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

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UBC
UBC Civil Engineering
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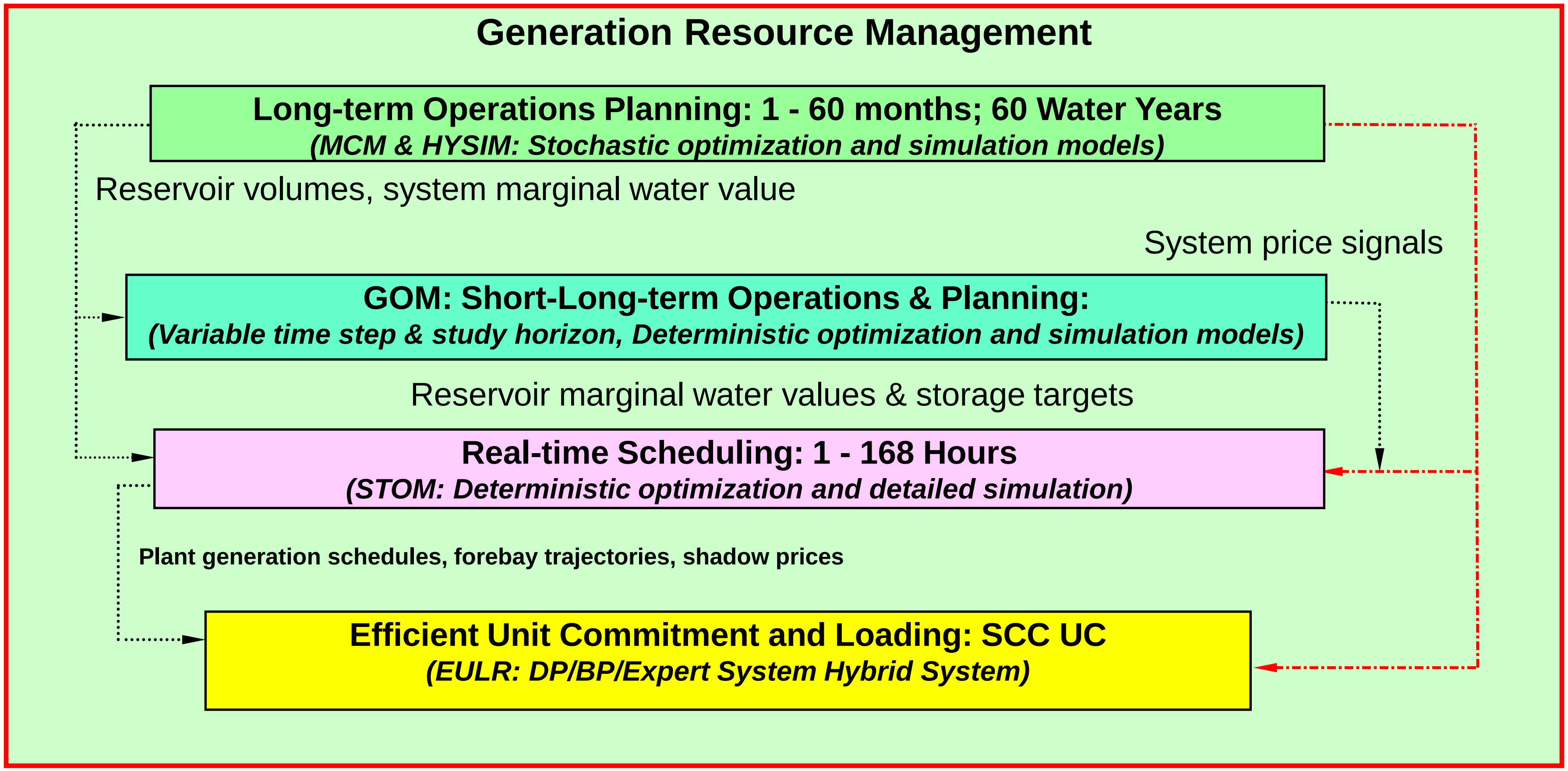
NSERC
BC hydro

Hydro System Modelling Hierarchy at BC Hydro

(Operations & Planning Models)



Introduction to BC Hydro GOM

- GOM: ***G**eneralized* **O**ptimization **M**odel developed in-house to model the BC Hydro system

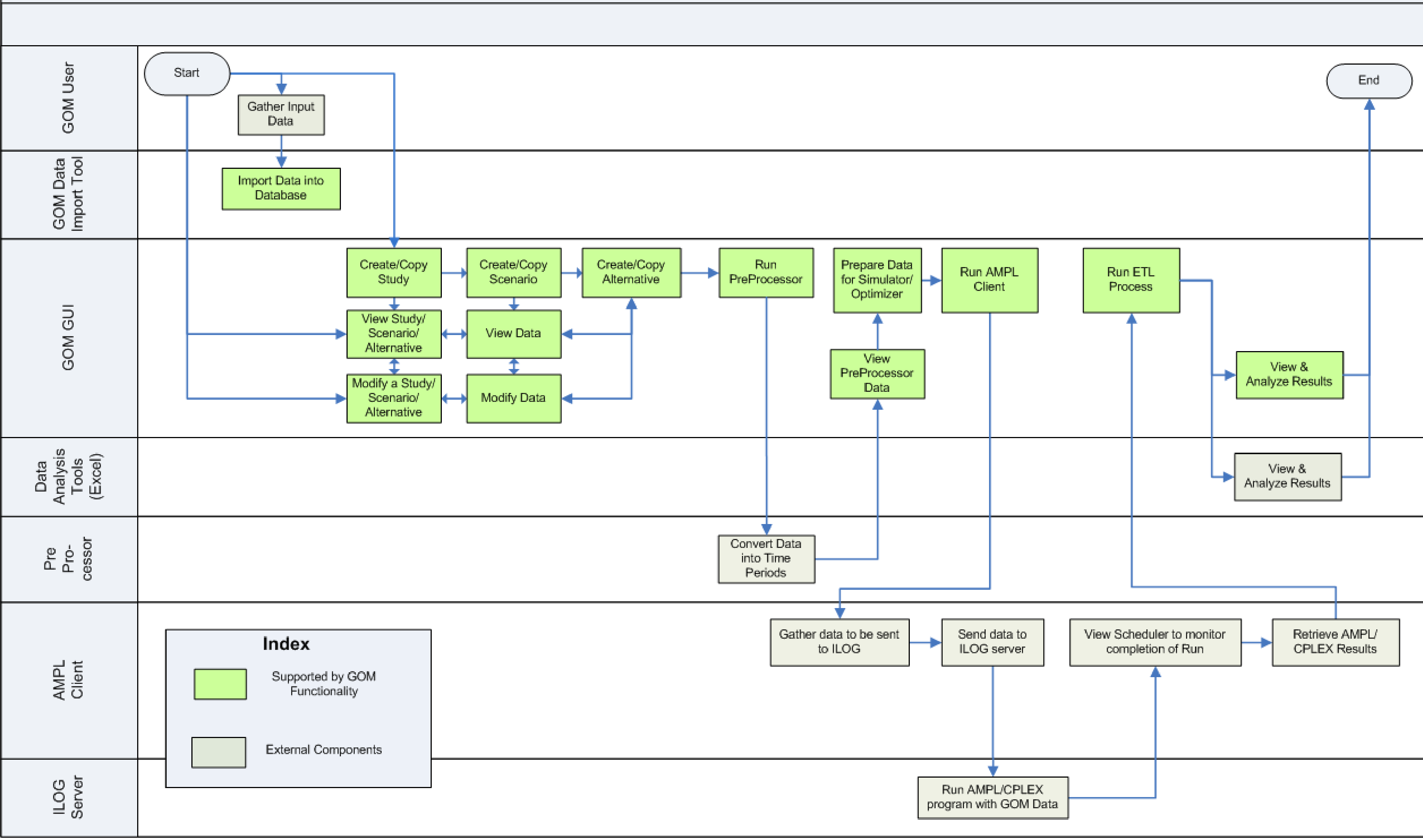
- GOM used to develop detailed system generation, trade and reservoir operations schedules

