TOTAL DISSOLVED GAS SIMULATION
CASE STUDY

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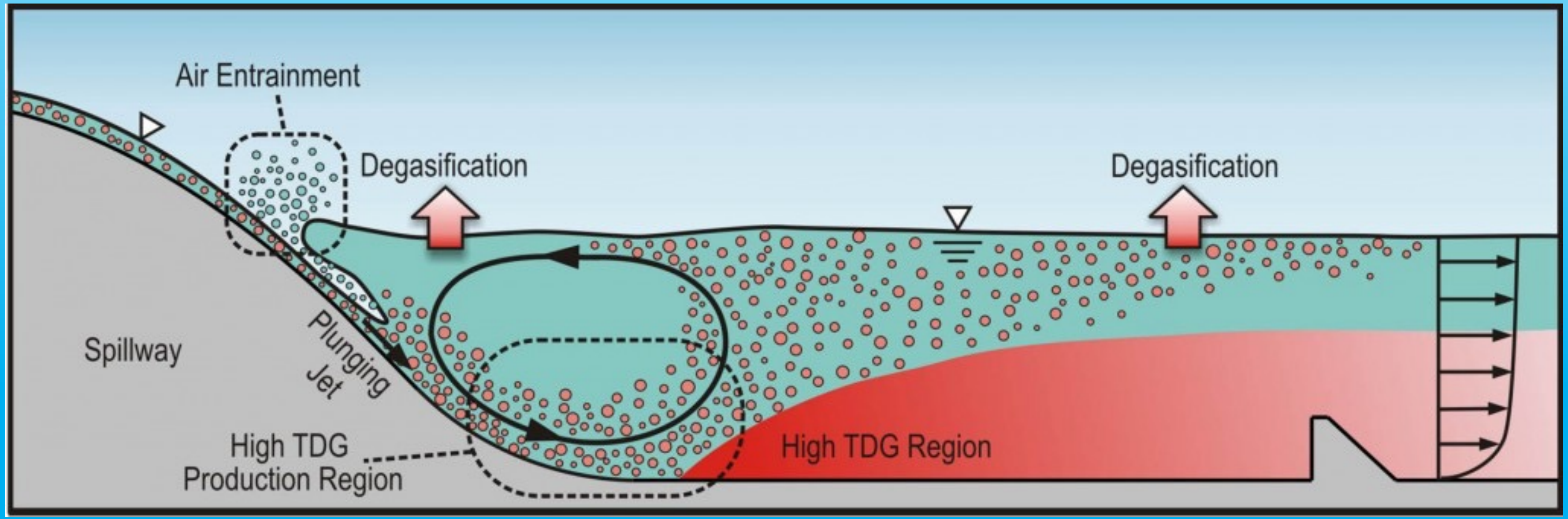
Total Dissolved Gas (TDG) Saturation

- Total Dissolved Gas (TDG) refers to the total concentration of all gases dissolved in water. This typically includes gases such as nitrogen, oxygen, carbon dioxide, and others that are present in the aquatic environment.

TDG Sources

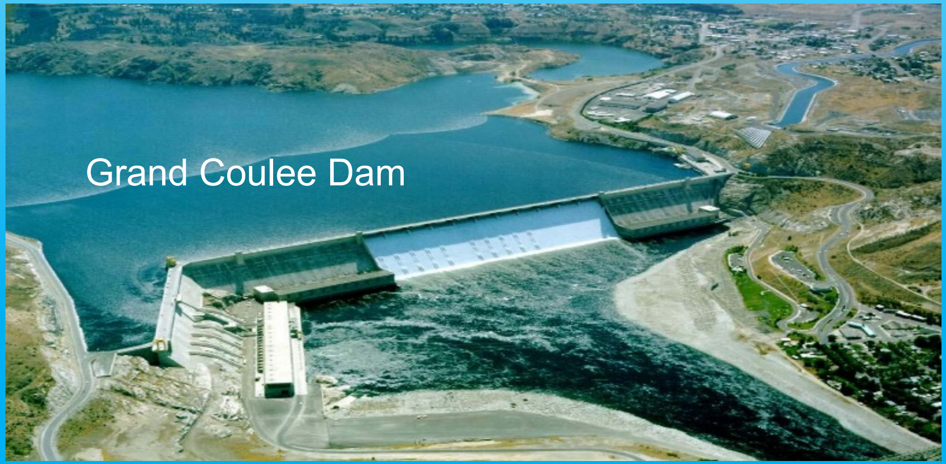
- Hydropower Dams and Spillways: Water released from dams and spillways can become aerated, leading to increased TDG levels.
  - Spillway operations result in atmospheric gases being forced into the water. The TDG concentrations below the dam are increased by spills, and TDG supersaturation occurs.
- Natural Processes: Photosynthesis by aquatic plants can increase oxygen levels, contributing to TDG.
- Temperature Changes: Can affect the solubility of gases, influencing TDG levels.



