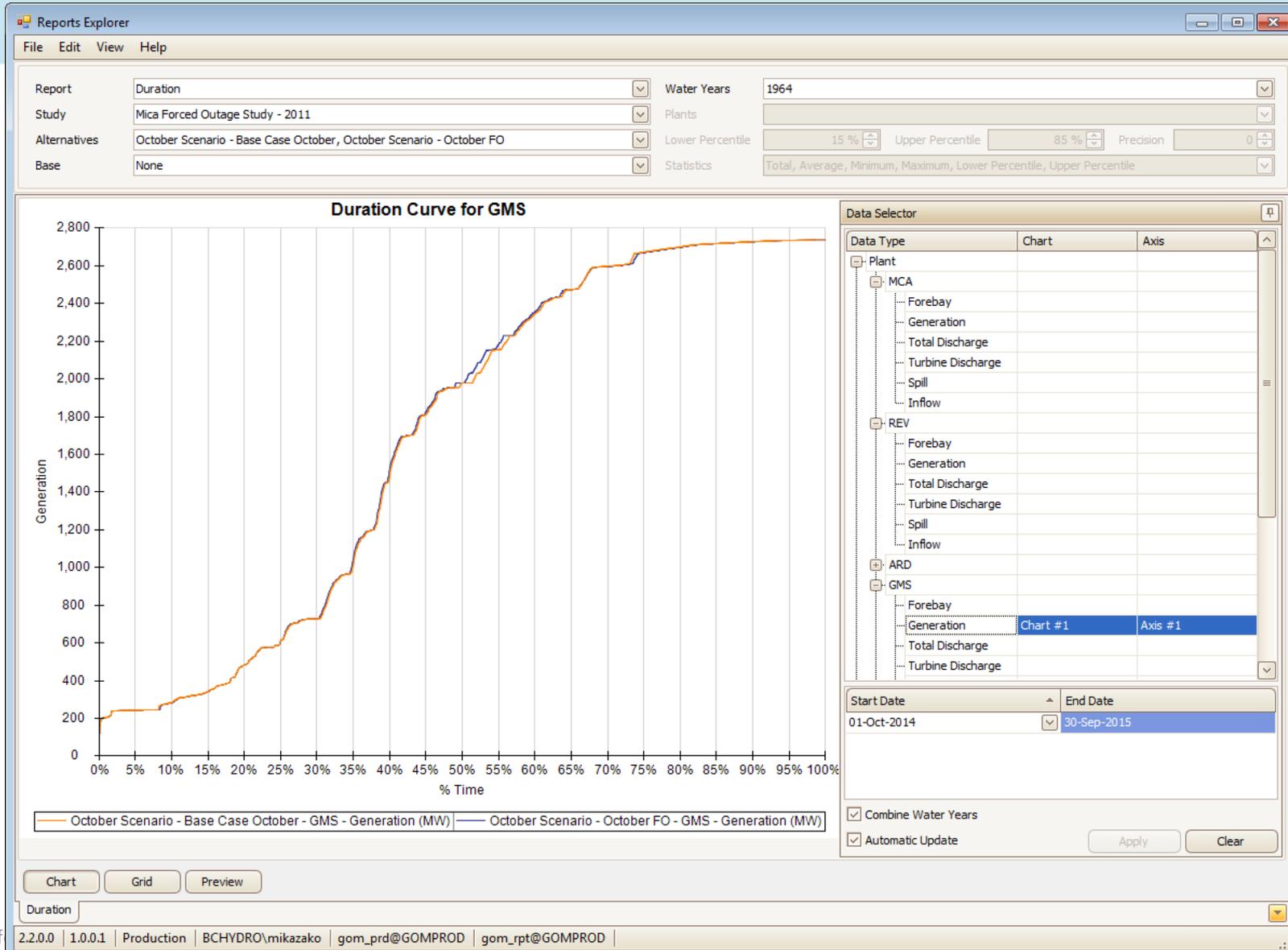
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GOM Model Results – Optimized Forebay, Generation, Import/ Export



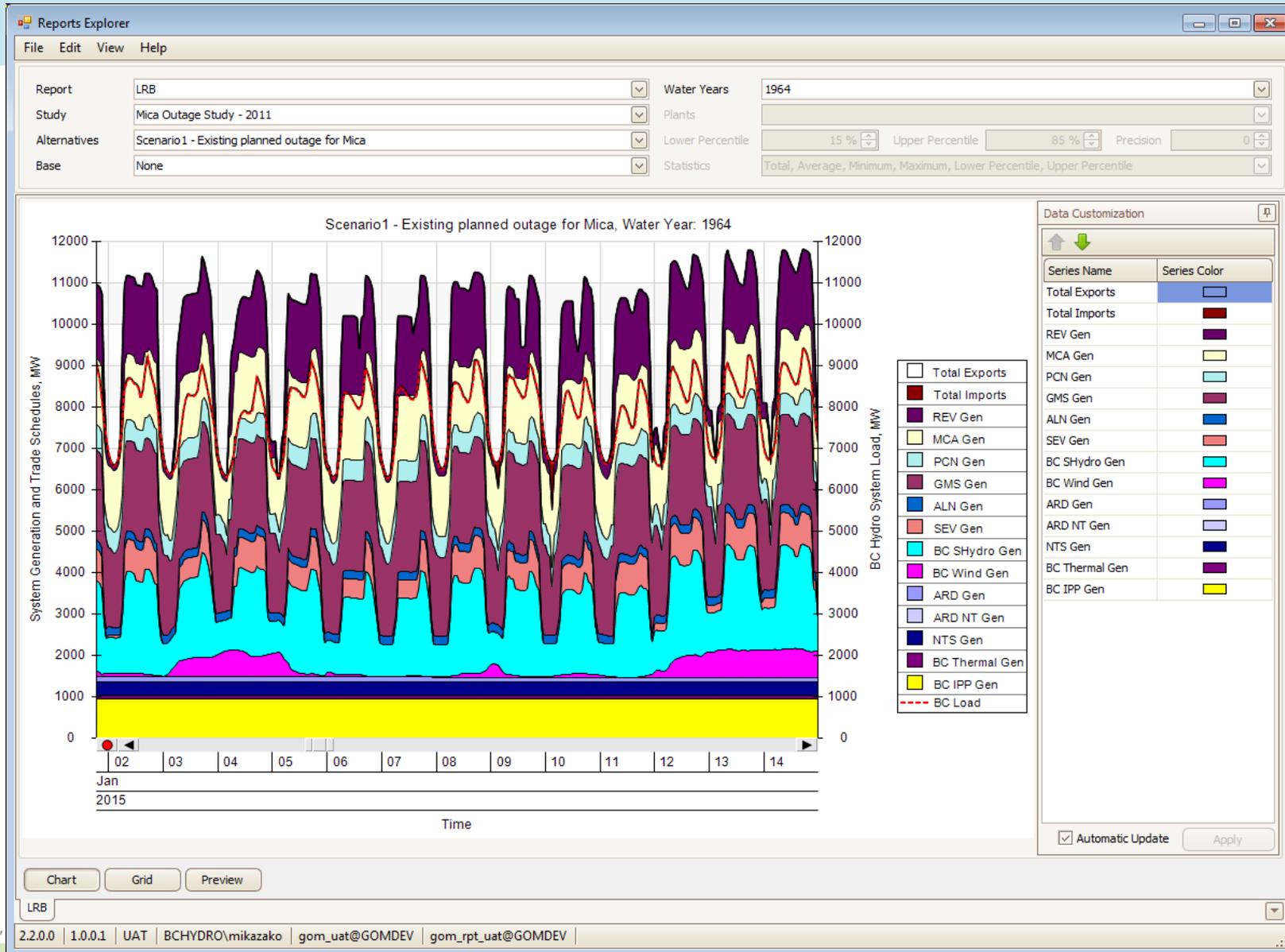
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GOM Model Results – Generation Duration Curves