- 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

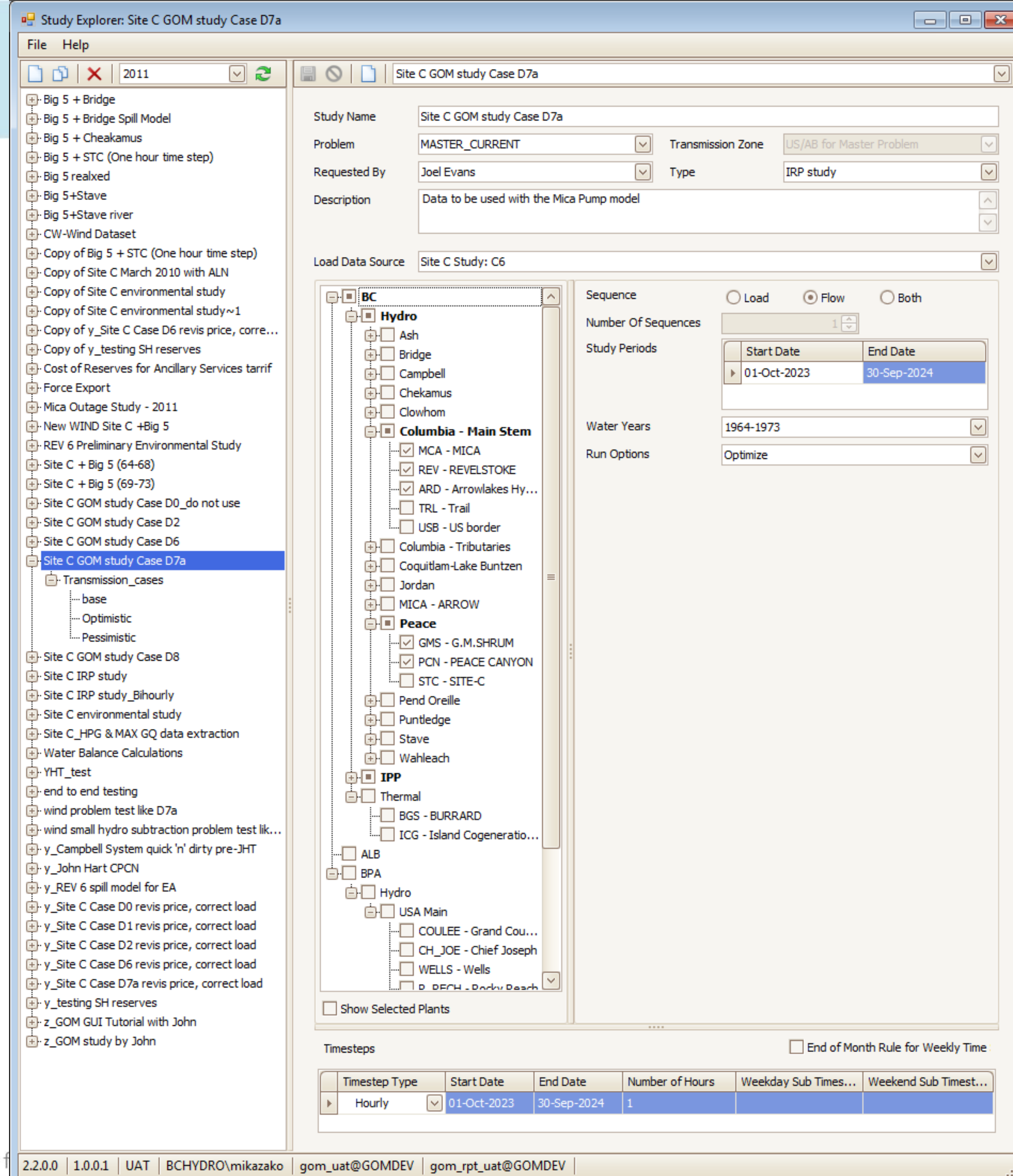
GOM Components and Process



GOM GUI

Easy to use **Study** interface

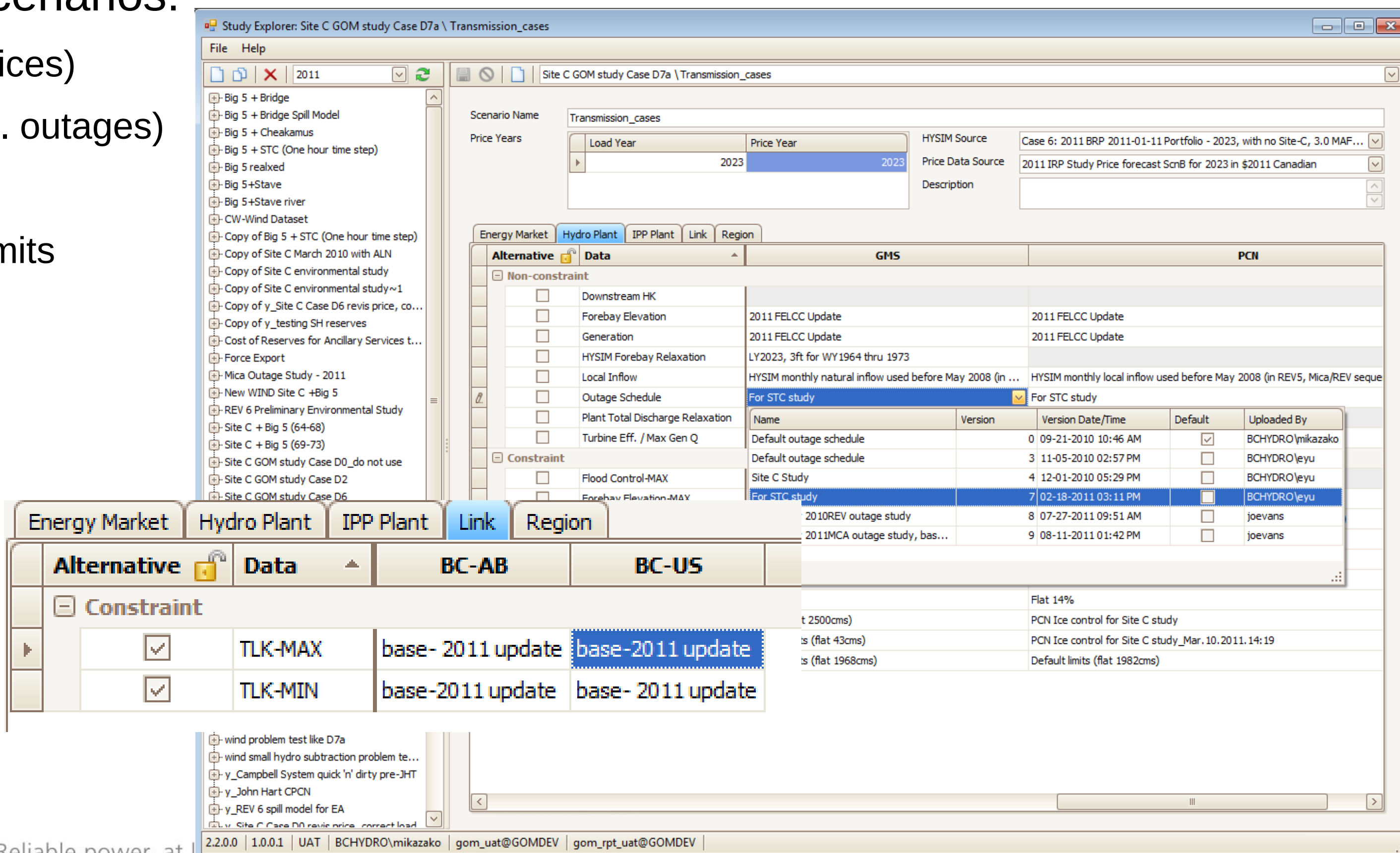
- Define optimization problem
  - Standard/ w/wo Wind, Regional (TX), CRT …
- Select plants optimized
  - Hydro, Thermal, IPPs
- Select study type
- Select study sequence
  - Flow, load or both
- Select Run Option
  - Simulate/ Optimize or both



