Optimizing Flex Spill on the Columbia River for BPA Short Term Planning

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RiverWare User Group Meeting
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Presentation Overview

- Function of Short Term Planning group at BPA
- Explain how PNW region arrived at “Flex Spill”
- What is flex spill and what are the rules?
- Importance of implementing flex spill in RiverWare
- CADSWES discussion on model implementation

RiverWare Optimization at BPA

- Short Term Planning group is responsible for the coordination and implementation of multiple operational objectives of the Federal Columbia River Power System (FCRPS)
  - Flood control, fish passage, navigation, irrigation, recreation, power generation
  - Also responsible for the coordination and scheduling of all generator outages and transmission line outages that impact the generators
  - Short Term = Current Day -> Approx. 2-3 weeks out
  - Dams owned by Army COE and BOR
- Priority based RiverWare optimization model to determine the most economic solution within all non-power operational constraints
  - Hourly timestep
  - Single day capacity study and 2-3 week Planning Study model runs
  - Provide marketing guidance to energy traders

Columbia River Basin Flex Spill Projects

<u>Lower Snake River</u>

1. Lower Granite
2. Little Goose
3. Lower Monumental
4. Ice Harbor

<u>Lower Columbia River</u>

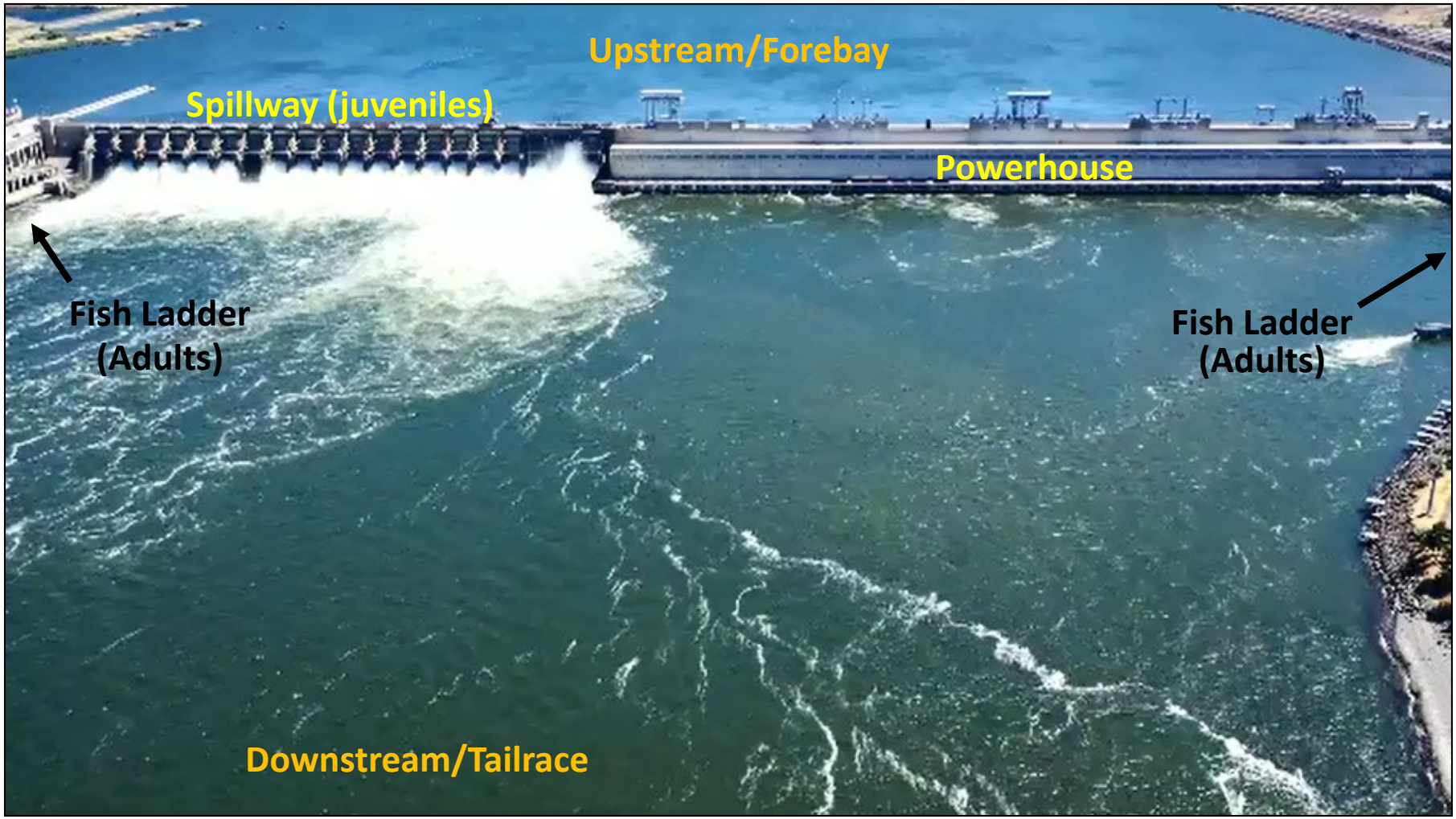
1. McNary
2. John Day
3. The Dalles
4. Bonneville