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GOM Model Results – Load – Resource Balance



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Current Uses of the GOM Model

- Estimate trading and other benefits (energy & capacity capabilities) of proposed developments at BCH
- Optimize plant & turbine and unit characteristics
- Estimate changes in river flows for the determination of environmental effects caused by new or project upgrades
- Estimate planned/ forced outage costs
- Evaluate proposed system operating criteria
- Estimate wind integration cost and impacts & integration limits

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Current Uses of the GOM Model ...

- Analysis of pump-storage operation and impacts
- Impact on trading benefits due to changes in transfer and inter-tie capability
- Peace and Columbia WUPs
- Resource Smart Studies Supported, for example:
 - Addition of REV 5
 - Addition of Mica 5&6, REV 6 and their Sequencing
 - GMS G1 – U10 Turbines Upgrade and Generators Upgrade
 - Site C studies
 - Rehabilitation and upgrade of Campbell system
- Modelling of non-power flow requirements for CRT analysis

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GOM Optimization Model

- **Objective:** Maximize the value of BC Hydro Resources
- **Optimal Trade-off:** between present benefit/revenue with potential long-term value of resources
- **Decision:** When and how much energy to import/or export, as well as when, where and how much water to store or draft while meeting the firm domestic load and system constraints

Subject to meeting system load obligation and constraints

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GOM Optimization Model: Objective Function

- Maximize:
 - + \sum Spot sales in US * US Price
 - + \sum Spot sales in AB * AB Price
 - \sum Thermal Cost
 - + \sum (End Storage - End Target) * Marginal value of water

Other objectives for special cases:

- Max. revenue given fixed storage targets:
 - \sum Spot sales in US * US Price +
 - \sum Spot sales in AB * AB Price
- Max Efficiency given a fixed market:
 - \sum (End Storage – End Reference)* HK

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GOM Optimization Model: Variables

Decision Variables:

- Non-Hydro variables: Import and Export, Thermal
 - Decision: When and how much to import or export?
 - Information needed: Market information (import/export prices and tie limits)
- Hydro variables:
 - Turbine and spill releases
 - Power generation
 - Additional decision: store or draft? When, where and how much?
 - Information needed: Marginal cost of water and operation target for each reservoir

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GOM Optimization Model: Constraints

- Meeting firm demand (Load-Resource Balance)
- Meeting all plant and reservoir planning limits (including established non-power requirements, ramping up/ down etc)
- Meeting all transmission transfer capability limits
- Meeting special operational and planning restrictions
- Meeting operating reserves and control margins
- Hydraulic (mass) balance:
 - Dynamic formulation of problem facilitated by use of matrices to describe hydraulic interconnectivity between reservoirs:

$$S_{j,t+1} = S_{j,t} + \left[\pm \sum_{j=1}^J \sum_{h=1}^{\forall h} (QT_{j,t,h} * HC_{j,k}^T + QS_{j,t,h} * HC_{j,k}^S) * H_{t,h} + Q_{j,t}^{in} * H_t \right] / 24.$$

$$HC_{j,k}^T = \begin{matrix} & j & j+1 & j+2 & \dots & J-1 & J \\ k & 0 & 1 & 0 & \dots & 0 & 0 \\ k+1 & 0 & 0 & 0 & \dots & 0 & 0 \\ k+2 & 0 & 0 & 1 & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ K-1 & 0 & 0 & 0 & \dots & 1 & 1 \\ K & 0 & 0 & 0 & \dots & \vdots & 0 \end{matrix}$$

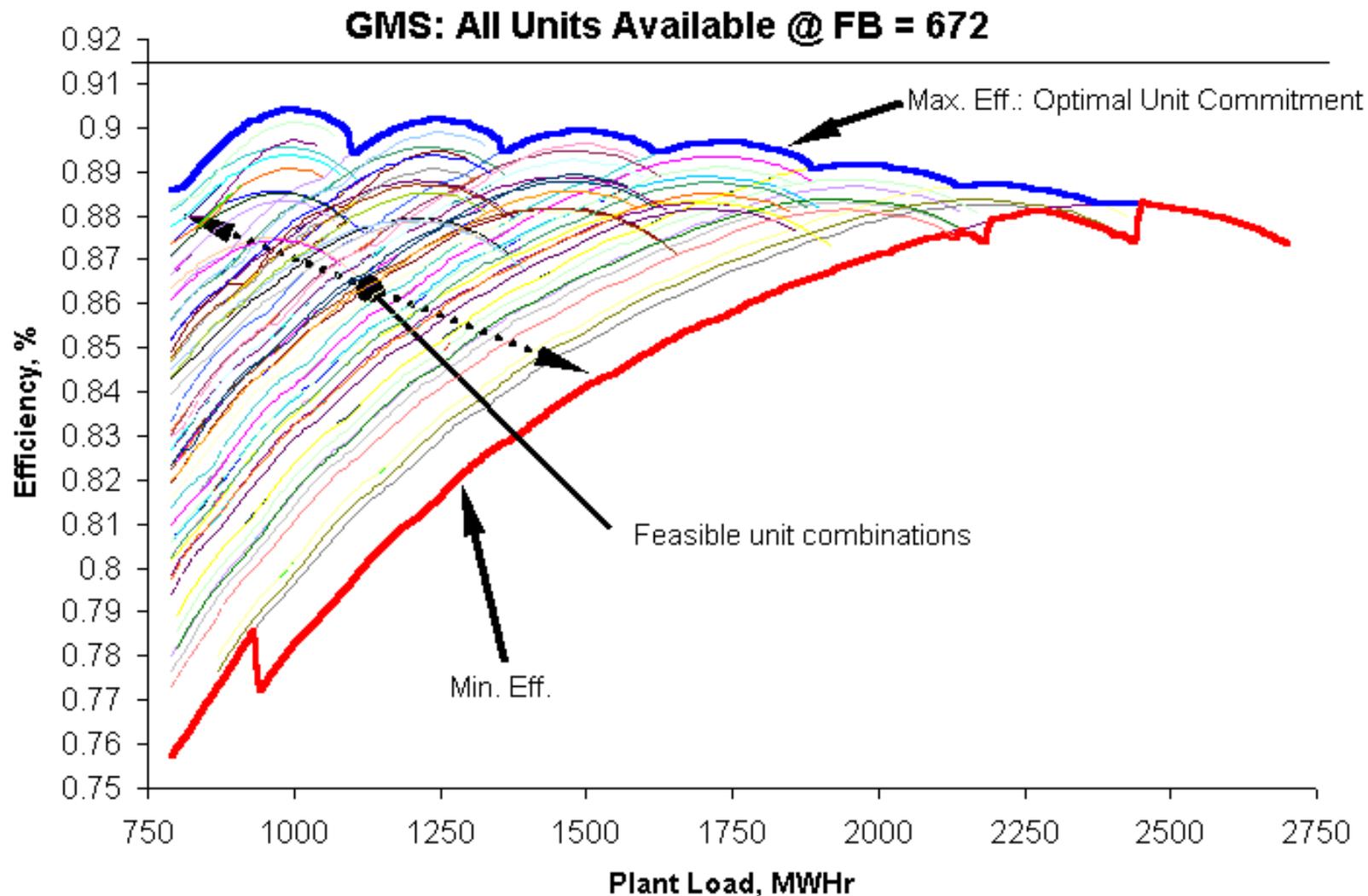
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GOM Main Assumption

