Grand Coulee Dam/Chief Joseph Dam Joint Operations Study 2011

Grand Coulee/Chief Joseph Joint Operations Study 2011

- Summary
  - Construction of spillway deflectors at Chief Joseph Dam resulted in a significant decrease in the TDG generated by spillway releases. This reduced TDG loading allows Chief Joseph Dam to accept a greater volume of outlet works spill from Grand Coulee compared to the original 2003 joint operations study.

Grand Coulee/Chief Joseph Joint Operations Study 2011

- Introduction
  - The General Re-evaluation Report (2000) recommended installation of flow deflectors at Chief Joseph combined with joint operation of Chief Joseph with Grand Coulee to provide the greatest benefit in TDG reduction in the Mid-Columbia River.
  - Detailed study of joint operations of Chief Joseph Dam without flow deflectors and Grand Coulee Dam was conducted in 2003. Reductions in TDG could be achieved below Grand Coulee and Chief Joseph by taking advantage of:
    - The larger generating capacity of Grand Coulee.
    - Lower average TDG loading below Chief Joseph during spill releases due to dam/river geometry.
  - Updated joint operations study of Chief Joseph Dam with flow deflectors was conducted in 2011. Joint operations with flow deflectors result in:
    - Substantial reduction in TDG saturations in Lake Rufus Woods.
    - A modest reduction in TDG saturations in the Columbia River below Chief Joseph Dam.

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- Objectives
  - Minimize the average TDG saturation in the Columbia River above and below Chief Joseph Dam over a wide range of river flows, background TDG concentrations, and surplus power outputs.
  - Update 2003 joint operations policy using new spillway flow defector TDG exchange characteristics at Chief Joseph Dam.
  - Develop updated guidance for the joint operation of Grand Coulee Dam and Chief Joseph Dam when spill operations ***via the outlet works*** are required at Grand Coulee.

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- Background
  - Chief Joseph and Grand Coulee have spilled during the spring snowmelt season in about half of all years.
  - Grand Coulee has the greatest generation flow capacity (280 kcfs) in the Mid Columbia and Chief Joseph has the second largest at 220 kcfs. Most spill occurs due to lack of load (surplus generating capacity) rather than due to river flow exceeding generating capacity.
  - Dam/River geometry of Grand Coulee and Chief Joseph are very different which impacts the total loading of TDG to the Columbia River from spill at both projects.
  - Chief Joseph spillway and powerhouse flows remain separate until several miles downstream resulting in a lower mixed river or average TDG concentration in the river.
  - Grand Coulee powerhouse flows are entrained into outlet works spillway flows resulting in a greater mixed river or average TDG concentration in the river below the dam.

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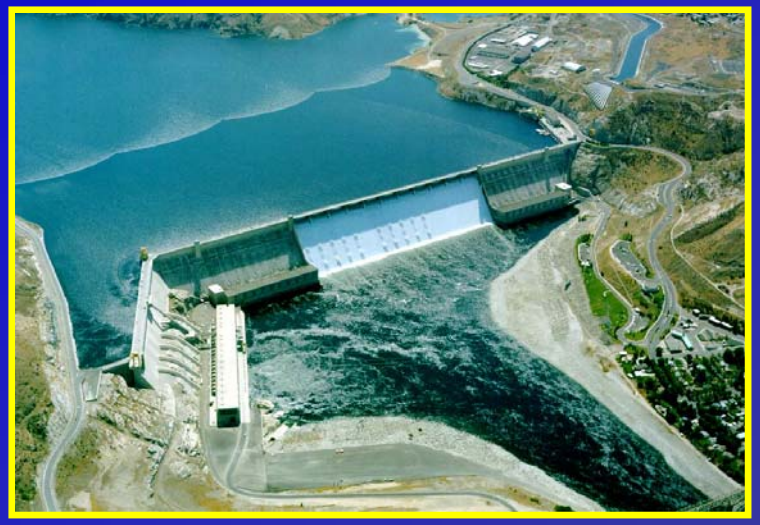

Grand Coulee Dam

- At forebay elevation below 1260 spills from outlet works, at forebay above 1260 spills from drum gates
- In general, spills from outlet works in spring
- Highest TDG production during spill from outlet works
- Strong Entrainment of Powerhouse Flows
- Powerhouse Capacity 280 kcfs
- Total Head 300+

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Chief Joseph Dam

- Reduced TDG Production in spillway flows with deflectors
- Powerhouse Oriented Normal to Spillway
- Little entrainment of powerhouse flows into spill
- Powerhouse Capacity 220 kcfs
- TDG Production Related to Spill Discharge and Tailwater Elevation
- Total Head 170 ft
- Rufus Woods Lake 51.5 miles
  - Travel Time 2+ days

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- Gas Production Characteristics
- Grand Coulee
  - Spill from outlet works produces higher TDG than spill from drum gates
  - Powerhouse flows are entrained into spill resulting in higher cross sectional average TDG concentrations.
  - TDG exchange characteristics of the outlet works are not well understood.
- Chief Joseph
  - Powerhouse flows are not entrained into spill resulting in lower cross sectional average TDG concentrations .
  - TDG exchange characteristics have been extensively studied and are well understood.