<u>Fish Passage Season</u>

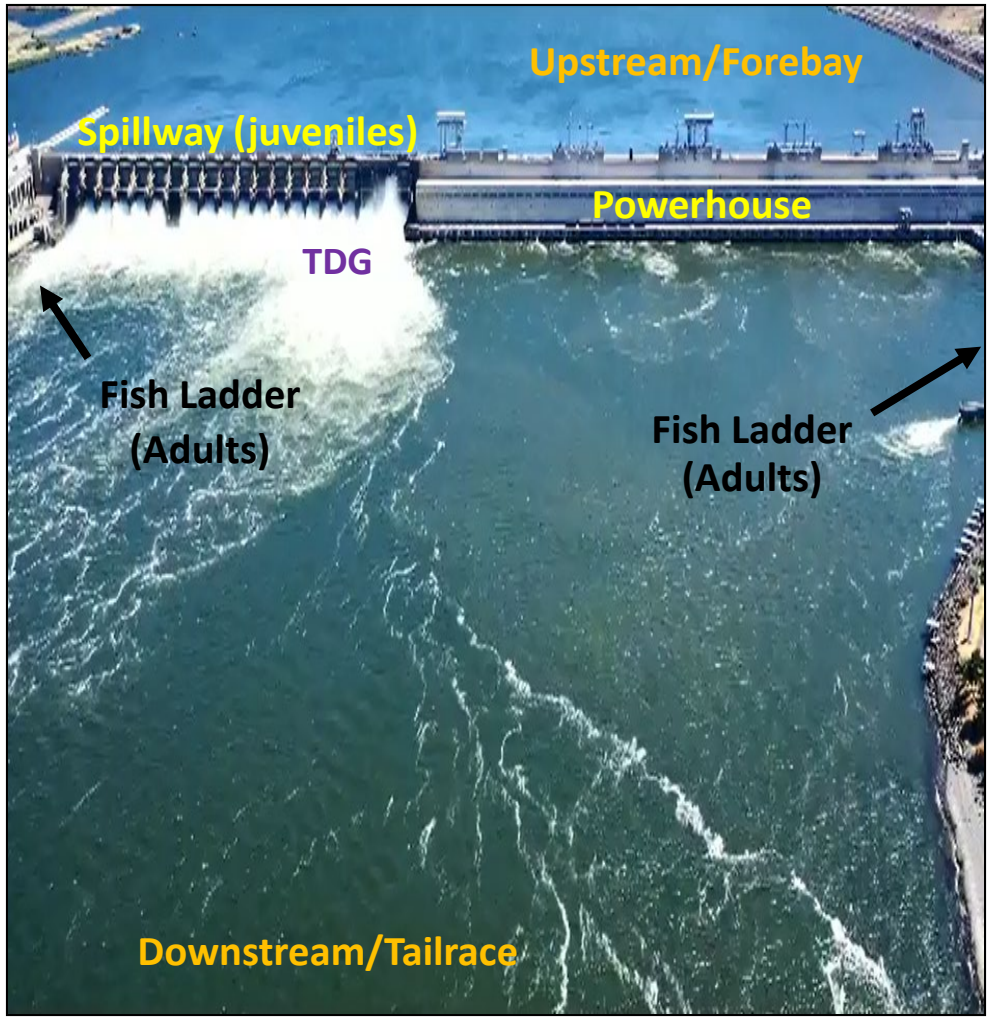
Spring: Apr 3 – Jun 20

Summer: Jun 21 – Aug 31

Fish Passage Dam Layout



Fish Passage Spill Requirements



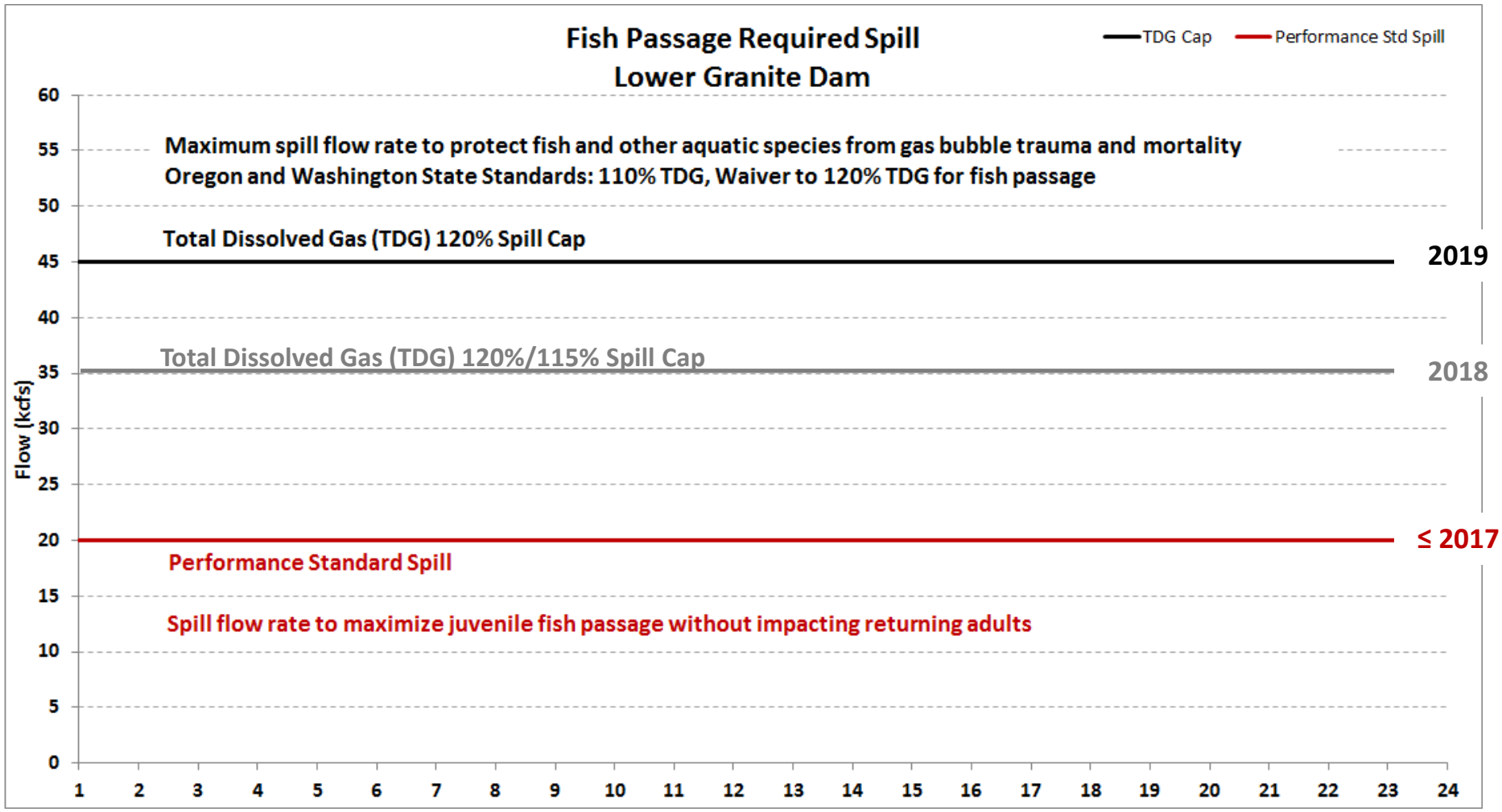
- Prior to 2018
  - Performance Standard spill
  - Maximize juvenile spillway passage without impacting returning adults
  - Gas cap = 120%/115% TDG (maximum)
- 2018
  - Court ordered spill to gas cap (120%/115%)
  - Gas cap is request, not maximum
  - Minimize juvenile encounters with powerhouse
- 2019 Proposal
  - Gas cap increased to 120% TDG
  - Risk of impacting adult returns
  - Significant loss of power generation (clean energy bills)

2019 – 2020 Flex Spill Agreement

- Major regional effort to test a collaborative approach to juvenile fish passage that preserves flexibility for power generation
- Principle 1: Fish Benefit
  - Test higher spill flow rates to provide benefits to juvenile fish by limiting powerhouse passage
- Principle 2: Power Financial Benefit
  - Flexibility to reduce spill and increase power generation on certain hours to offset the cost of higher spill levels
- Principle 3: Implementation
  - Flex spill operational constraints must be implementable
    - Hydro scheduling, project operators, reporting