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

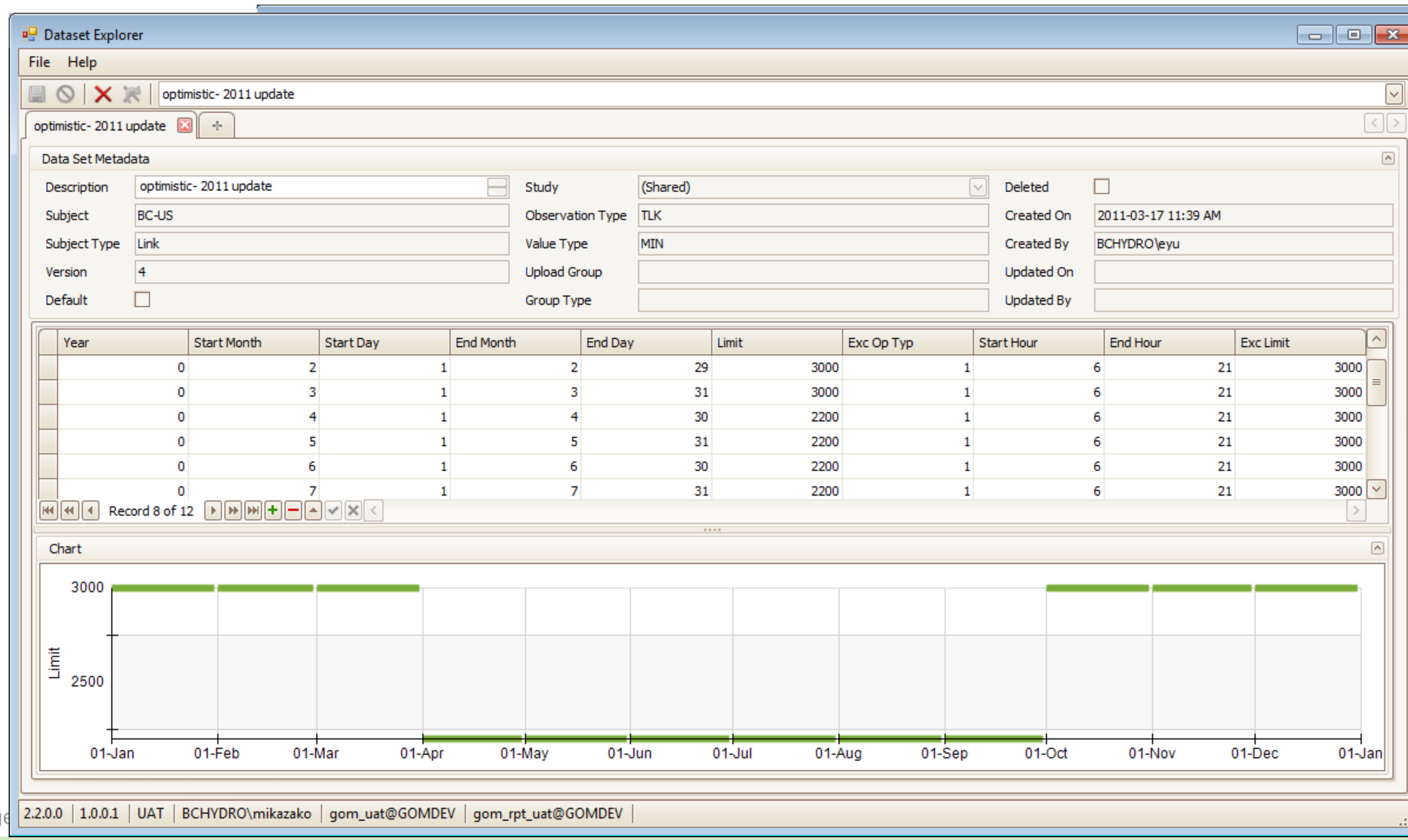


Reliable power, at low cost, for generations. Reliable power, at l

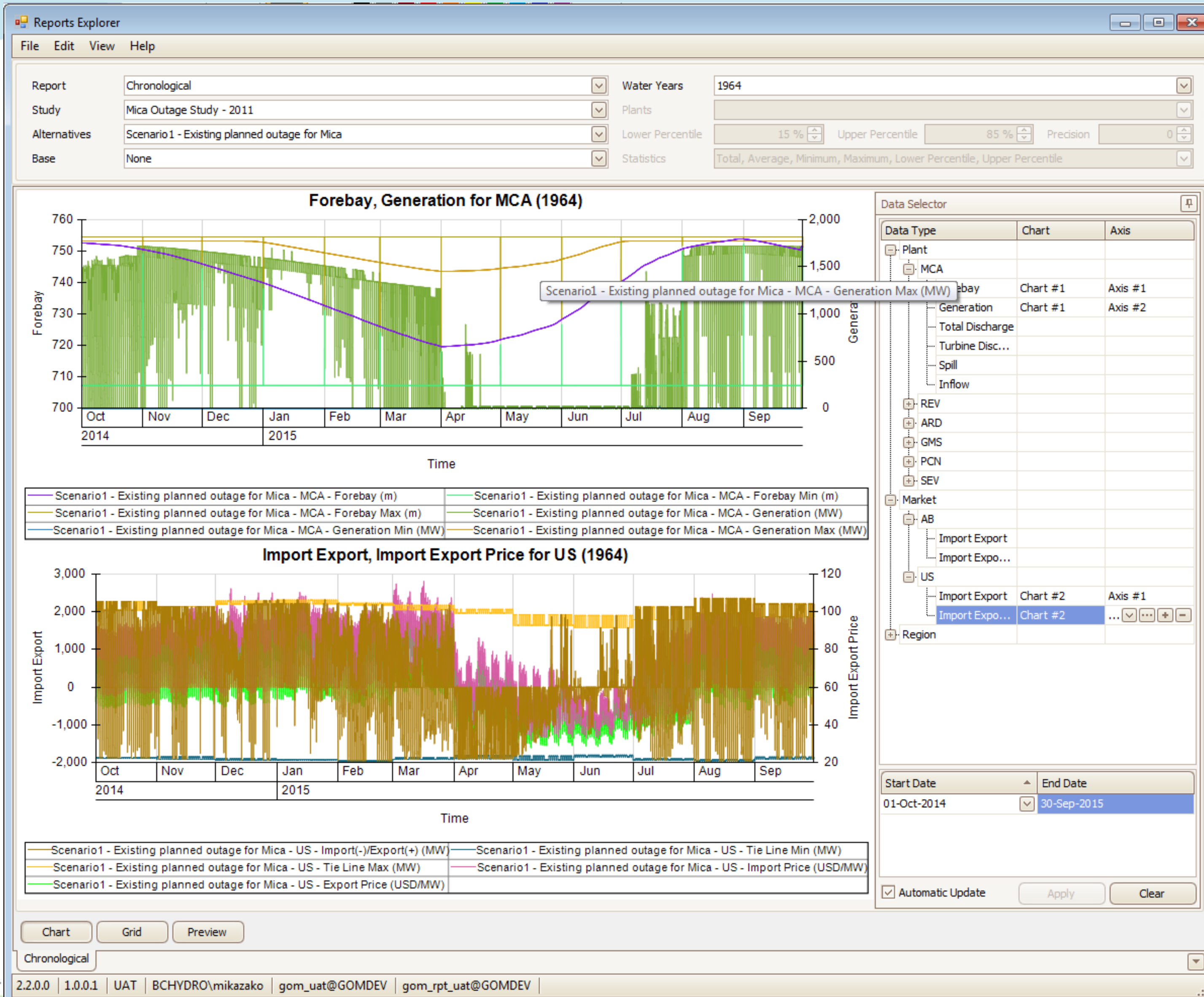
GOM GUI

Easy to use **Alternative GUI**

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

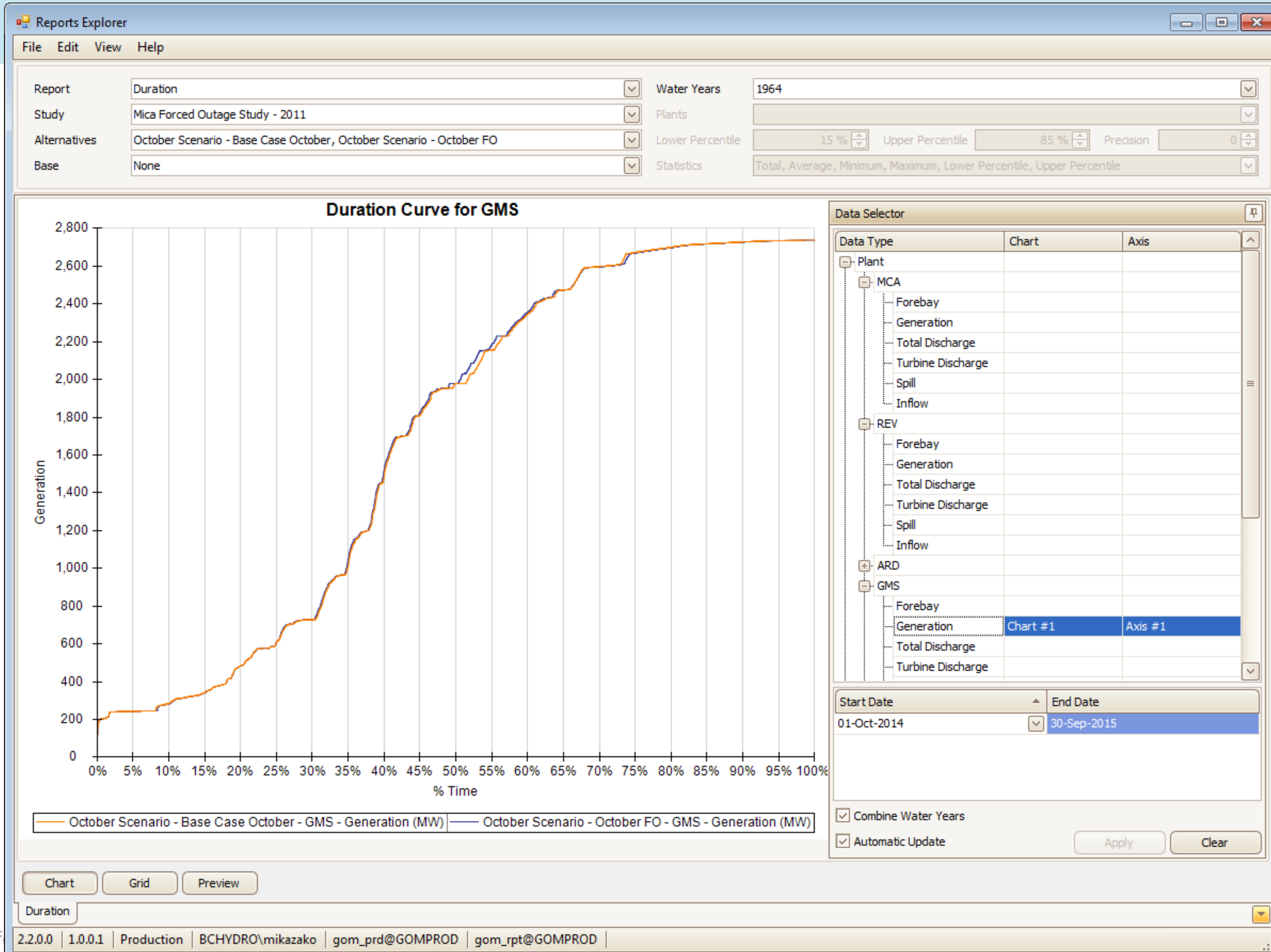


GOM Model Results – Optimized Forebay, Generation, Import/ Export

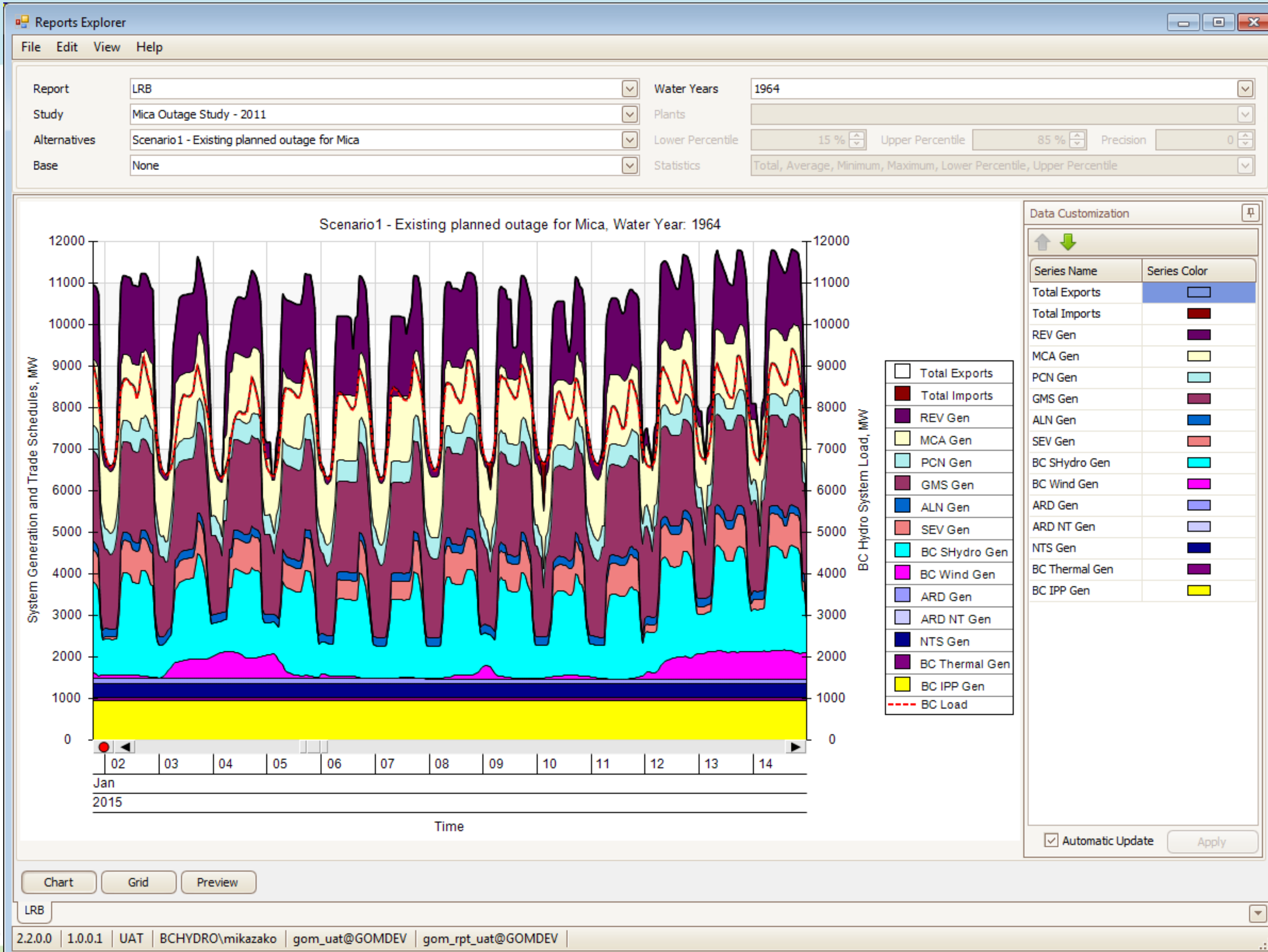


Reliable power, at low cost, for generations.

GOM Model Results – Generation Duration Curves



GOM Model Results – Load – Resource Balance



Reliable power, at low cost,

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

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 Uprate
  - Site C studies
  - Rehabilitation and upgrade of Campbell system
- Modelling of non-power flow requirements for CRT analysis

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

