

System Model for Total Dissolved Gas

by

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US Army Corps of Engineers

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Grand Coulee Dam

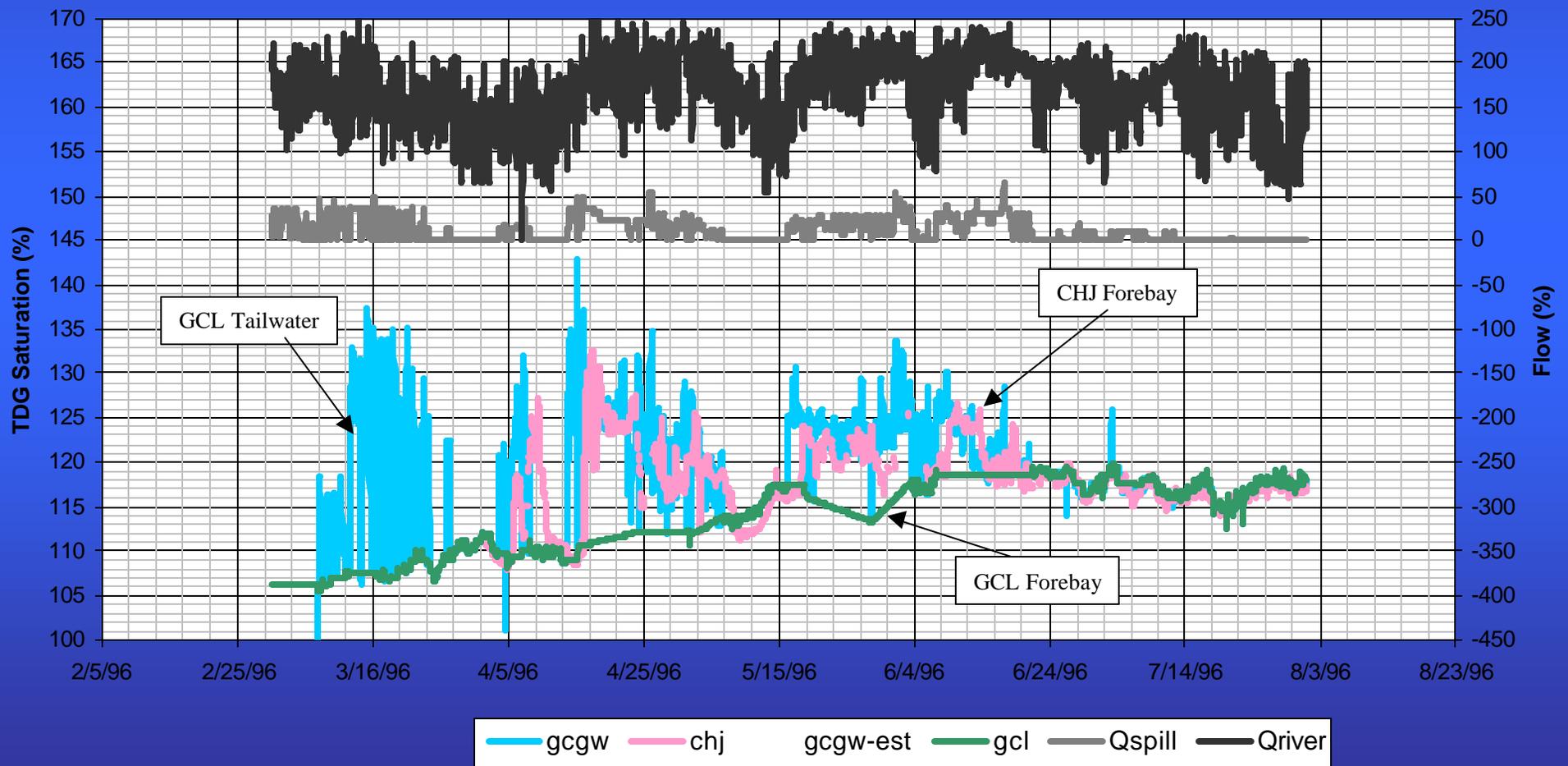


Chief Joseph Dam

System Model for Total Dissolved Gas Grand Coulee Dam



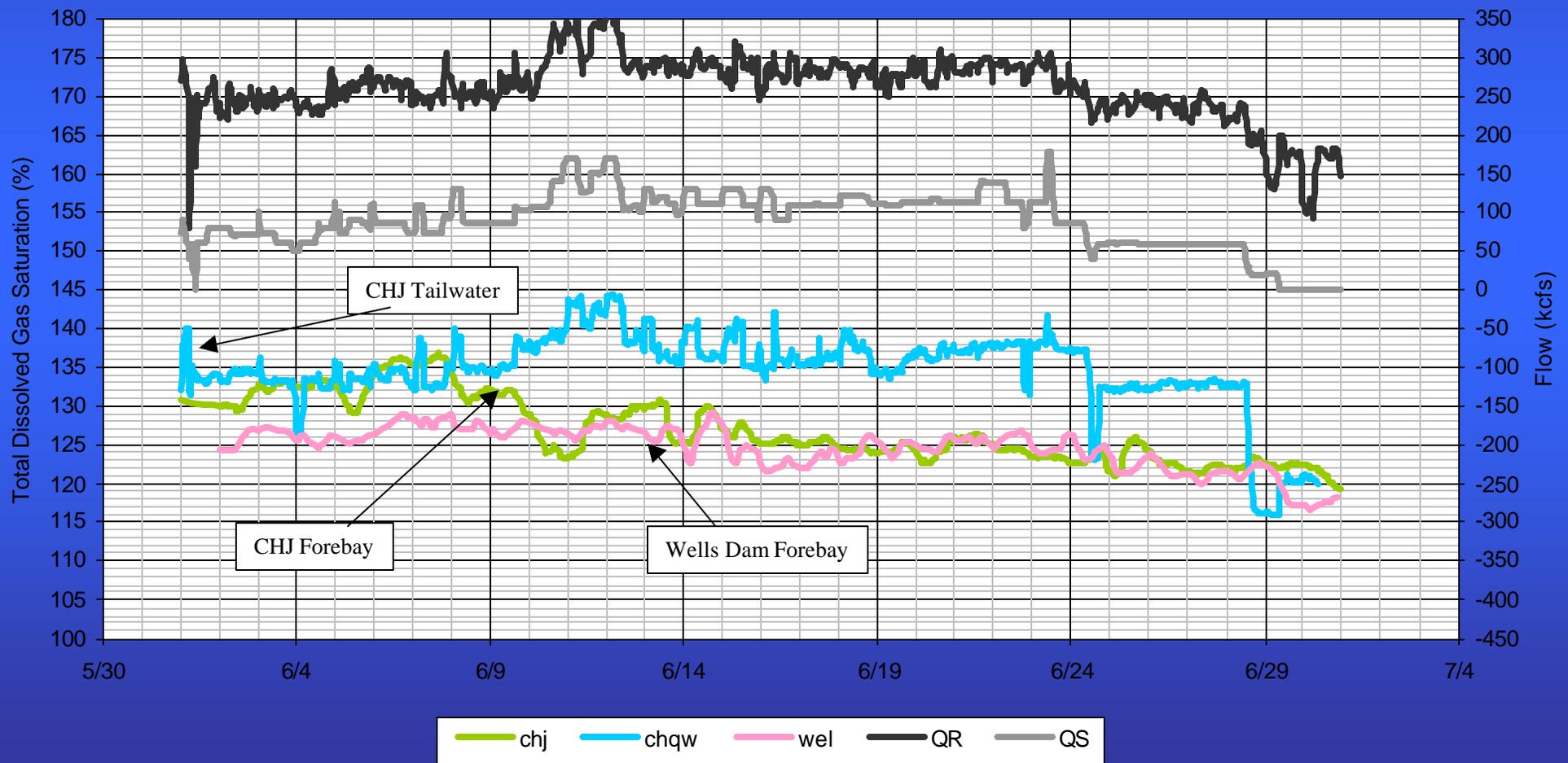
System Model for Total Dissolved Gas



System Model for Total Dissolved Gas Chief Joseph Dam



System Model for Total Dissolved Gas



System Model for Total Dissolved Gas

- **Introduction** - DGAS Abatement Called for by the NMFS Biological Opinion
 - Joint Study at Chief Joseph and Grand Coulee Dam for Abatement of TDG
 - Funded by BPA
 - System Approach Spill Management and Power Production

System Model for Total Dissolved Gas

- Objectives
 - Prediction/Forecasting
 - Operational
 - Structural
 - Hydrologic Conditions
 - Optimization
 - Minimize TDG
 - Generation Constraints
 - Quality Control
 - Monitoring System

System Model for Total Dissolved Gas

- Approach

- TDG Production at Dams

- Spillway
 - Powerhouse

- TDG Transport

- Degassing
 - Temperature

- Linked Node Network

- Ledger of Flow and TDG Pressure
 - Spreadsheet Basis
 - Prediction of TDG upstream and downstream of Dam

System Model for Total Dissolved Gas

- **Approach**

- Model Input

- Total Flow – Stage - Temperature
 - Spill Management Strategy
 - Spill Caps and Priority
 - Minimized TDG subject to System Power Need
 - Operational Parameters and Constraints
 - TDG Exchange Coefficients

- Domain

- Columbia River RM 42-Grand Coulee Dam
 - Snake River RM 140

- Boundary Conditions

- Historic TDG Loading at GCL and LGW

System Model for Total Dissolved Gas



System Model for Total Dissolved Gas

- Findings

- TDG Production

- Grand Coulee Dam – FMS and Supplemental Field Data
 - Drum Gate
 - Sluiceway
 - Chief Joseph Dam – Near Field Study and FMS Data
 - Wells Dam – FMS Data and Supplemental Field Data
 - Rocky Reach Dam – FMS Data
 - Rock Island Dam – Near Field Study and FMS Data
 - Wanapum Dam – Near Field Study and Supplemental Field Data
 - Pending Flow Deflectors
 - Priest Rapids Dam – FMS Data and Supplemental Field Data