Link to Flexible Spill Agreement

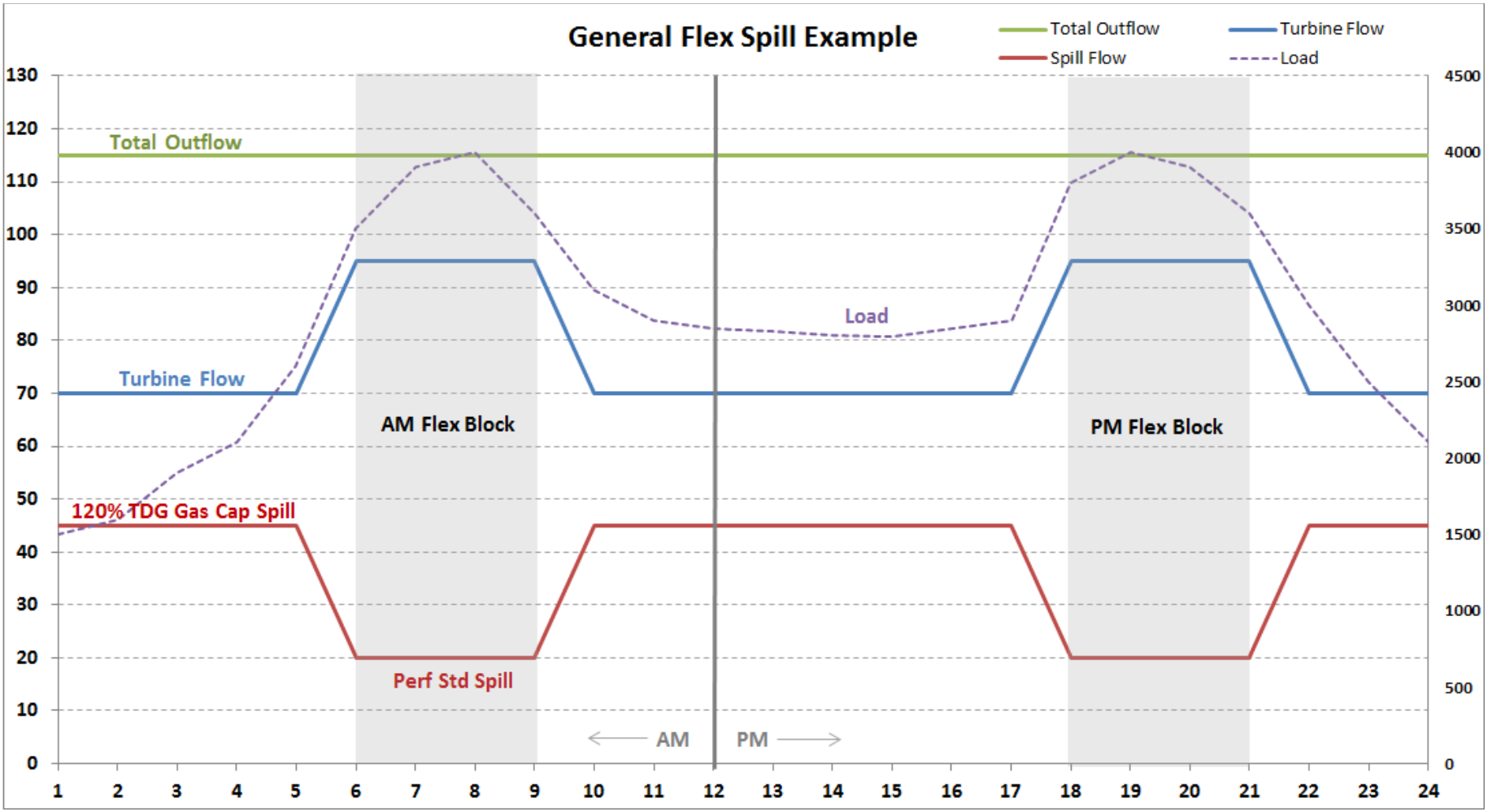
Changes to Fish Spill Requirements



Flex Spill Constraints

- "Flex hour" is an hour of reduced spill for power flexibility as requested by BPA
  - Reduce spill from 120% TDG down to performance standard amount
- ≤ 8 flex hours/day (0001 – 2359)
- ≤ 5 consecutive flex hours
- ≤ 2 flex blocks/day (0001 – 2359)
  - If 2 blocks, one must start in AM (0001 – 1159) and one must start in PM (1200 – 2359)

Flex Spill Example



Flex Criteria	1. Spill cap = hourly target spill rate defined for 120% TDG. *Also includes hours that spill is above or below the spill cap due to involuntary spill, min gen, or adjustments for nav safety, transmission reliability, etc.*
≤ 5 Consecutive Hours	
≤ 8 hours/day (0001-2359)	
≤ 2 blocks/day (0001-2359)	2. Flex = hours of reduced spill for power flexibility, as requested by BPA. Flex spill hours must be no lower than the performance standard level and must meet ALL criteria defined to the right in red.
If 2 blocks/day, start one AM and one PM	

