# Optimal Price-Based Operations Scheduling of a Single Reservoir within a Multireservoir Cascade

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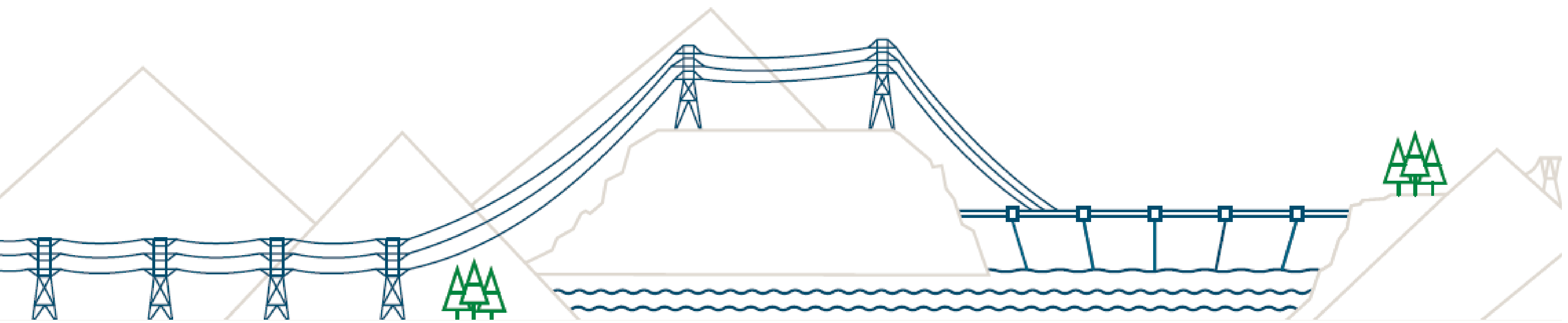

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**Sep 13, 2018**

# Presentation Outline

1. Who are we?
2. BC Hydro System
3. Generation Portfolio
4. Energy Studies
5. Why do we have so many models?
6. Columbia System
7. Revelstoke Modeling and Results
8. What is Next?

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# 1/8- Who are we?

Generation System Operations is the department I belong to.

It is organized in five groups:

- **Operations Planning**
- Planning, Scheduling and Operations (PSOSE)
- Hydrology ( Data, Meteorology, Hydrology)
- Planning & Licensing
- Business Operations



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# 1/8- Who we are: Operations Planning Duties

## OPE

- Reservoir operating plans;
- Optimize the timing and duration of plant and transmission outages as they impact generation;
- Assess the impact of reservoir elevations and flow releases of various operating scenarios on dam safety, fish, wildlife habitat, and upstream and downstream communities;
- Liaise with System Controllers (FVO) to minimize generation losses due to transmission constraints;
- Plan and track non-power releases of water to meet regulatory requirements for fish flows and communicating with BC Hydro's biologists regarding effects of operations on fish during different stages of their life cycles;

## Energy Studies Team

- Assess economic value of the water in the reservoirs based on reservoir forecasts and system needs;
- Optimize energy generation schedules for net income while balancing operations for other constraints ;

- Operations related to coordination agreements including Columbia River Treaty (CRT), Canal Plant Agreement (CPA), Independent Power Producers (IPP) contracts;

**Obligations**

- Columbia River Treaty Operating Committee (CRTOC), Columbia Operations Fish Advisory Committee (COFAC), and Arrow Lakes Hydro Operating Committee (ALHOC)

**International Treaty with the US**

# 2/8- BC Hydro System: Composition

- The total installed generating capacity of the BC Hydro system is 12.05 GW , of which more than 90% is hydropower;
- BC Hydro serves 95% of the population in British Columbia and produces about 80% of the total power generated in the province;
- There are 61 dams and more than 30 hydro plants in the BC Hydro system;
- The major river systems in BC are: the Peace system, the Columbia system, the Kootenay Canal and Seven Mile plants;
- 23 small hydropower plants meeting ~16% of electrical demand;
- The remaining demand is served by independent power producers (IPPs) and thermal generating facilities (gas-fired and combustion turbines);
- BC Hydro meets the domestic electrical load of its service area and also trades energy in regional markets in Alberta, the Northwest USA and California through its subsidiary Powerex.



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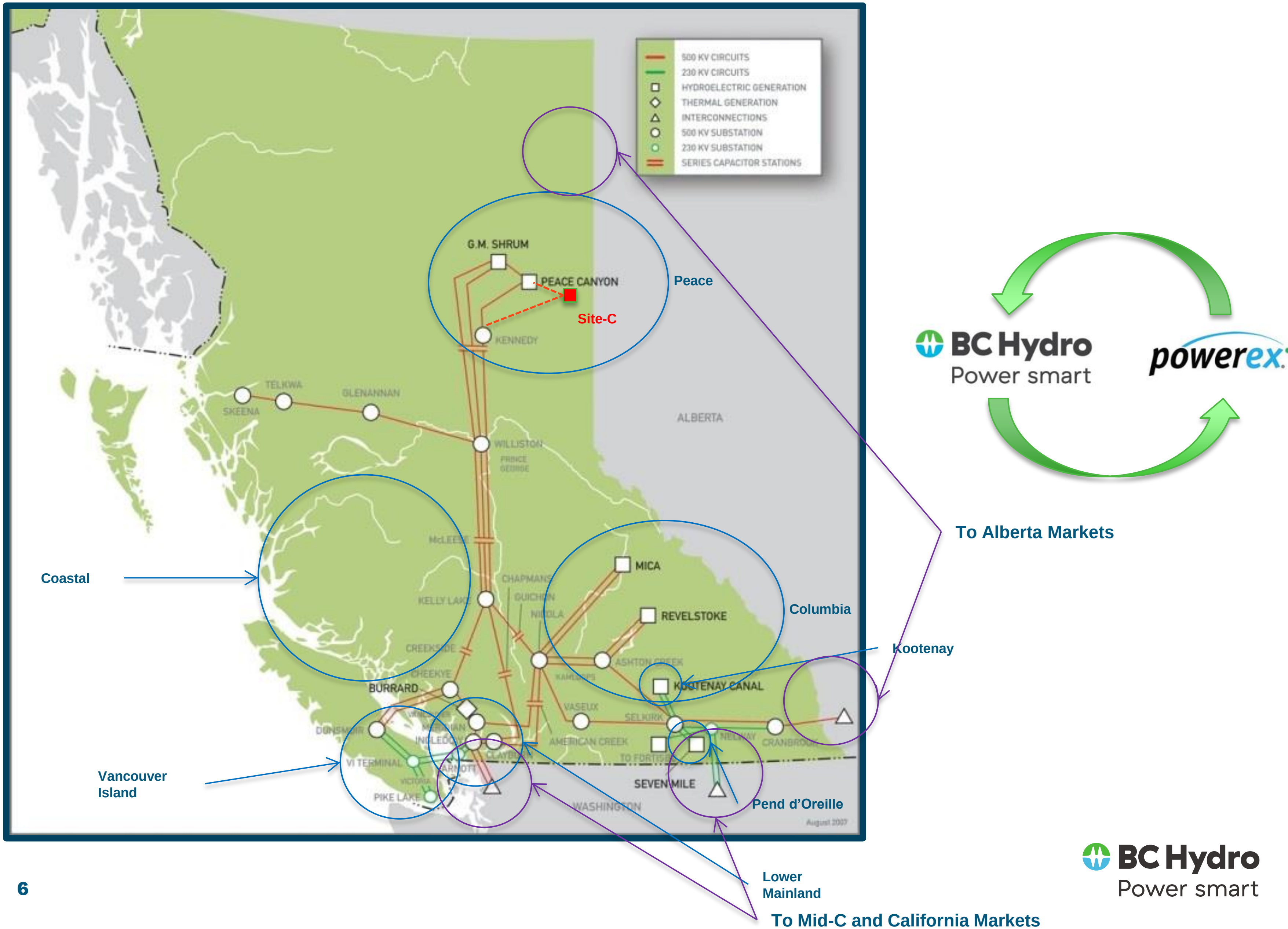
# 2/8- BC Hydro System: Composition



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# 2/8. BC Hydro System: How hard to model?

- Optimizing the operation of the main storage reservoirs in the BC Hydro system is quite challenging due to the uncertainties that must be dealt with given the significant multi-year reservoir storage capabilities;

- The existence of a transmission network connecting the system with regional markets adds one more dimension to the complexity of the system;

- It is not an easy task to optimize the planning of operations of the system under the various constraints that the BC Hydro system encounters such as: the physical generation constraints, environmental and non-power requirements, water licenses and international treaties, to name a few.