GOM Optimization Model: Objective Function

- Maximize:

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

Other objectives for special cases:

- Max. revenue given fixed storage targets:

    ∑ Spot sales in US * US Price +
    ∑ Spot sales in AB * AB Price

- Max Efficiency given a fixed market:

    ∑ (End Storage – End Reference)* HK

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

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:

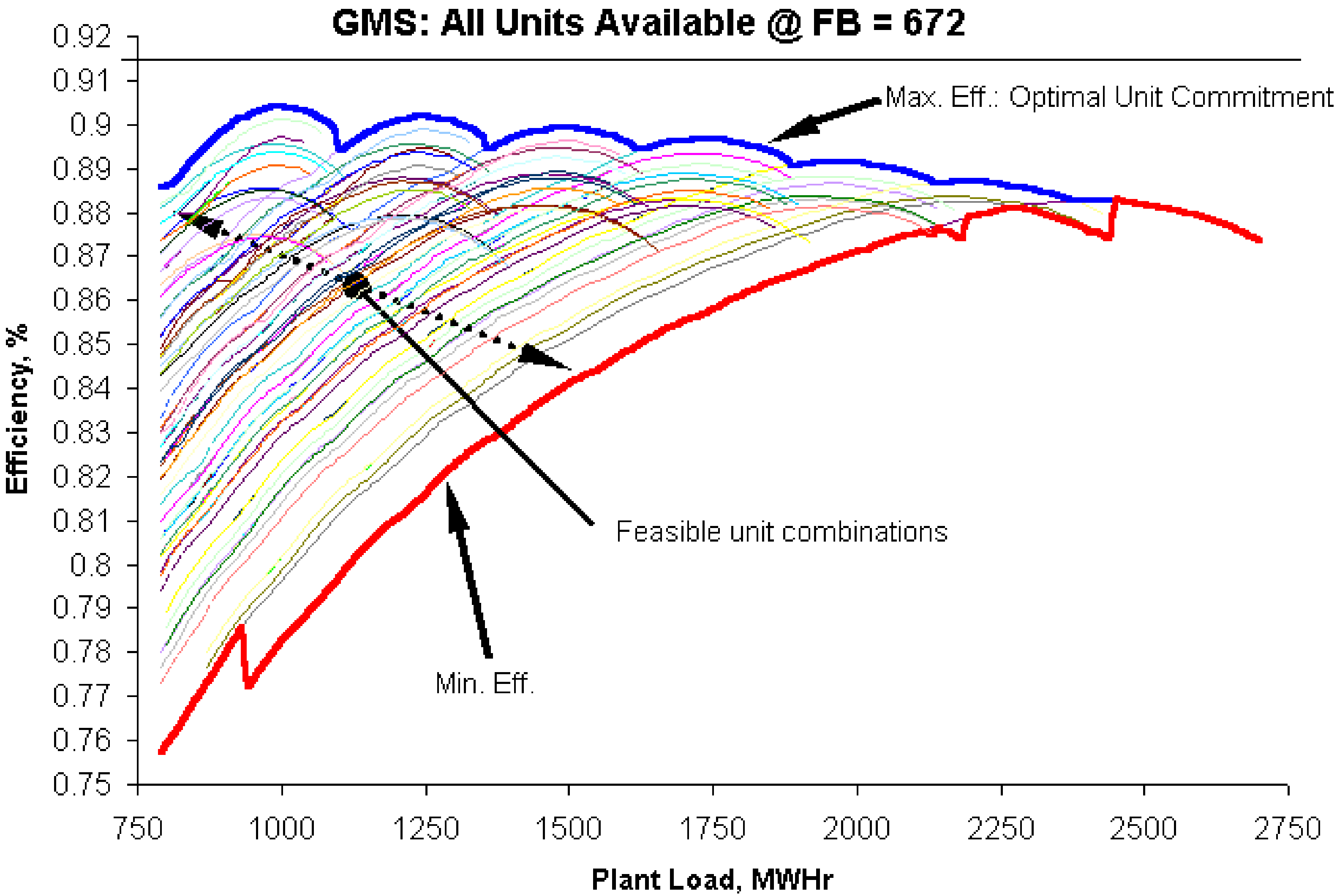
$$S_{j,t+1} = S_{j,t} + \left[\pm \sum_{j=1}^{J} \sum_{h=1}^{\forall h} \left(QT_{j,t,h} * HC_{j,k}^{T} + QS_{j,t,h} * HC_{j,k}^{S} \right) * H_{t,h} + Q_{j,t}^{in} * H_t \right] / 24.$$

$HC_{j,k}^{T} =$	j	$j+1$	$j+2$	$\cdots$	$J-1$	J
k	0	1	0	$\cdots$	0	0
$k+1$	0	0	0	$\cdots$	0	0
$k+2$	0	0	1	$\cdots$	0	0
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
$K-1$	0	0	0	$\cdots$	1	1
K	0	0	0	$\cdots$	$\vdots$	0