GENERIC EXAMPLE OF FLEX SPILL OPERATION *(does NOT apply to LGS)*

	Hour Ending	Example Day 1	Example Day 2	Example Day 3	Example Day 4	Example Day 5	Example Day 6	Example Day 7
AM	1:00	spill cap	spill cap	spill cap	spill cap	spill cap	spill cap	Flex PM 5
	2:00	spill cap	Flex AM 1	spill cap	spill cap	spill cap	spill cap	spill cap
	3:00	spill cap	Flex AM 2	spill cap	spill cap	spill cap	spill cap	Flex AM 1
	4:00	spill cap	Flex AM 3	spill cap	spill cap	spill cap	spill cap	Flex AM 2
	5:00	Flex AM 1	Flex AM 4	spill cap	spill cap	spill cap	spill cap	Flex AM 3
	6:00	Flex AM 2	Flex AM 5	spill cap	spill cap	Flex AM 1	spill cap	Flex AM 4
	7:00	Flex AM 3	spill cap	spill cap	spill cap	spill cap	spill cap	Flex AM 5
	8:00	Flex AM 4	spill cap	spill cap	spill cap	spill cap	spill cap	spill cap
	9:00	spill cap	spill cap	spill cap	spill cap	spill cap	spill cap	spill cap
	10:00	spill cap	spill cap	spill cap	spill cap	spill cap	spill cap	spill cap
	11:00	spill cap	spill cap	spill cap	spill cap	spill cap	spill cap	spill cap
	12:00	spill cap	spill cap	spill cap	spill cap	spill cap	Flex AM 1	spill cap
PM	13:00	spill cap	Flex PM 1	spill cap	spill cap	spill cap	Flex AM 2	spill cap
	14:00	spill cap	Flex PM 2	spill cap	spill cap	spill cap	Flex AM 3	spill cap
	15:00	spill cap	Flex PM 3	spill cap	spill cap	spill cap	spill cap	spill cap
	16:00	Flex PM 1	spill cap	spill cap	Flex PM 1	spill cap	spill cap	Flex PM 1
	17:00	Flex PM 2	spill cap	spill cap	Flex PM 2	spill cap	spill cap	Flex PM 2
	18:00	Flex PM 3	spill cap	spill cap	Flex PM 3	spill cap	spill cap	spill cap
	19:00	Flex PM 4	spill cap	spill cap	Flex PM 4	spill cap	spill cap	spill cap
	20:00	spill cap	spill cap	spill cap	Flex PM 5	spill cap	spill cap	spill cap
	21:00	spill cap	spill cap	spill cap	spill cap	spill cap	Flex PM 1	spill cap
	22:00	spill cap	spill cap	spill cap	spill cap	spill cap	Flex PM 2	spill cap
	23:00	spill cap	spill cap	spill cap	spill cap	spill cap	Flex PM 3	spill cap
	0:00	spill cap	spill cap	spill cap	spill cap	spill cap	Flex PM 4	spill cap
	Total Hrs/Day Spill Cap (>= 16)	**16**	**16**	**24**	**19**	**23**	**17**	**16**
	Total Hrs/Day Flex Spill (<= 8)	**8**	**8**	**0**	**5**	**1**	**7**	**8**
	Total #/Day Flex Blocks (<= 2)	**2**	**2**	**0**	**1**	**1**	**2**	**2**

BPA Flex Spill Optimization

- Model Inputs
  - Streamflow
  - Generator Outages/Available Generation
  - Non-power Operational Constraints
  - Load
  - Market Price
  - Flex Spill Constraints
- Objective
  - Determine the optimal (most valuable) allocation of flex spill hours for each of the fish passage dams

Flex Spill Challenges

- Modeling
  - Prescribed flex hour regulations
  - Each dam may have a different set of flex hours
  - Partial flex hours allowed (between 120% TDG gas cap and performance standard spill)
- Time
  - Finalized flex spill regulations not known until early Feb 2019
  - Flex spill operations began on April 3, 2019
  - Flex spill model logic needed to be developed, implemented, tested, and deployed to our production system

Importance of RiverWare Implementation

- Customers
  - Some customers receive a percentage of our system generation
  - Very important to provide them with accurate generation forecasts that include the flex spill operations
- System Reliability
  - Required to provide reliability coordinator with expected, minimum, and maximum hourly generation forecasts to prove we can meet all our requirements
- Efficiency
  - Not enough time to hand-regulate flex spill for each day in our 2-3 week Planning Study, but still important to provide accurate data

Technical Challenges for Flex Spill in Optimization

- Technically, a Mixed integer Program (MIP)
  - Binary variable: flex or not at each timestep (0/1)
- Constraints on flexed hours are discrete
  - Flex no more than 5 consecutive hours
  - Only one flex block in each a.m. and p.m.
  - At least one non-flexed hour between flex blocks
  - More like IF/THEN logic – can't do this in opt

Linear Programming and Heuristic

Continuous Solution & Heuristic

- **Continuous Solution:** Optimize with "binary" variables as continuous variables; $0 \leq var \leq 1$
- "Tight" formulation gets close
- **Heuristic:** Use information from the solution to set binary variables to 0 or 1
- Re-optimize with binary variables fixed
- Possibly multiple iterations – lock in more binary variables with each iteration

