Hydro 101

The Subtleties of River Operations

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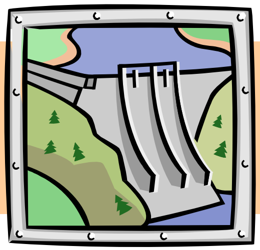
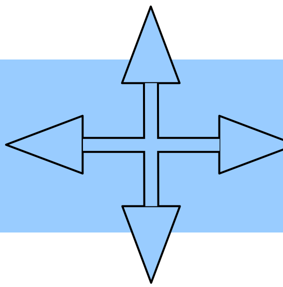
Adapted for the BP-14 Generation Inputs Workshop
from material prepared to explain the Slice Water Routing Simulator

- Hydro 101
  (the subtleties of river operation)

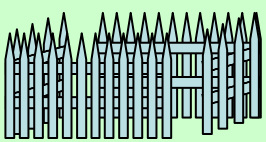
- Key points
  (juggling multiple uses)



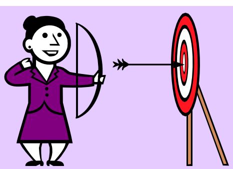
- Water routing model
  (basic river hydraulics)



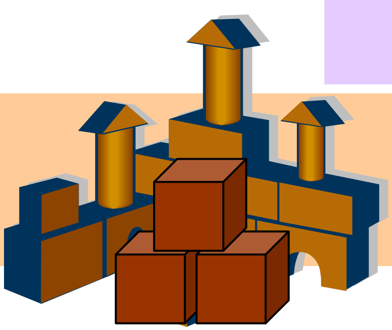
- Model variables
  (flows, elevations & generation)



- Operational constraints
  ('fencing in' the hydro system)

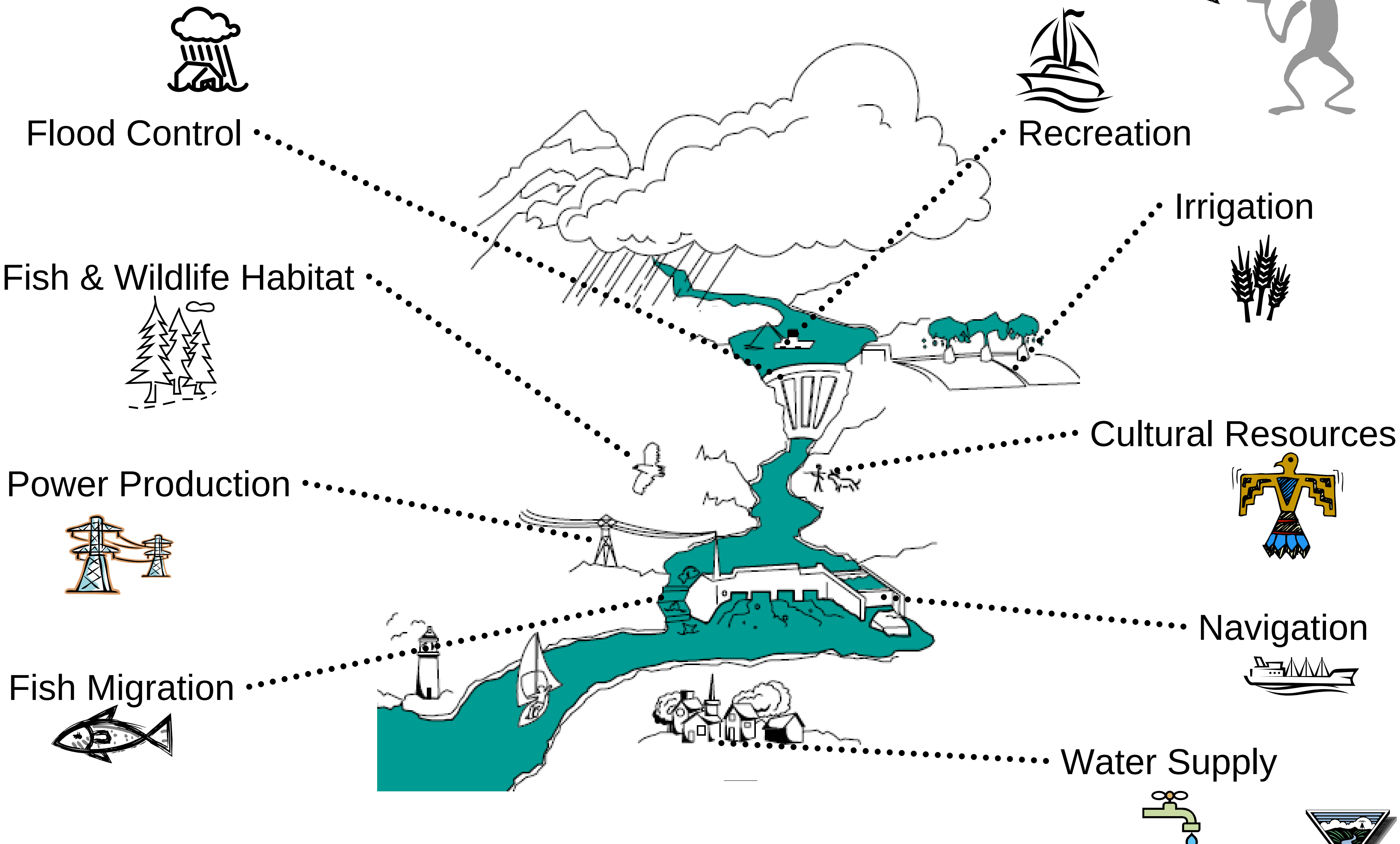


- Operational objectives
  (immediate & longer-range targets)



- Putting it all together
  (iterating over projects & hours)

Multiple-Use River



Multiple Power Uses

- The FCRPS is a large interconnected system
  - Plant operations: Army Corps of Engineers, Bureau of Reclamation
  - System planning & power marketing: Bonneville Power
- Firm capacity
  - Sold to preference customers on long-term contracts
  - Must be set aside on ongoing basis for operating & balancing reserves
- With variable water supply, surplus capacity is available most years
  - Selling this additional capacity on short-term contracts keeps rates low
- BPA plans capacity use on many time horizons
  - Longer-horizon plans inform shorter-horizon capability
  - Long-term commitments restrict shorter-term capability

Multi-Year → Water Year → Seasonal → Monthly → Balance of Month → Pre-sched → Day ahead → Real Time

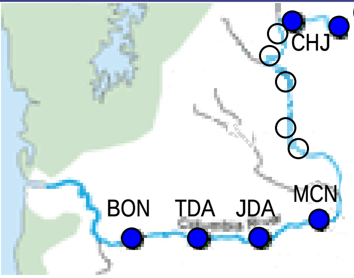
Major PNW Hydro Projects

31 Federal

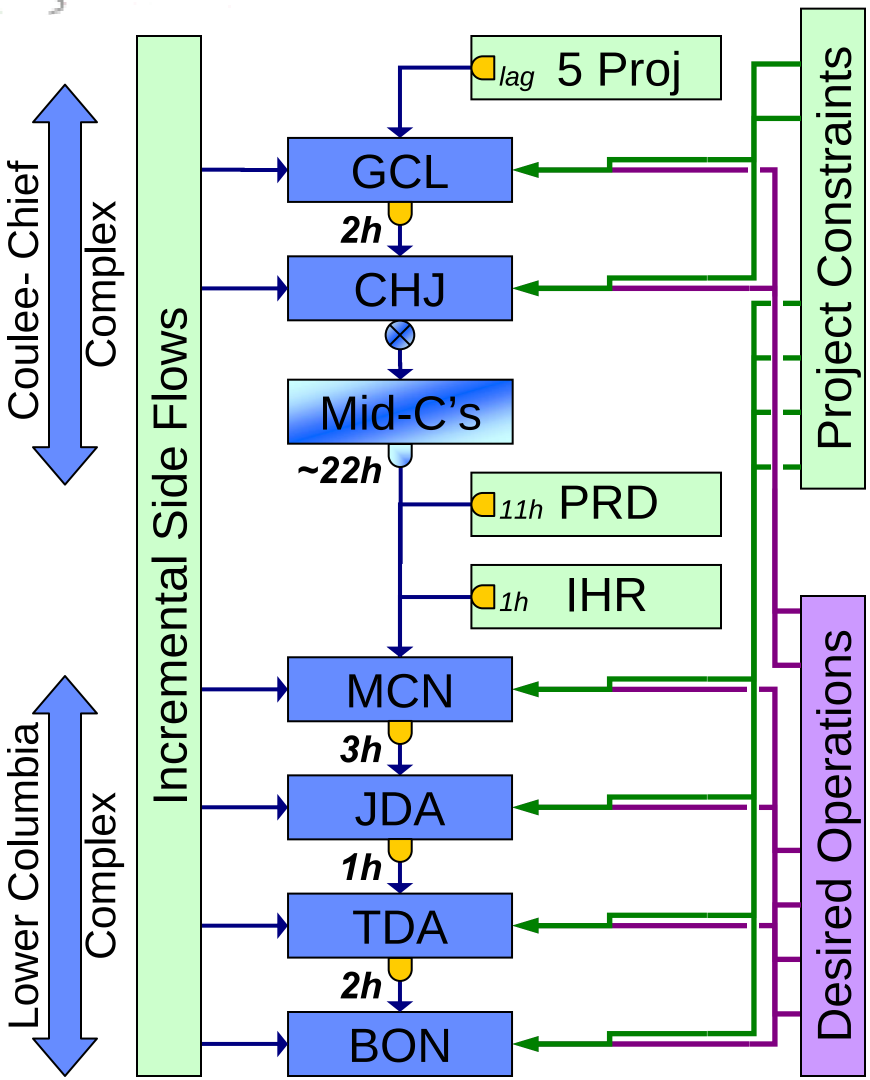
- 4 Headwaters Projects
- 6 Main Stem Projects
- 4 Lower Snake Projects
- *(17 less inter-connected)*