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- Supporting Information
  - Grand Coulee spills via the outlet works when forebay elevation is less than about 1260 ft. and spills via the drum gates when elevation is greater than 1260 ft.
  - The annual period for outlet works usage typically occurs from March through early June.
  - The 7Q10 flow (241 kcfs) can be entirely passed with generation flow and no spill at Grand Coulee (powerhouse capacity = 280 kcfs), while Chief Joseph must spill (powerhouse capacity = 220 kcfs).
  - Spill is required from Grand Coulee and Chief Joseph dams when a surplus power capacity is present (power production exceeds demand).
  - When considering alternative operations for a constant joint power output the difference in head was considered. For example, a 1 kcfs reduction in spill at Grand Coulee must be accompanied by a 1.8 kcfs increase spill at Chief Joseph based on typical operating conditions.

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- Study Approach
  - Focused on reducing spill from the outlet works at Grand Coulee when Lake Roosevelt forebay is less than 1260 ft. Did not consider spill from the drum gates.
  - Used updated TDG equations developed in 2010 at Chief Joseph Dam. Used TDG exchange equations at Grand Coulee developed in the 1990s.
  - Maintained joint power production capacity during operations.
  - Used an optimization model
    - Objective of minimizing the average TDG saturation in the Columbia River below Grand Coulee and Chief Joseph dams.
    - Maintained powerhouse outputs, below Chief Joseph Dam over a range of flows, background TDG levels, forebay elevations, and surplus power outputs.

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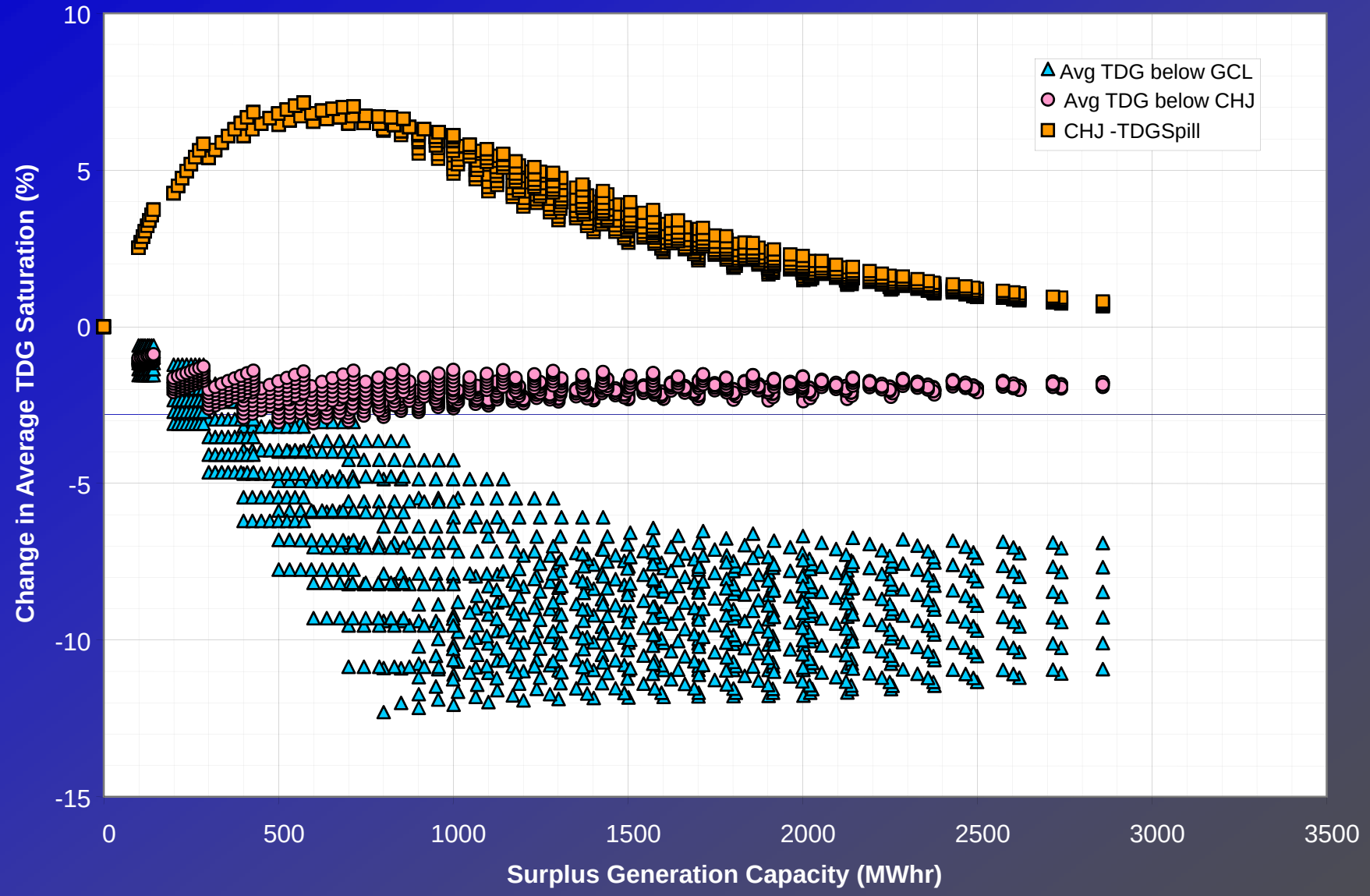
Table 1. Joint Project Operations and TDG Saturation at Grand Coulee (GCL) and Chief Joseph (CHJ) Dams for a Constant Power Output of 6289 MW_{hrs}.
(Power Generation Ratio = 0.96, Total River Flow=200 kcfs, Lake Roosevelt TDG=115%)