Run time restrictions for BPA did not allow for multiple complete solutions

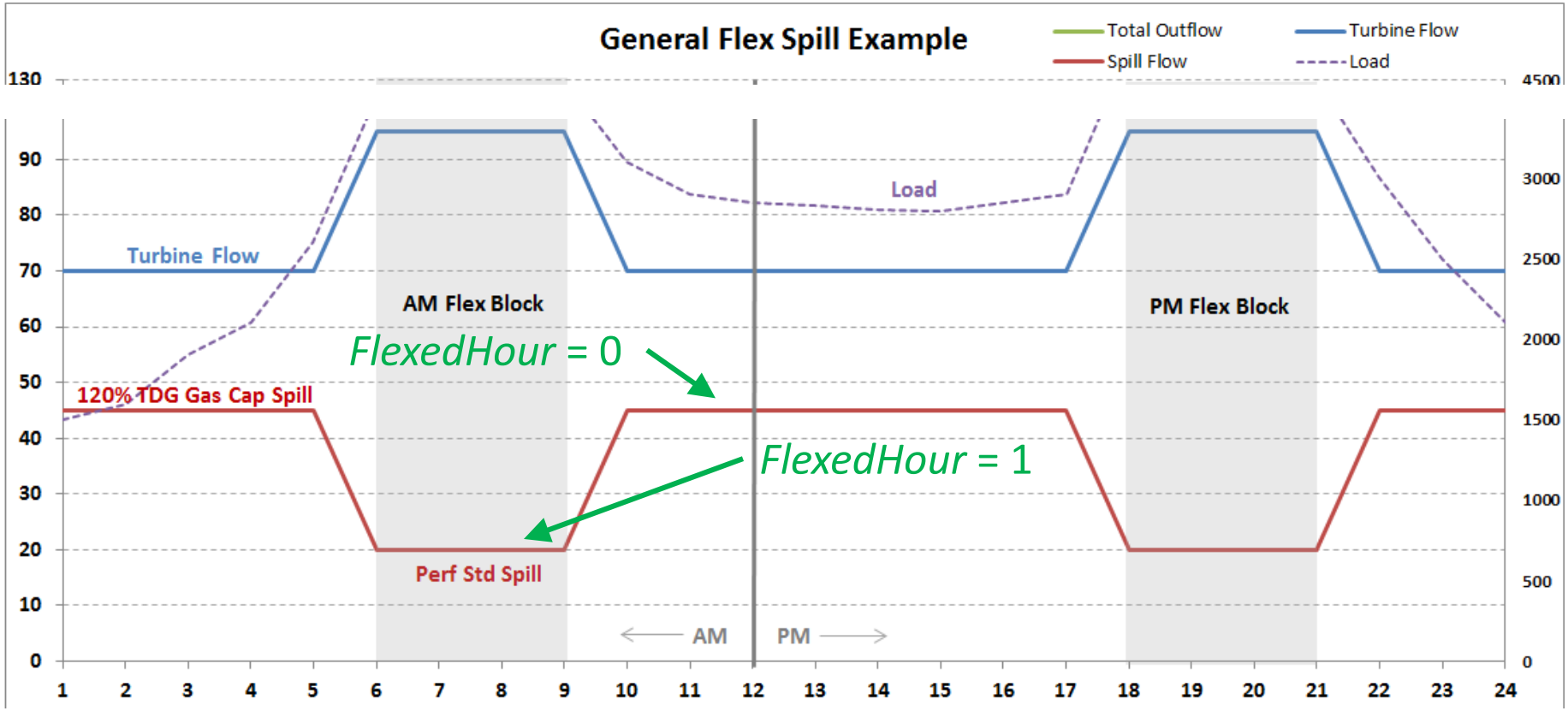
BPA Flex Spill MIP Approach

- Trial objective at a medium priority (continuous solution)
- Single Heuristic – set binary variables to 0/1
- Apply spill constraints based on heuristic: Gas Cap Spill or Performance Standard Spill
- Additional constraints for high and low flow conditions
- All within a single run

Flex Spill Variables

Conceptually:

$$FlexedHour[t] = \frac{QSMax[t] - Spill[t]}{QSMax[t] - QSMin[t]}$$



Flex Spill Variables

- Flex Block Variables
  - One variable for each possible block length starting at each *t*
  - Six slots on each reservoir: 1-5 hours + No Flex
  - $0 \leq$ Flex Block ≤ 1
  - $\sum$ All Block Variables = 1, for each A.M. & P.M.
- Flexed Hour Variables
  - $0 \leq$ Flexed Hour[t] ≤ 1
  - Flexed Hour[t] = $\sum$ Overlapping Block Variables
  - $\sum$ Flexed Hour[t] ≤ 8, for each day

Flex Spill Trial Objective

Maximize:

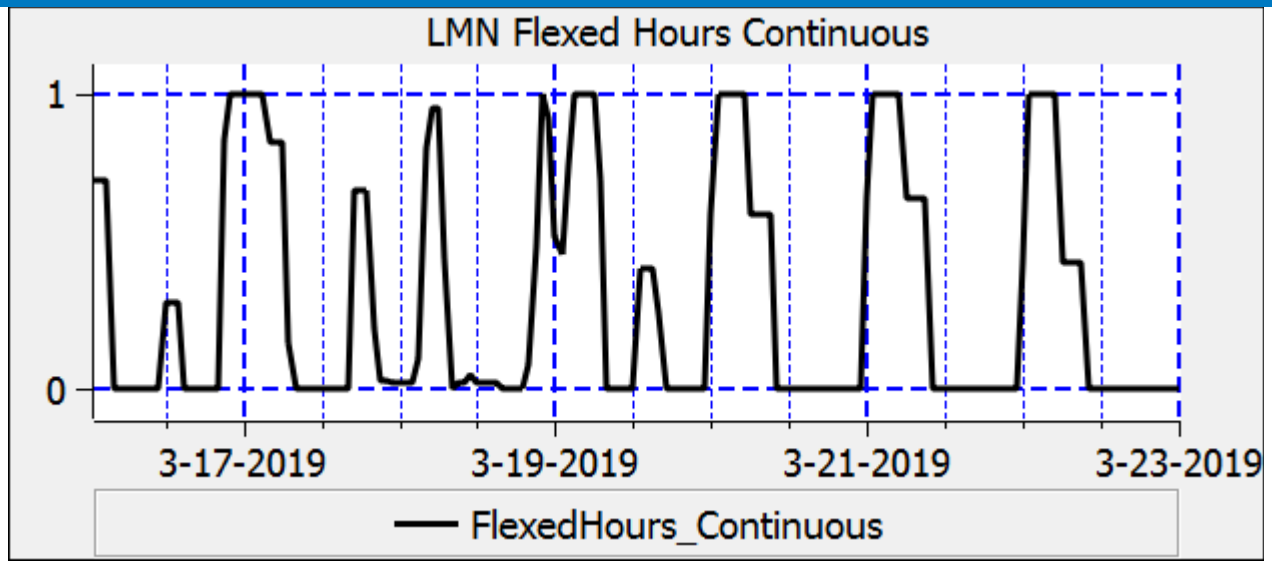
Required Spill

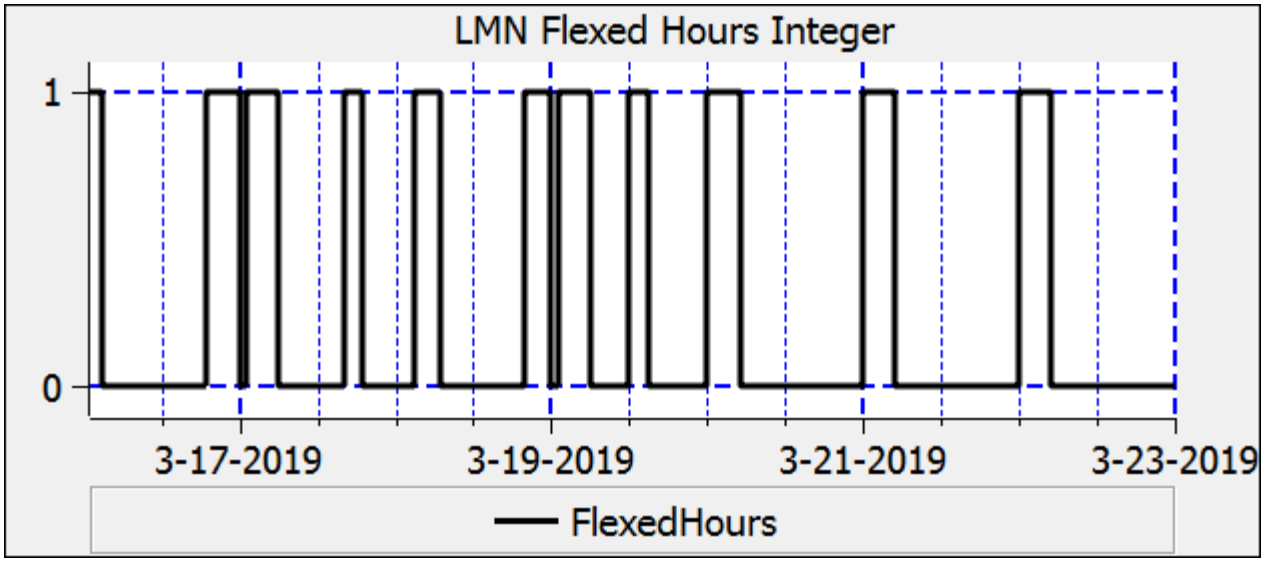
$$Economic\ Value - \left(Penalty * \left[\sum_{all\ t,all\ res} \left(\begin{matrix}[QSMax - \boldsymbol{FlexedHour}[\boldsymbol{t}] * (QSMax - QSMin)] \\ -Spill[t]\end{matrix}\right)\right]\right)$$

- Penalizes spill below required with Flex applied
- Drives Flex (lowered spill requirement) to most beneficial hours

Flex Spill Continuous Solution vs. Integer

Timestep	Day	FlexedHrs_Cont NONE	FlexedHours NONE
3/16 24:00	Sat	1.00	1.00
3/17 1:00	Sun	1.00	0.00
3/17 2:00	Sun	1.00	1.00
3/17 3:00	Sun	1.00	1.00
3/17 4:00	Sun	0.84	1.00
3/17 5:00	Sun	0.84	1.00
3/17 6:00	Sun	0.84	1.00
3/17 7:00	Sun	0.16	0.00
3/17 8:00	Sun	0.00	0.00
3/17 9:00	Sun	0.00	0.00
3/17 10:00	Sun	0.00	0.00
3/17 11:00	Sun	0.00	0.00
3/17 12:00	Sun	0.00	0.00
3/17 13:00	Sun	0.00	0.00
3/17 14:00	Sun	0.00	0.00
3/17 15:00	Sun	0.00	0.00
3/17 16:00	Sun	0.00	0.00
3/17 17:00	Sun	0.67	1.00
3/17 18:00	Sun	0.67	1.00
3/17 19:00	Sun	0.67	1.00
3/17 20:00	Sun	0.21	0.00
3/17 21:00	Sun	0.03	0.00
3/17 22:00	Sun	0.03	0.00
3/17 23:00	Sun	0.02	0.00
3/17 24:00	Sun	0.02	0.00
3/18 1:00	Mon	0.02	0.00
3/18 2:00	Mon	0.02	0.00
3/18 3:00	Mon	0.10	0.00
3/18 4:00	Mon	0.82	1.00
3/18 5:00	Mon	0.95	1.00
3/18 6:00	Mon	0.95	1.00