# 2/8- BC Hydro System: Columbia River Treaty

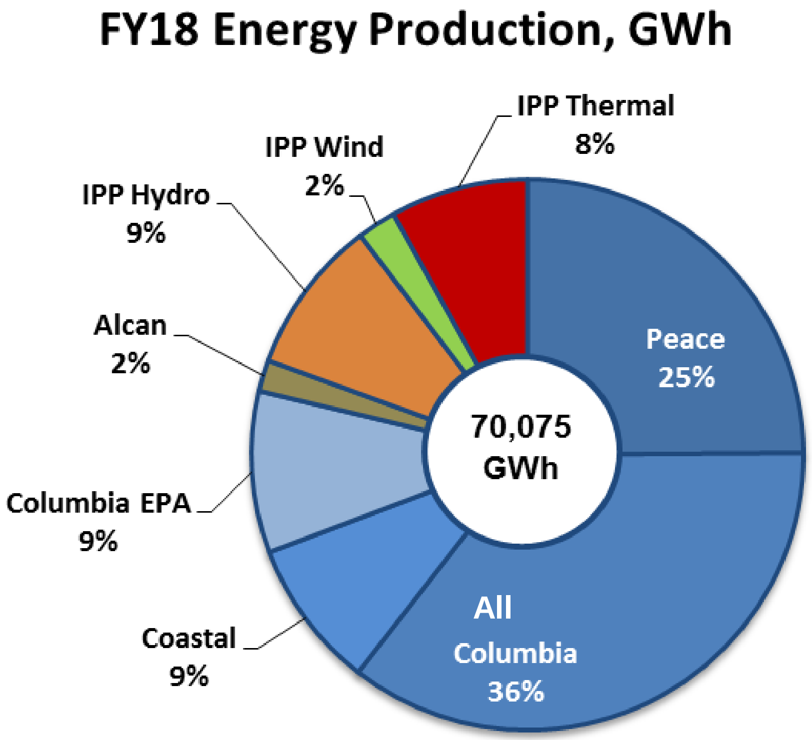
- The Columbia River Treaty (CRT) between Canada and the United States was ratified in 1964;

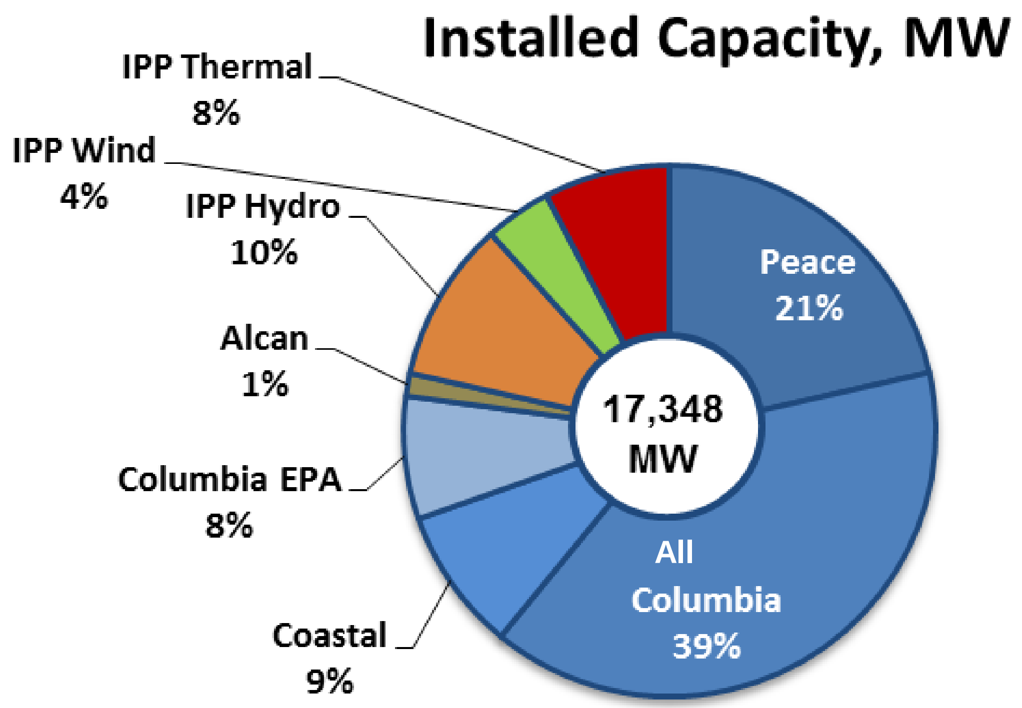
- The implementation of the treaty is the responsibility of the Canadian entity (BC Hydro) and the two American entities (Bonneville Power Administration and the US Army Corps of Engineers);

- The main features of the CRT include: building large storage reservoirs (completed in the 60’s and 70’s), streamflow regulation, sharing flood control benefits, sharing power generation benefits, determining the authorities on evacuation of flood control space, water diversion, mechanisms to resolve emerging disputes and the options to terminate or extend the treaty;

- The CRT imposes a number of constraints on Canadian reservoir operations and these constraints are included in operations planning models developed/used by BC Hydro.

# 3/8- Generation Portfolio: Generation vs. Capacity



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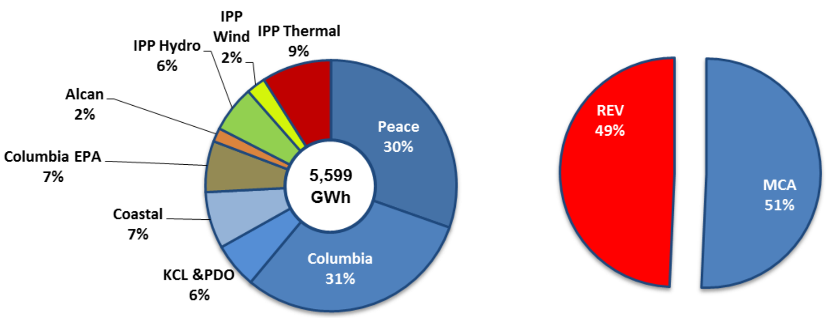
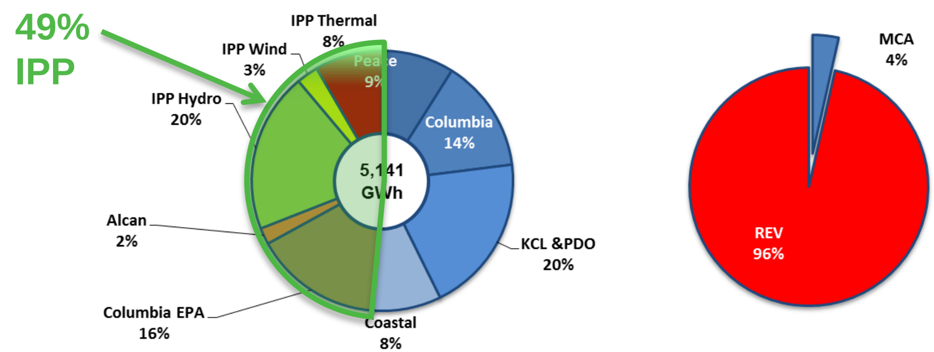
# 3/8- Generation Portfolio: Mica vs Revelstoke, for Different Months