System Model for Total Dissolved Gas

- Findings

- TDG Production (DGAS Program)

- Lower Granite – FMS and Supplemental Field Data
 - Little Goose Dam – Near Field and FMS Data
 - Lower Monumental Dam – Near Field and FMS Data
 - Ice Harbor Dam – Near Field and Supplemental Field Data
 - McNary Dam – Near Field and FMS Data
 - John Day Dam – Near Field and FMS Data
 - The Dalles Dam – Near Field and Supplemental Data
 - Bonneville Dam – Near Field and FMS Data

System Model for Total Dissolved Gas

Mass Conservation

$$TDG_{rel} = \frac{(Q_{sp} + Q_{ent})TDG_{sp} + (Q_{ph} - Q_{ent})TDG_{ph}}{Q_{sp} + Q_{ph}} \quad (1)$$

Empirical TDG Production

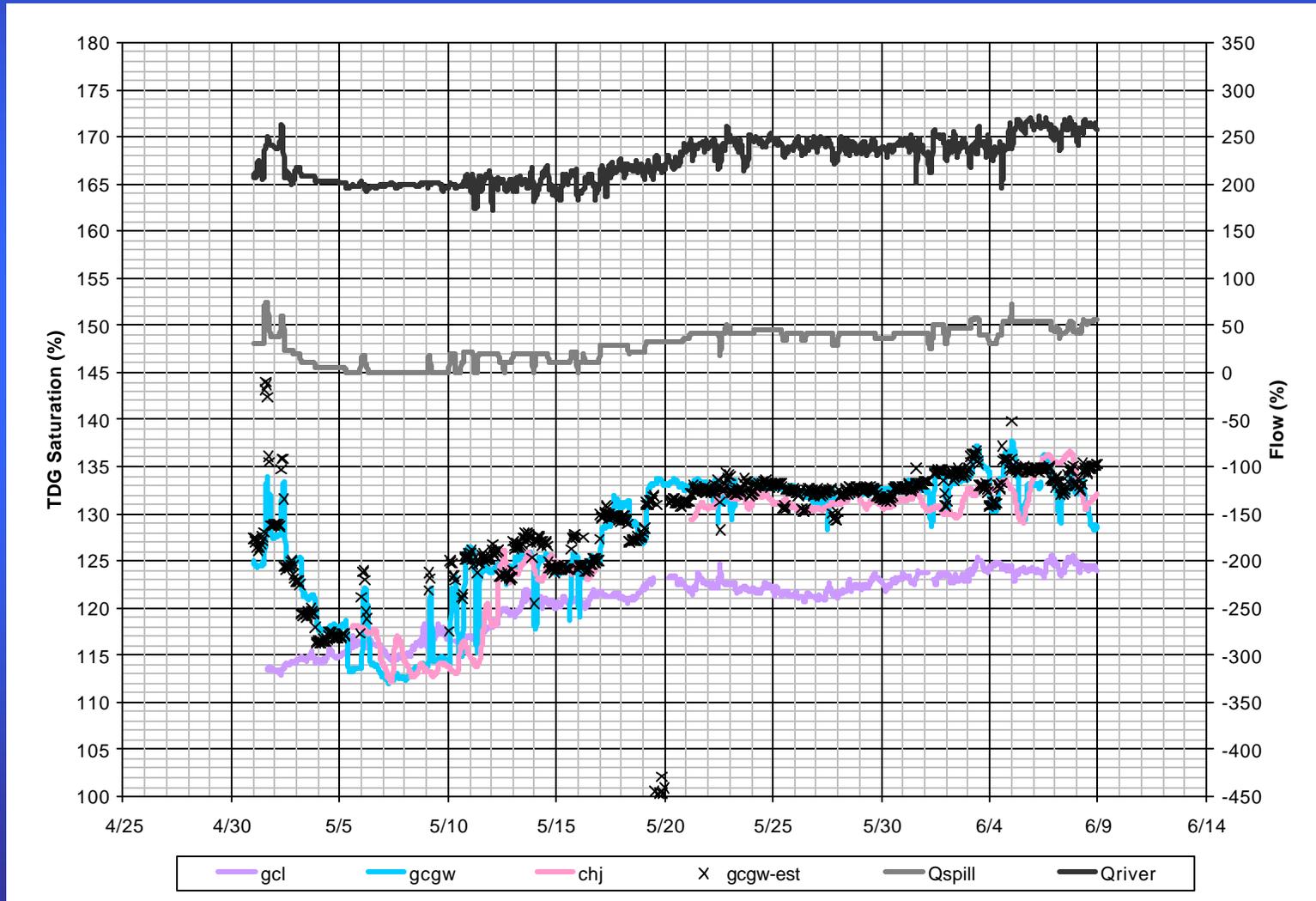
$$\begin{aligned} \text{Case 1} \quad TDG_{sp} &= C_1 & (2) \\ Q_{ent} &= 0 \end{aligned}$$