Many non-Federal

- 5 Canadian Storage
- 4 Mid Columbia
- 3 Middle Snake
- *(others less inter-connected)*



Simplified Water Routing



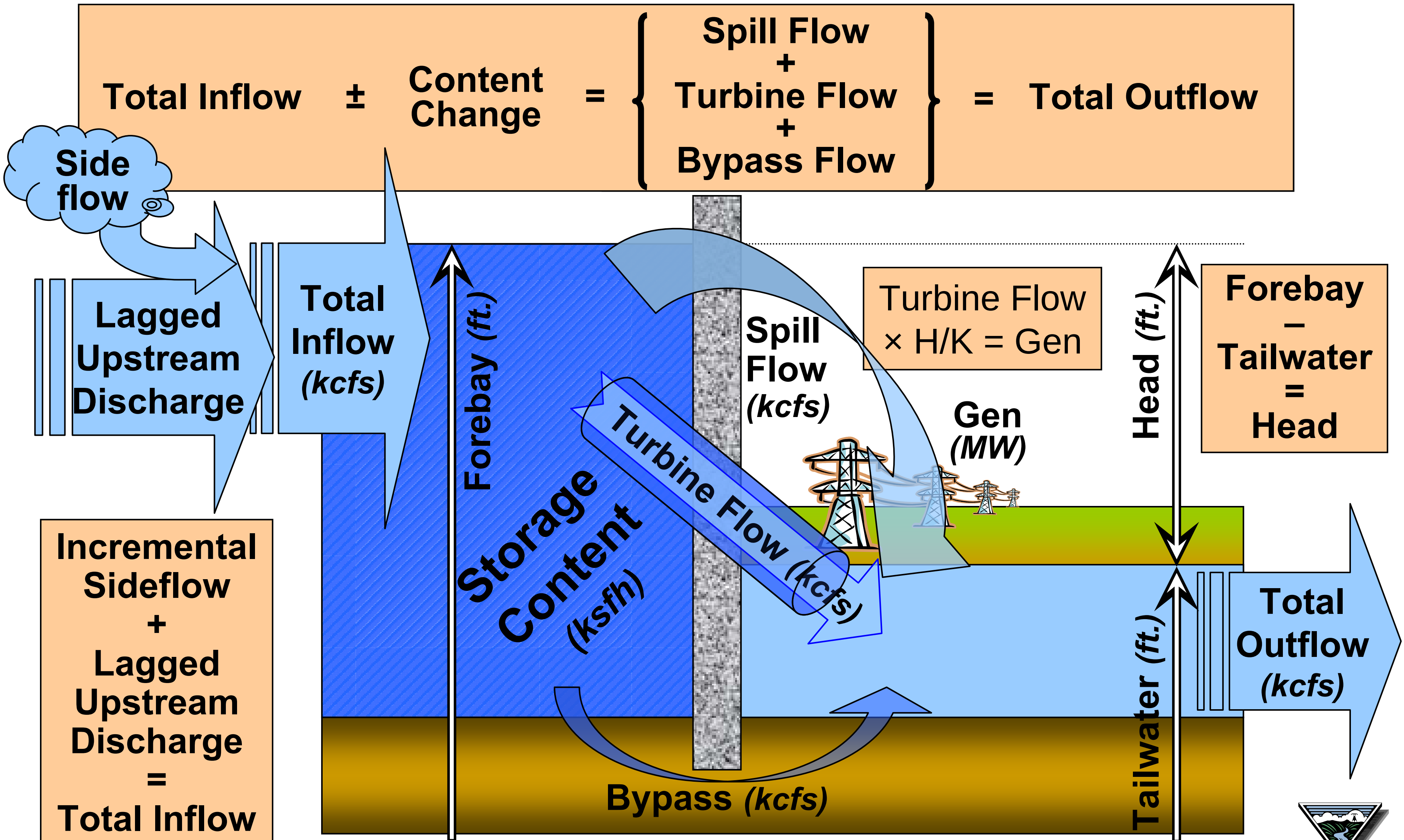
Calculations

- Single-project models
- Δt Hydraulic time lags
- Mid Columbia Operations

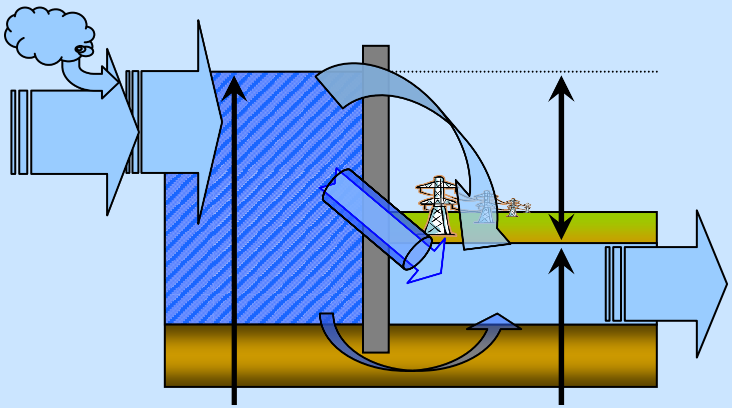
External inputs

- Measured discharges
  - Lagged flows into GCL/MCN
- Incremental side-flows (6)
- Operating Constraints
- Desired operations

Single Project Hydraulics



All Model Variables



Model inputs ***(with no directly associated output)***

External Inputs ***(or)***

History of operations

Model outputs ***(some having associated inputs)***

Min/Max Constraints

Change Constraints

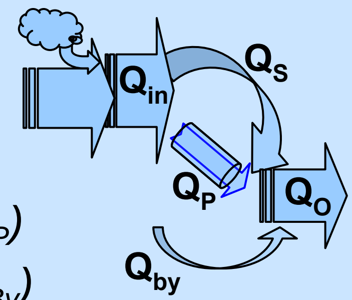
Average Constraints

Prudent

Targets

Margins

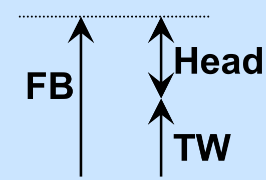
Flows (kcfs)



- Total Inflow *(Q_{In})*
- Spill Flow *(Q_S)*
- Turbine Flow *(Q_P)*
- Bypass Flow *(Q_{By})*
- Total Outflow *(Q_O)*

Elevations (ft.)

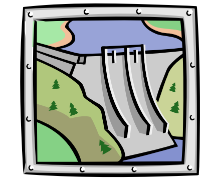
- Forebay
- Head
- Tailwater



Other variables

- Generation
  $= Q_P \times (H/K)$
- Storage Content
  $= f(FB)$
- Percent Spill
  $= Q_S \div Q_O$