Input Parameters			Operations (kcfs)						TDG Saturation (%)						Power Production (MWhrs)					
			GCL			CHJ			GCL			CHJ			GCL		CHJ		Joint	
Event	TDG_{fb} GCL[1]	PGR[2]	Q_{total}[3]	Q_{ph}[4]	Q_{sp}[5]	Q_{bypass}	Q_{ph}	Q_{sp}	TDG_{ph}[6]	TDG_{sp}[7]	TDG_{avg}[8]	TDG_{ph}	TDG_{sp}	TDG_{avg}	MW_{max}[9]	MW[10]	MW_{max}	MW	MW_{Cap}	MW
1	115	0.96	200.0	200.0	0.0	200.0	177.6	22.4	115.0	146.1	115.0	115.0	119.6	115.5	4206.4	4206.4	2344.6	2062.6	6551.1	6289.0
2	115	0.96	200.0	198.1	1.9	200.0	181.1	18.9	115.0	146.1	115.8	115.8	118.0	116.0	4206.4	4166.4	2344.6	2122.6	6551.1	6289.0
3	115	0.96	200.0	196.7	3.3	200.0	183.6	16.4	115.0	146.1	116.3	116.3	116.8	116.4	4206.4	4137.1	2344.6	2151.9	6551.1	6289.0
4	115	0.96	200.0	195.6	4.4	200.0	185.5	14.5	115.0	146.1	116.7	116.7	115.8	116.7	4206.4	4114.6	2344.6	2174.4	6551.1	6289.0
5	115	0.96	200.0	194.8	5.2	200.0	187.0	13.0	115.0	146.1	117.1	117.1	114.9	116.9	4206.4	4096.8	2344.6	2192.2	6551.1	6289.0
6	115	0.96	200.0	194.1	5.9	200.0	188.2	11.8	115.0	146.1	117.3	117.3	114.2	117.2	4206.4	4082.4	2344.6	2206.6	6551.1	6289.0
7	115	0.96	200.0	193.5	6.5	200.0	189.2	10.8	115.0	146.1	117.6	117.6	113.6	117.4	4206.4	4070.5	2344.6	2218.5	6551.1	6289.0
8	115	0.96	200.0	193.1	6.9	200.0	190.1	9.9	115.0	146.1	117.8	117.8	113.1	117.5	4206.4	4060.5	2344.6	2228.6	6551.1	6289.0
9	115	0.96	200.0	192.7	7.3	200.0	190.8	9.2	115.0	146.1	117.9	117.9	112.6	117.7	4206.4	4051.9	2344.6	2237.1	6551.1	6289.0
10	115	0.96	200.0	192.3	7.7	200.0	191.5	8.5	115.0	146.1	118.1	118.1	112.2	117.8	4206.4	4044.5	2344.6	2244.5	6551.1	6289.0
11	115	0.96	200.0	192.0	8.0	200.0	192.0	8.0	115.0	146.1	118.2	118.2	111.9	117.9	4206.4	4038.1	2344.6	2250.9	6551.1	6289.0
12	115	0.96	200.0	191.7	8.3	200.0	192.5	7.5	115.0	146.1	118.3	118.3	111.5	118.1	4206.4	4031.9	2344.6	2257.1	6551.1	6289.0
13	115	0.96	200.0	191.4	8.6	200.0	193.1	6.9	115.0	146.1	118.4	118.4	111.1	118.2	4206.4	4025.1	2344.6	2263.9	6551.1	6289.0
14	115	0.96	200.0	191.0	9.0	200.0	193.7	6.3	115.0	146.1	118.6	118.6	110.7	118.3	4206.4	4017.9	2344.6	2271.1	6551.1	6289.0
15	115	0.96	200.0	190.7	9.3	200.0	194.4	5.6	115.0	146.1	118.7	118.7	110.3	118.5	4206.4	4010.0	2344.6	2279.0	6551.1	6289.0
16	115	0.96	200.0	190.3	9.7	200.0	195.1	4.9	115.0	146.1	118.9	118.9	109.8	118.7	4206.4	4001.6	2344.6	2287.5	6551.1	6289.0
17	115	0.96	200.0	189.8	10.2	200.0	195.9	4.1	115.0	146.1	119.1	119.1	109.2	118.9	4206.4	3992.2	2344.6	2296.8	6551.1	6289.0
18	115	0.96	200.0	189.3	10.7	200.0	196.8	3.2	115.0	146.1	119.3	119.3	108.5	119.1	4206.4	3982.0	2344.6	2307.0	6551.1	6289.0
19	115	0.96	200.0	188.8	11.2	200.0	197.8	2.2	115.0	146.1	119.5	119.5	107.8	119.3	4206.4	3970.7	2344.6	2318.3	6551.1	6289.0
20	115	0.96	200.0	188.2	11.8	200.0	198.8	1.2	115.0	146.1	119.7	119.7	107.0	119.6	4206.4	3958.2	2344.6	2330.8	6551.1	6289.0
21	115	0.96	200.0	187.5	12.5	200.0	200.0	0.0	115.0	146.1	120.0	120.0	106.1	120.0	4206.4	3944.5	2344.6	2344.5	6551.1	6289.0