Flexed Spill Heuristic

- Retrieve all FlexedHour_Continuous values from trial objective
- Select best (highest sum) 3-hour block for each day
- Select best 3-hour block in other half of each day
- Sort remaining hours, highest to lowest
- For each sorted hour, check if adding it to the closest block would still satisfy all requirements
  - Maximum of 8 flexed hours per day
  - Maximum of 5 consecutive flexed hours
  - Minimum of 1 non-flexed hour between flexed blocks
- If requirements satisfied, add the hour

Flex Spill Policy Application

1. High Priority Constraints
2. Flex Spill Variable Definitions
3. Performance Standard Spill Constr.

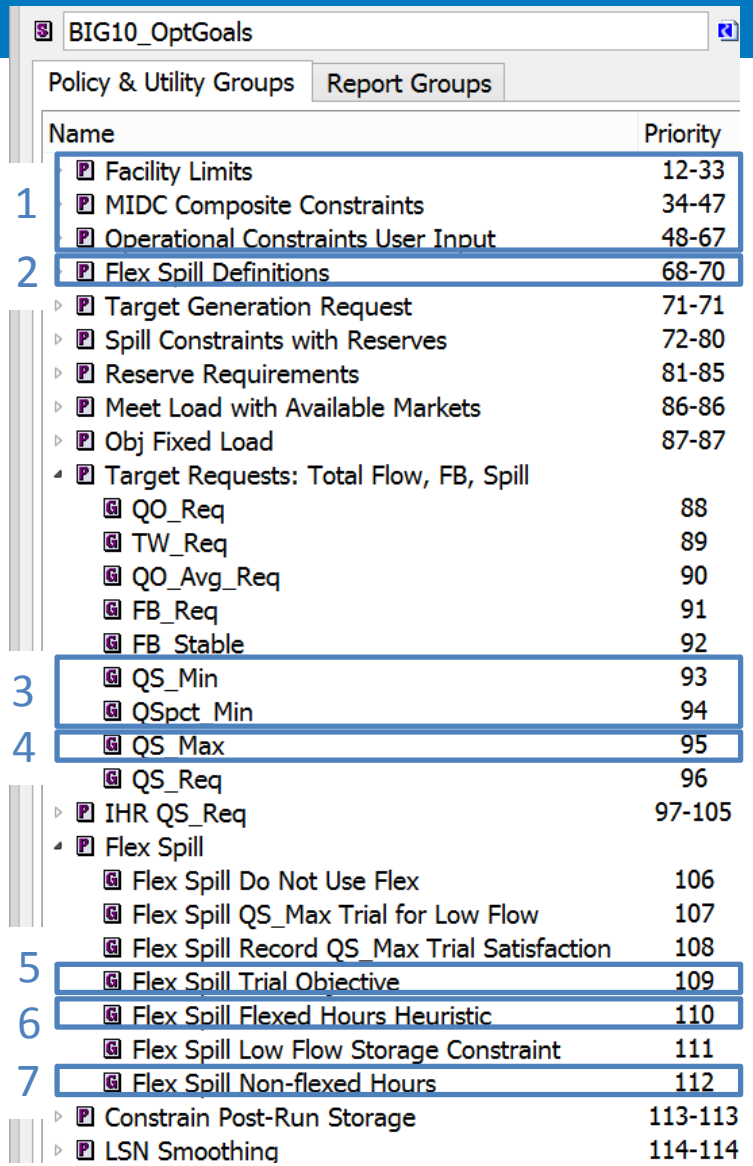
   Spill[t] ≥ QSMin
4. Gas Cap Max Spill Constraint

   Spill[t] ≤ QSMax
5. Flex Spill Trial Objective
6. Flex Spill Heuristic

   FlexedHour[t] = 0/1
7. Non-flexed Hours Spill at Gas Cap

   IF (FlexedHour[t] = 0) THEN

   Spill[t] ≥ QSMax



Low Flow Considerations

- Low Flow: Insufficient water to meet both Gas Cap Spill and Min Generation requirements
- Original Solution:
  - Kept generation at minimum during flexed hours
  - Stored water to minimize violations of Gas Cap Spill in non-flexed hours
- BPA not obligated to store water on flexed hours
- Desired Solution:
  - Non-flexed hours: Generate at min, spill the rest
  - Flexed hours: Increased generation, spill at performance standard

Additional Low Flow Constraints

- Trial objective to detect low flow

  Spill[t] ≥ QSMax, for all t (no Freeze)

  – If not fully satisfied ⟶ flag as Low Flow

  – Evaluated on a per day basis

- For Low Flow days

  – Flexed Blocks: new constraint – do not store water

  Storage[End of Flex Block] ≤ Storage[Start of Flex Block]

  – Non-flexed Hours: reduced spill requirement based on trial objective results, force to minimum generation

  Spill[t] ≥ QSMax_Reduced[t]

  Power[t] ≤ Minimum Generation

Thank you!