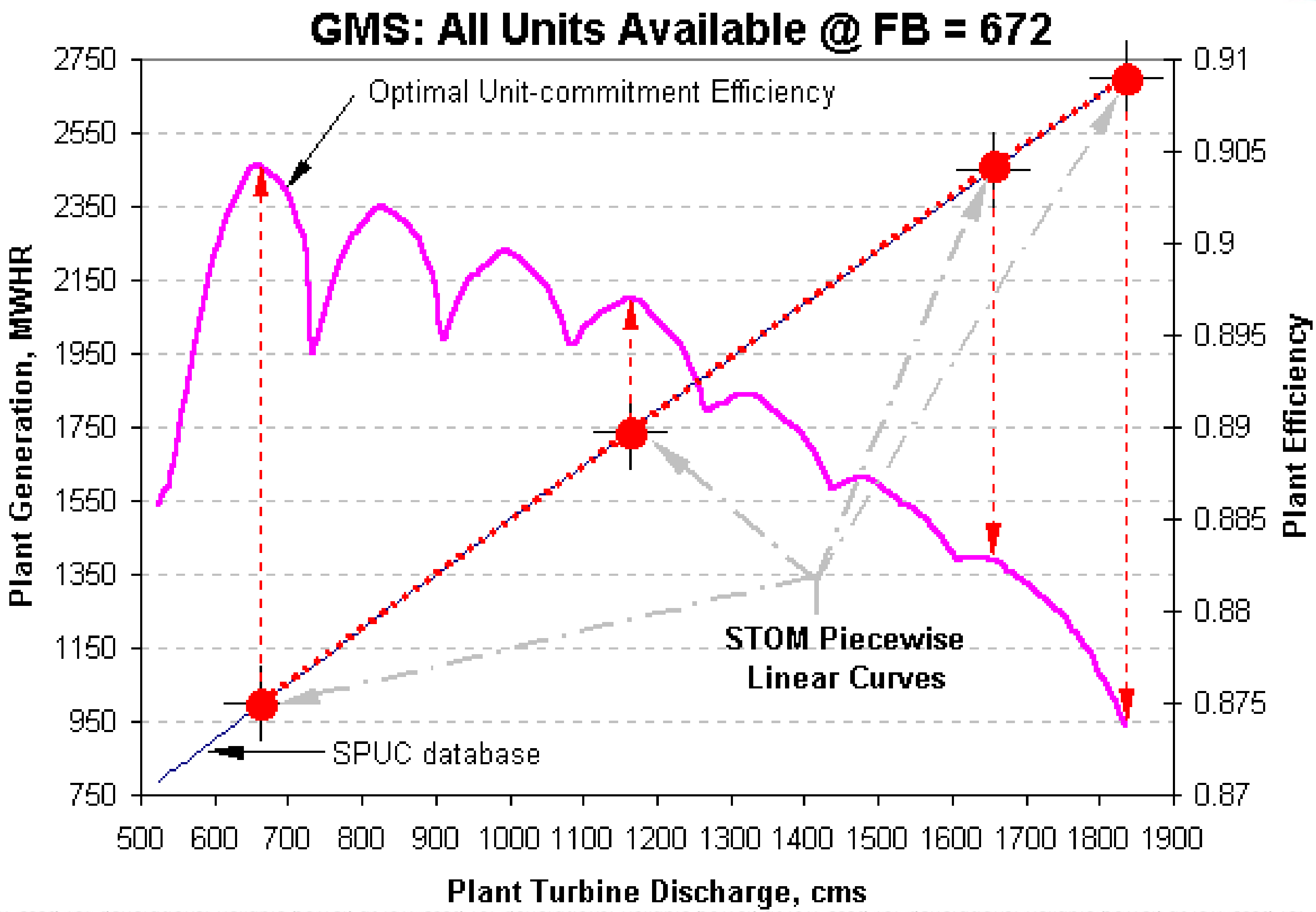
GOM Main Assumption

- **Main Assumption:**
  - Optimal Unit Commitment & Loading (**S**tatic **P**lant **U**nit **C**ommitment)
- **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 (plant flow, GH), HK derived from results of hourly studies**

GOM Main Assumption



GOM Main Assumption



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

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.

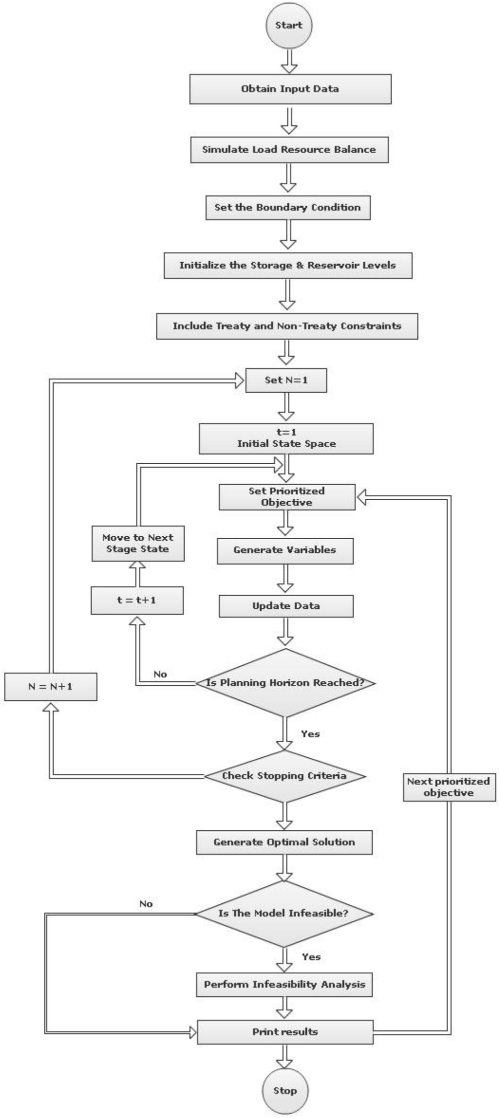
Different Non-Power Requirements:

- 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

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



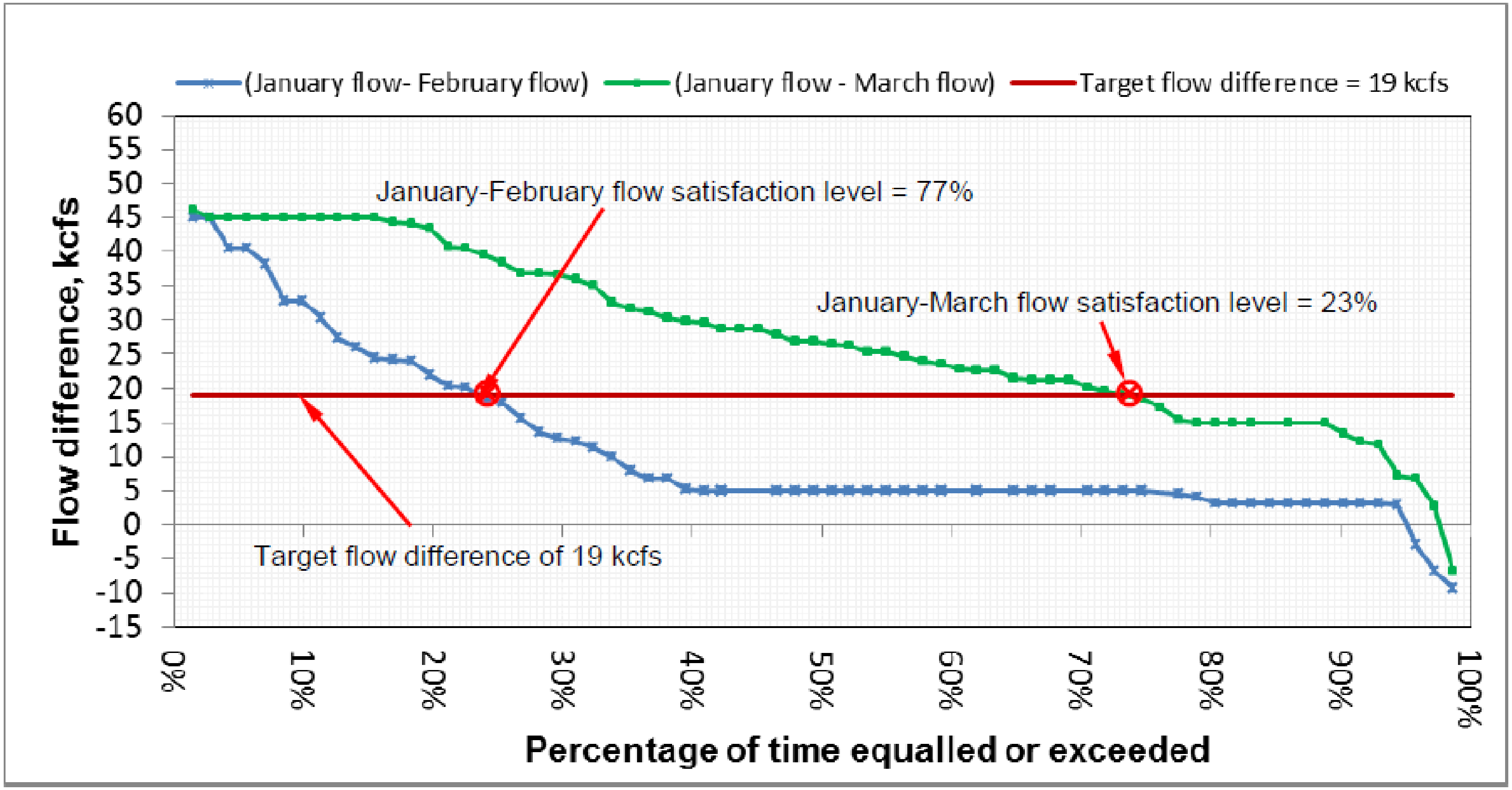
Al-Mamun MASc Thesis, 2012
(coming soon to dSpace UBC)