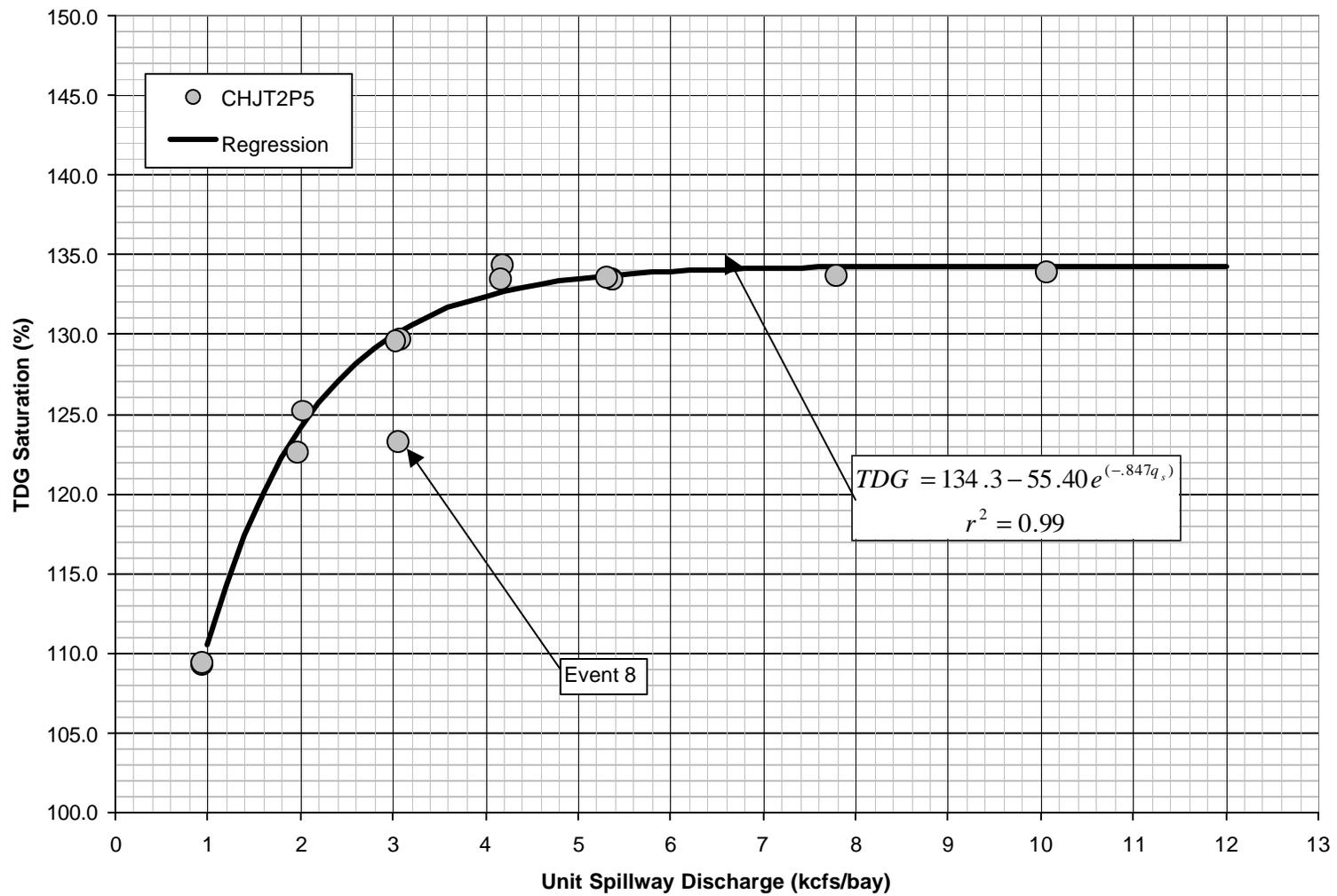
$$\begin{aligned} \text{Case 2} \quad TDG_{sp} &= C_1 & (3) \\ Q_{ent} &= C_2 Q_{sp} \end{aligned}$$

$$\begin{aligned} \text{Case 3} \quad TDG_{sp} &= C_1 + C_2 e^{-C_3 q_s} & (4) \\ Q_{ent} &= 0 \end{aligned}$$

$$\begin{aligned} \text{Case 4} \quad TDG_{sp} &= C_1 + C_2 e^{-C_3 q_s} & (5) \\ Q_{ent} &= C_2 Q_{sp} \end{aligned}$$