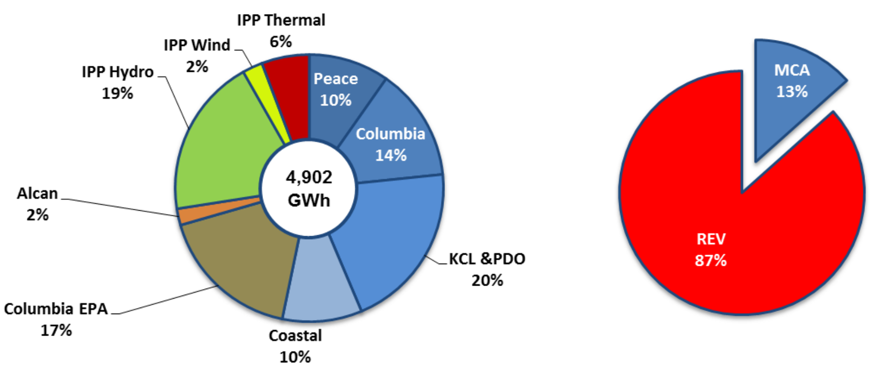
Apr 2018 System Energy Production



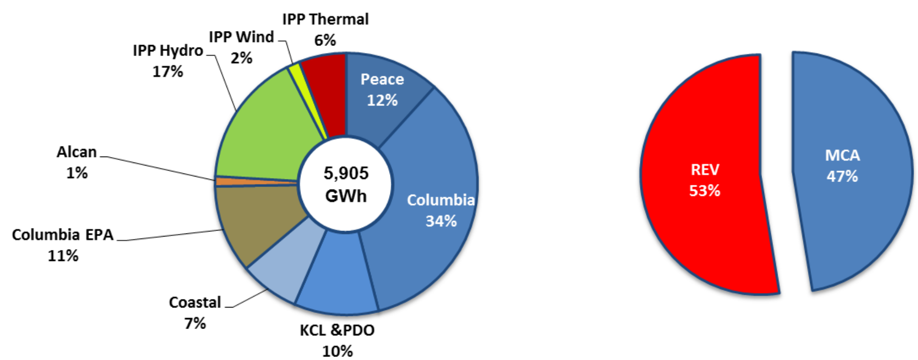

May 2018 System Energy Production




June 2018 System Energy Production




July 2018 System Energy Production



# 4/8- Energy Studies: Models on the Map

Thermal IPPs: Simulation

Peace River + Markets: SDP Optimization

Wind Independent Power Producers (IPPs): Contract

Alcan: Simulation

Biomass IPPs: Contract

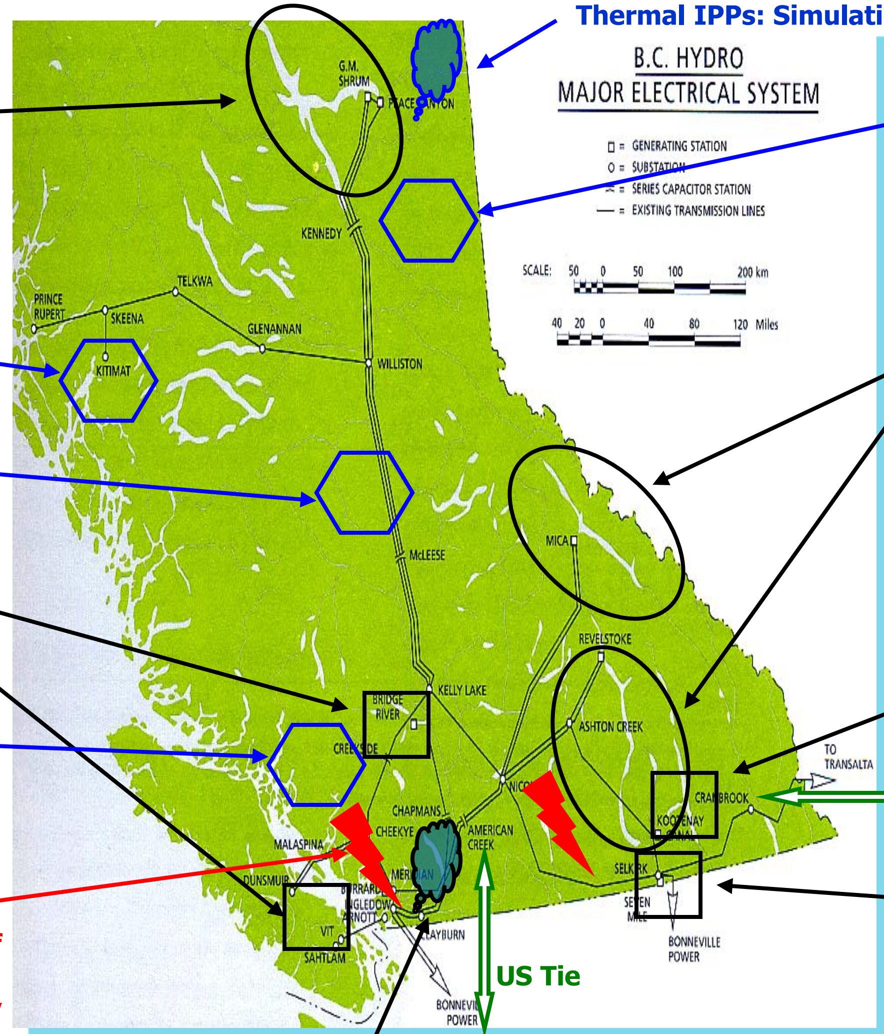
Columbia River: SSDP Optimization Model

Small Hydro: Simulation

Hydro Independent Power Producers (IPPs): Contract

Kootenay River: LP Optimization

Alberta Tie




Pend-d'Oreille River: Simulation

Loads : Simulation of Temperature Impacts Only

US Tie

Thermal: Reserve Capacity Only

+ System Simulator



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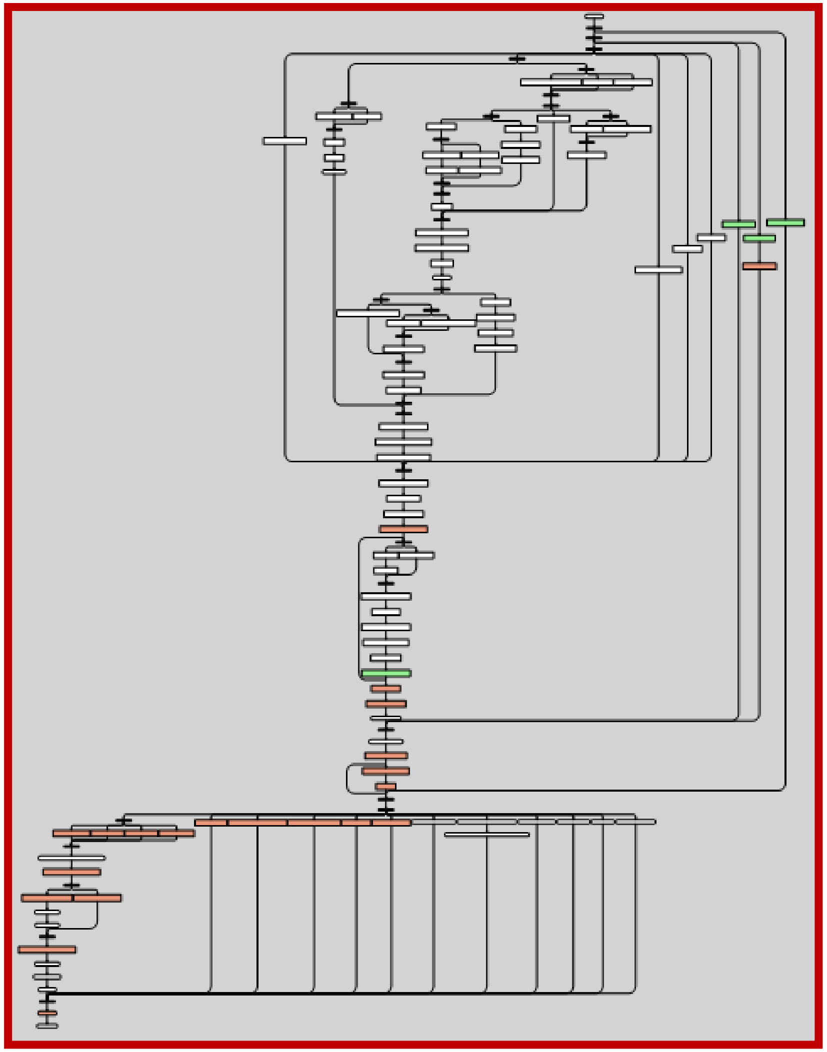
# 4/8- Energy Study: Workflow

1 Optimization/ Simulation

2 Analysis and Intermediate Reporting

3 Allocation, Price Signals and Cost Estimates

4 Reporting



**We will only focus on 1 &3**



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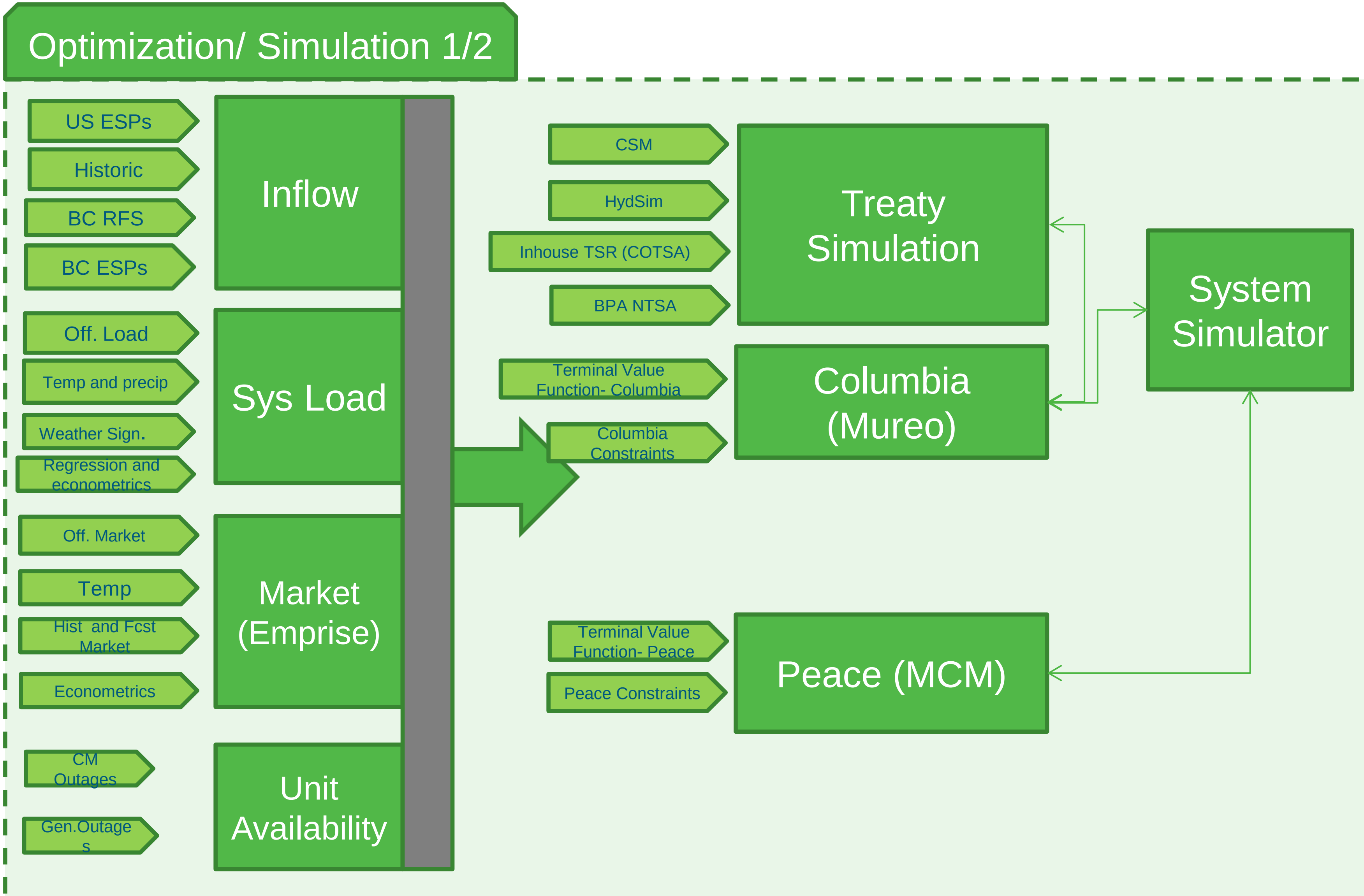
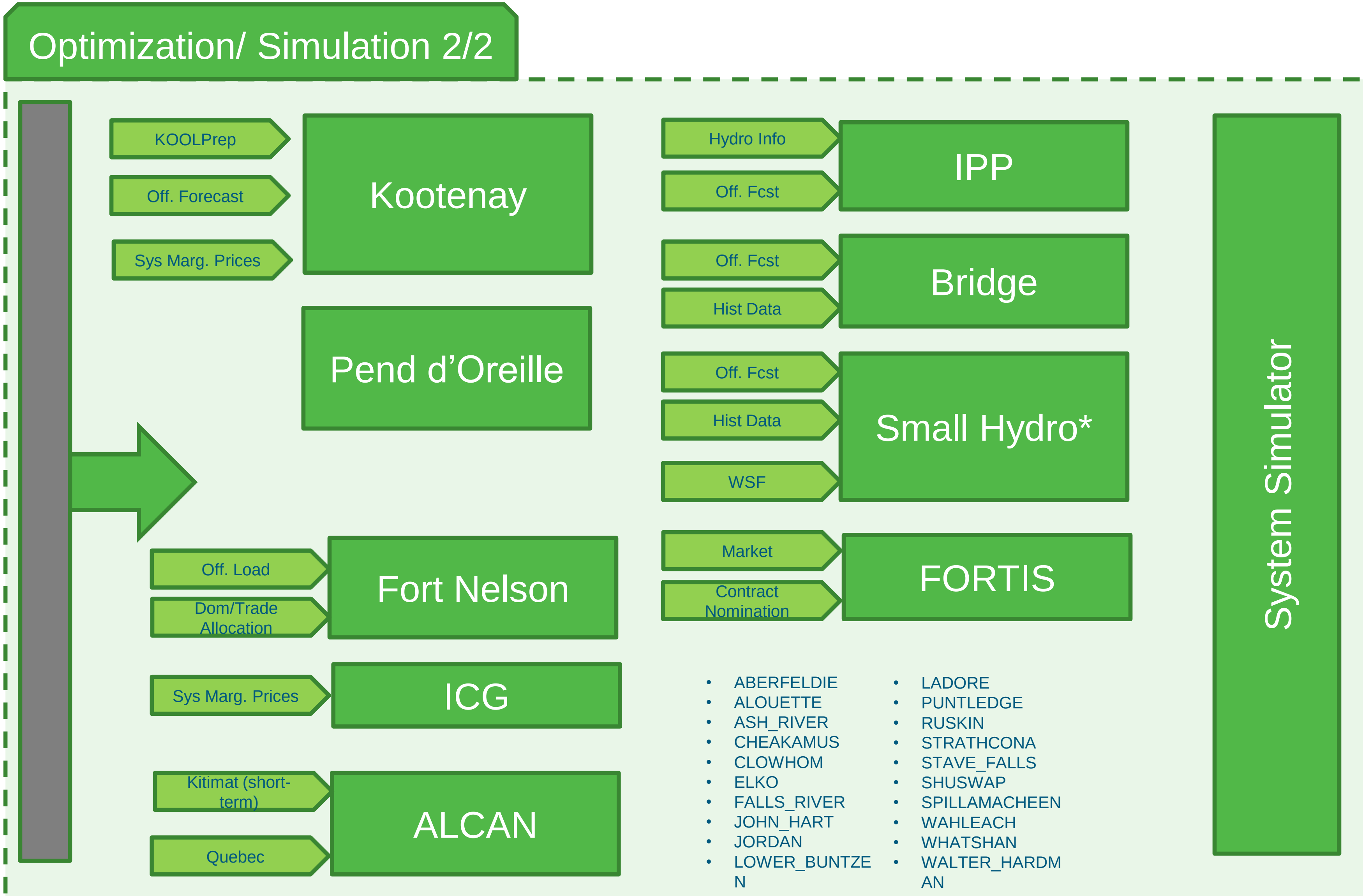
## 4/8-