1 TDG saturation in Lake Roosevelt (%).
2 Power Generation Ratio = Power Output / Capacity Power Output.
3 Total Columbia River Flow (kcfs).
4 Total Powerhouse Flow (kcfs).
5 Total Spill Discharge (kcfs), outlet works discharge at Grand Coulee Dam.
6 TDG saturation of powerhouse discharge, assumed to equal the TDG saturation in the forebay (%).
7 TDG saturation in undiluted spill discharge (%).
8 Average TDG saturation in the Columbia River (%).
9 Capacity Power Output (MWhrs).
10 Power output (MWhrs).

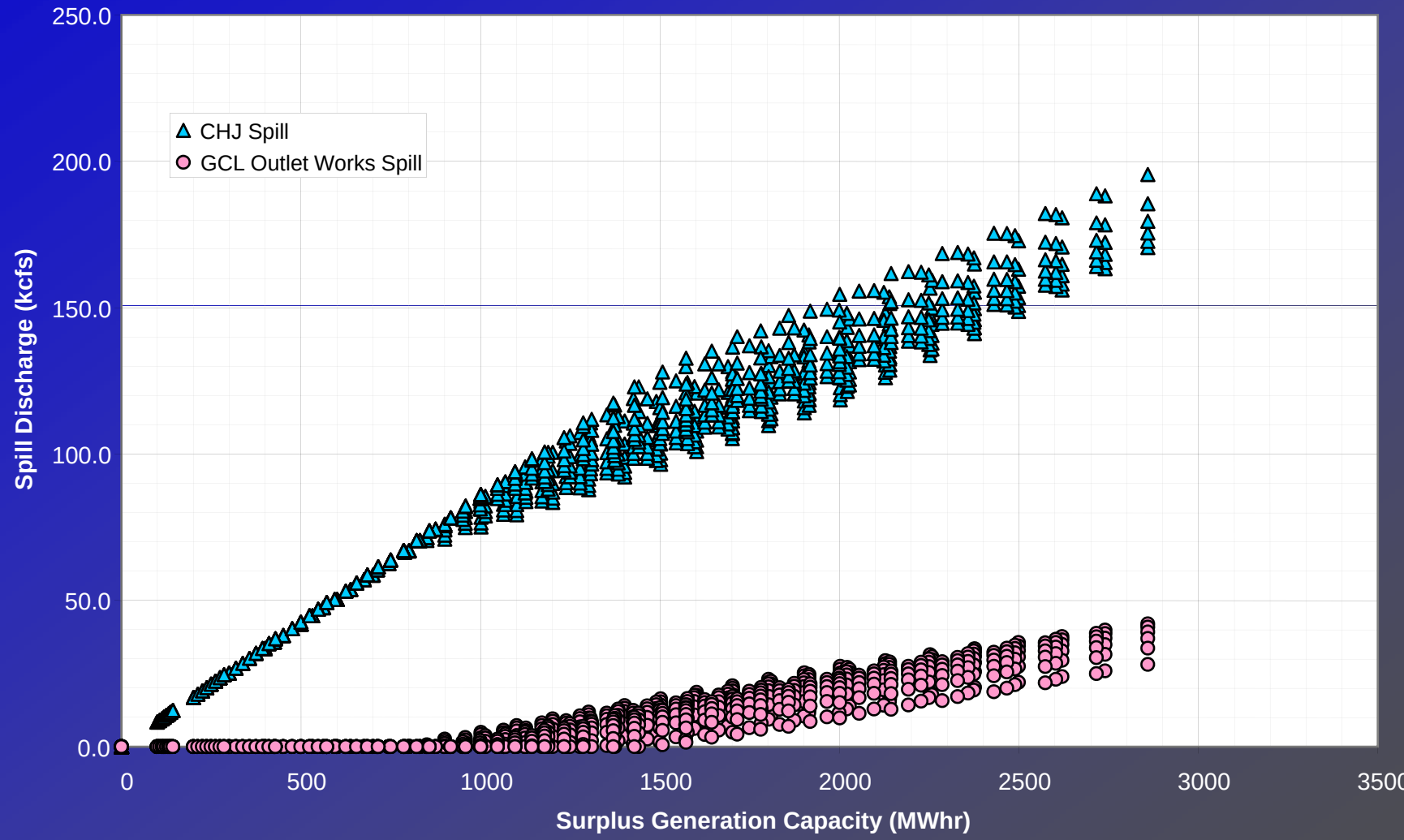
Joint operations optimization model results



Changes in TDG saturation for base and optimal operating conditions for Chief Joseph and Grand Coulee Dams.

(Negative/positive change in TDG saturation indicates a reduction/increase in TDG caused by optimal conditions)

Operating Conditions for Minimizing Average TDG Saturation below Chief Joseph Dam
Case 1 Management Stategy



Optimal Joint Spill Discharge as a Function of the Surplus Generation Capacity for Chief Joseph and Grand Coulee Dams, (TDG Objective was to minimize the average TDG saturation below Chief Joseph Dam)

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- Results and Discussion
  - Updated joint operations policy is still being developed and final recommendations have not been made. Some general findings are presented below:
    - Updated joint operations of Grand Coulee Dam and Chief Joseph Dam will reduce the average TDG saturations in the Columbia River above and below Chief Joseph Dam due to the lower TDG loading produced at Chief Joseph Dam with the recently completed spillway deflectors.