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

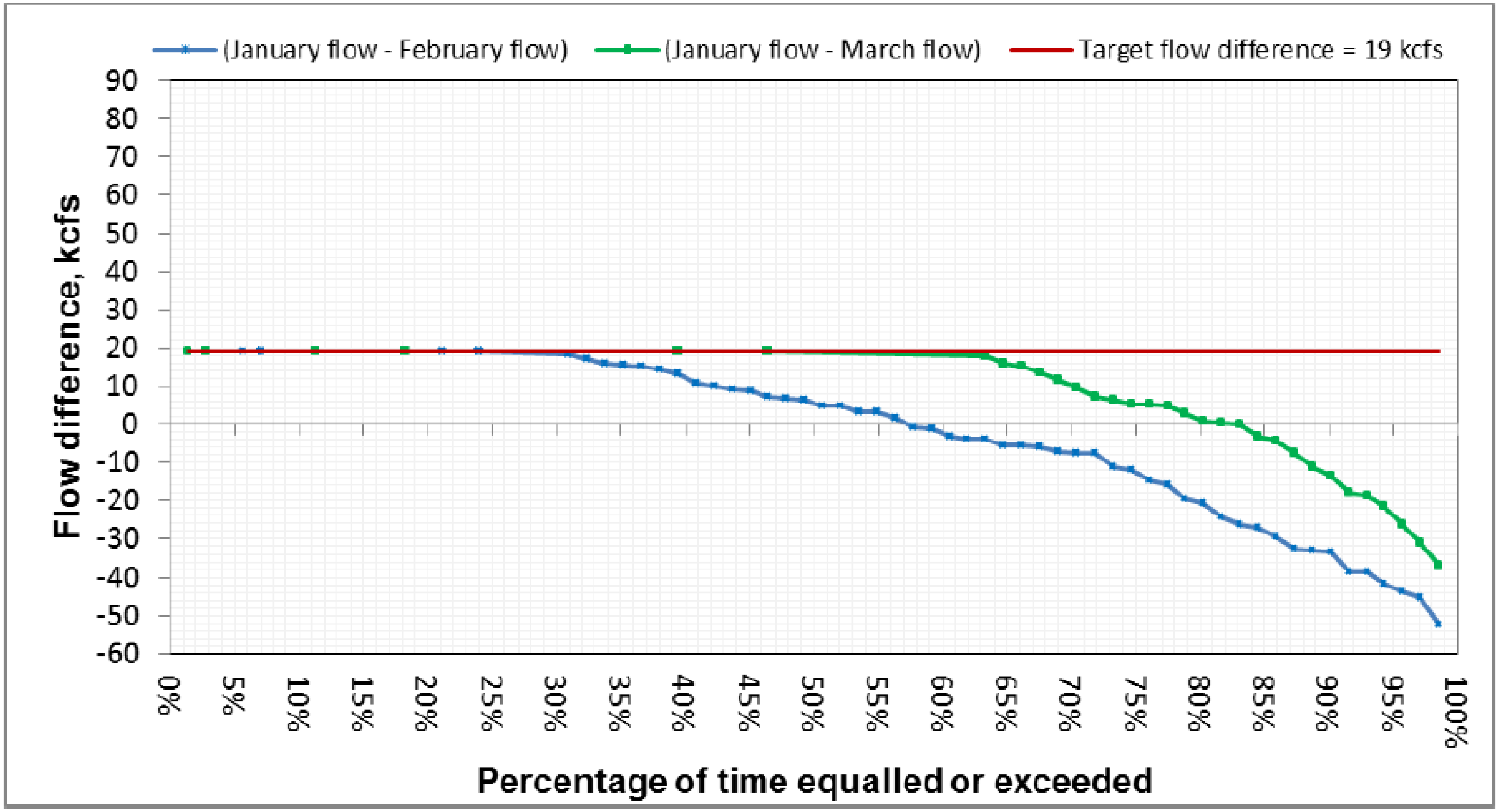
- Treaty flow without any Non-Treaty and Non-power requirements.
- Study year: 1928-1998



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

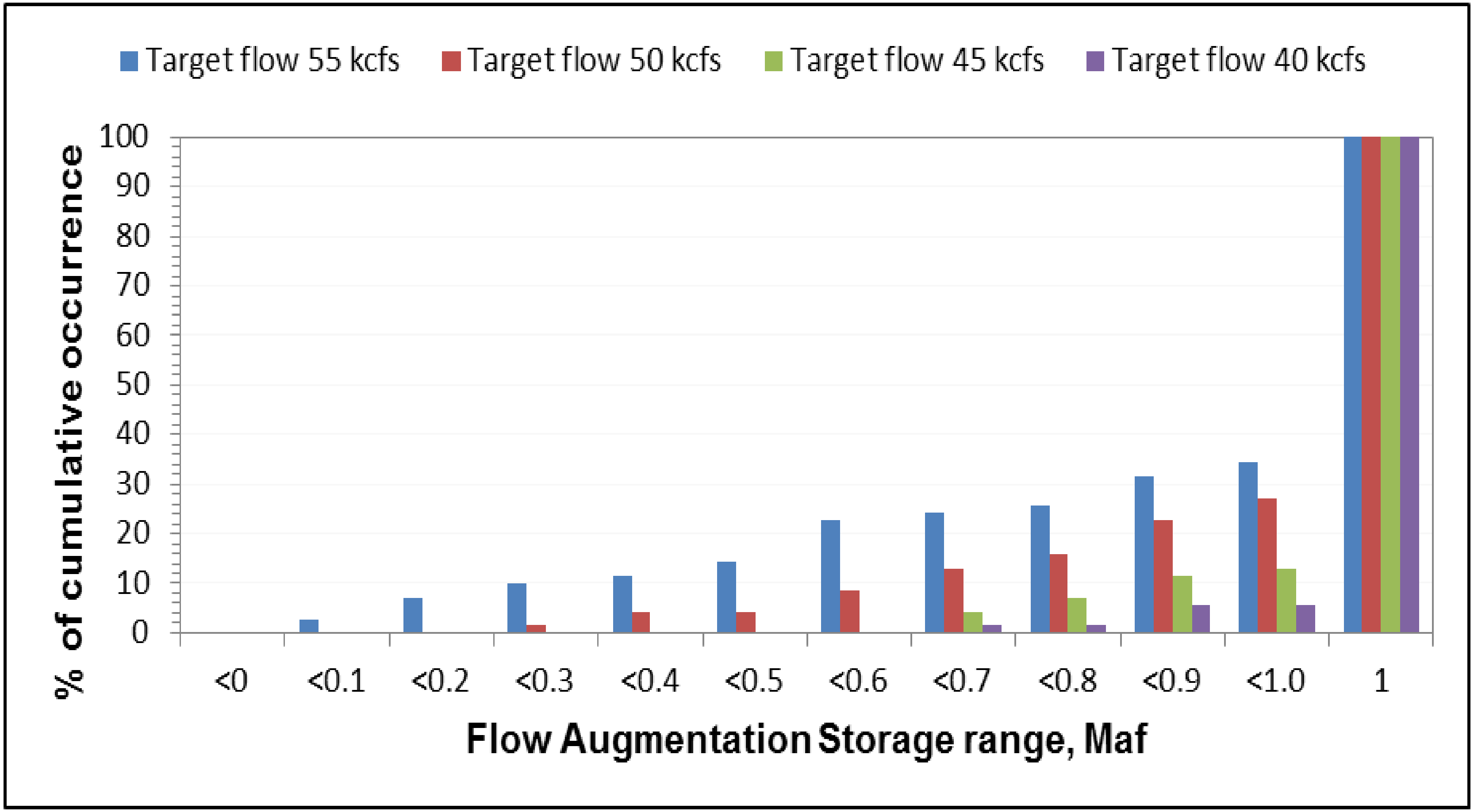
Fish Friendly Operation

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



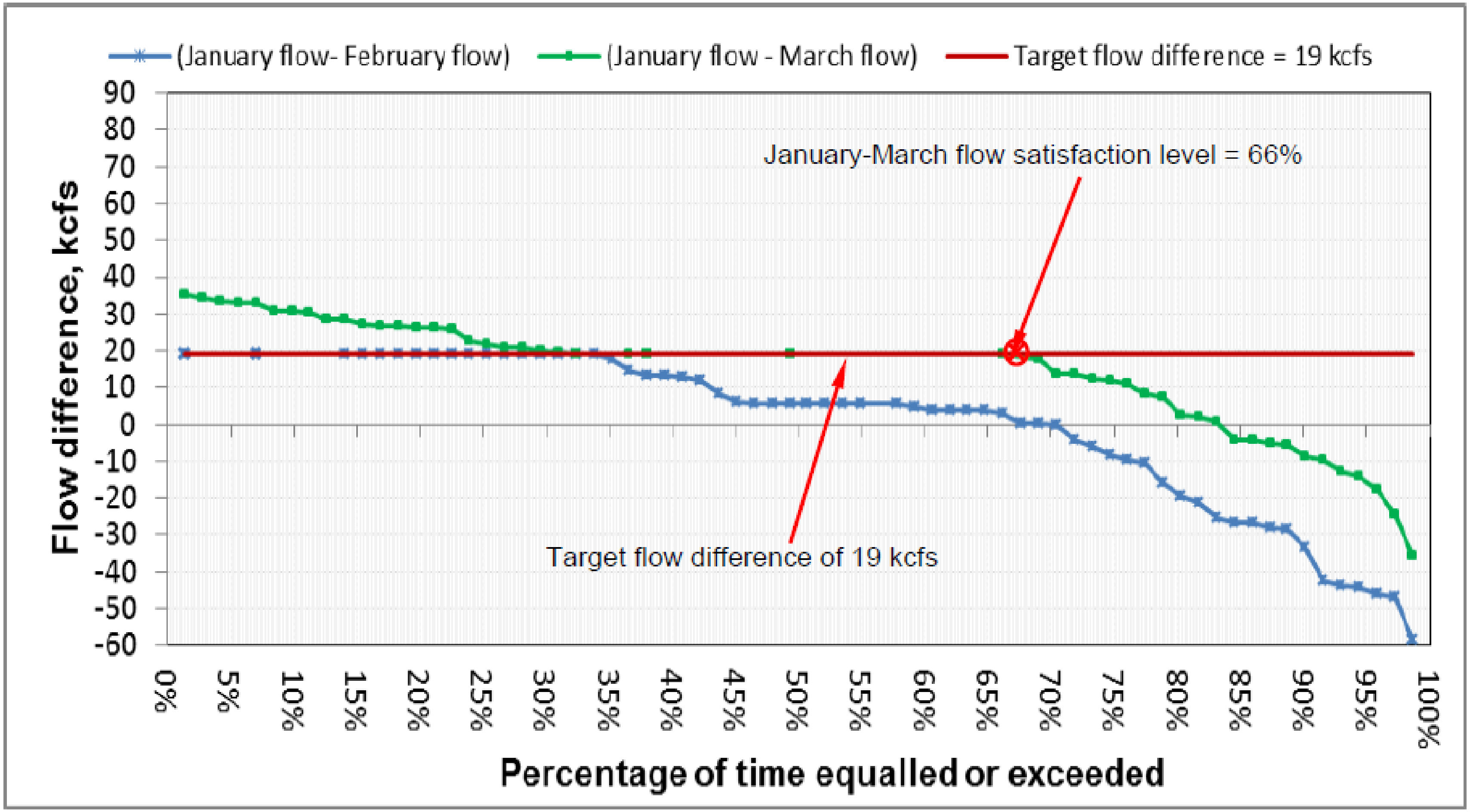
Flow Duration Curves for (January Flow-February Flow) and (January Flow – March Flow)