Optimization/ Simulation 1/2
US ESPs
Historic
BC RFS
BC ESPs
Inflow
Off. Load
Temp and precip
Weather Sign.
Regression and econometrics
Sys Load
Off. Market
Temp
Hist and Fcst Market
Econometrics
Market (Emprise)
CM Outages
Gen.Outages
Unit Availability
CSM
HydSim
Inhouse TSR (COTSA)
BPA NTSA
Treaty Simulation
Terminal Value Function- Columbia
Columbia Constraints
Columbia (Mureo)
System Simulator
Terminal Value Function- Peace
Peace Constraints
Peace (MCM)

# 4/8-

## Optimization/ Simulation 2/2




- ABERFELDIE
- ALOUETTE
- ASH_RIVER
- CHEAKAMUS
- CLOWHOM
- ELKO
- FALLS_RIVER
- JOHN_HART
- JORDAN
- LOWER_BUNTZEN
- LADORE
- PUNTLEDGE
- RUSKIN
- STRATHCONA
- STAVE_FALLS
- SHUSWAP
- SPILLAMACHEEN
- WAHLEACH
- WHATSHAN
- WALTER_HARDMAN



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# Allocation, Price Signals and Cost Estimates

Trade Account Limits

Market ( volume and prices)- ITM-

Thermal Dispatch

CODA

Logic to Calculate System Marginal Price

Load Revenue

Finance Cost

IPP Cost

ALCAN Cost

- System marginal price (SMP) is:
  - Second preference reservoir marginal price if not constrained; or,
  - Market price at BC border if constrained.



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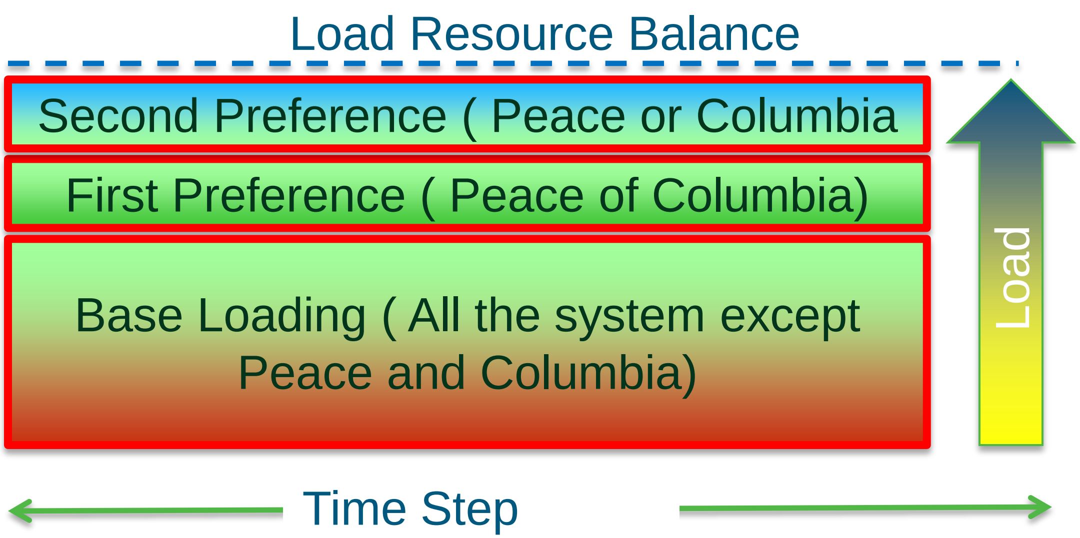
# 4/8- Energy Studies: Preference Order Stack



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# 5/8- Why we have so many models: A Previous Examination of SDP Application on One big model

- SDP modeling algorithm to model six hydropower plants.
- The main output of the algorithm is the water value function for the two biggest reservoirs in BC, Williston and Kinbasket reservoirs.
- Six plants and their associated reservoirs on two river systems are explicitly included in the optimization model.
- Three on the Peace River: G.M. Shrum (GMS) and Williston Reservoir, Peace Canyon (PCN) and Dinosaur Reservoir downstream of GMS, and Site-C (STC) and Site-C Reservoir downstream of PCN.
- The other three are on the Columbia River: Mica (MCA) and Kinbasket Reservoir, Revelstoke (REV) and Revelstoke Reservoir downstream of MCA, and Arrow Lakes Hydro (ALH) and Arrow Lakes Reservoir downstream of REV.

# 5/8-

- A storage plant  is defined as a plant that has multi-year storage capacity and thus its storage is modeled as a state variable in the optimization model. GMS and MCA are modeled as storage plants because they are immediately downstream of the two largest reservoirs in the BC Hydro system.
- A run-of-the-river plant (ROTR) is a plant that does not have much storage capability and it simply passes all the water it receives within a period that is less than the time step modeled. PCN, STC, REV and ALH  are modeled as run-of-the-river (ROTR) plants.