- **Main Assumption:**
 - Optimal Unit Commitment & Loading (Static Plant Unit Commitment)
- **Allowed the use of Piecewise Linear curves to curve-fit SPUC database**
 - Piecewise Linear Curves features
 - Advantages when used in Linear Programming
 - Algorithms used to solve LP problems search the vertices
- **Mainly used in hourly, daily & weekly with sub-time steps**
- **For weekly-monthly studies, use $HK = f(\text{plant flow, GH})$, HK derived from results of hourly studies**

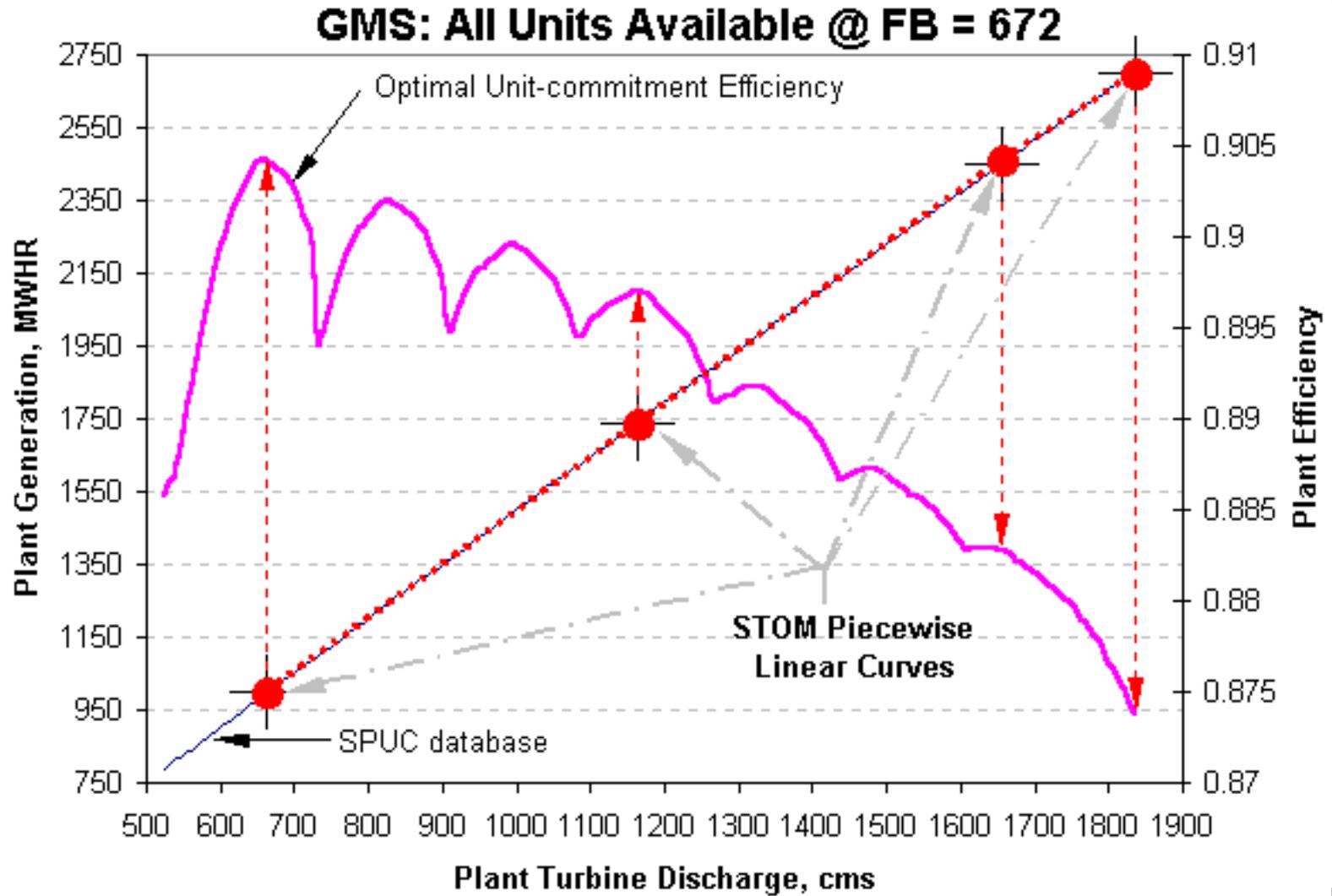
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GOM Main Assumption



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GOM Main Assumption



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generations.

Modeling Non-power Flow Requirement in GOM

Objective of Research

- Development and implementation of multi-objective optimization model that can be used in CRT studies
- Implementation of the existing and proposed non-power requirements
- Study impacts of non-power requirements on operations by Trade-off analysis

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Supplemental Operating Agreement Between Canada & US

A Non-power Uses Agreement developed to provide fisheries and recreation benefits in Canada and the U.S. for the period December to July.

Different Non-Power Requirements:

- Flow Augmentation (FA)
 - Store 1 MAF by mid April to be released in May-July to aid migration of salmon
- Whitefish (WF)
 - Meet Arrow outflow objectives Jan-March to protect WF eggs broadcast from Jan 1st – Jan 21st
- Trout Spawning (TS)
 - Avoid reduction in Arrow outflow April-June to protect Trout eggs deposited in April-May