Single Project Hydraulics

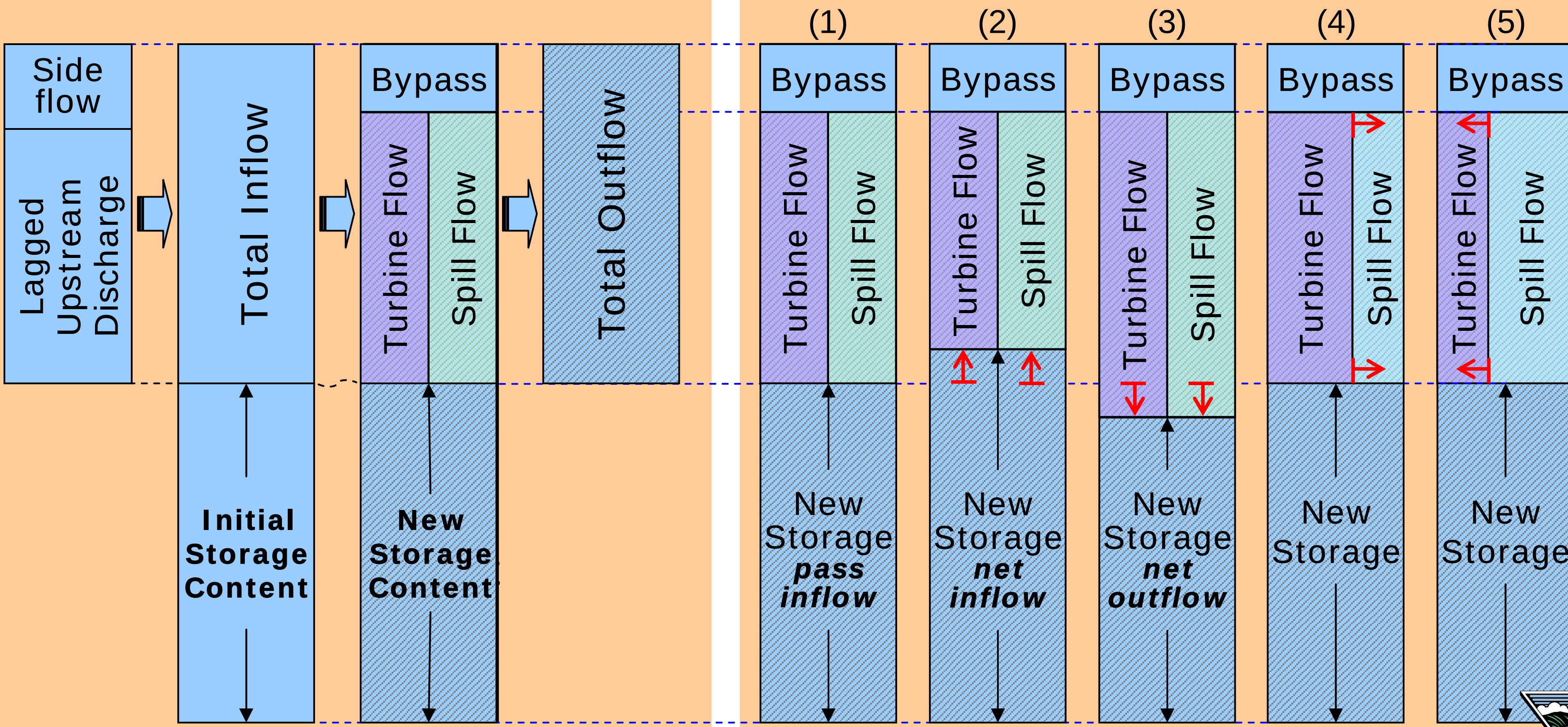


Each project / hour model has:

- *Multiple Input Values*
- *2 Degrees of Freedom*
- *Computed Outputs*

Adjust the two degrees of freedom to:

(1) pass inflow *(unchanged storage)* ***or***
(2) increase ***or*** (3) decrease storage ***or***
(4) increase ***or*** (5) decrease generation



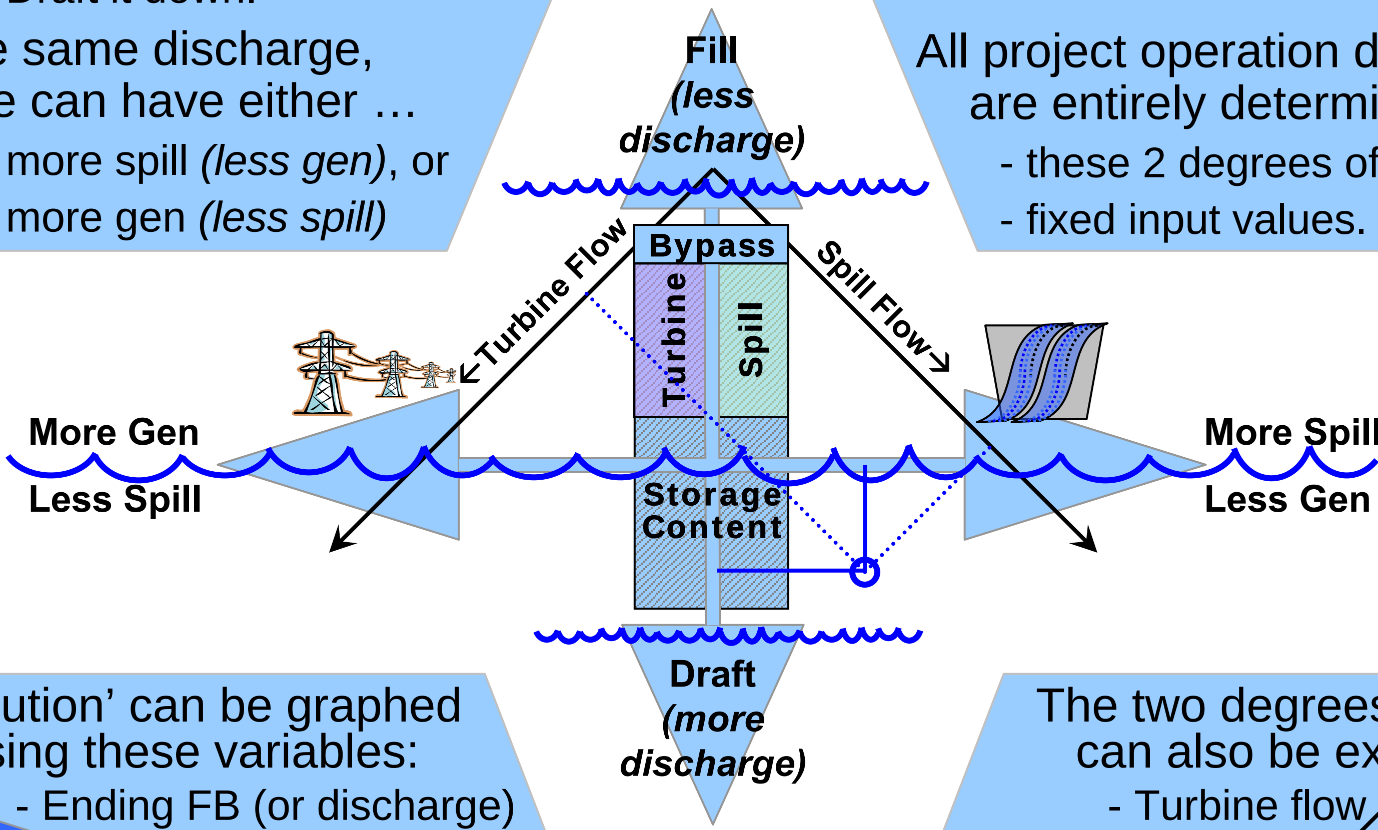
Two degrees of freedom

By modifying discharge, we can
- Fill the reservoir up, or
- Draft it down.

At the same discharge,
we can have either …
- more spill *(less gen)*, or
- more gen *(less spill)*

These two degrees of freedom determine all other values.

All project operation details are entirely determined by
- these 2 degrees of freedom
- fixed input values.



A 'solution' can be graphed using these variables:
- Ending FB (or discharge)
- The Gen/Spill split

The two degrees of freedom can also be expressed as:
- Turbine flow
- Spill flow

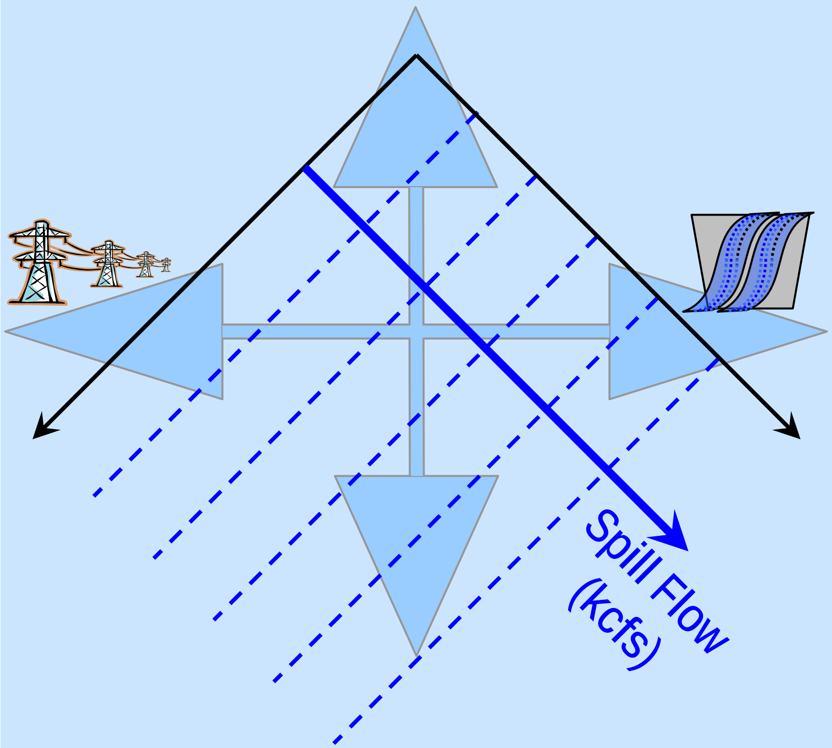
This gives us two alternate coordinate systems

Graphing Model Variables

On this graph …

- Rising diagonals represent

  Fixed Spill Flow (kcfs)