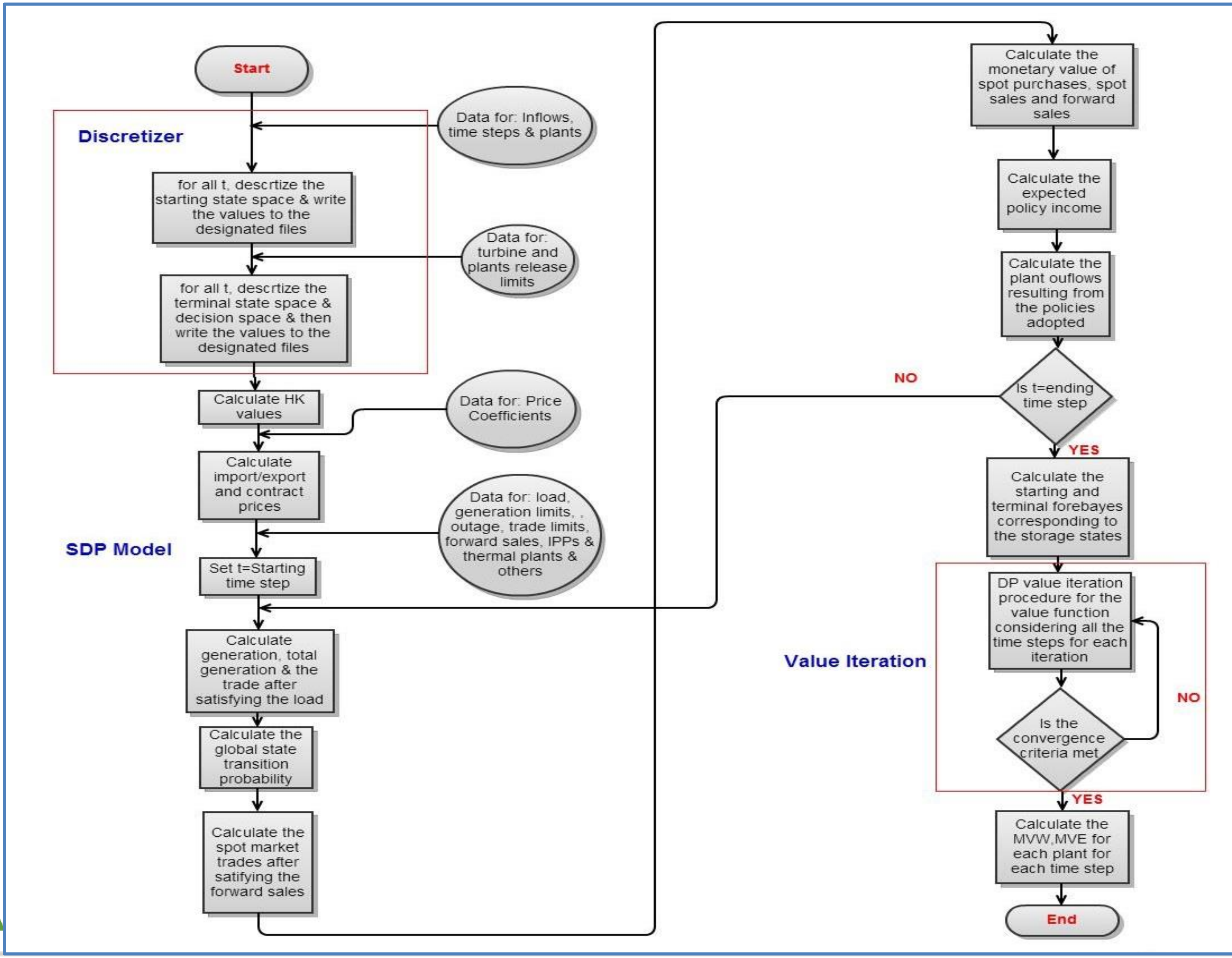
- Extensive testing has shown that the program is able to solve the problem producing acceptable water value and marginal value functions up to a problem size of ~ 164 million states per time step using the computing resources available on one of the BC Hydro's servers.

# 5/8-

# Flowchart

# of the

# Model



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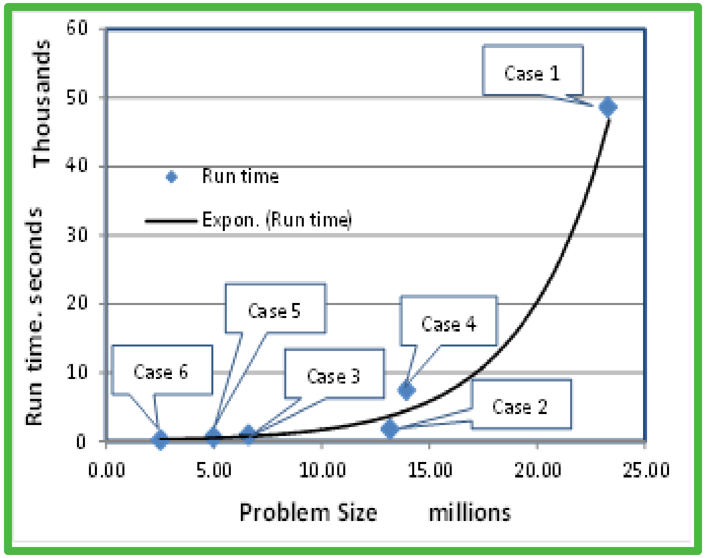
# 5/8-

- Assessing the sensitivity of solution efficiency and precision for several storage state and decision space discretizations.
- It was found that finer state-space increments give more precise results but the granularity was limited to the computing resources available.
- Introducing the storage state-space corridor provided several advantages; nevertheless, care should be taken in the design of such corridors so that the solution efficiency and accuracy are not jeopardized.



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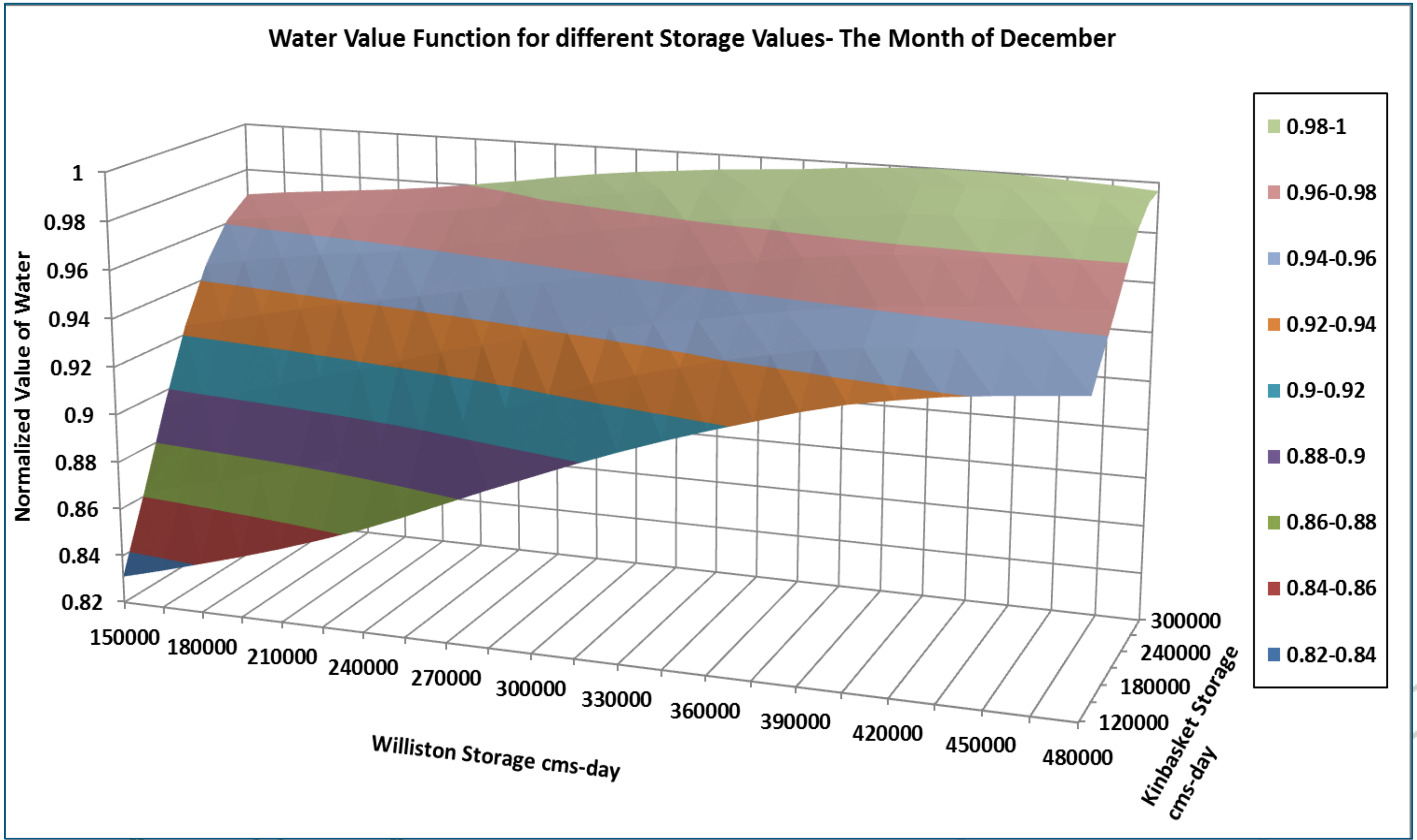
# 5/8-