System Model for Total Dissolved Gas



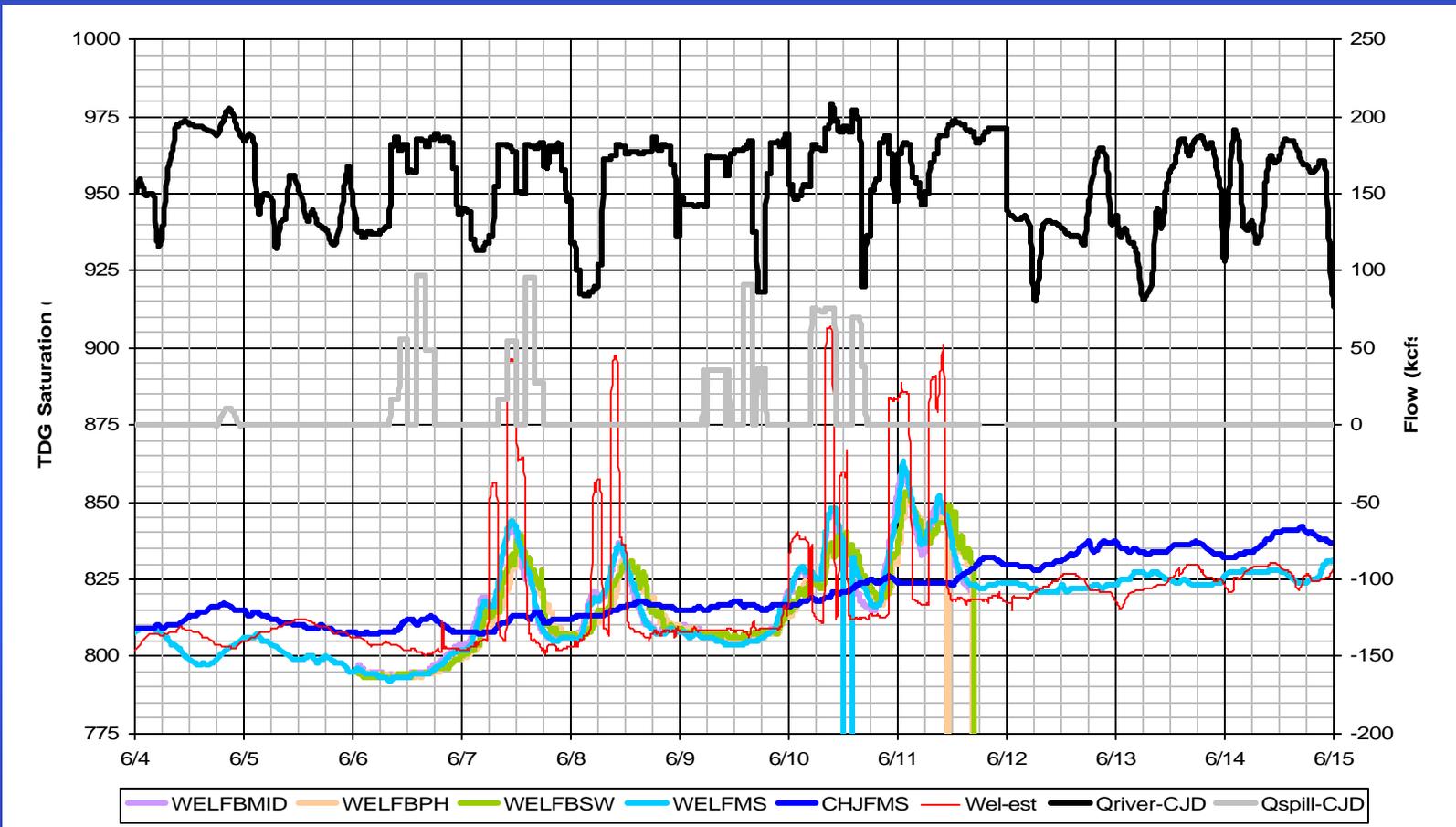


Total Dissolved Saturation at CHJT2P5 as a Function of Unit Spillway Discharge at Chief Joseph Dam, June 6-12, 1999.