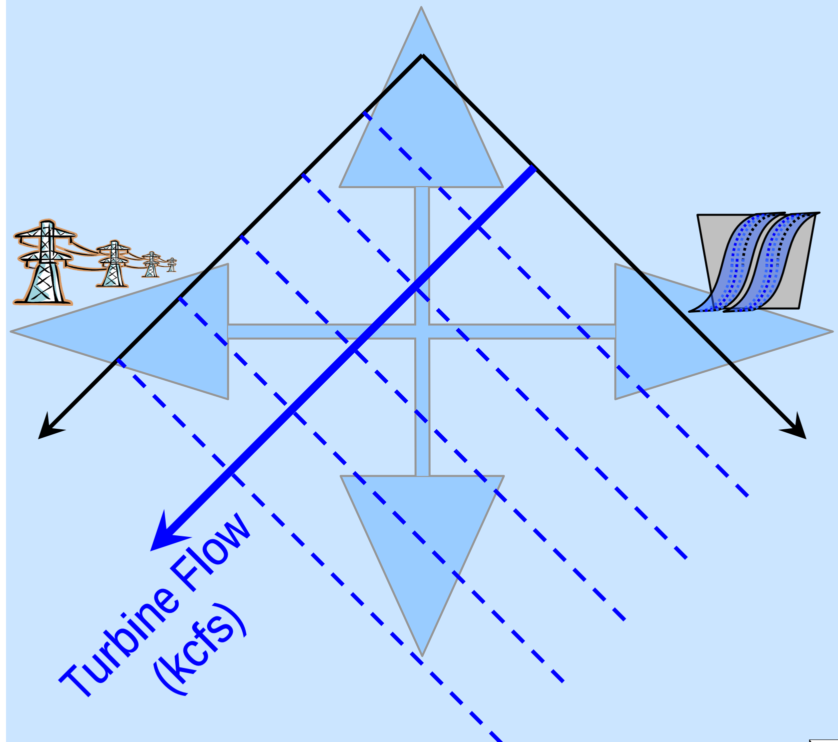


- Falling diagonals represent

  Fixed turbine flow (kcfs)

  Fixed generation (MW)

  (assuming no in-hour H/K change)

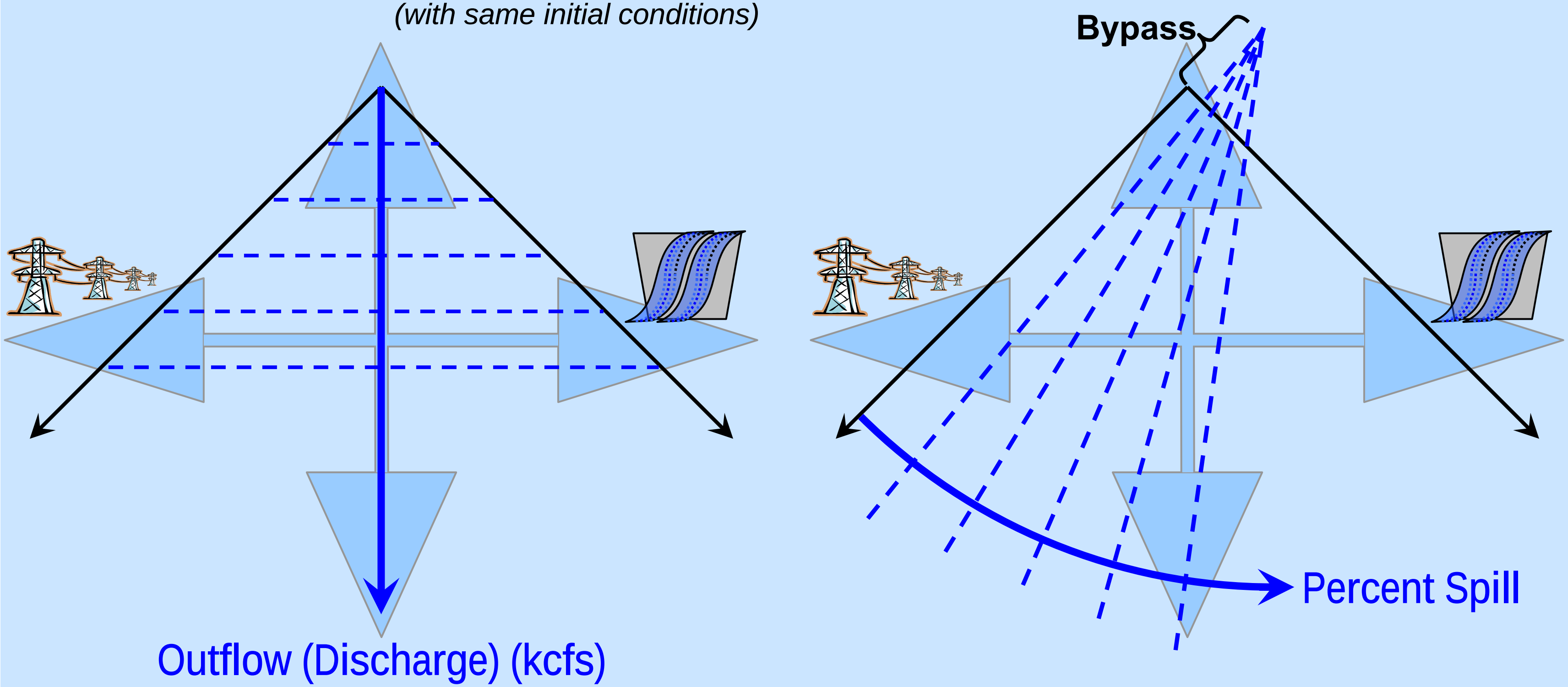


Graphing Model Variables

- Horizontal lines represent
  - Fixed Outflow *(in kcfs)*
  - Fixed forebay or tailwater

(with same initial conditions)

- Slanted lines represent fixed Spill Flow % *(as a % of Total Flow)*



Operating Constraints

Powerhouse constraints

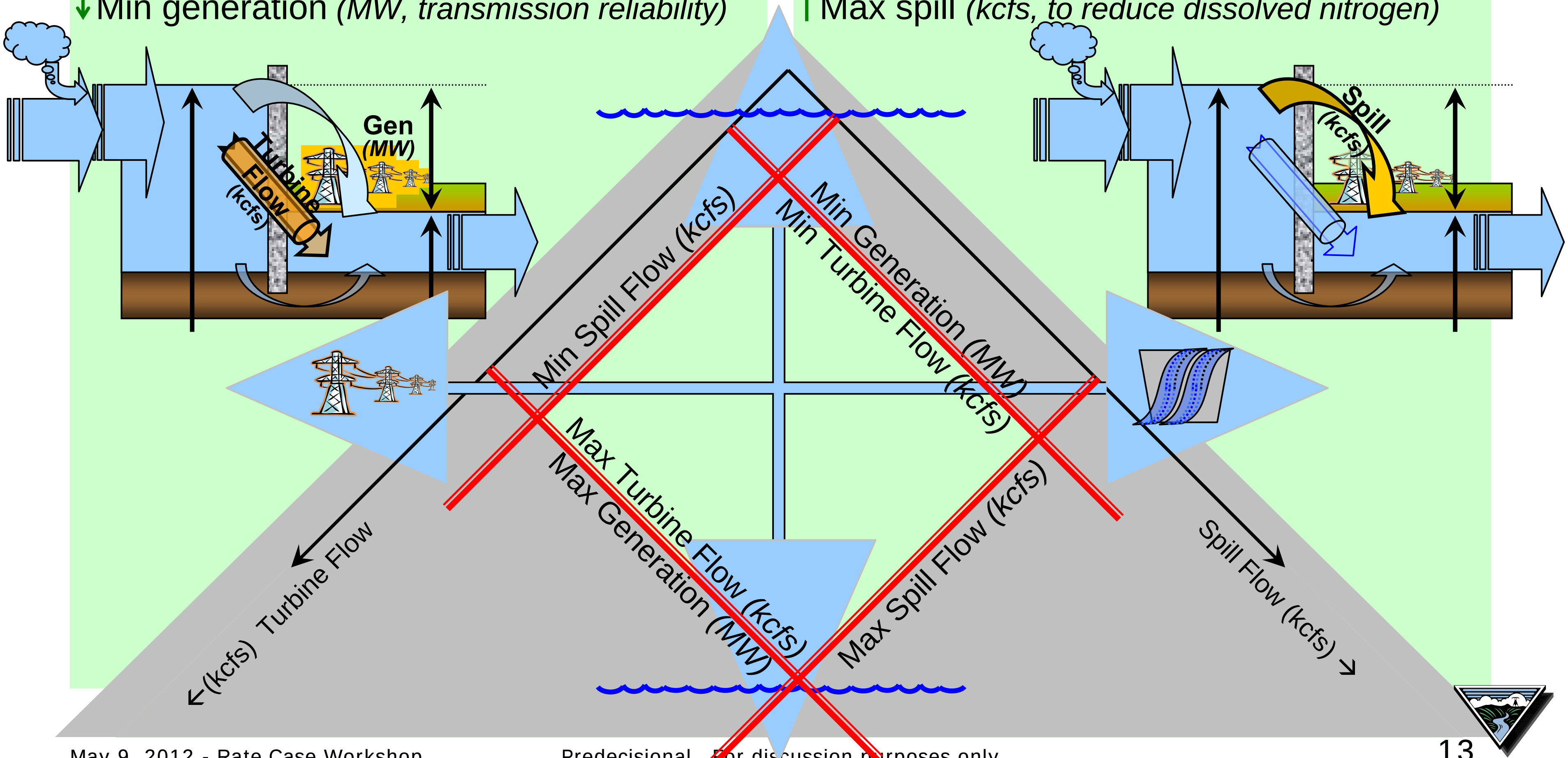
↑ Max generation
- Unit outages & de-ratings *(kcfs or MW)*
- Line outages & de-ratings *(MW)*