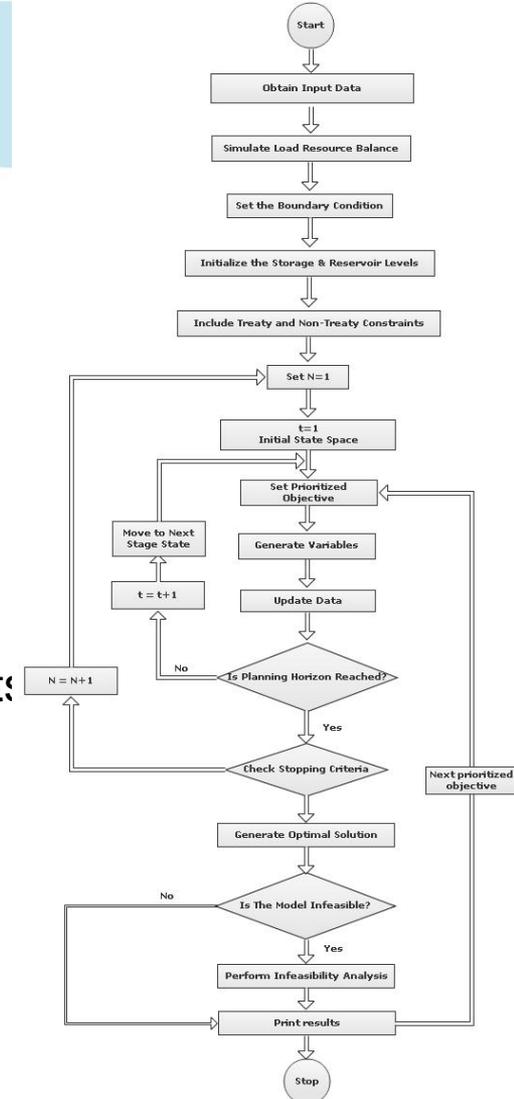
Columbia River Reservoir System



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Components of GOM-GP model

- Additional decision variables
 - Different storage accounts in a reservoir
 - Non-power flow and storage at Arrow
 - FA, WF, and TS Flow
 - Positive and negative deviation from the target
- Additional new GOM Non-power Constraints
 - Treaty, Non-treaty, Flex, Non-power Storage accounts
 - Non-power flow constraints at Arrow
 - FA Storage constraints
 - FA Release constraints
 - WF Flow constraints
 - TS Flow constraints
 - FA and WF Equity constraints
- Priority Ordering of Objectives/ Constraints Algorithm



Al-Mamun MSc Thesis, 2012
(coming soon to dSpace UBC)

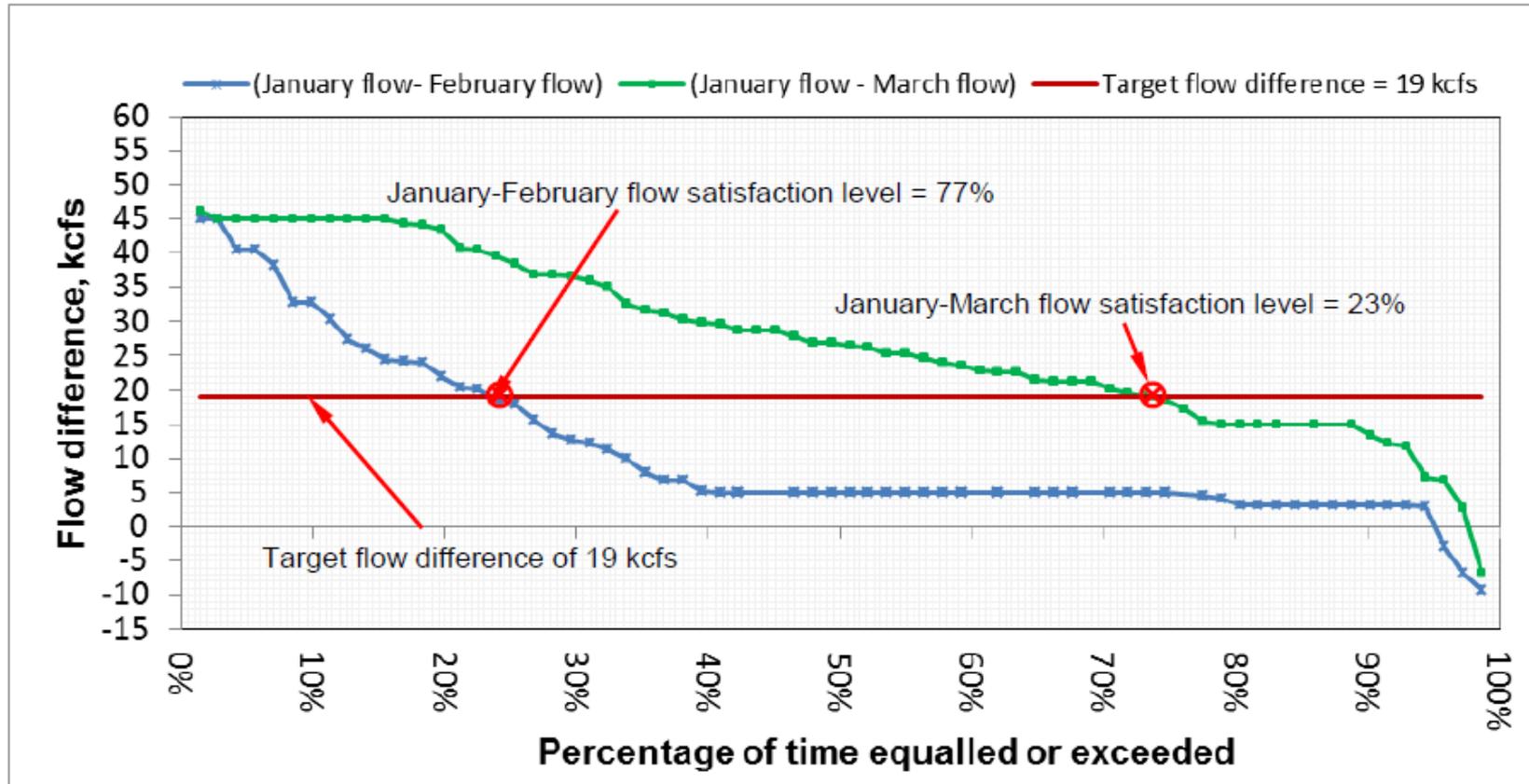
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Case studies

- Base case
 - Treaty Operation
- Fish Friendly Operation
 - All Non-power Treaty Operation
- Trade-off between FA & WF, TS and Power Obligations
 - Combined Arrow + Duncan outflow in January : 55 kcfs
 - Combined Arrow + Duncan outflow in January : 50 kcfs
 - Combined Arrow + Duncan outflow in January : 45 kcfs
 - Combined Arrow + Duncan outflow in January : 40 kcfs

Base Case study – Treaty Operation

- Treaty flow without any Non-Treaty and Non-power requirements.
- Study year: 1928-1998