TDG Importance

High levels of TDG, especially when supersaturated, can be harmful to aquatic life. Supersaturation occurs when the concentration of dissolved gases exceeds the solubility limit of the water, often due to physical processes like turbulence, pressure changes, or temperature shifts.

- Gas Bubble Trauma:
  - Aquatic organisms, especially fish, can suffer from gas bubble trauma (GBT) when exposed to supersaturated conditions.
  - GBT occurs when dissolved gases come out of solution inside the organisms' tissues, forming bubbles that can cause physical damage, impede blood flow, and even lead to death.
- Susceptibility to Predation:
  - Fish affected by GBT often become disoriented, exhibiting erratic swimming patterns. This disorientation makes it difficult for them to evade predators effectively.
  - Bubbles in the tissues, especially in the fins and muscles, can impair a fish's ability to swim swiftly and with agility, making them easier targets for predators.



TDG Saturation

Calculating and reporting dissolved gas levels from water quality monitoring

1) Ratio of total dissolved gas pressure (TGP) to atmospheric pressure.

$$TDG(\%) = 100\,\frac{P_a + \Delta P}{P_a}$$

TDG = percent of total dissolved gas saturation (%),

P_a = local barometric pressure or atmospheric pressure (mmHg),

ΔP = gauge pressure (mmHg), which can be directly measured by several types of instruments.

2) Gas concentrations measured in mg/L

$$TDG(\%) = \left(79\,\frac{N2}{N2_s} - 21\,\frac{DO}{DO_s}\right)$$

$N2$ = dissolved nitrogen gas (mg L^{-1}),

$N2_s$ = nitrogen gas saturation (mg L^{-1}),

DO = dissolved oxygen [mg-O_2 L^{-1}],

DO_s = dissolved oxygen saturation [mg-O_2 L^{-1}].

Overview of TDG Simulation in CE-QUAL-W2

TDG is computed as a derived variable

1) N_2 + DO

$$\frac{dN2}{dt} = -\frac{1}{h}k_{aN2}(N2 - N2_s)$$

k_{aN2} = nitrogen gas reaeration coefficient, m s^{-1}.

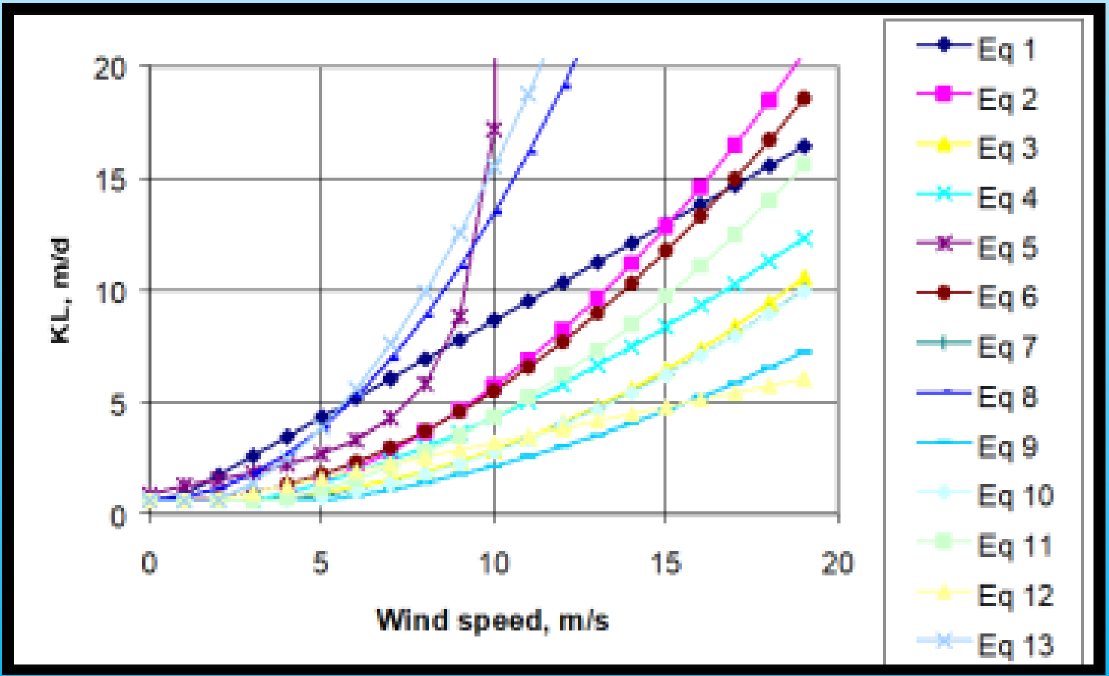
2) DGP (Dissolved Gas Pressure)