↓ Min generation *(MW, transmission reliability)*

Spillway constraints

↓ Min spill *(to promote fish passage)*
- Absolute *(kcfs)*
- Percent *(of total flow)*

↑ Max spill *(kcfs, to reduce dissolved nitrogen)*



Operating Constraints

Discharge Constraints

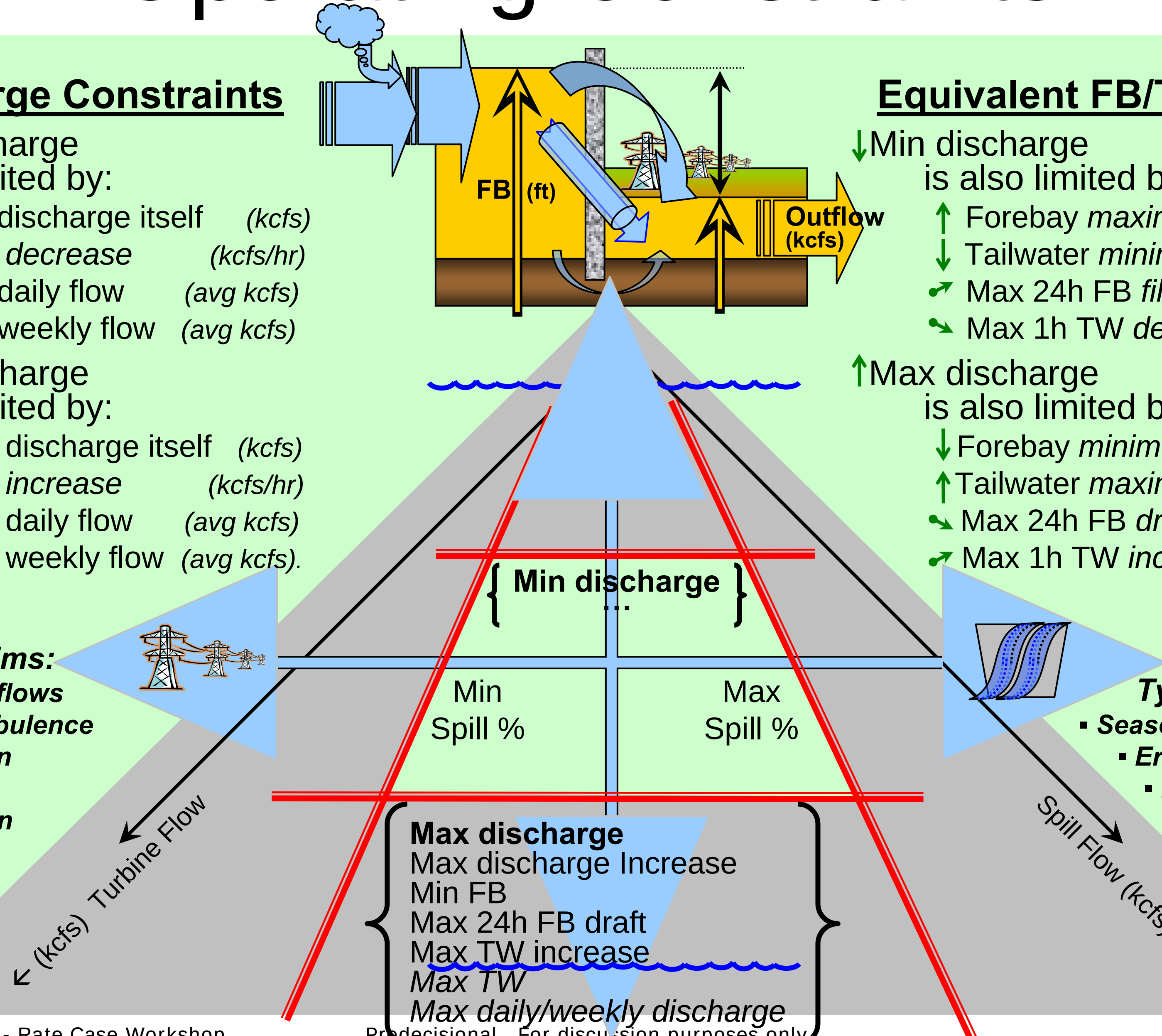
↓Min discharge
is limited by:
- ↓ *Min* discharge itself *(kcfs)*
- Max *decrease* *(kcfs/hr)*
- *Min* daily flow *(avg kcfs)*
- *Min* weekly flow *(avg kcfs)*

↑Max discharge
is limited by:
- ↑ *Max* discharge itself *(kcfs)*
- Max *increase* *(kcfs/hr)*
- *Max* daily flow *(avg kcfs)*
- *Max* weekly flow *(avg kcfs).*

Equivalent FB/TW limits

↓Min discharge
is also limited by:
- ↑ Forebay *maximum* *(ft)*
- ↓ Tailwater *minimum* *(ft)*
- Max 24h FB *fill* *(ft/24hr)*
- Max 1h TW *decrease* *(ft/hr)*

↑Max discharge
is also limited by:
- ↓Forebay *minimum* *(ft)*
- ↑Tailwater *maximum* *(ft)*
- Max 24h FB *draft* *(ft/24hr)*
- Max 1h TW *increase* *(ft/hr)*



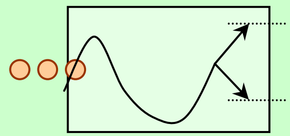
Typical aims:
- ***Regulate flows***
- ***Avoid turbulence***
- ***Navigation***
- ***Fisheries***
- ***Recreation***
- ***etc…***

Typical aims:
- ***Seasonal planning***
- ***Erosion control***
- ***Flood control***
- ***etc…***

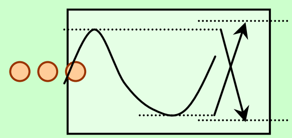
Constraints Equivalences

Many constraints depend on history:

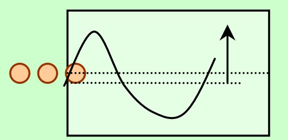
Hour-to-hour change
- Tailwater change
- Discharge change



24-Hour fluctuation
- FB fill / draft
- TW fluctuation



Averages
- Min daily discharge
- Min weekly discharge



If prior operation is known,
can convert to simple min/max

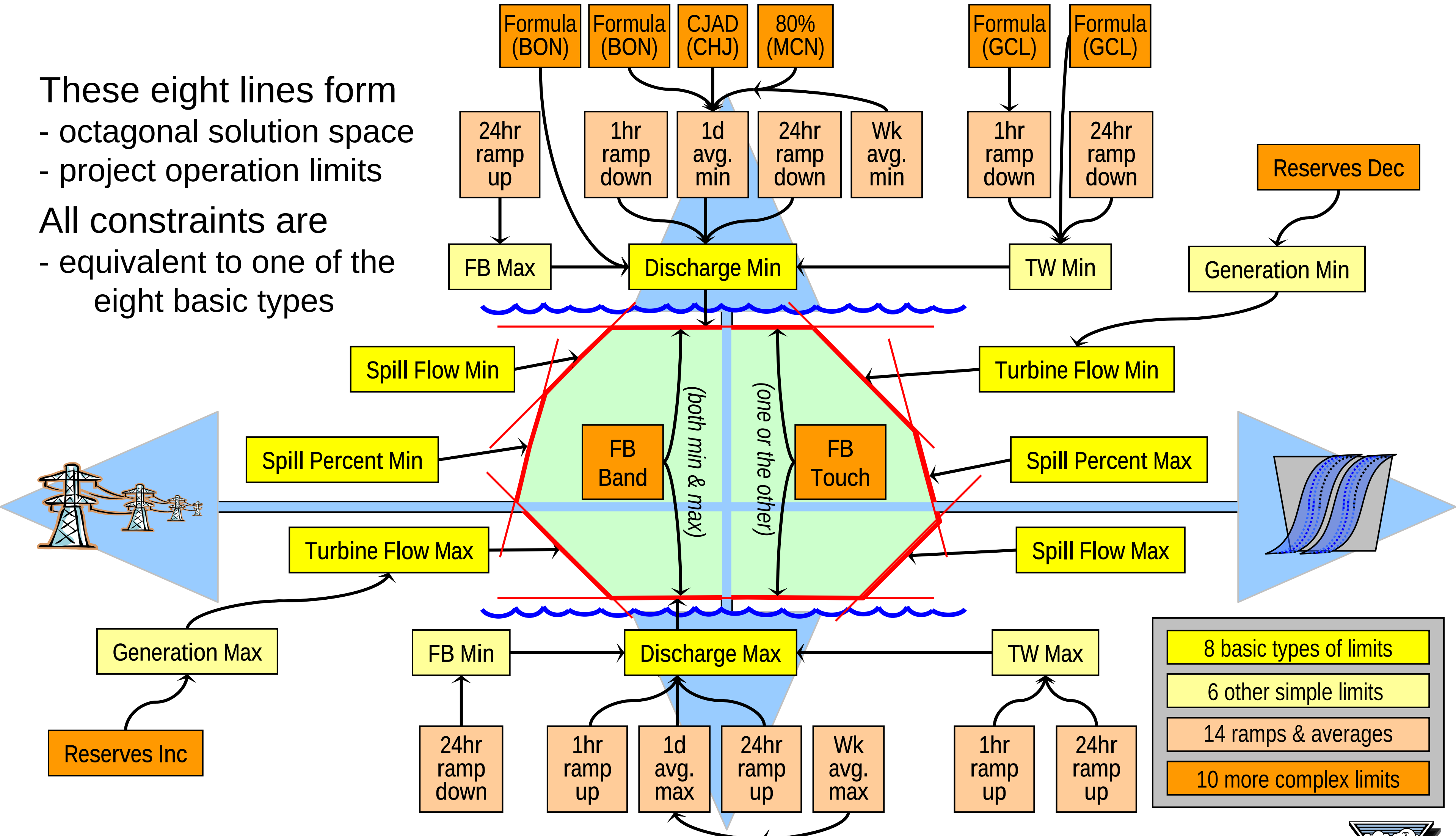
Additional conversions are possible
- FB/TW to discharge limits
- Generation to Turbine Flow limits