**What are we missing in this big model?**



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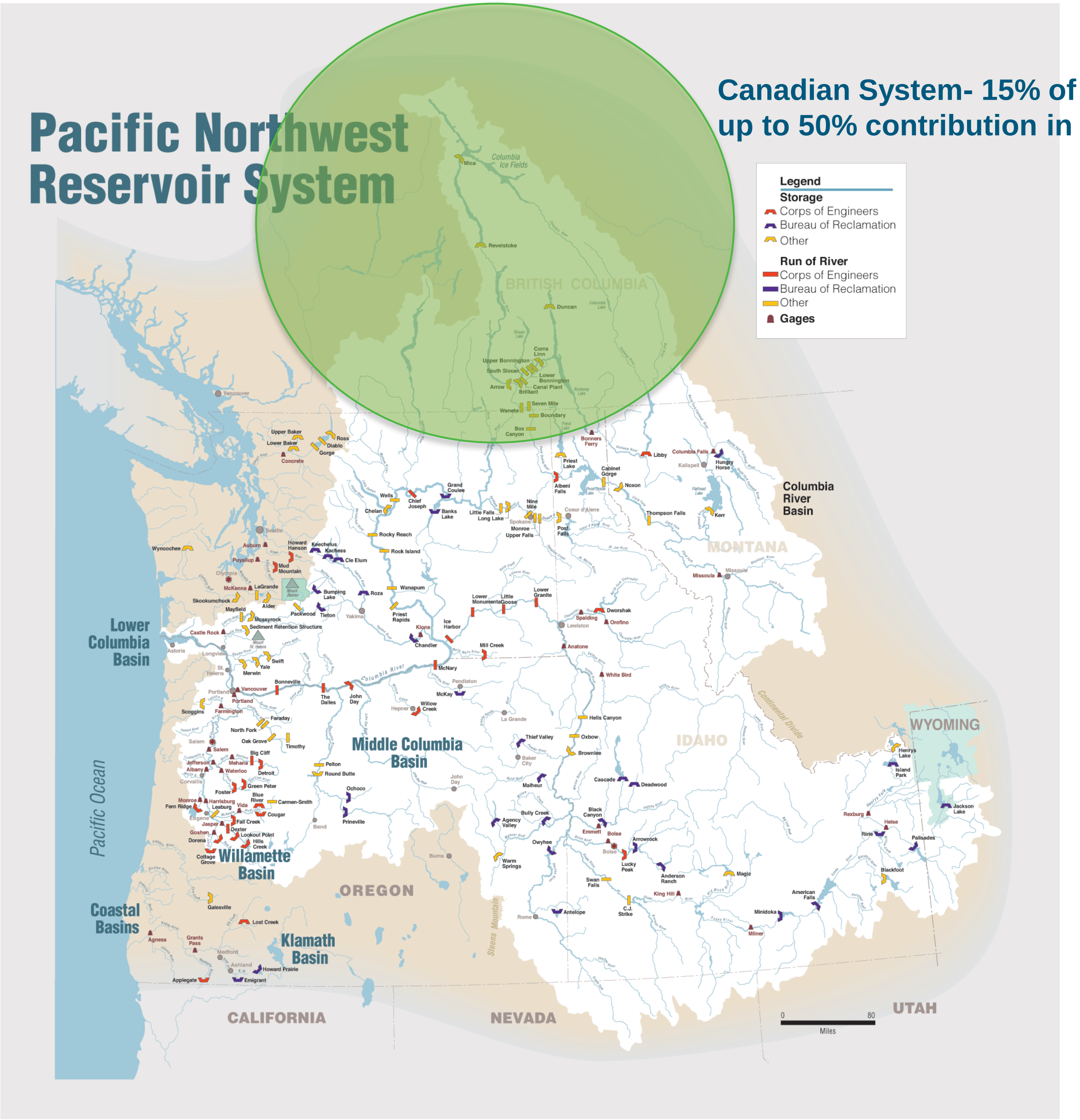
# 6/8- Columbia System




Canadian System- 15% of the area and up to 50% contribution in the freshet



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# 6/8- Columbia System: Revelstoke Reservoir





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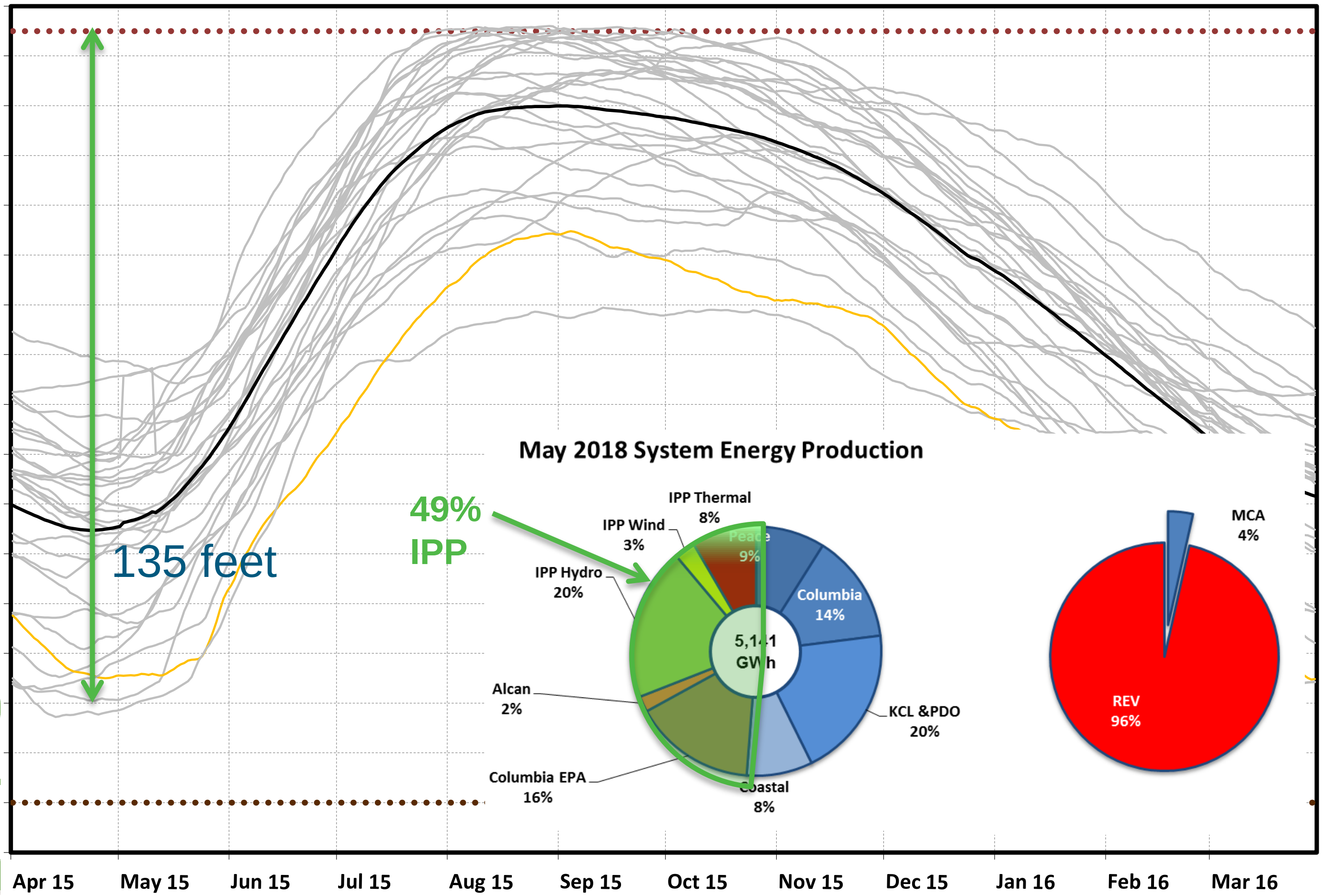
# 6/8- Columbia System: How Kinbasket(MCA) Forebay is Operated



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# 7/8- REV Model*

## Purpose

- To be used in the Energy Study suite of model → Enhanced REV/Columbia operation
- To be used by Resource Coordinators of the generation system in daily and weekly planning