$$\frac{dDGP}{dt} = -k_{DGP}(DGP - PALT_{atm})$$

$$k_{DGP} = max(k_{DGP}, MINKL)$$

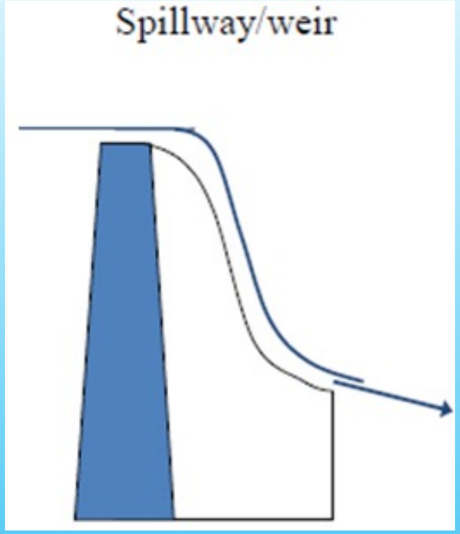
k_{DGP}= air/water gas exchange rate, d^{-1}.

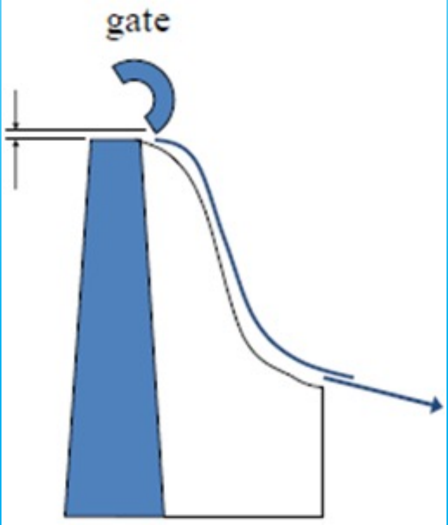
Lake/reservoir Reaeration equations



It is assumed that wind is the dominant forcing function for reaeration.

Reaeration Effects of Spillways, Weirs, and Gates





#, EQGT	Equation	Empirical Coefficient Description
1. Linear function of spill on a per spillway basis; 2 empirical coefficients: a and b	$\%TDG = aq_s + b$ $C_{O_2} = \%TDG * C_{sO_2}$	$\%TDG$ = total dissolved gas saturation, % q_s = spill through an individual spillway, *kcfs* C_{sO2} = dissolved oxygen saturation, $g\ m^{-3}$
2. Bounded exponential of the spill on a per spillway basis; 3 empirical coefficients: a, b, c	$\%TDG = a + be^{cq_s}$ $C_{O_2} = \%TDG * C_{sO_2}$	q_s = spill through an individual spillway, *kcfs* C_{sO2} = dissolved oxygen saturation $g\ m^{-3}$
3. Reaeration effect for a small height weir or dam (<10 m); 3 empirical coefficients: a, b, c (Butts and Evans, 1983)	$\frac{D_a}{D_b} = 1 + 0.38ab(1 - 0.11c)$ $(1 + 0.046T)c$ $C_{O2} = C_{sO2} - D_b$	D_a = DO deficit above dam, $g\ m^{-3}$ D_b = DO deficit below dam, $g\ m^{-3}$ T = temperature, °C C_{sO2} = dissolved oxygen saturation, $g\ m^{-3}$

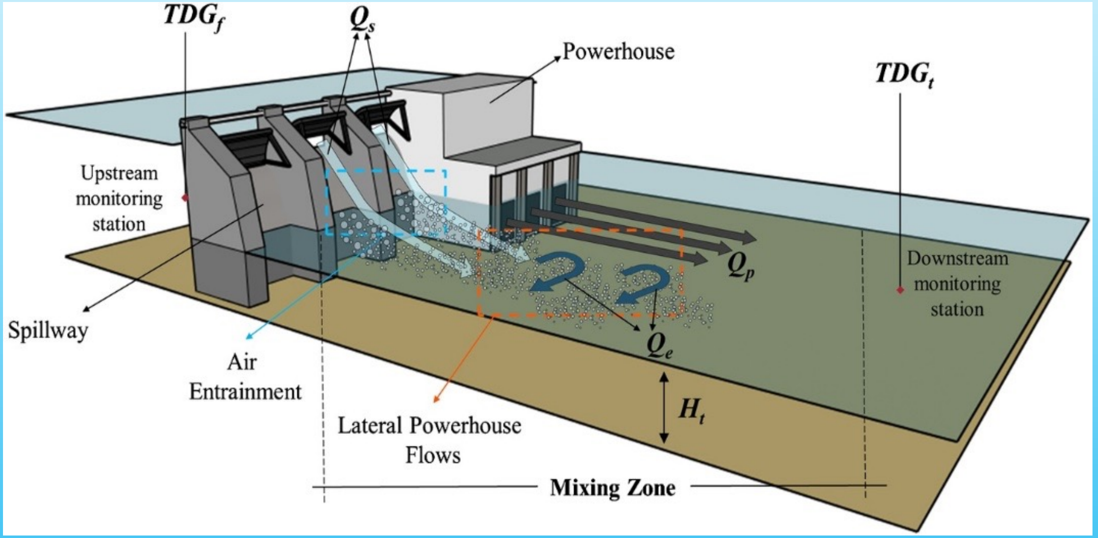
REAERATION	WB1
TYPE: LAKE, RIVER, or ESTUARY	LAKE
EQN#: Equation # (see User Manual)	14
COEF1 User defined parameter	0.3
COEF2 User defined parameter	0.2
COEF3 User defined parameter	0.5
COEF4 User defined parameter	0
DGPO2, fraction of dissolved gas to reaeration coefficient, typical value 1.027	1.027
MINKL (if LAKE, m/d) or MINKA (if RIVER/ESTUARY, day-1)	0.6