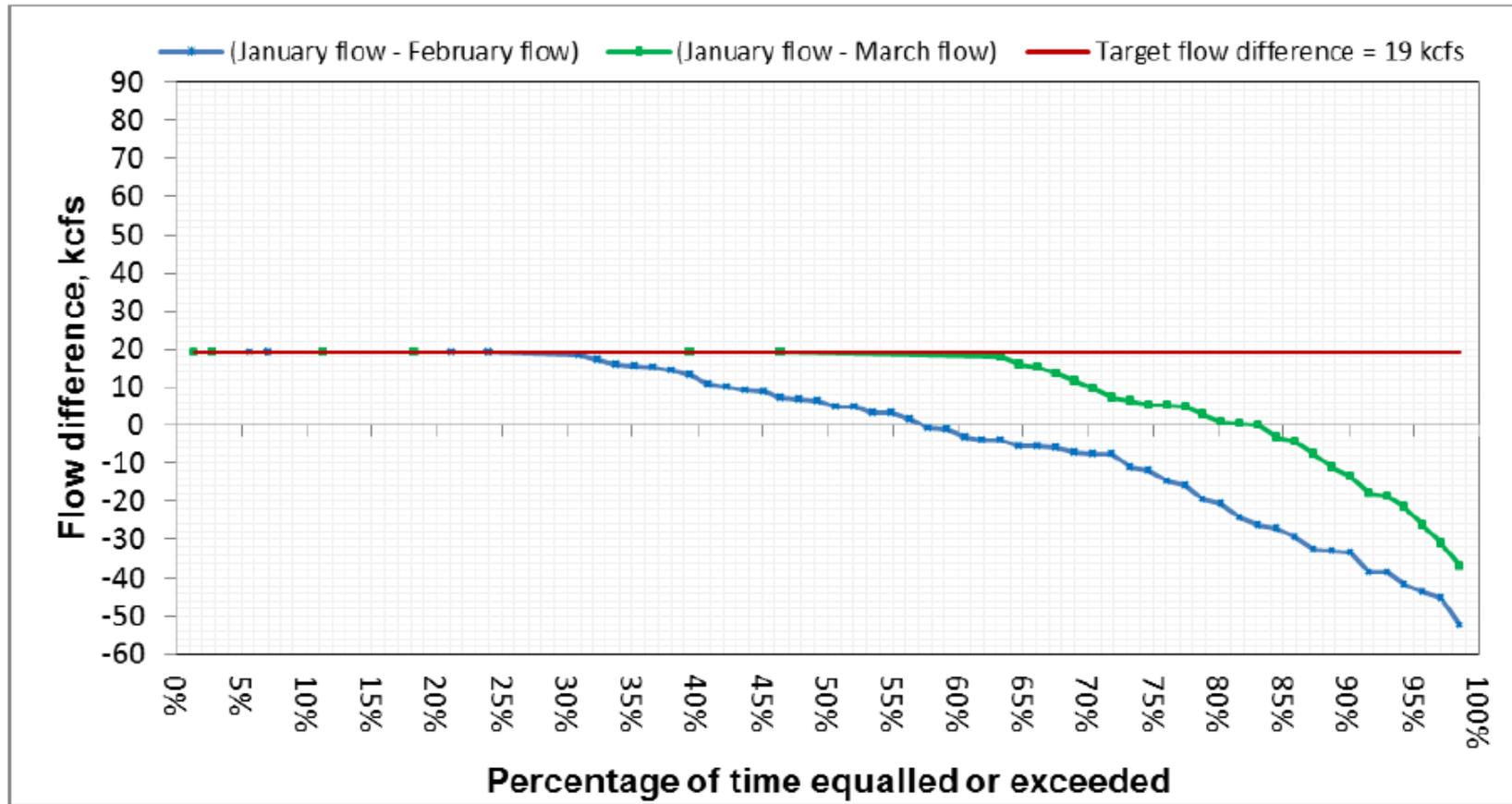


Flow Duration Curves for (January Flow-February Flow) and (January Flow – March Flow) (Base Treaty Case)

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Fish Friendly Operation

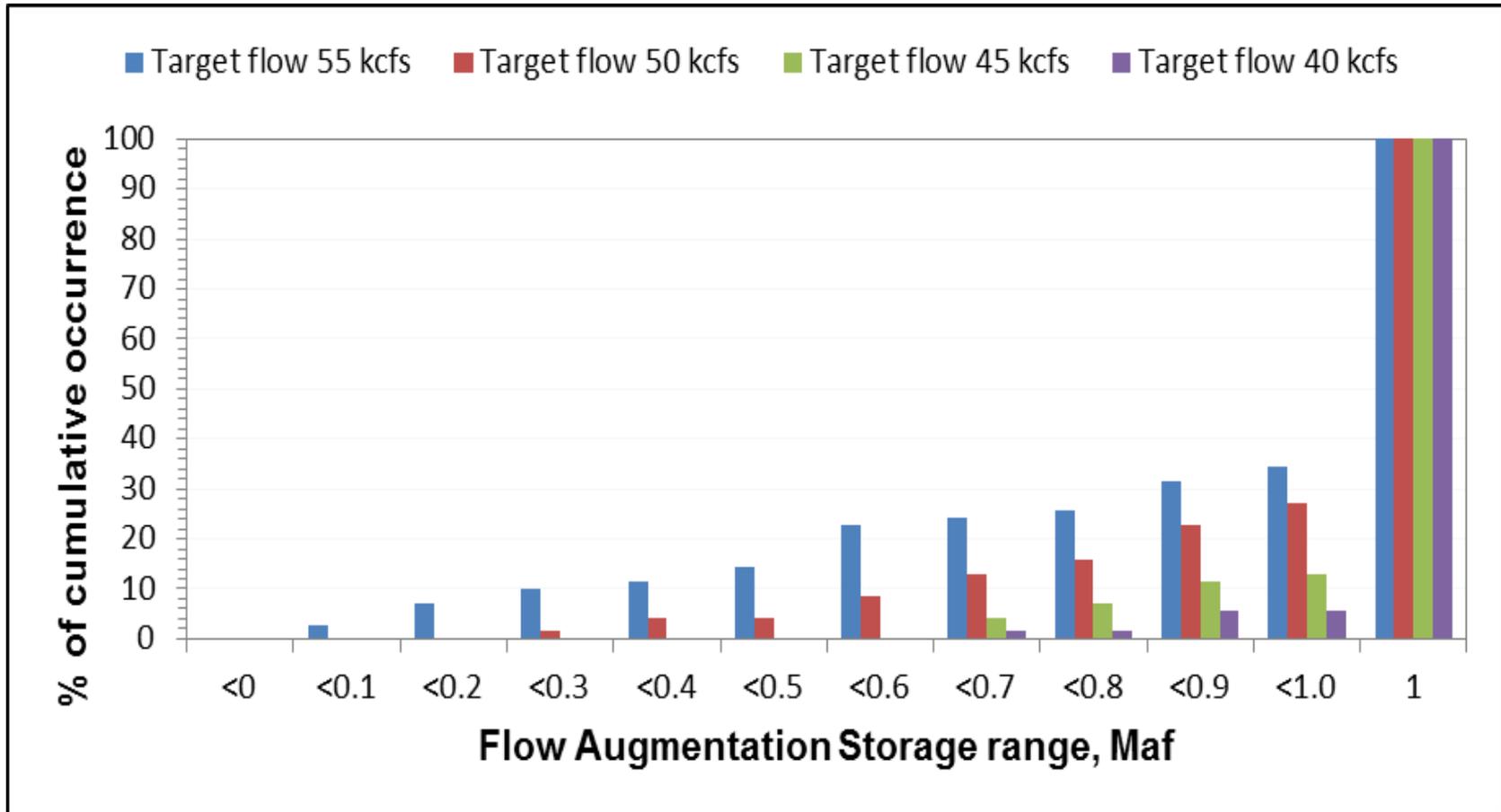
- All Non-power requirements (FA, WF & TS) are considered
- No target flow in January at Arrow reservoir



