Total Dissolved Gas submodel parameter calibration for use with CRiSP

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Introduction

This is a reevaluation of TDG modeling for use in CriSP at mid season 2003. *New methods are described in italics like this.*

Beginning in 1999, CRiSP downstream model began using a system of total dissolved gas (TDG) generation formulas that were:

- specific to each dam at which dissolved gas was produced
- included mechanisms for mixing of waters with differing gas levels
- included dissipation of gases in reservoirs
- included entrainment of powerhouse waters into spill water.

At that time, various parameters were calibrated and made available for use in the CRiSP model. This was reviewed prior to use of CRiSP1.6 in 2002 and now again due to our perception that the configurations of the dams are not going to change in order to reduce spill. Currently, the relationship between the spill level and the downstream gas level is tenuous. Alterations to the structures of the dams in the last decade have reduced the TDG problem significantly.

Parameters and Models

At each dam, TDG is produced according to the operations of the dam. *This was modeled for use in CRiSP with dam-specific, two or three parameter exponential production curves.* Other sources of TDG include inputs at headwaters, dams and the lower end of reaches. The gas is passed downstream with the flow of the river. Various other parameters control the mixing and dissipation of TDG and are described in detail in the Theory and Calibration Manual. These include:

- dam theta (tailrace mixing) used to be set at 0 or 10 based on ACOE studies to allow for “no” or “complete” mixing of waters in the tailrace at certain dams where it was believed to be known. This is pertinent because the monitoring station may be very close to the dam, significantly downstream and have a position that exposes it to more or less gassed flow depending on river conditions and dam operations. *These were allowed to take on in-between values for certain dams.*

- reach_theta (reach mixing) which is assumed to be 0.075 allowing 95% mixing in 40 miles. The parameter allows different gas levels on the left and right sides of the reservoirs to maintain some separation as the flows move downstream
- dam entrainment which allows for powerhouse-passed water to become gassed by spill water. The entrainment parameter was calibrated for certain dams (to reflect the specific operations of the dams) or fixed based on the perception that powerhouse water is either always or never mixed.

CRiSP parameters generally reflect changes in the dam structures over the years and should have settled since the structures are not anticipated to change for some time. Data files use the equation number to determine the form of the equation.

Name	Number
Linear Bounded:	29
Exponential Bounded:	30
Empirical Exponential	12
Empirical Hyperbolic	23

The gas production sites are: CHJ, WEL, RIS, RRH, WAN, PRD, MCN, JDA, TDA, BON, LWG, LGS, LMN, and IHR. *The respective monitoring sites are the associated downstream monitoring sites in the tailrace.* These were chosen as the calibration sites because these sites typically detect the higher gas values in the system, they are best associated with the spill operations, and they are used by our web tool that allows users to compare observed TDG levels with forecasts. Bounded exponential equations were fit to the spill data and downstream TDG levels at the monitoring sites.

An ACOE publication 2000 Appendix G on Spillway Discharge production of TDG was an important source for empirical production curves but they were sensitive to the actual spill conditions (gates used, tailrace depth, etc.) Some attempt was made to recognize this through day and night equations in the past, however this is considered unnecessary because nearly every spillway in the system has been modified to reduce gas generation. *Day and night production equations are now identical in CRiSP.*

Shaw (1998) developed production curves for dissolved gas generation using ACOE (1998) equations and empirical fits to tailwater gas levels measured until 1998. In 2000, ACOE published a new set of production equations based on tests that they did at various dams on the Snake and Columbia system. The empirical equations variously used tailwater depth, log functions, or a power function. Where possible, simple assumptions were made to allow the presentation of a TDG production curve in terms of an existing CRiSP-ready equation, including:

- Many ACOE production equations used tailrace depth. The high and low tailrace depths can vary TDG % by 3-8%. CRiSP was not re-programmed to accommodate these additional types of equations. Instead, the bounded exponential curve was fit to the observed data.
- Atmospheric pressure of 760 mm used for computation of percentages

- Day and night spill that formerly corresponded with “adult” and “juvenile” passage times respectively were the same in most cases, since the only possible differences in production based on operations are below the scale of modeling and are contingent upon the actual operations of the individual spill gates in different patterns. CRiSP1.7 will assume that spill is uniformly distributed across the operational spill gates as has been done in the past.
- The backup equations were unmodified because CRiSP did not tolerate the use of Bounded exponential and Bounded linear equations for the “backup”.