System Model for Total Dissolved Gas

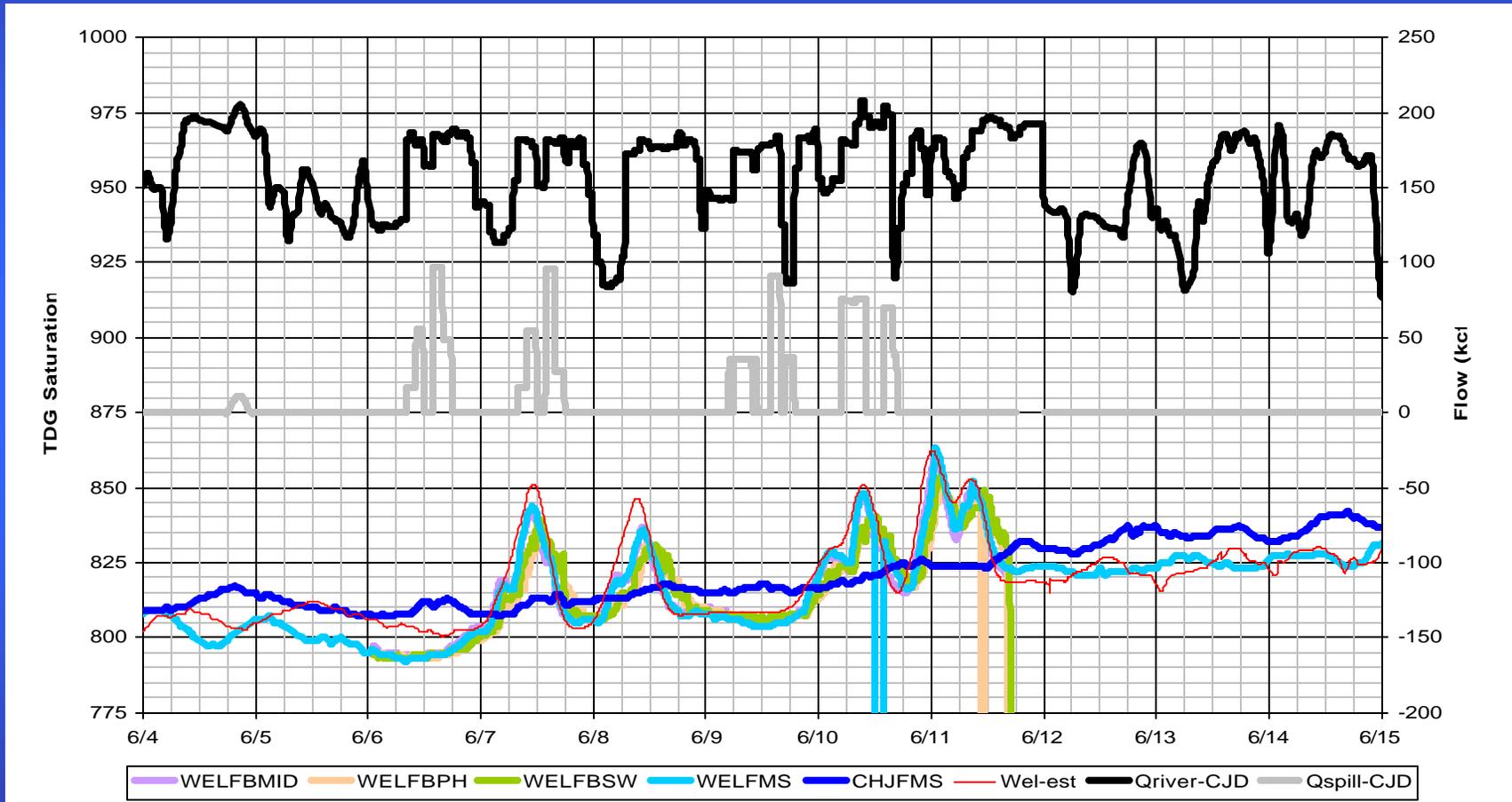
- Findings
 - TDG Transport
 - Retention Time = $f(\text{storage, flow})$
 - Dissipation – Normally Distributed
 - Wind Generated Degassing

System Model for Total Dissolved Gas



Routing of TDG Plume Through Lake Pateros with No Dispersion, June 4-15, 1999.

System Model for Total Dissolved Gas



Routing of TDG Plume Through Lake Pateros with Normally Distributed Dispersion, June 4-15, 1999.

System Model for Total Dissolved Gas

- Decision Support System
 - Optimization of Project Operations
 - TDG Objective Function
 - Minimize system TDG levels
 - Power generation constraints
 - TDG Constraints
 - FMS compliance

System Model for Total Dissolved Gas

Optimization Framework

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Notes: This worksheet poses a hypothetical problem where power production is scheduled

Notes: based upon the minimization of TDG loading throughout a system of projects.

Notes: Both Power Generation and TDG Production relationships are fictitious.

Notes: Enter Model Input Variables. (Generation Target and River Discharge)

Notes: Implement the Optimizer by selecting "tools-solver-solve"

Notes: The decision variables will be updated to meet the generation target while minimizing the TDG loading across all projects.