Flow Duration Curves for (January Flow-February Flow) and (January Flow - March Flow)

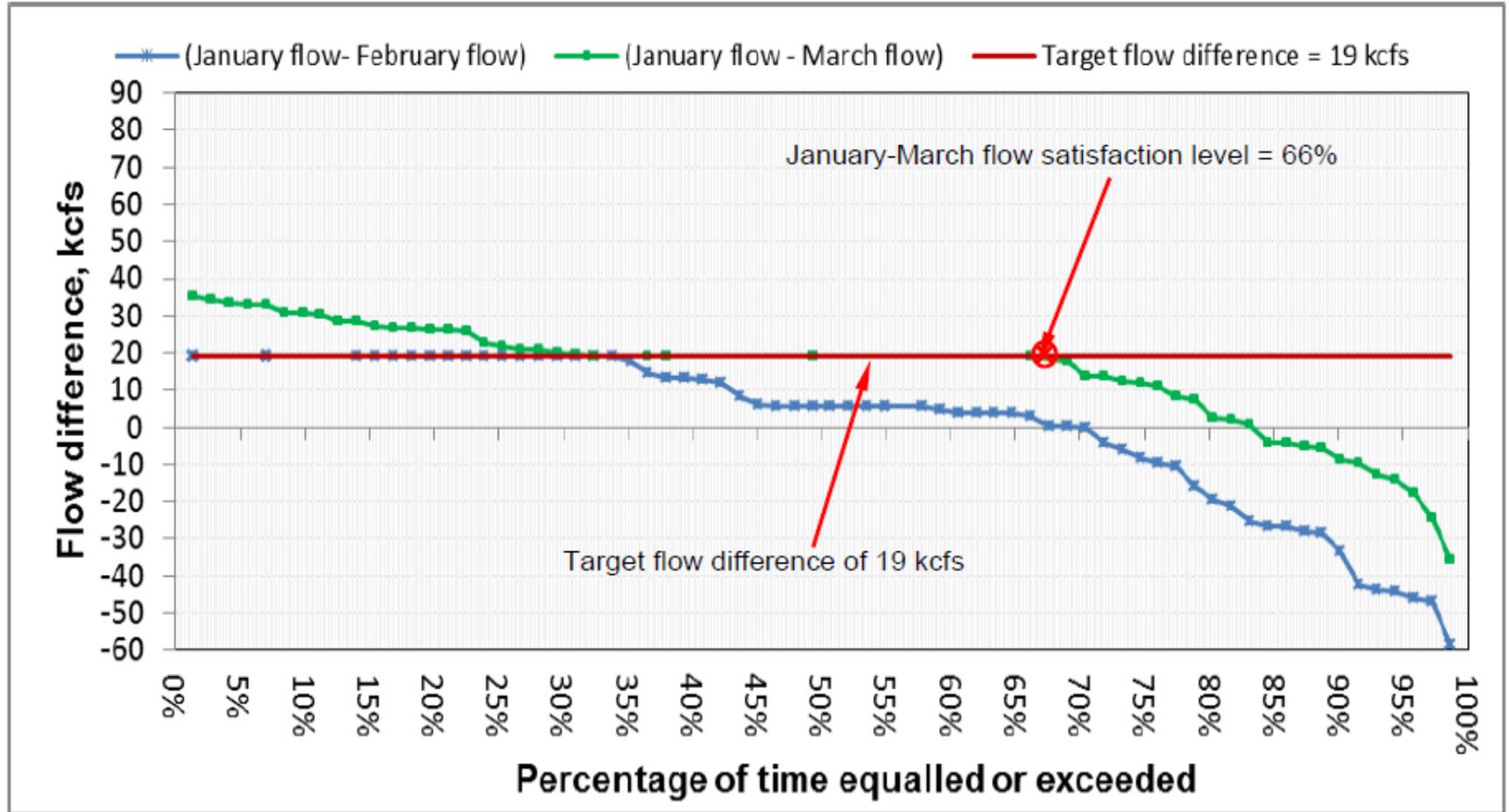
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Trade-off between FA & WF and Power Obligations



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Trade-off between FA & WF and Power Obligations (Min Jan Flow @ 55 KCFS Case – 48 KCFS at Arrow)