*This is work-in-progress and results are early results



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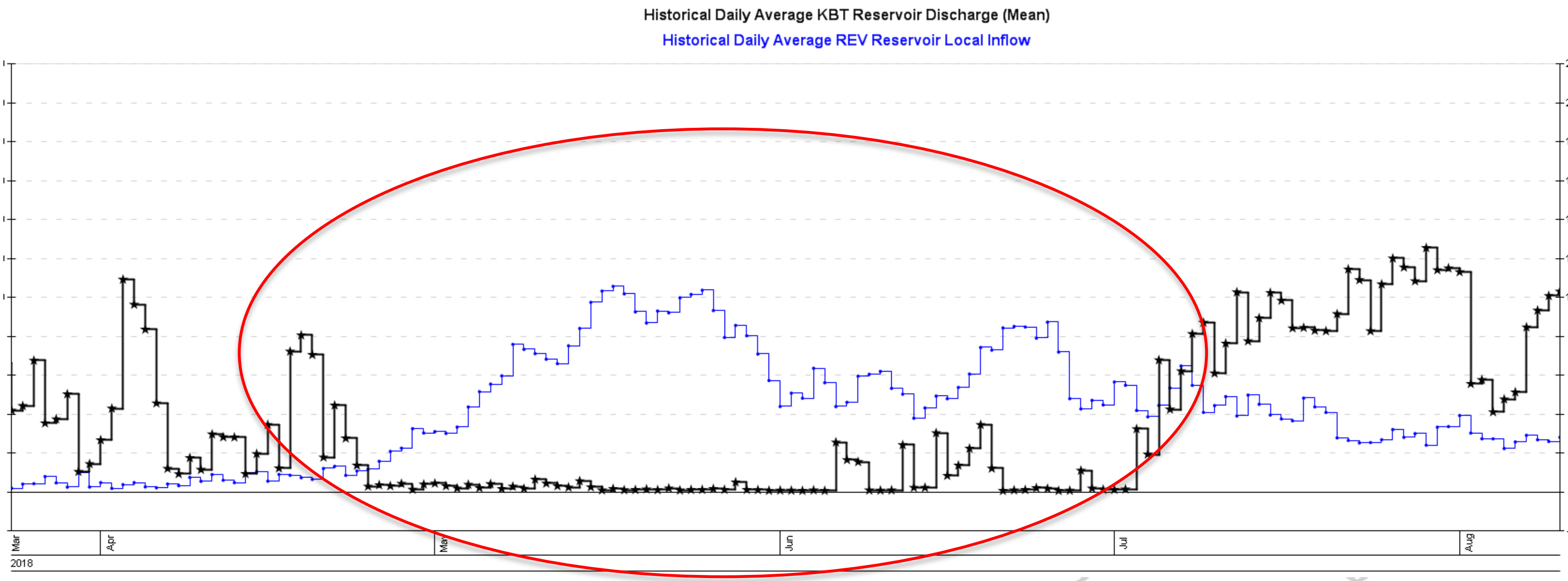
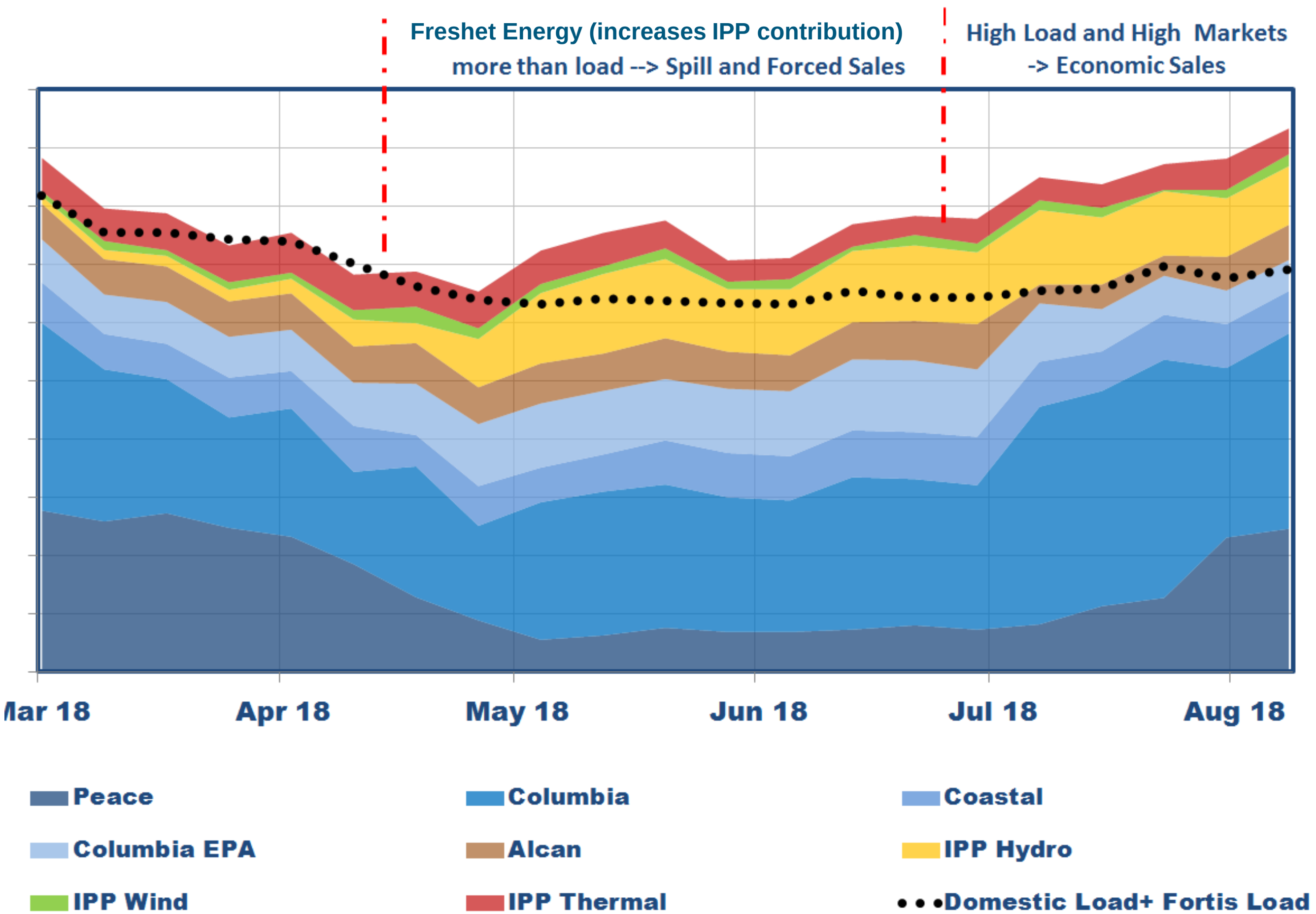
# 7/8-
# Why a Separate Model to Forecast Operation for This Period?



# 7/8-



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7/8-

# Assumptions and Approximations

- No Residual Load
- Assumes no flows from Kinbasket Reservoir (Mica)
- Spill is assumed to be forced
- Drafts and refills for market prices and to manage forebay
- Draft/ refill cycle is one week in a two week horizon

# State Variables

- Forebay state variable ( discretized space; Mass Balance)
- Hydrological State Variable ( current inflow to the reservoir)
  - Transition between inflows is through a transition probability matrix



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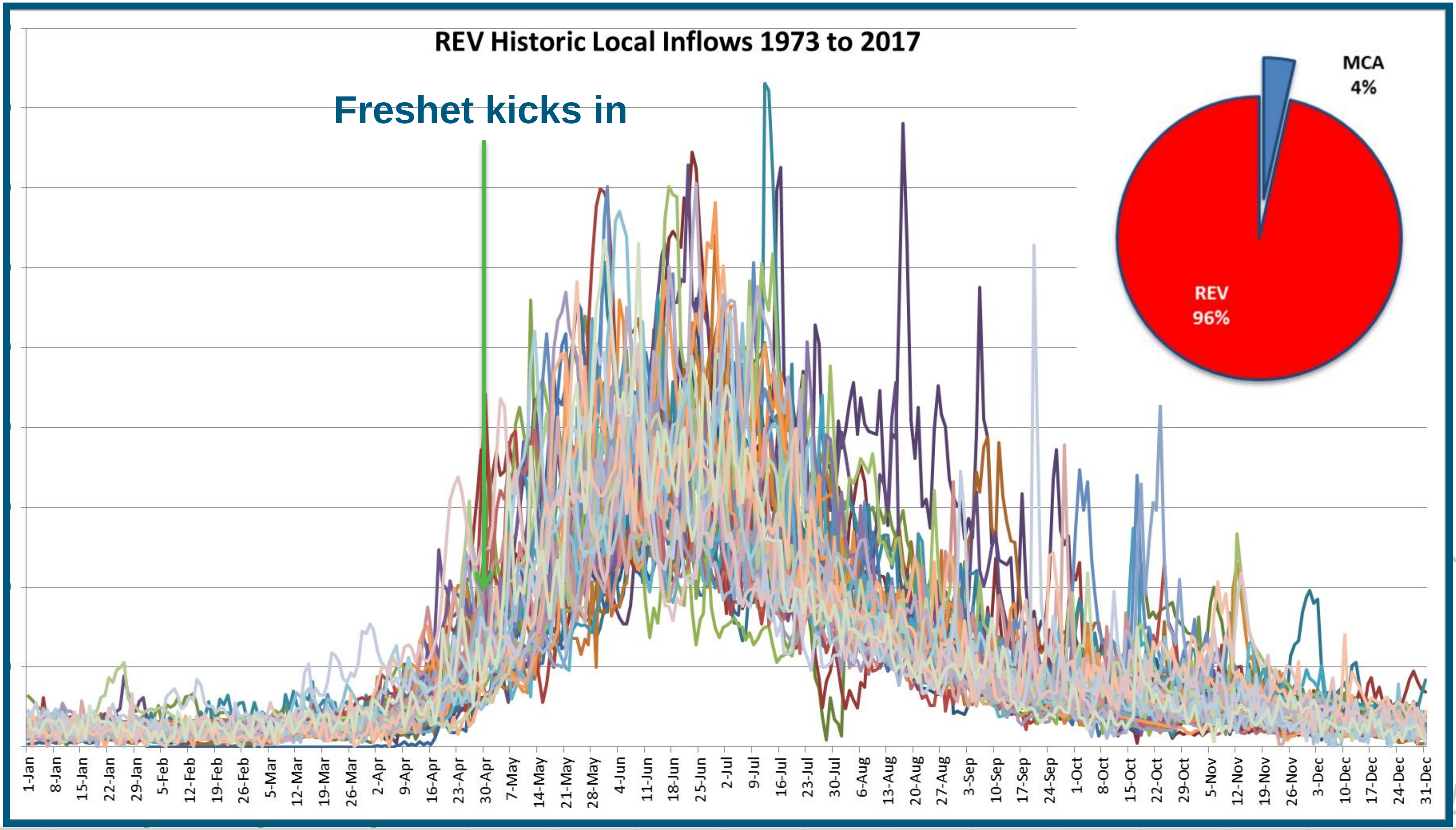
# 7/8-
# State Variables



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# Time Step and Horizon

- Daily time step ( stage and inflows) model with HL and LL split for the price blocks and the Release Policy
- Horizon is 14 days ( 2 weeks)

# Objective Function

- Maximize the value of electricity generated for domestic consumption and trading to regional markets over a short-term planning horizon.
- Using the traditional Bellman equation with no discount given the short horizon.