    - Original 2003 joint operations policy recommended avoiding the use of outlet works at Grand Coulee by shifting all spill to Chief Joseph for spill discharges up to 70 kcfs. Updated 2011 joint operations policy will recommended shifting even greater amounts of outlet works spill to Chief Joseph Dam.
    - Updated joint operations will produce a substantial reduction in TDG saturations in Lake Rufus Woods between Grand Coulee and Chief Joseph dams. The reduction in the average TDG saturation below Chief Joseph Dam, as measured at the Wells Dam forebay, will be small when compared to typical project operations. The TDG saturation in undiluted spillway releases from Chief Joseph will experience a small increase as measured at the FMS when compared to current spill plan.

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- Conclusions
  - Joint operation can be devised to meet power generation demands while minimizing average TDG saturation above and below Chief Joseph.
  - Joint operations should only occur when Lake Roosevelt forebay elevation is below 1260 ft. and Grand Coulee is spilling via the outlet works.
  - Avoid the use of the outlet works releases at Grand Coulee by shifting all spill to Chief Joseph for spill discharges up to a volume to be determined by the 2011 joint operations study.
  - The TDG saturation in Lake Rufus Woods will experience the greatest improvement.
  - The reduction in average TDG saturation in the Columbia below Chief Joseph, as measured at the Wells Dam forebay, will be small compared to historical data.
  - The TDG saturation of undiluted spillway releases below Chief Joseph will experience s small increase in TDG saturations.