Generation Capacity Mw	21030
Generation Target Mw	15000

Project	GCL	CHJ	WEL	RRH	RIS	WAN	PRD	DWR	LWG	LGS	LMN	IHR	MCN	JDA	TDA
Active (1=yes,0=no)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Qriver (kcfs)	150	150	150	150	150	150	150	50	100	100	100	100	250	250	250
Generaton-fraction	1.00	0.65	0.64	0.64	0.64	0.84	0.64	0.66	0.64	0.64	0.64	0.55	0.72	0.65	0.45
Qspill (kcfs)	0	52	54	54	55	25	54	17	36	36	36	45	70	87	136
Qpowerhouse (kcfs)	150	98	96	96	95	125	96	33	64	64	64	55	180	163	114
GenCoef (Mw/kcfs)	25.2	13	5.3	6.9	3.1	6.1	6	47.6	7.3	7.2	7.2	7.4	5.2	7.7	6.3
Net Generation Mw	3780	1270	508	664	296	765	576	1562	466	460	460	405	934	1253	716
TDG C1	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
TDG C2	40	35	35	35	35	40	35	35	35	35	35	35	45	35	29
# spillbays	12	12	12	12	12	12	12	4	8	8	8	10	23	20	22
TDG spill (%)	100.0	120.4	120.8	120.7	120.9	113.4	120.8	120.2	120.8	120.8	120.8	120.9	120.6	120.4	120.6
TDG powerhouse (%)	121.0	121.0	121.0	121.0	121.0	125.0	121.0	121.0	121.0	121.0	121.0	121.0	121.0	121.0	121.0
TDG avg (%)	121.0	120.8	120.9	120.9	121.0	123.1	120.9	120.7	120.9	120.9	120.9	120.9	120.9	120.8	120.8

Calculated
Decision Variables
Objective Function
Model Input
Constraints
Model Parameters

System Model for Total Dissolved Gas

Microsoft Excel - CRDGAS.xls

File Edit View Insert Format Tools Data Window Help

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X38 =

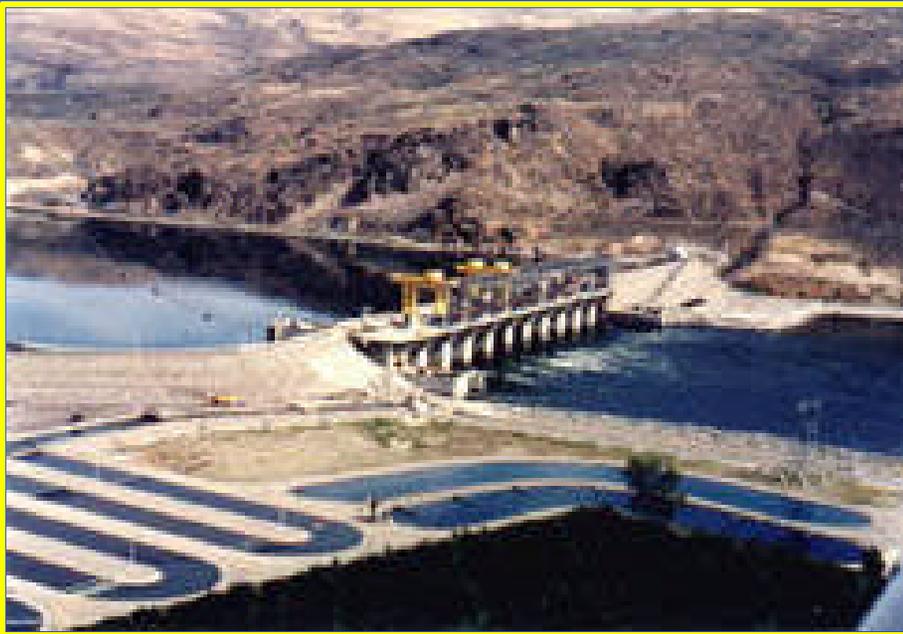
Project Feature		Lower Columbia and Snake River Project							
		Bon	TDA	JDA	MCH	IHR	LMN	LGS	LGW
Current Conditions	Date	###	###						
	Spillway Flow (cfs)	88.5	165.0						
	Generation Flow (cfs)	223.8	87.6						
	Total River Flow (cfs)	312.3	252.6						
	Farabay Water Elevation (ft)	73.0	158.2						
	Tailwater Elevation (ft)	23.3	79.4						
	Farabay TDG (%)	115.7	111.7						
	Tailwater 1 TDG (%)	116.7	119.1						
	Tailwater 2 TDG (%)	117.8							
	Farabay Water Temp (C)	16.4	16.4						
Tailwater 1 Water Temp (C)	16.3	16.5							
Tailwater 2 Water Temp (C)	16.3								
Forecasted Conditions	Passerflow Flow (cfs)	223.8	87.0						
	Spillway Flow (cfs)	150.0	165.0						
	Total River Flow (cfs)	373.8	252.0						
	Tailwater Elevation (ft)	27.1	81.1						
	Number of Spillways (# of unit)	15.7	21.4						
	Unit Spillway Discharge (cfs)	9.6	7.7						
	Water Temperature (C)	16.4	16.4						
	Atmospheric Pressure (mm.Hg)	760.0	755.0						
	Farabay TDG Saturation (%)	115.7	111.7						
	Spillway TDG Saturation (%)	123.0	122.9						
Average TDG Release (%)	118.6	119.0							
Two Week Average TDG (%)	116.8	118.2							
Two Week Maximum TDG (%)	118.3	119.3							
Two Week Minimum TDG (%)	115.3	117.1							
Data Worksheet	Bon	TDA							
Forecast Worksheet	Bon-fore	TDA-fore							
Graph of TDG Time History	ar1-bon	ar1-tda							
Graph of TDG Forecast	ar2-bon	ar2-tda							
Graph of TDG Routing	ar2-bon								

summary / sp / bon / bonfor / DLS-wd / gr1-bon / gr2-bon / gr3-bon / tda / tdafor / gr1-tda