Total Dissolved Gas (TDG)

SPILLWAYS	SP1
IUSP- Upstream segment number, spillway segment locatio	
IDSP- Downstream segment number, Downstream segment	
ESP - spillway elevation (crest), m	
A1SP-α1, empirical coefficient for free-flowing conditions	
B1SP-β1, empirical coefficient for free-flowing conditions	
A2SP-α2, empirical coefficient for submerged conditions	
B2SP-β2, empirical coefficient for submerged conditions	
LATSPC-Downstream or lateral withdrawal, DOWN or LAT	
PUSPC-How inflows enter into the upstream spillway seg-m	
ETUSP-Top elevation spillway inflows enter using SPECIFY o	
EBUSP-Bottom elevation spillway inflows enter using SPECI	
KTUSP-Top layer above which selective withdrawal will not	
KBUSP-Spillway Up Selective withdrawal bottom layer, Bott	
PDSPC-How inflows enter into the downstream spillway seg	
ETUSP-Top elevation spillway inflows enter using SPECIFY o	
EBUSP-Bottom elevation spillway inflows enter using SPECI	
KTDSP-Top layer above which selective withdrawal will not	
KBDSP-Spillway Down Selective withdrawal bottom layer bo	
GASSPC Dissolved gas computations ON or OFF	
EQSP Equation number for computing dissolved gas	
AGASSP a empirical coefficient	
BGASSP b empirical coefficient	
CGASSP c empirical coefficient	

GATES	GATE1	GATE2	GTE3	GATE4
IUGT- Upstream segment number	76	76	76	76
IDGT- Downstream segment number	0	0	0	0
EGT - Gate elevation m	11.7	7.3	7.3	7.3
A1GT α1 coefficient in gate equation for free flowing conditions	10	10	10	10
B1GT β1 coefficient in gate equation for free flowing conditions	1.5	1.5	1.5	1.5
G1GT gamma1 coeff for free flowing conditions	1	1	1	1
A2GT α2 coefficient in gate equation for submerged conditions	10	10	10	10
B2GT β2 coefficient in gate equation for submerged conditions	1.5	1.5	1.5	1.5
G2GT gamma2 coeff for submerged conditions	1	1	1	1
LATGTC downstream or lateral withdrawal LAT or DOWN	DOWN	DOWN	DOWN	DOWN
GTA1 α1 in gate equation for free flowing conditions as a spillway	10	10	10	10
GTB1 β1 in gate equation for free flowing conditions as a spillway	1.5	1.5	1.5	1.5
GTA2 α2 in gate equation for submerged conditions as a spillway	10	10	10	10
GTB2 β2 in gate equation for submerged conditions as a spillway	1.5	1.5	1.5	1.5
DYNGTC Either 'B', 'ZGT', or 'FLOW'	FLOW	FLOW	FLOW	FLOW
GTIC EITHER ON or OFF interpolate gate file	ON	ON	ON	ON
PUGTC Specifies how inflows enter the upstream gate segment, DISTR, DENSITY, or SPECIFY	DISTR	DISTR	DISTR	DISTR
ETUGT Top elevation gate inflows enter using the SPECIFY option, m				
EBUGT Bottom elevation gate inflows using the SPECIFY option, m				
KTUGT Top layer above which selective withdrawal will not occur	2	2	2	2
KBUGT-Selective withdrawal bottom layer, Bottom layer below which selective withdrawal will not occur	55	55	55	55
PDGTC Specifies how inflows enter the downstream gate segment, DISTR, DENSITY, or SPECIFY	DISTR	DISTR	DISTR	DISTR
ETDGT Top elevation gate inflows enter using the SPECIFY option, m				
EBDGT Bottom elevation gate inflows using the SPECIFY option, m				
KTDGT Top layer above which selective withdrawal will not occur	2	2	2	2
KBDGT-Selective withdrawal bottom layer, Bottom layer below which selective withdrawal will not occur	55	55	55	55
GASGTC Dissolved gas computations ON or OFF	OFF	ON	ON	ON
EQGT Equation number for computing dissolved gas	2	2	2	2
AGASGT a empirical coefficient	135	135	135	135
BGASGT b empirical coefficient	-35	-35	-35	-35
CGASGT c empirical coefficient	-0.1	-0.1	-0.1	-0.1