- In this way, any constraint can be converted to one of these eight:
  - Min/Max discharge *(kcfs)*
  - Min/Max turbine flow *(kcfs)*
  - Min/Max spill *(kcfs)*
  - Min/Max spill % *(% of discharge)*
- Constraint conversions
  - depend on current configuration
    (that is, on prior operation history)
  - must be recomputed
    for each hour simulated.
- These eight limits constrain the two degrees of freedom
  - for each project
  - for each hour

Constraint Equivalences

These eight lines form
- octagonal solution space
- project operation limits

All constraints are
- equivalent to one of the eight basic types



Constraint Application

All constraints must be satisfied:

1. Min & max generation

2. Min & max forebay and other discharge-equivalent constraints

3. Min & max spill flow

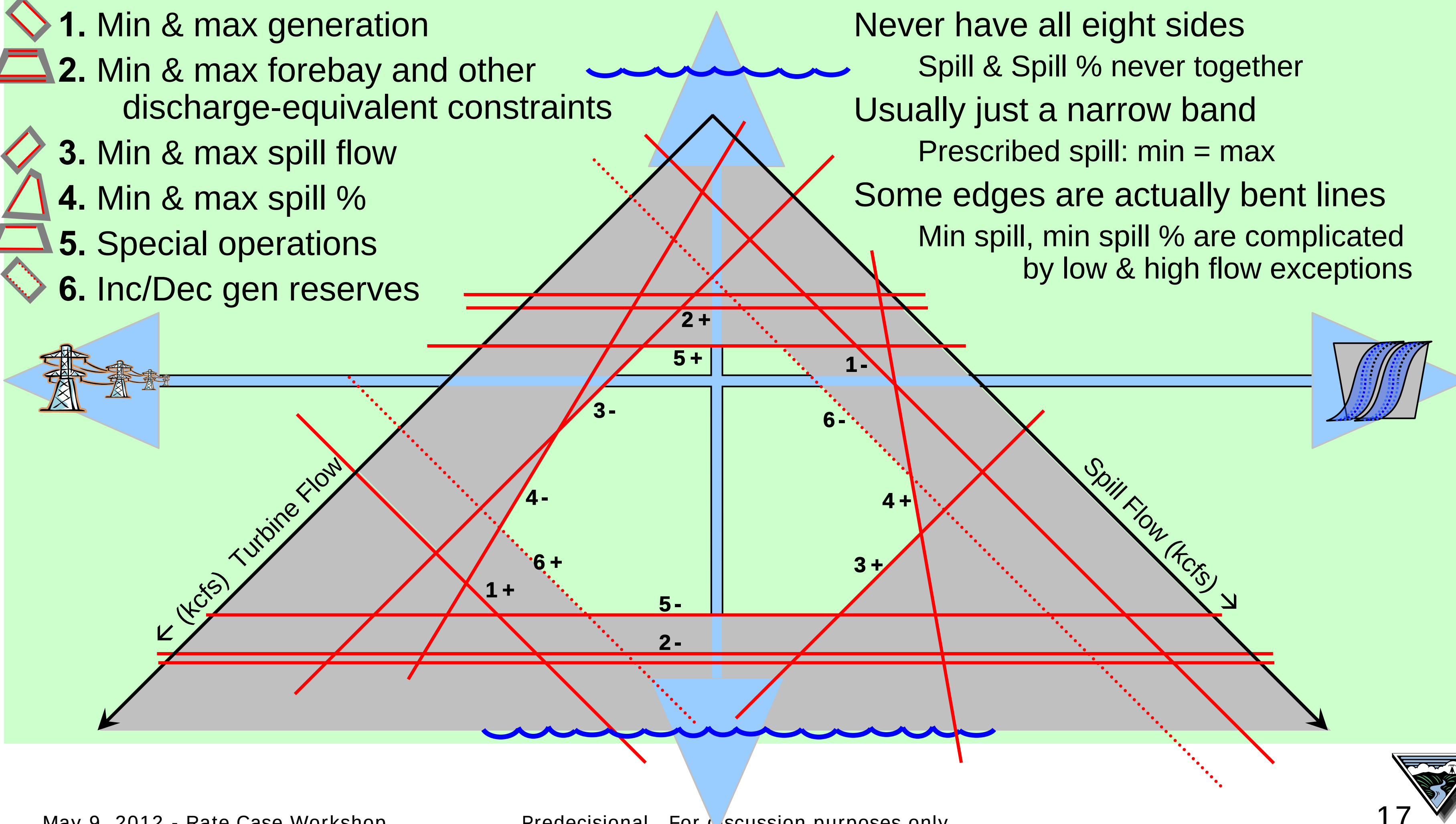
4. Min & max spill %

5. Special operations

6. Inc/Dec gen reserves

Feasible area is ***not*** a simple octagon

- Never have all eight sides
  - Spill & Spill % never together
- Usually just a narrow band
  - Prescribed spill: min = max
- Some edges are actually bent lines
  - Min spill, min spill % are complicated by low & high flow exceptions