The CRiSP model code has not changed in several years regarding TDG generation. In the meantime the dam structures have changed (deflectors added) and recent calibrations by ACOE have suggested some modeling relationships that are beyond the scope of CRiSP at present. New parameters for existing equations are comparatively easy. New relationships are more complicated and require new definitions within the CRiSP code.

In this iteration, the ACOE production equations are not used but rather the existing data that spans multiple years and operational conditions are used to fit the production equations. The best fit is a result of:

- *The CRiSP form of equation fitted to minimize the mean absolute deviation (MAD) of the modelTDG to the downstream monitoring site observations.*
- *Parameters θ (dam_ theta) and K (k_entrain) were either “fixed” meaning their values were set as a result of insight into the physical layout of the dam or they were calibrated and fitted to reduce MAD. For example, there can be no entrainment at Bonneville dam because the spillway and the powerhouses are separated by islands, thus the value is 0.*

Applications

The gas generation parameters in the above table are found in nsat_eqn_params.dat appended below and found at http://www.cbr.washington.edu/~nick/work/ nsat_eqn_params.dat. We will use this for gas generation in CRiSP1.7 calibrations.

Accurately predicting TDG levels is especially important at very high levels due to the direct impact on salmonid smolt survival. In CRiSP, TDG super-saturation related mortality is modeled directly and influences computed survival rates. Above a threshold TDG level (near 113%) the mortality rates become sensitive to the TDG.

Further refinement of the TDG generating methods may be in order if we are interested in improving our prediction accuracy. Although great effort was made to accomplish this, things have changed since then:

- Mitigation measures at the dams are effective and gas levels in the river are significantly reduced from their values ten years ago.
- Entrainment of powerhouse flow is reported either to be constant or have a specific relationship with spill volume. Neither form is available in CRiSP at present.

- Code and legacy documentation show a mixture of methods used to model TDG percentages and concentrations. These are converted between as needed, but we now use % as the "currency" of TDG. Production curves report TDG generation in terms of TDG pressure. CRiSP assumes one atmosphere of pressure in order to compute percentage.
- Dissipation is currently done as a decay in the TDG %. In fact, this rate should be a function of the temperature (as it was in the past) because the equilibrium (0%) TDG concentration levels vary with temperature.