Reaeration Effects of Gates - SYSTDG



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

- Qtot, Qspill, Qph, Qent
- TDGspill is computed from spillway TDG production equation
- TDGrel is computed as the flow weighted average value

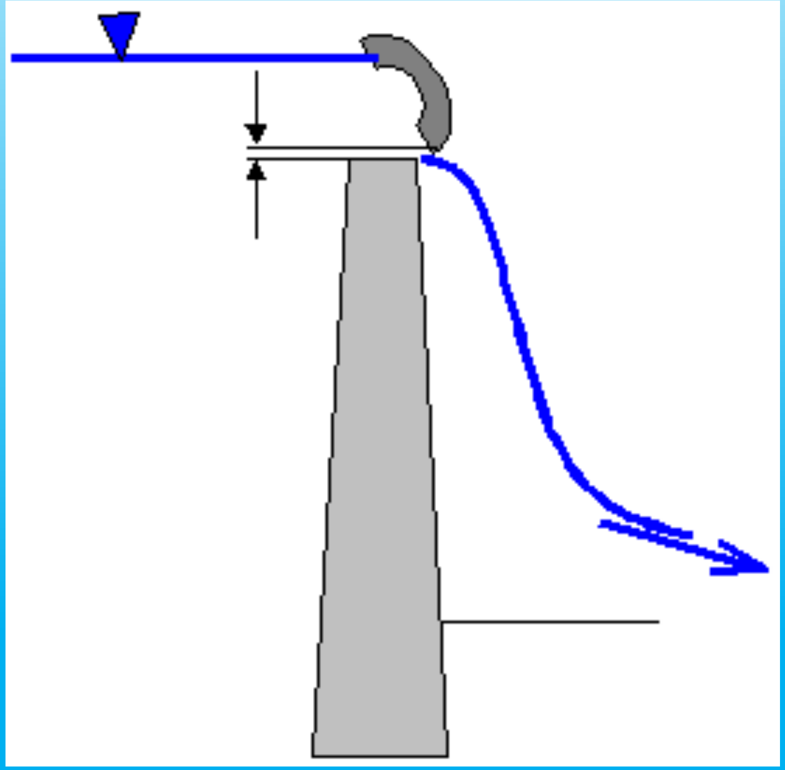
Schneider, M., Hamilton, L., 2015. SYSTDG Developer's Manual. U.S. Army Corps of Engineers, Northwestern Division, Reservoir Control Center.

SYSTDG Algorithms

No	TDG Production Equation
1	$TDG_{sp} = P1 * \left(1 - e^{P3 * Q_{sp}}\right) + bp$
2	$TDG_{sp} = P1 * (twe - twce)^{P2} * \left(1 - e^{P3 * q_s}\right) + P4 + bp$
3	$TDG_{sp} = P1 * (twe - twce)^{P2} * q_s{}^{P3} + P4 + bp$
4	$TDG_{sp} = P1 * (twe - twce) + P2 * q_s{}^{P3} + P4 + bp$
5	$TDG_{sp} = P1 * \left(1 - e^{P2 * q_s}\right) + P3 * (Temp_{tw} - P4) + bp$

No	Powerhouse Flow Entrainment Equation
1	$Q_{ent} = E1 * Q_{sp} + E2$
2	$Q_{ent} = min[(Q_{tot} / 60) , 1] * E1 * Q_{sp} + E2$
3	$Q_{ent} = min[(Q_{sp} / 20) , 1] * E1 * Q_{sp} + E2$

SYSTDG is an Excel-based spreadsheet model used to compute TDG saturation levels in reservoir and riverine systems.