Trade-off between FA & WF and Power Obligations



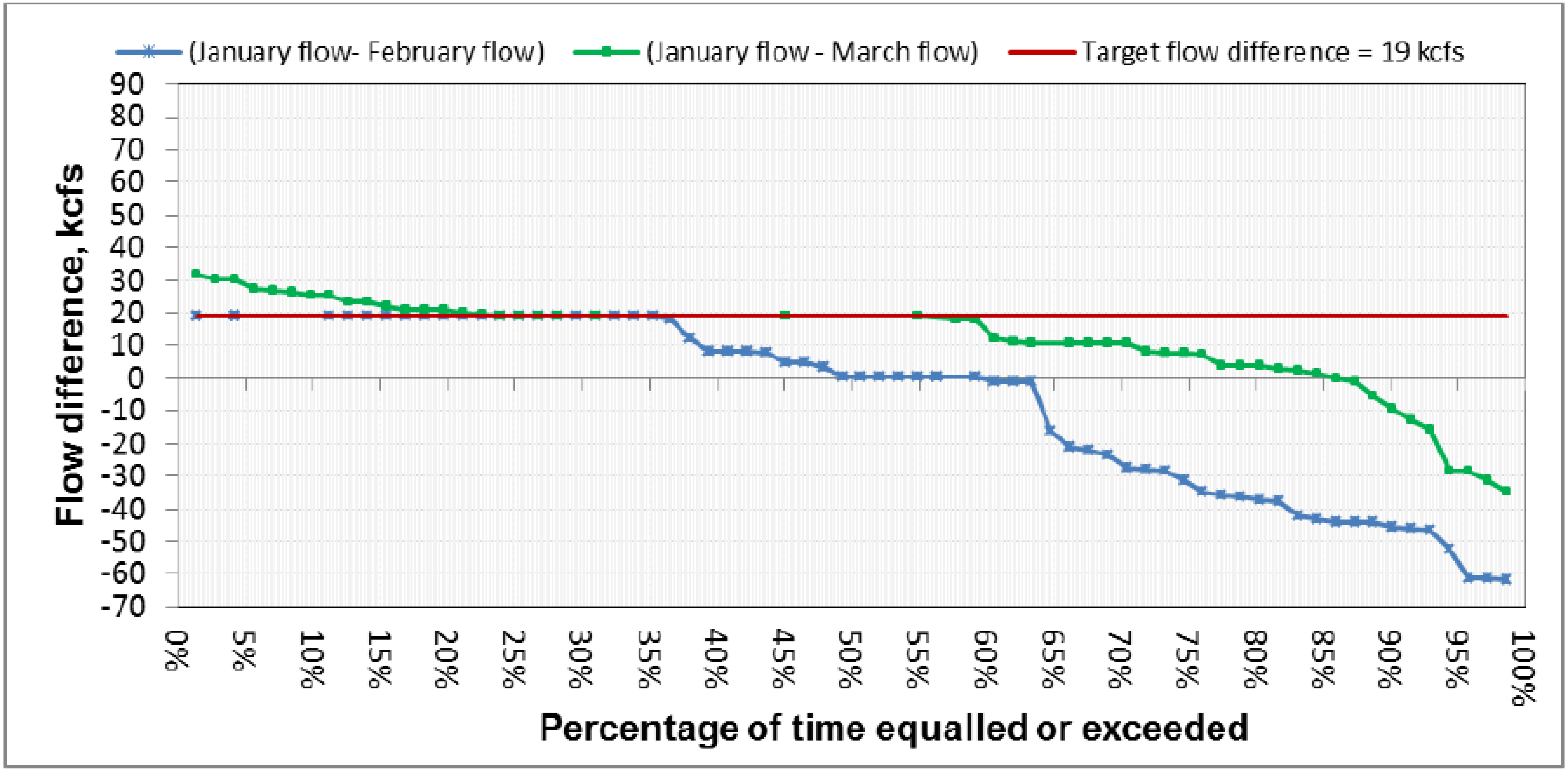
Trade-off between FA & WF and Power Obligations

(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)

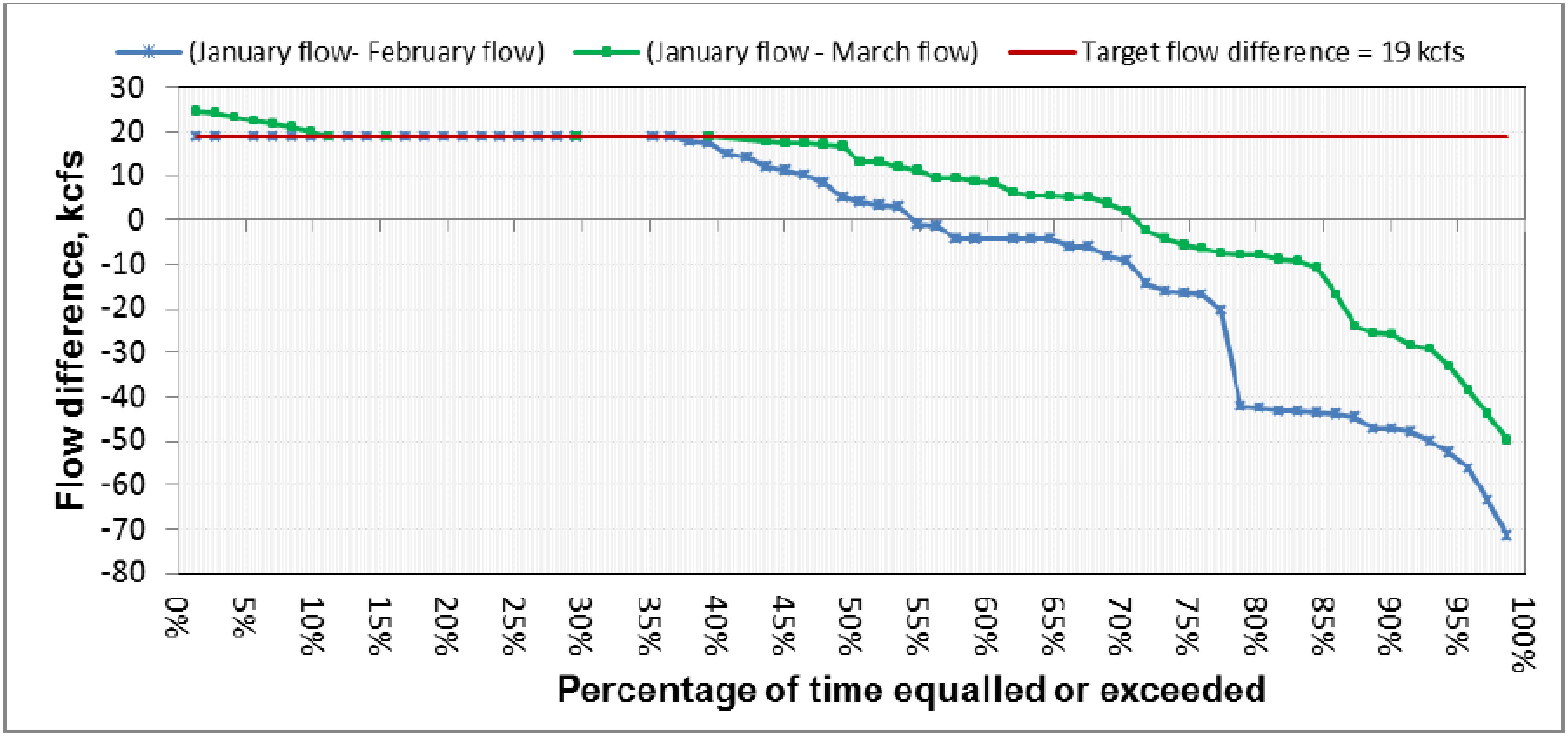
Trade-off between FA & WF and Power Obligations
(Min Jan Flow @ 50 KCFS Case – 43 KCFS at Arrow)