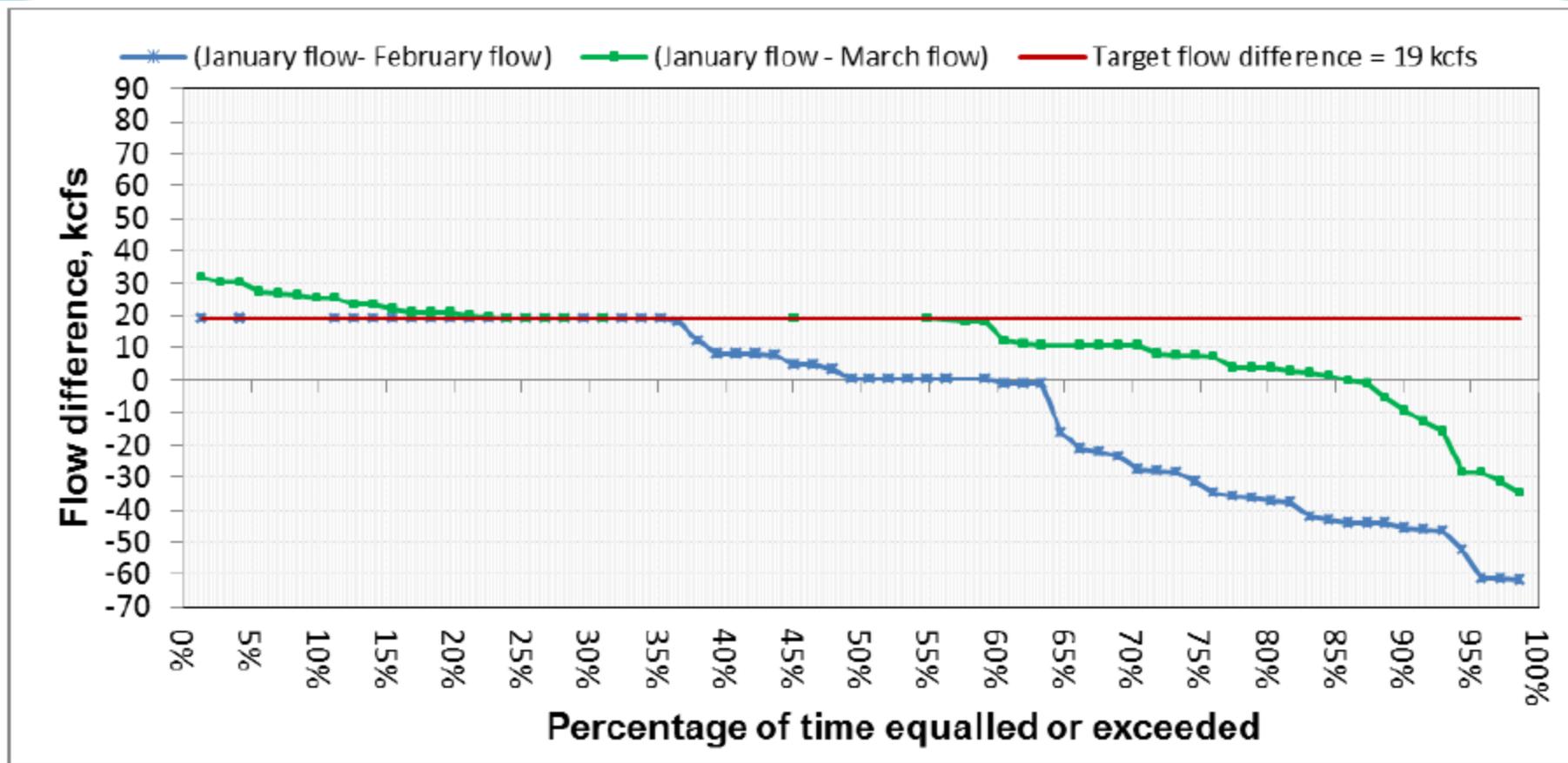


Flow Duration Curves for (January Flow-February Flow) and (January Flow – March Flow)
(Trade-Off Case: Target Flow 48 kcfs)

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Trade-off between FA & WF and Power Obligations

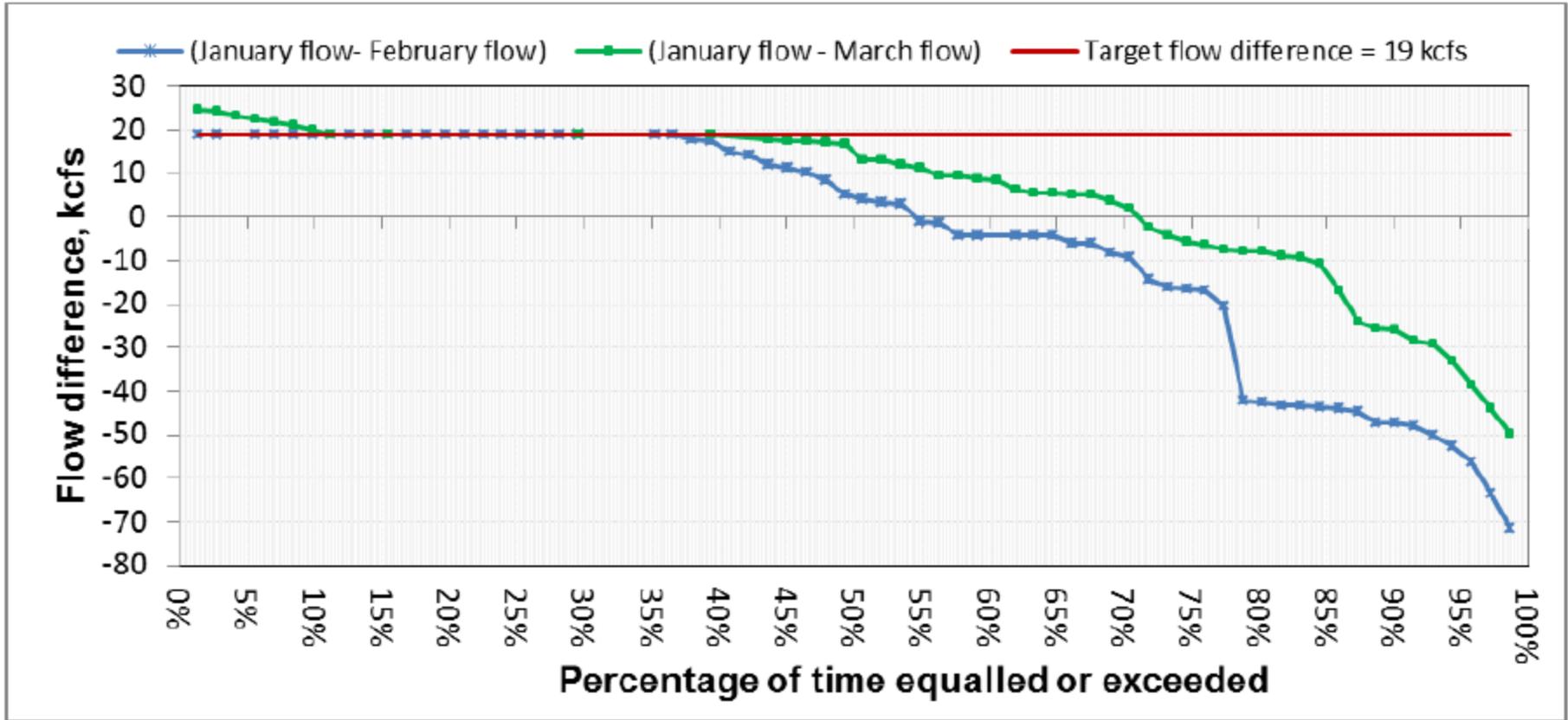
(Min Jan Flow @ 50 KCFS Case – 43 KCFS at Arrow)



Flow Duration Curves for (January Flow-February Flow) and (January Flow – March Flow)
(Trade-Off Case: Target Flow 43 kcfs)

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Trade-off between FA & WF and Power Obligations (Min Jan Flow @ 45 KCFS Case – 38 KCFS at Arrow)