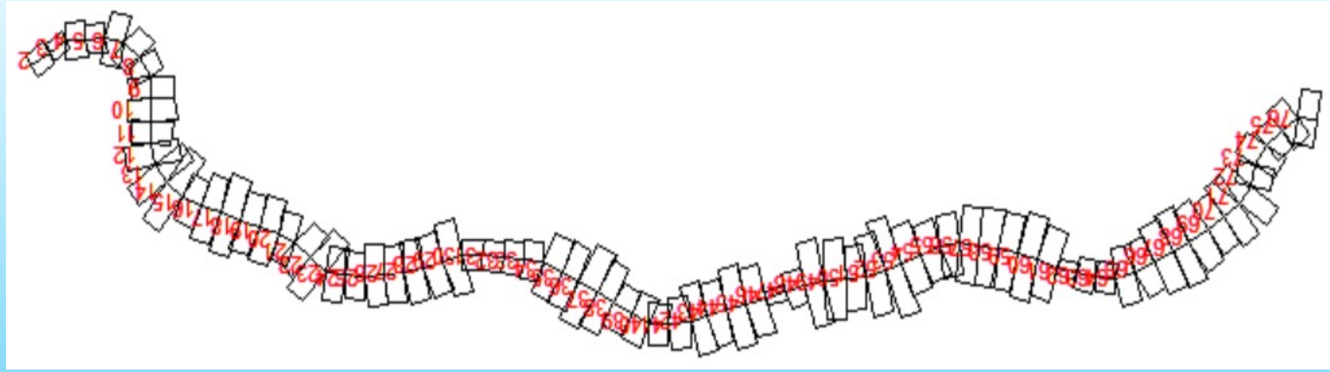
System Total Dissolved Gas (SYSTDG) Control File

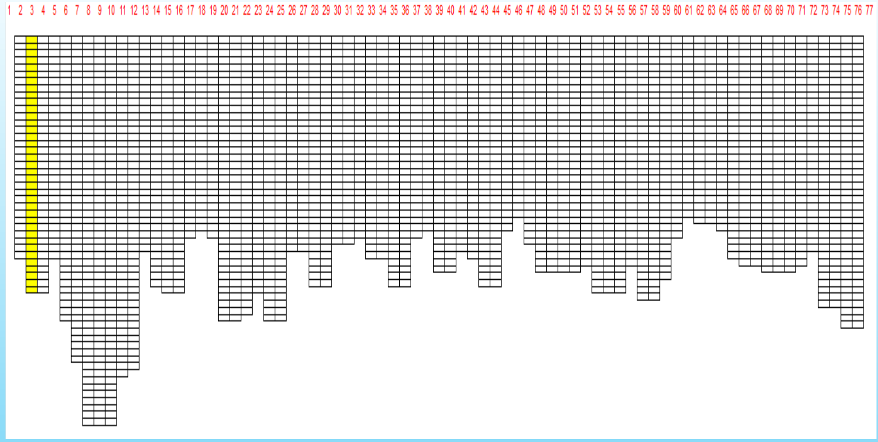
15	SYSTDGC	SYSTDG	N2BND	DOBND	DGPBN	TDGTA				
16		OFF	OFF	OFF	OFF	OFF				
17										
18	GATE GAS	GTTYPE	SPBC							
19	POWR1	POW	1							
20	SB1	SPB	2.03							
21	SB2	SPB	2.03							
22	SB3	SPB	2.03							
23	SB4	SPB	2.03							
24	SB5	SPB	2.03							
25	SB6	SPB	2.03							
26	SB7	SPB	2.03							
27	SB8	SPB	2.03							
28	SB9	SPB	2.03							
29	SB10	SPB	2.03							
30	SB11	SPB	2.03							
31	SB12	SPB	2.03							
32	SB13	SPB	2.03							
33	SB14	SPB	2.03							
34	SB15	SPB	2.03							
35	SB16	SPB	2.03							
36	SB17	SPB	2.03							
37	SB18	SPB	2.03							
38	OTHER	FLD	1							
39										
40	GATE	FBE	TWCE	TWEMOI	TWE	TWETS	TDGLOC	QSPILL	TDGSPMN	
41	SPB1	-1	0	0	18.92	ON	SPB	0	110	
42										
43	GATE TDG	TDGEQ	P1	P2	P3	P4	P1	P2	P3	P4
44	SPB1	4	1.84	18.64	0.73	29.47				

Bonneville Dam

- Bonneville Dam is located on Columbia River Mile (RM) 146.1 and is a run-of-river dam.
- The reservoir is 48 miles long, from Bonneville Dam to the foot of Dalles Dam upstream, with a surface area of 29.5 square miles, and a capacity of 537,000 acre-feet.
- The full forebay elevation is 77 feet, and the maximum forebay elevation is 82.5 feet.
- The Dam is 171 feet high and 2,477 feet long.
- The spillway is 1,070 feet long and contains 18 spill bays each with a 50 feet by 60 feet lift gate.
- Bonneville Dam is equipped with 2 powerhouse units, 18 spillbays, and 1 fish ladder.
- Columbia River System Operations Final Environmental Impact Statement:
    - https://www.nwd.usace.army.mil/CRSO/Final-EIS/