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

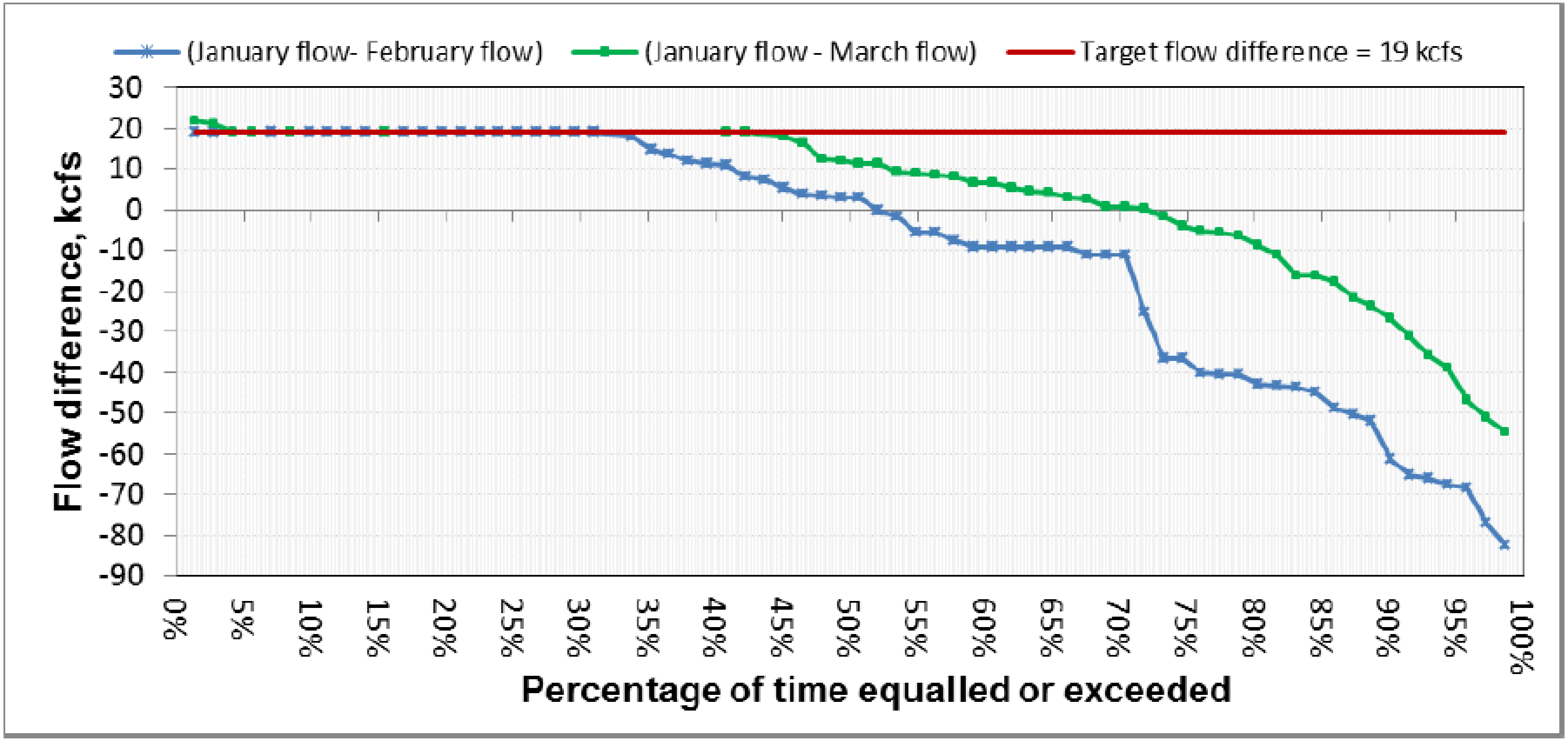
Trade-off between FA & WF and Power Obligations

(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)

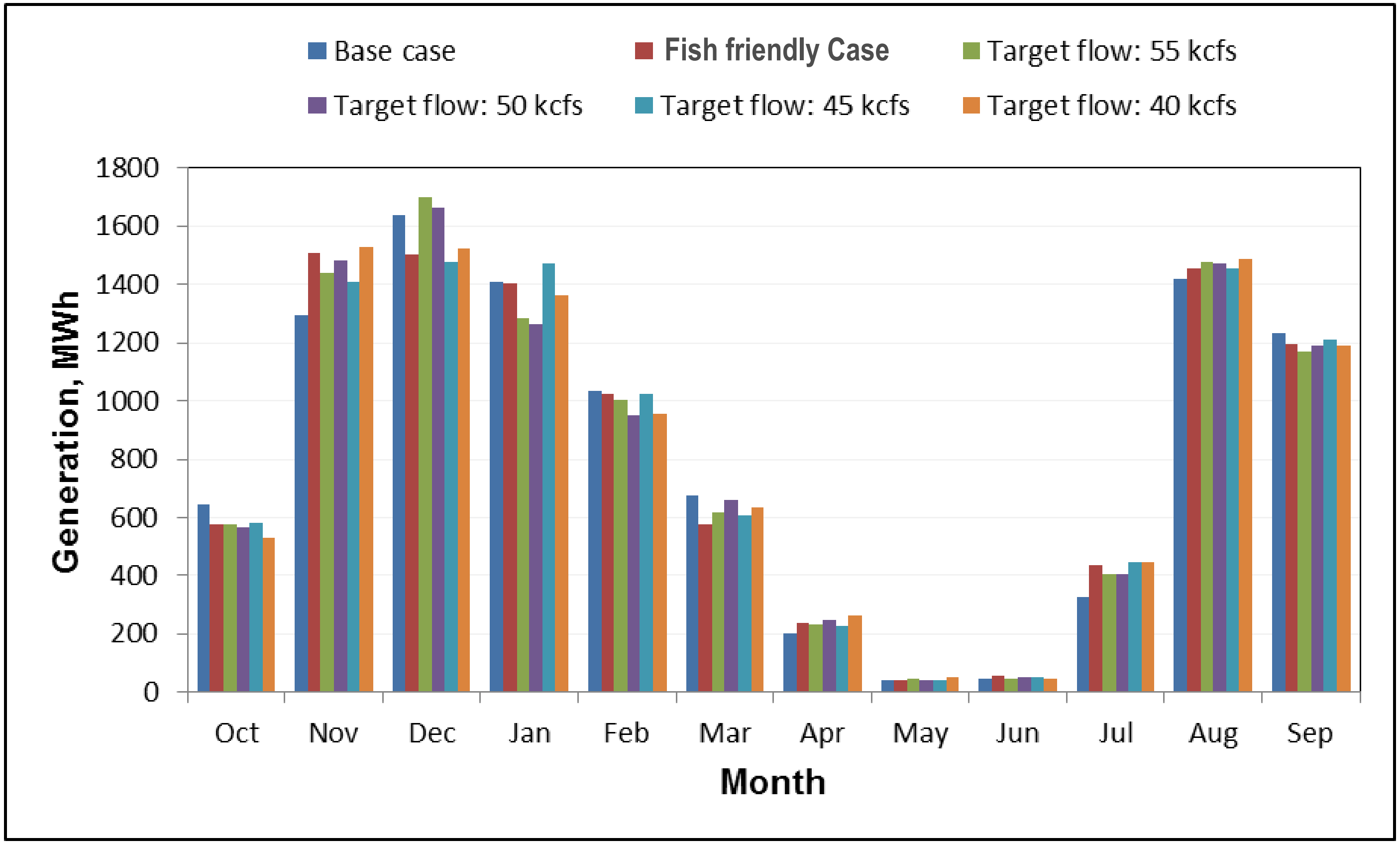
Trade-off between FA & WF and Power Obligations
(Min Jan Flow @ 40 KCFS Case – 33 KCFS at Arrow)



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

Non-Power Impacts on generation

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



BC hydro

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.

Acknowledgements

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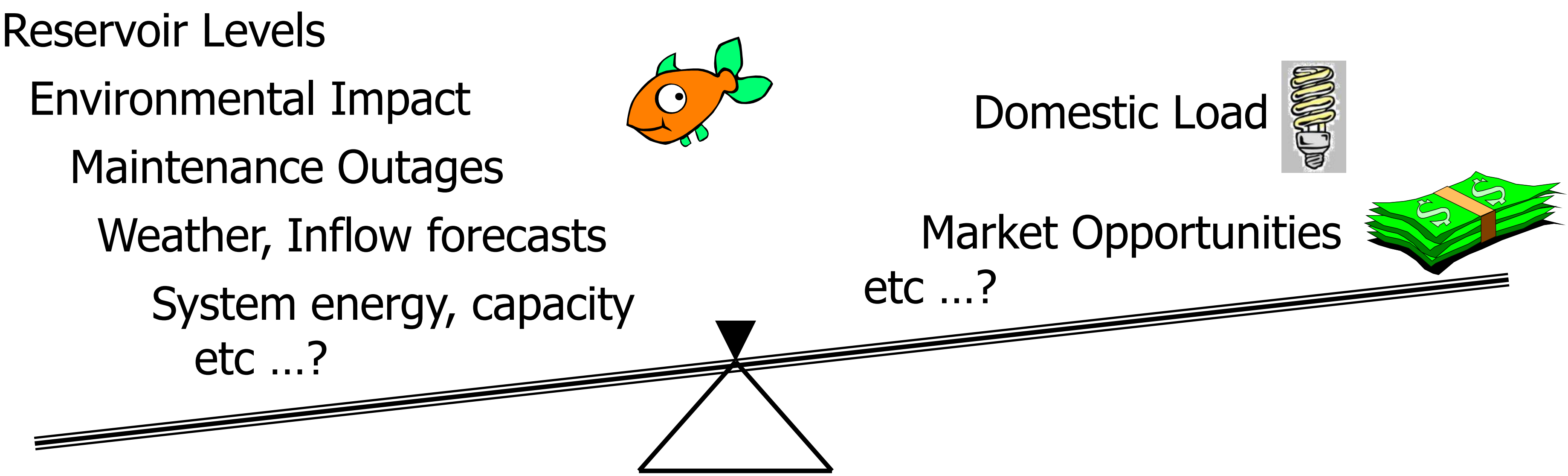
Questions?

Good Models Help in Maintaining Balanced Operations



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