Draw AutoShapes

Ready NUM SCRL

System Model for Total Dissolved Gas Wells Dam



System Model for Total Dissolved Gas Rocky Reach Dam



System Model for Total Dissolved Gas Rocky Island Dam



System Model for Total Dissolved Gas Wanapum Dam



System Model for Total Dissolved Gas Priest Rapids Dam



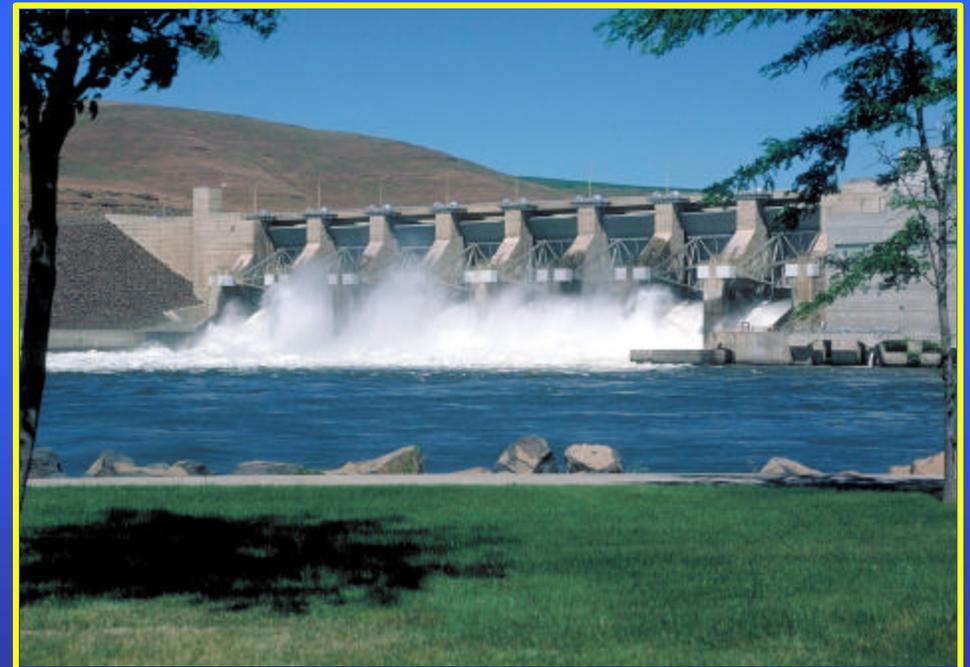
System Model for Total Dissolved Gas Dworshak Dam



System Model for Total Dissolved Gas Lower Granite Dam



System Model for Total Dissolved Gas Little Goose Dam



System Model for Total Dissolved Gas Lower Monumental Dam



System Model for Total Dissolved Gas Ice Harbor Dam



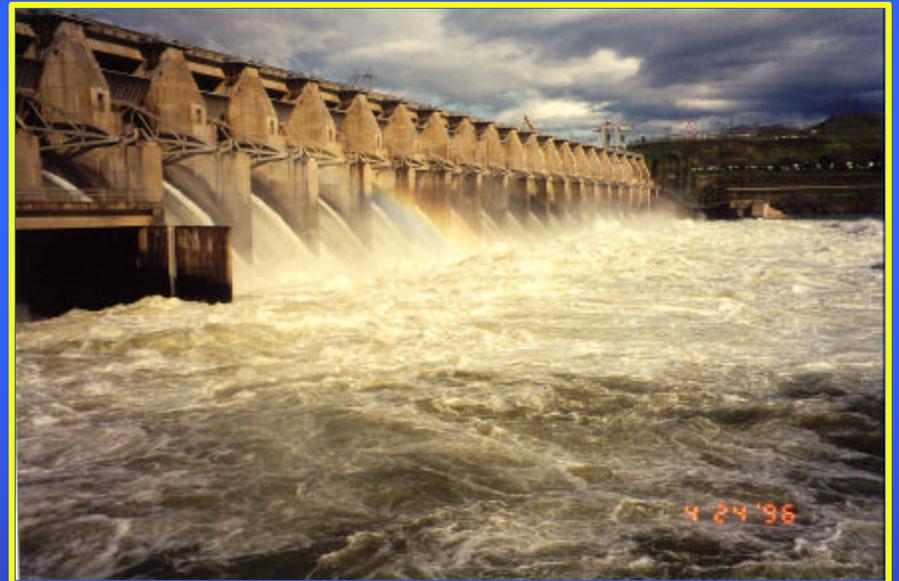
System Model for Total Dissolved Gas McNary Dam



System Model for Total Dissolved Gas John Day Dam



System Model for Total Dissolved Gas The Dalles Dam



System Model for Total Dissolved Gas Bonneville Dam