Bonneville Dam W2 Model





File type		File name
Wind sheltering	WSC FILE WSCFN	BON_WSC.npt
Shading	SHDFN	BON_SHD_1.npt
Bathymetry	BTHFN	BON_NAVD88_BTH_2011.csv
Meteorological	METFN	BON_2011_2015_MET.csv
Branch inflow	QINFN branch inflow	DALLES_OUTFLOW.csv
	TINFN branch temp	two_41_TDA.opt
	CINFN branch conc	cwo_41_TDA.opt
	QDTFN Distributed flow	BON_DistributedTribInflow.npt
	TDTFN Distributed temp	two_41_TDA.opt
	CDTFN Distributed conc	cwo_41_TDA.opt
Spillway/Gate	QGTFN	QGT_BON_2011_2015.csv

W2 Modeled TDG Results with N2+DO

SYSTDG = ON

Eq 4: $TDG_{sp} = P1 * (twe - twce) + P2 * q_s^{P3} + P4 + bp$

P1 = 1.84, P2 = 18.64, P3 = 0.73, P4 = 29.47

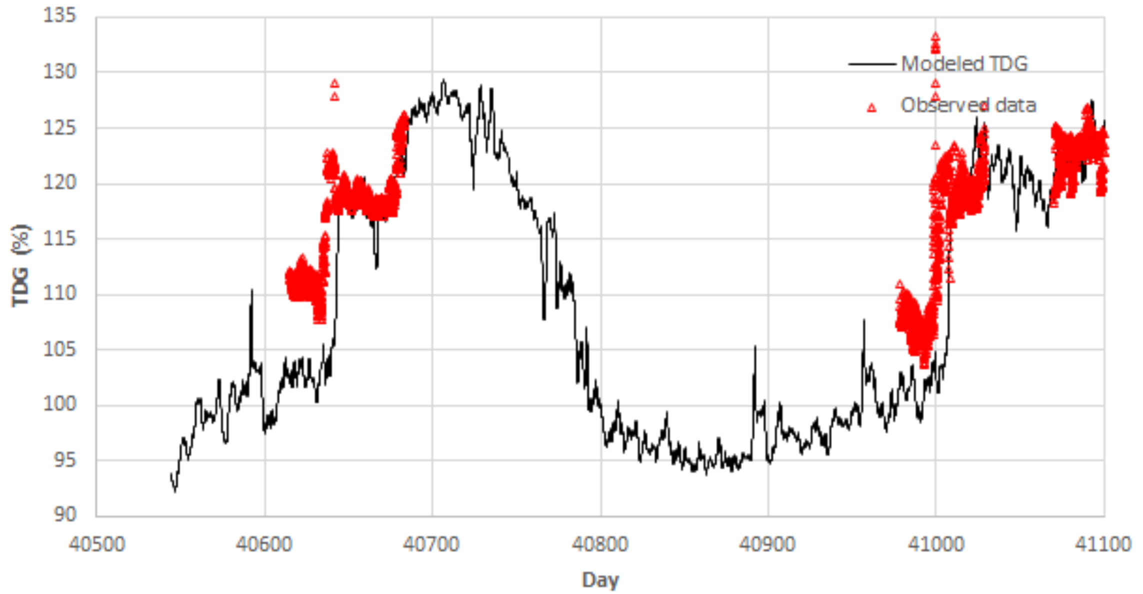