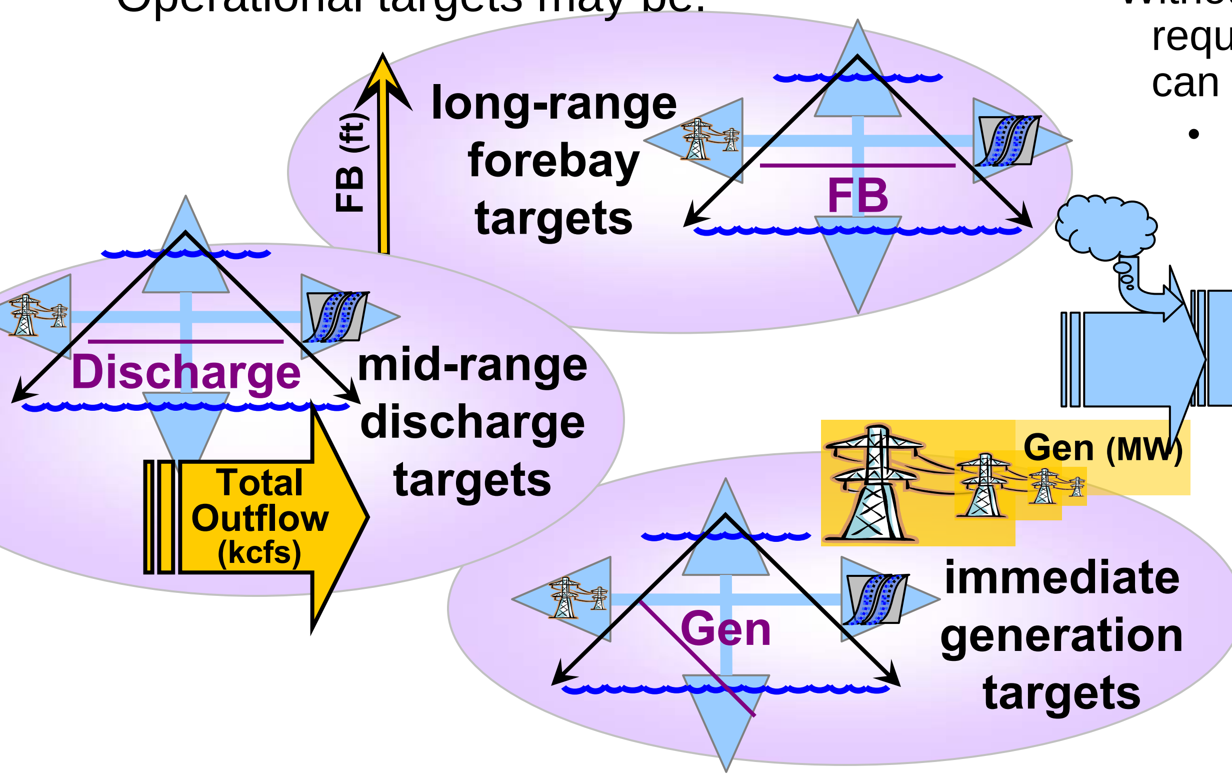
Constraints & Targets

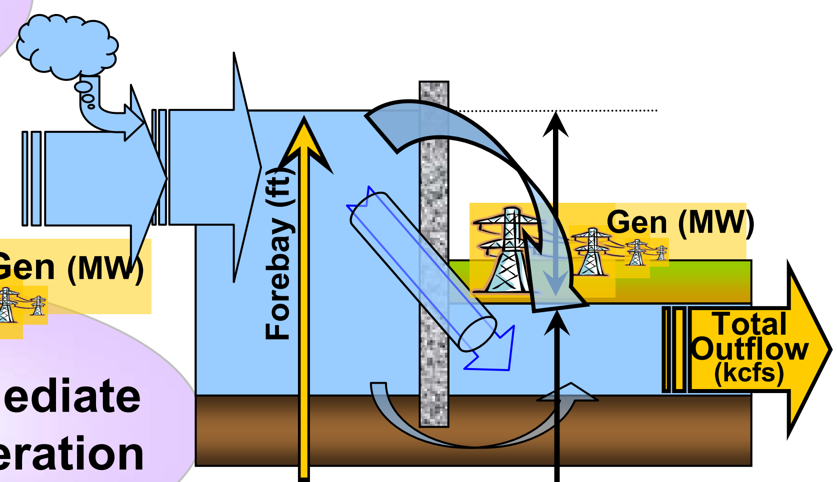
After all constraints are met, the area in the constraint octagon indicates
- all feasible project operations
- flexibility to meet operational targets

Project operators *(Corps, Bureau)*
- will prevent immediate violations.

BPA operations & planning
- must prevent future violations.
- Without careful planning, requests at a project ***in one hour*** can force violation ***in a later hour***
  - at the ***same*** or a ***different*** project.

Operational targets may be:





Constraint Conflicts

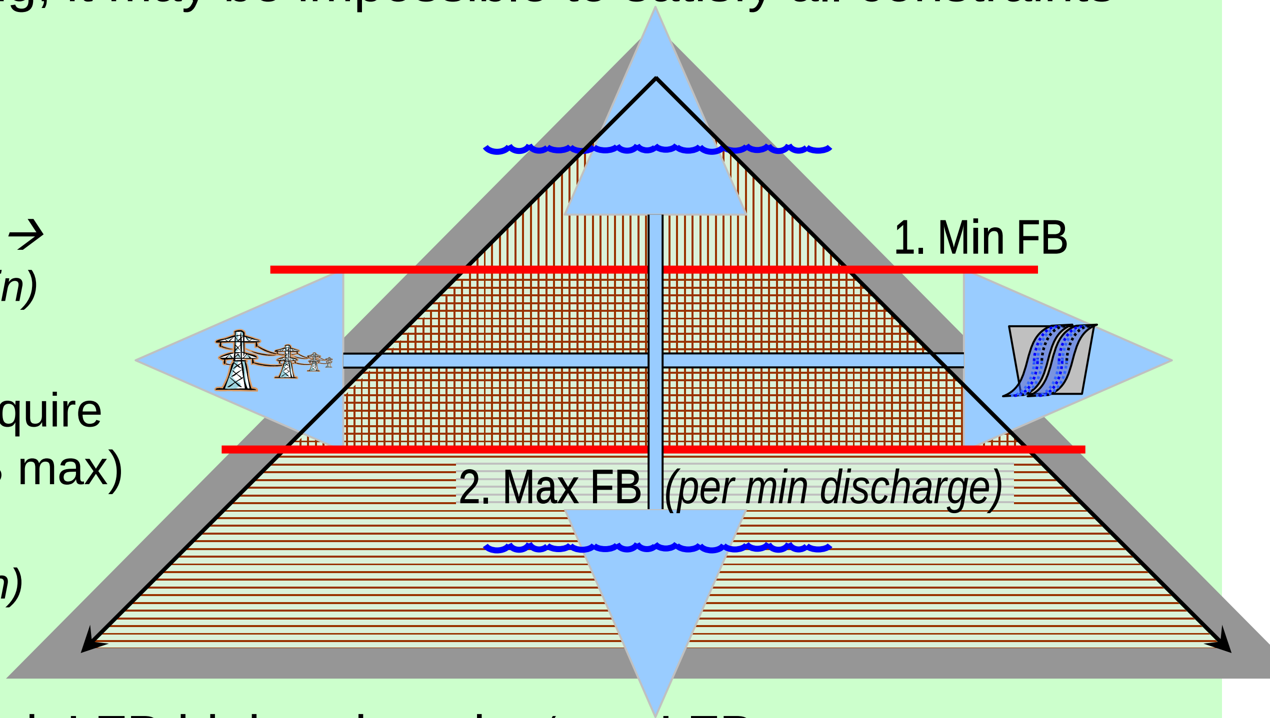
Without careful planning, it may be impossible to satisfy all constraints

- In a drafted reservoir,
  min FB may require
  small max discharge

  (any greater discharge → FB drafted below min)

- With low inflow,
  min discharge may require
  large FB draft (low FB max)

  (any higher FB → discharge below min)



If both occur,
this will result in a 'min' FB higher than the 'max' FB

- FB max (Discharge min) is normally on the top
- FB min (Discharge max) is normally on the bottom
- If they are reversed, cannot satisfy both