# Stochastic Variables

- Inflows
- Mid –C Market Prices



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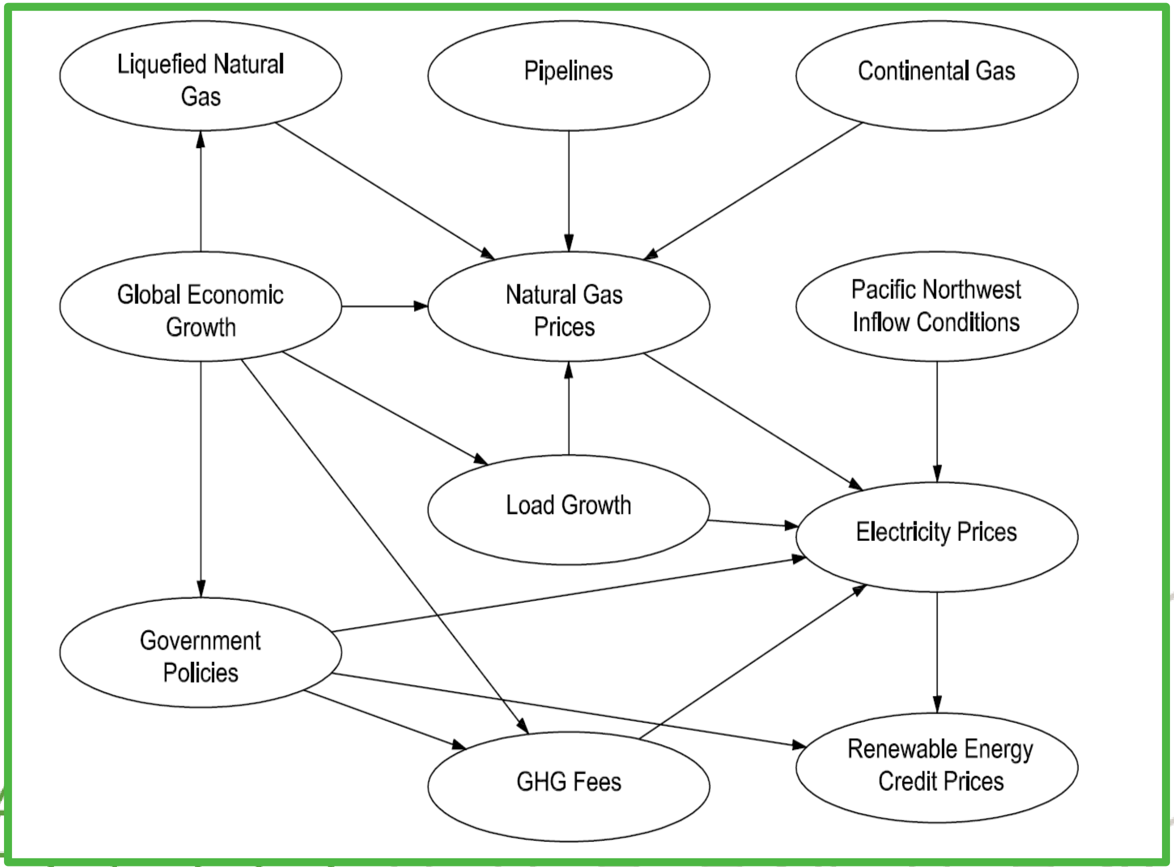
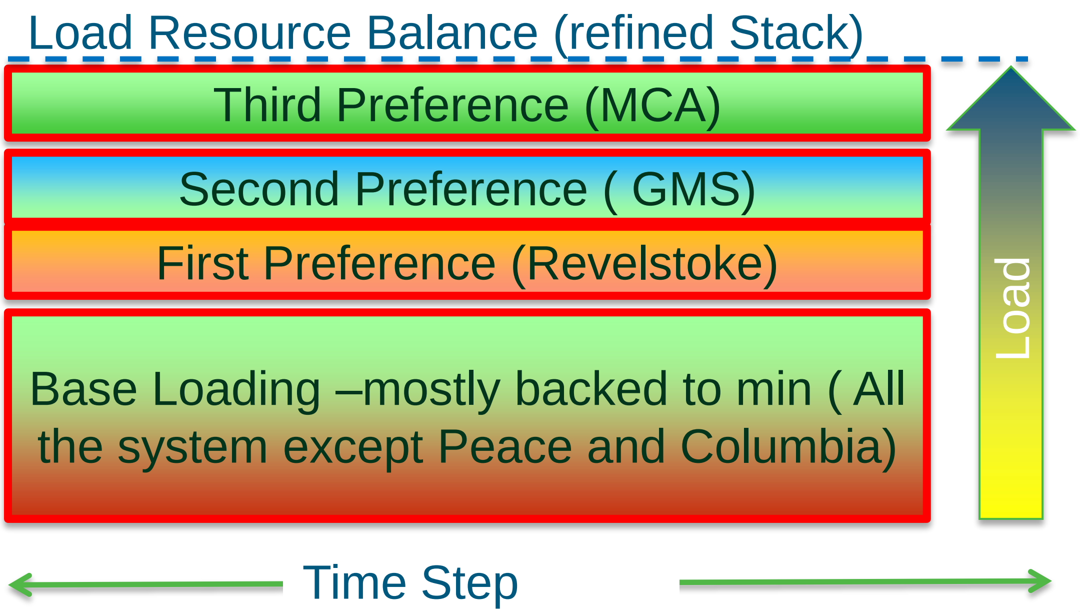
# 7/8- Drivers of the Market Prices at Mid-Columbia Market



7/8-

# Outputs

- Turbine Releases (Policy in the form of opt tables)
- Marginal Value of water in the Revelstoke Reservoir
- Communicating this to the system simulator

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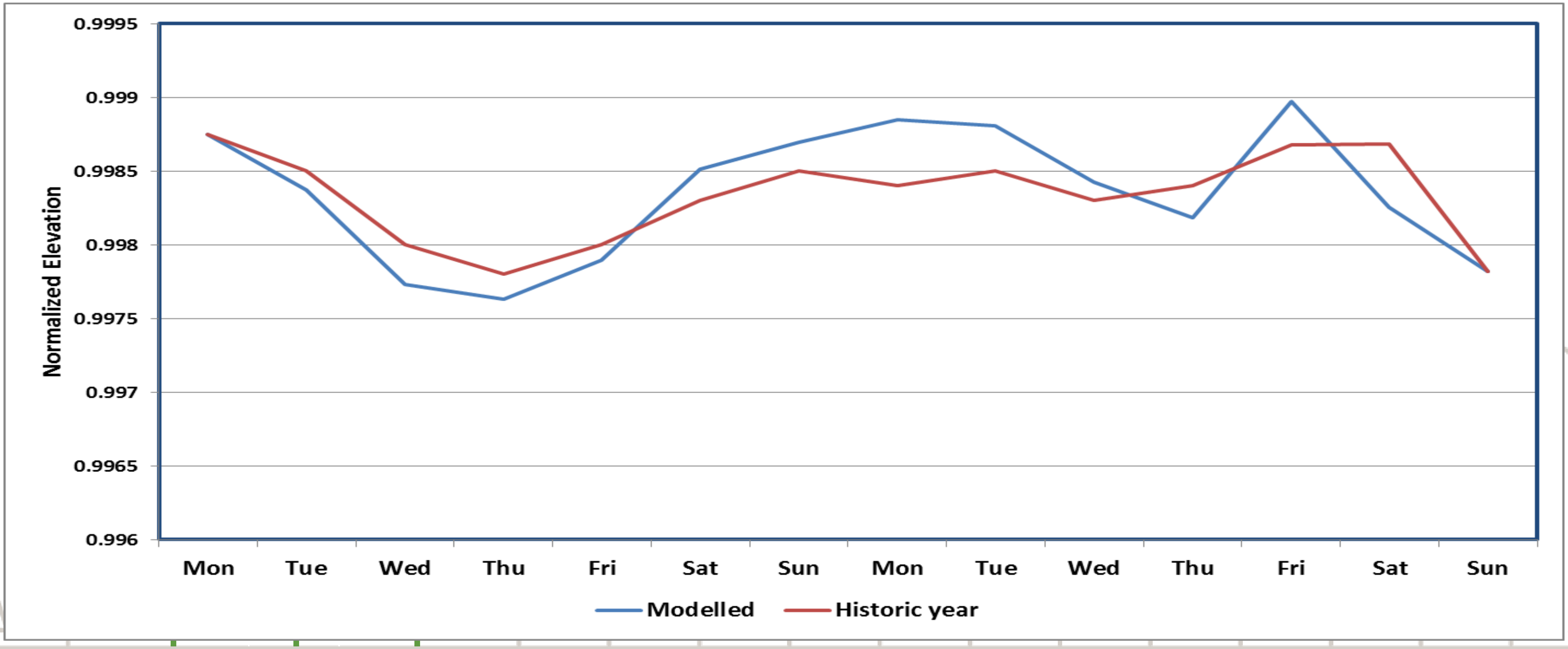
# 7/8-

## Results

- Forebay likely to start high on Monday given the low prices over the weekend;
- Starts drafting on Monday given the relatively higher load and the prices
- Exact elevation going to the weekend is dependent on the combination od prices and inflows in the second week relative to the first week



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# 8/8- What is Next?

- Include System residual load
- Enhance the stochastic representation of variables ( inflows)
- Better representation of the market ( inclusion of California market?)
- Dynamic Inputs from Kinbasket Reservoir (Mica)
- Consider Economic Spill
- Consider connecting it to the Columbia Optimization Model in an iterative way
- Consider drafting and filling for Columbia River Treaty operation
- Extend the model for high market price periods ( December, January and August)



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# Questions?

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