$Q_{ent} = E1 * Q_{sp} + E2$

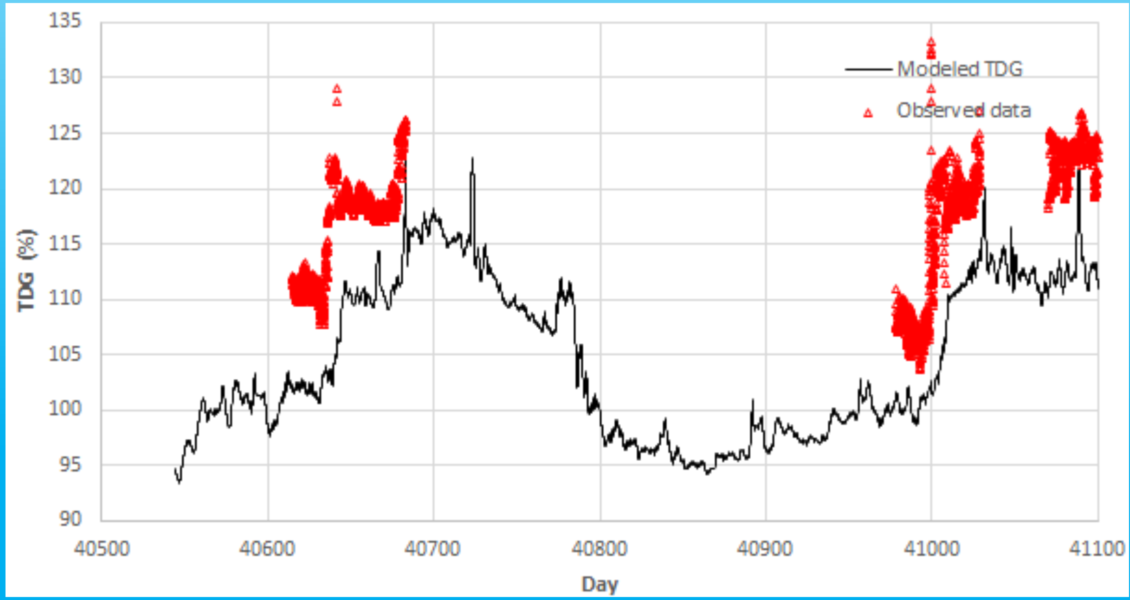
E1 = 0, E2 = 0

SYSTDG = OFF

Eq 1: $TDG(\%) = a * Q_s + b$

a = 0.12, b = 105.61





W2 Modeled TDG Results With DGP

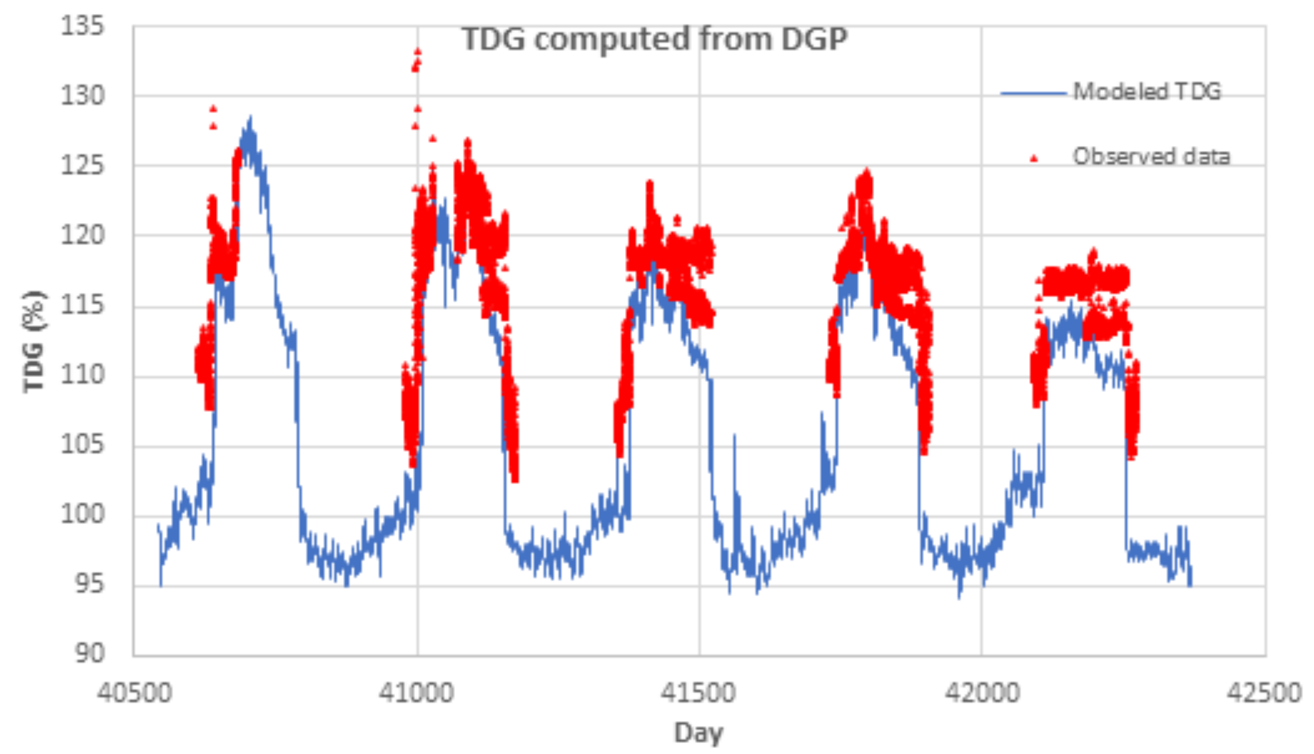
SYSTDG = ON

Eq 4: $TDG_{sp} = P1 * (twe - twce) + P2 \ * q_s{}^{P3} + P4 + \ bp$

$Q_{ent} = E1 * Q_{sp} + E2$

P1 = 1.84, P2 = 18.64, P3 = 0.73, P4 = 29.47

E1 = 0, E2 = 0



Hands-On Exercises

- Review model input files from “Bonneville W2 Project”
- Run the W2 model and review the model outputs of withdrawal TDG in **dwo_76.csv**
- Change SYSTDG parameters and rerun the model and see the difference of TDG in **dwo_76.csv**
  - P1, P2, P3, P4
  - E1, E2

Questions?