One-Project Model Iterated

Iterate
Downstream Inflow ← Upstream Outflow
Starting FB ← Ending FB

Operations History

System Configuration
Starting forebay
Total Inflow
Other History

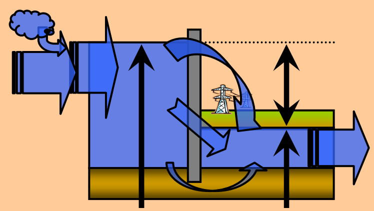
Input Data

System Conditions
Streamflows
Plant Characteristics
Constraints

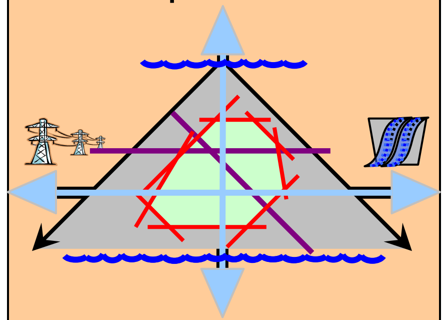
Ops & Planning

Operational Targets
Generation
Total Outflow
Forebay Elevation

1-Project Model



Two degrees of freedom:
Turbine Flow
Spill Flow

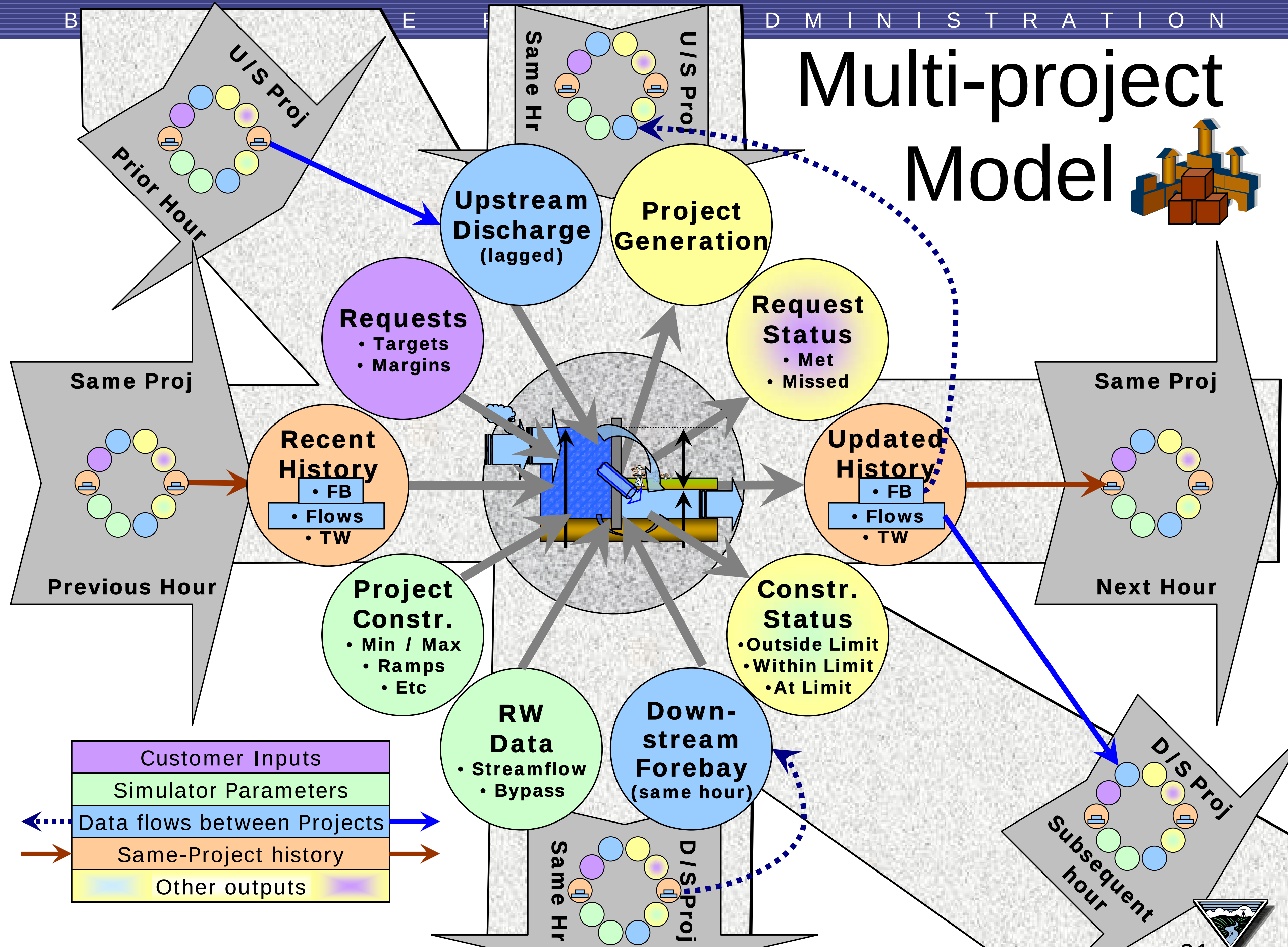


Project Operation
Ending forebay
Total Outflow
Other operations

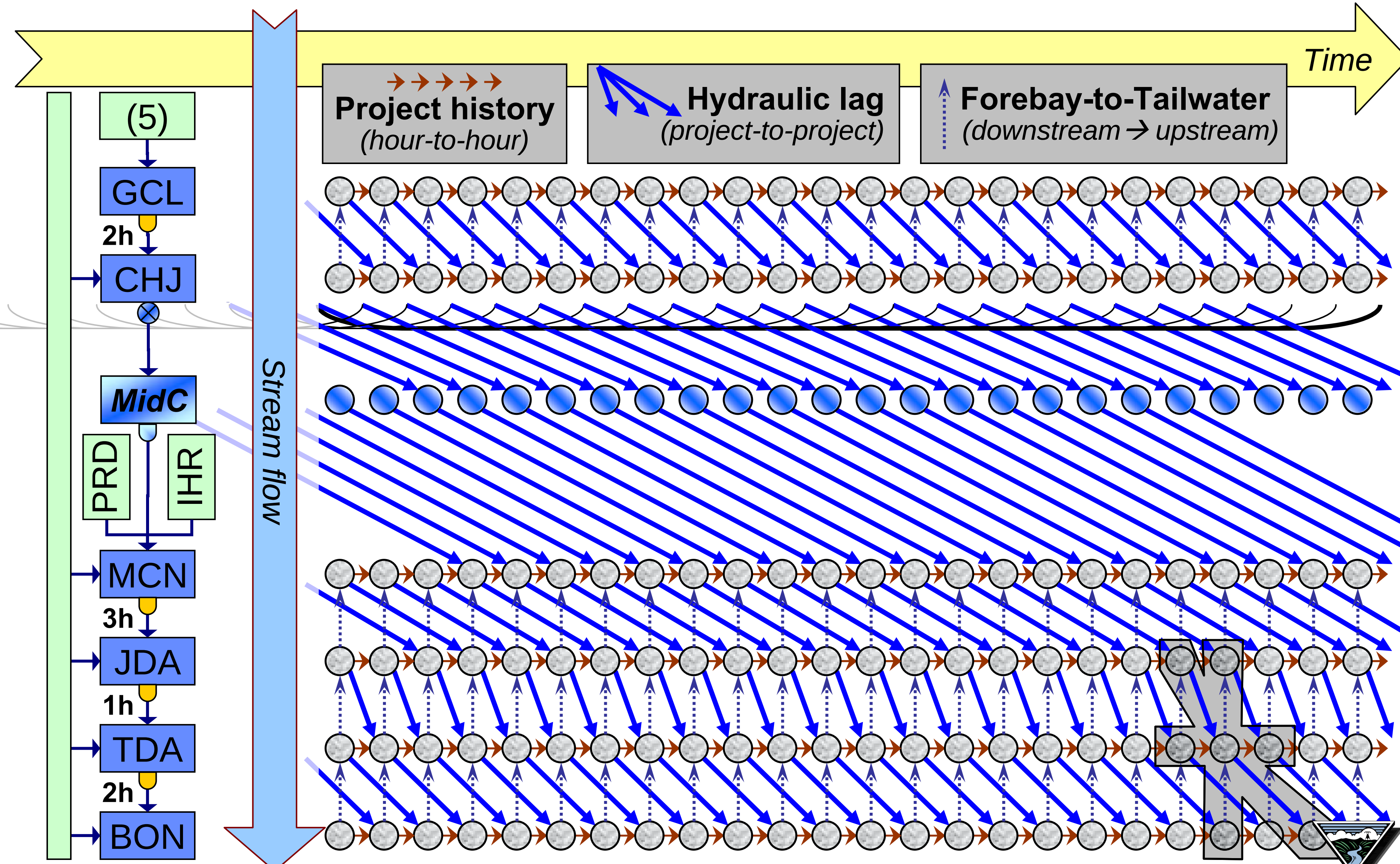
Constraint Status
Within limit
At limit
Outside limit

Target Status
Target Met
Target Missed

Multi-project Model



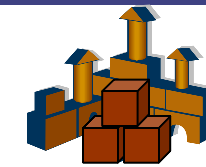
Multi-Project Water Routing

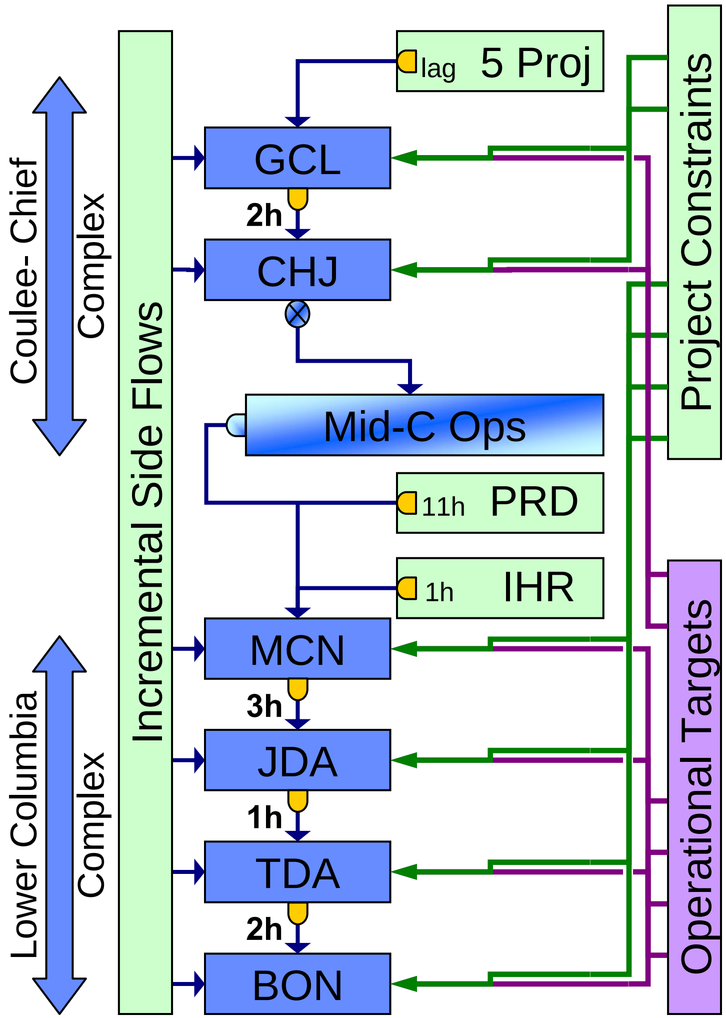


Summary

- The FCRPS is a complex, interconnected system
  - Many competing uses
  - Power production is the lowest priority
- Actions at one project affect other interconnected projects
- Actions at one time have long-term system impacts
  - Future commitments and contingencies restrict current use
  - Immediate actions can have a long-lasting impact
  - As real-time approaches, very little flexibility remains in the system
- BPA manages operational uncertainty and price risk by selling a variety of products and services over a variety of time frames.
- Flexibility may appear "physically available" at any given time, but unpredictable use of flexibility …
  - … affects BPA's ability to meet power and non-power obligations
  - … affects multiple time horizons, not just the immediate moment

? Questions ?




Coulee- Chief
Complex
Lower Columbia
Complex
Incremental Side Flows
lag 5 Proj
GCL
2h
CHJ
Mid-C Ops
11h PRD
1h IHR
MCN
3h
JDA
1h
TDA
2h
BON
Project Constraints
Operational Targets