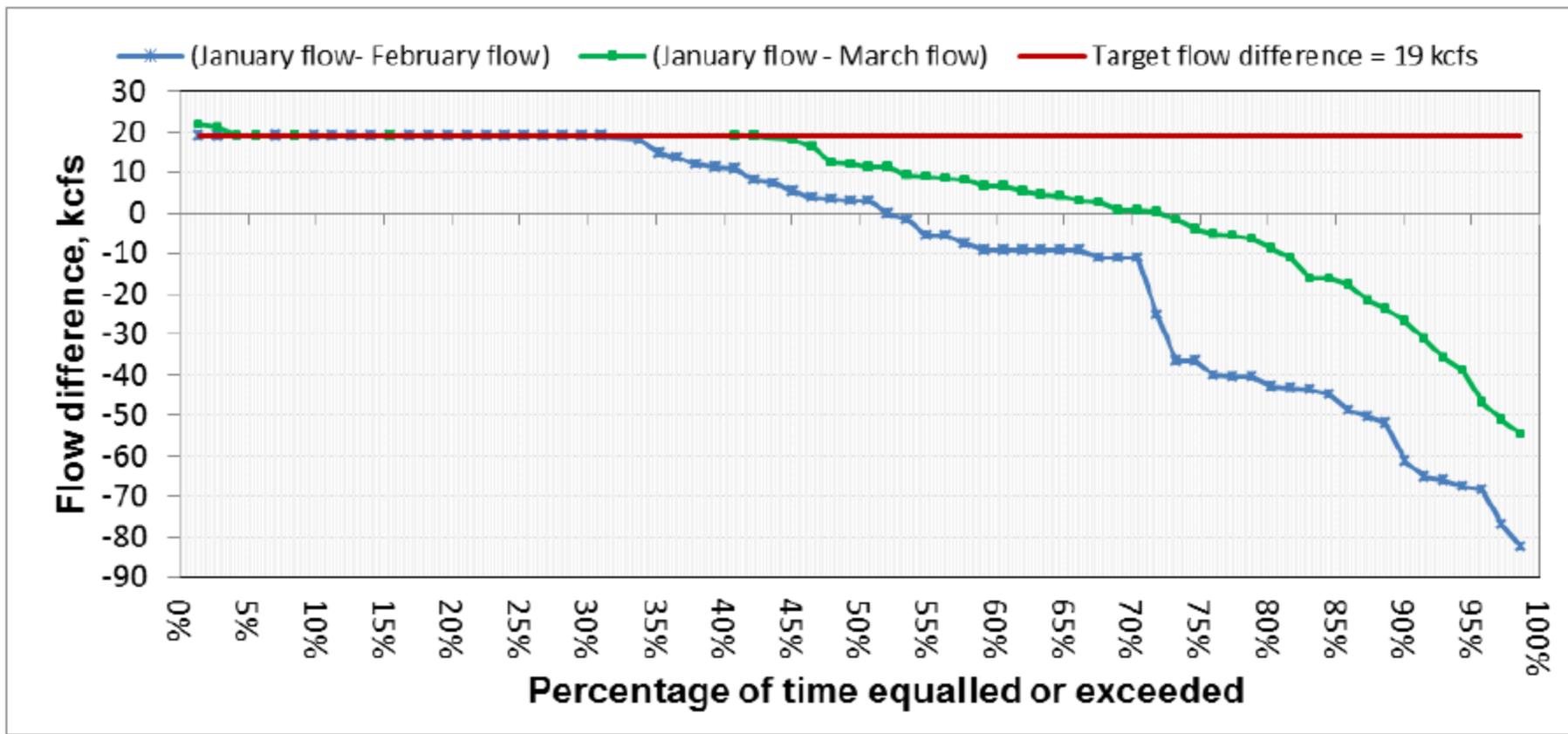


Flow Duration Curves for (January Flow-February Flow) and (January Flow – March Flow)
(Trade-Off Case: Target Flow 38 kcfs)

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Trade-off between FA & WF and Power Obligations

(Min Jan Flow @ 40 KCFS Case – 33 KCFS at Arrow)

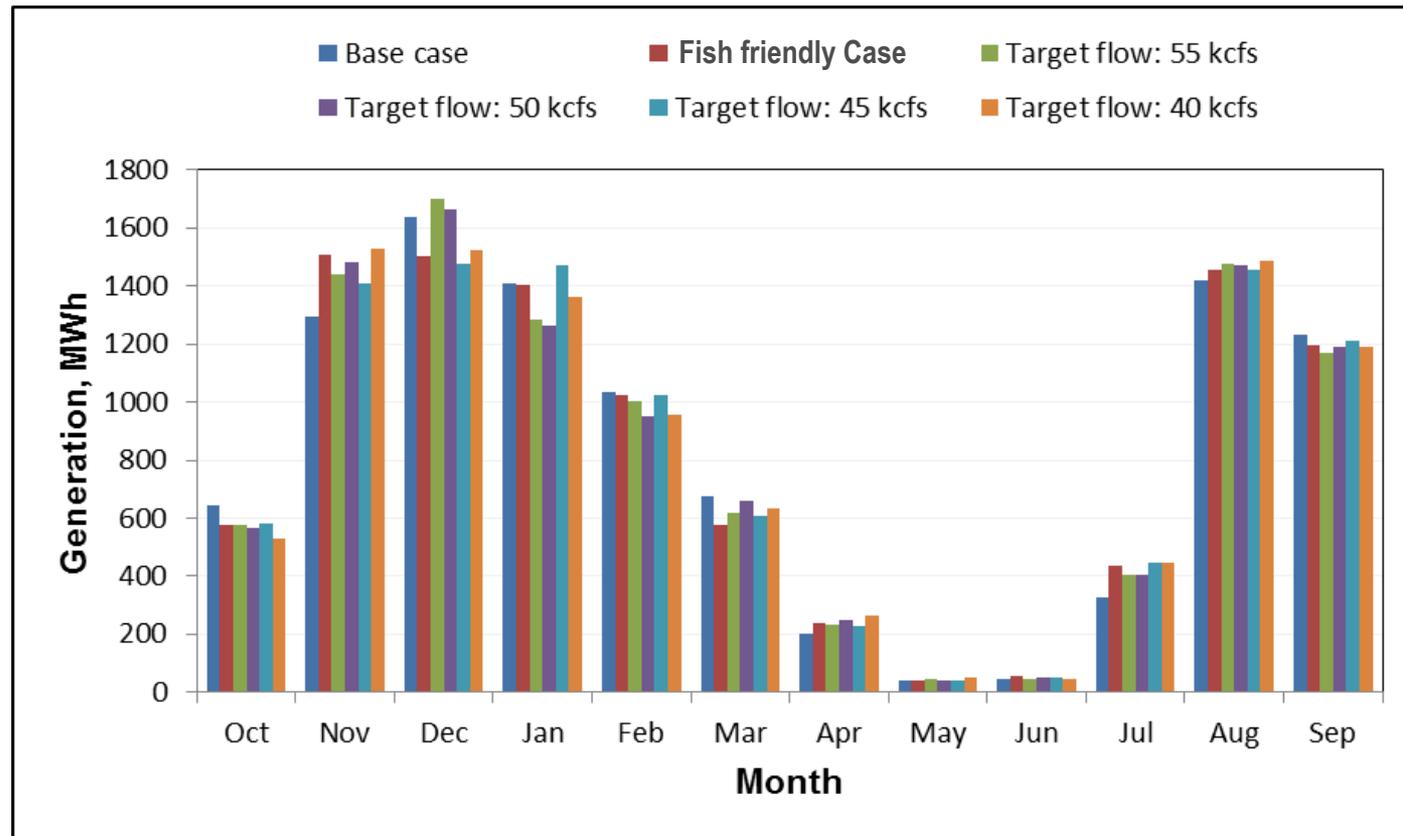


Flow Duration Curves for (January Flow-February Flow) and (January Flow – MarchFlow)
(Trade-Off Case: Target Flow 33 kcfs)

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Non-Power Impacts on generation

- No significant changes in the generation pattern
- Overall revenue increases with lowering January target flow



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Conclusions

- GOM model is flexible and easy to use in modeling hydroelectric systems
- GOM Optimization model is an excellent example of successful Industry-University Collaboration
- Optimization model can be easily and quickly expanded to model emerging issues and concerns
- GOM-GP model formulation captured complex, real life requirements more realistically than other methods
- GP Priority ordering of Objectives and constraints can be used for reliable operations planning of complex multi-reservoir system like the BC Hydro system.

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Acknowledgements

GOM Development Team:

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 - Ziad Shawwash
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 - Mikhail Kazakov
 - Alexander Feldman

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Questions?

Good Models Help in Maintaining Balanced Operations

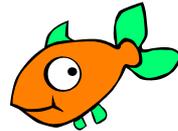
Reservoir Levels

Environmental Impact

Maintenance Outages

Weather, Inflow forecasts

System energy, capacity
etc ...?



Domestic Load



Market Opportunities
etc ...?



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