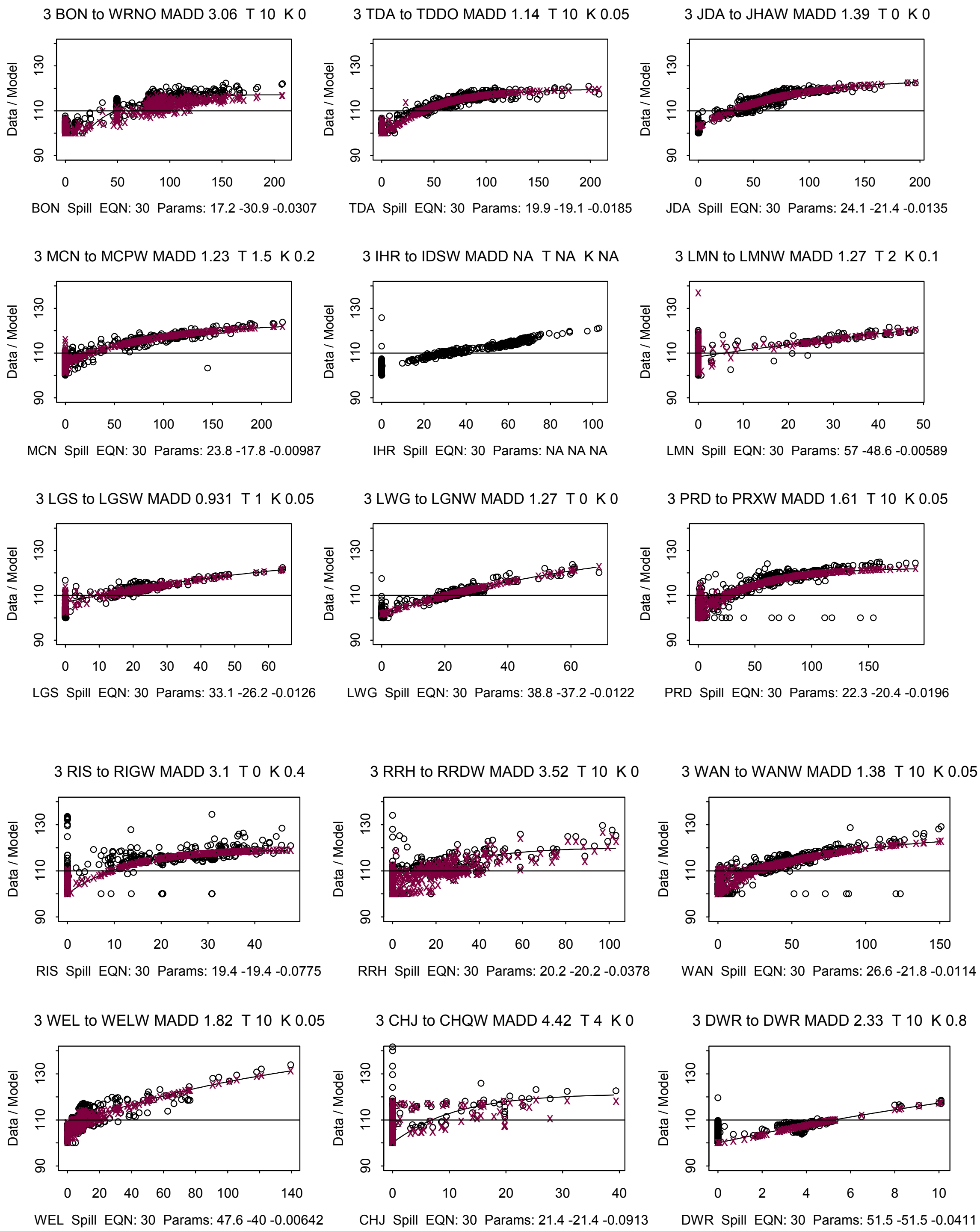
Results

The TDG production parameters are shown in Table 1. The resulting CRiSP input file is in the Appendix. Figure 1 shows all available spill and TDG daily average values for 2000, 2001, and 2002.

Table 1. Calibrated spill production parameters, θ and K values for 14 sites based on 2000, 2001, and 2002 observed TDG.

sites	θ	K	MAD	Was θ fixed?	Was K fixed ?	Eqn	A	B	C	low	hi
BON	10.0	0.00	3.060	TRUE	TRUE	30	17.2	-30.9	-0.03070	0	400
TDA	10.0	0.05	1.140	TRUE	TRUE	30	19.9	-19.1	-0.01850	0	400
JDA	0.0	0.00	1.390	FALSE	FALSE	30	24.1	-21.4	-0.01350	0	400
MCN	1.5	0.20	1.230	FALSE	TRUE	30	23.8	-17.8	-0.00987	0	400
IHR	3.5	0.10	1.000	FALSE	FALSE	30	36.3	-36.3	-0.00837	0	200
LMN	2.0	0.10	1.270	FALSE	FALSE	30	57.0	-48.6	-0.00589	0	200
LGS	1.0	0.05	0.931	FALSE	FALSE	30	33.1	-26.2	-0.01260	0	200
LWG	0.0	0.00	1.270	FALSE	FALSE	30	38.8	-37.2	-0.01220	0	200
PRD	10.0	0.05	1.610	TRUE	FALSE	30	22.3	-20.4	-0.01960	0	200
RIS	0.0	0.40	3.100	FALSE	FALSE	30	19.4	-19.4	-0.07750	0	200
RRH	10.0	0.00	3.520	TRUE	FALSE	30	20.2	-20.2	-0.03780	0	200
WAN	10.0	0.05	1.380	TRUE	FALSE	30	26.6	-21.8	-0.01140	0	200
WEL	10.0	0.05	1.820	TRUE	FALSE	30	47.6	-40.0	-0.00642	0	200
CHJ	4.0	0.00	4.420	FALSE	TRUE	30	21.4	-21.4	-0.09130	0	100
DWR	10.0	0.80	2.330	TRUE	FALSE	30	51.5	-51.5	-0.04110	0	100

Figure 1. Drawn lines are TDG production curves. X is predicted gas level and O are the downstream monitoring station data (2000 – 2002 data).



Appendix: nsat_eqn_params.dat

```
version 8
dam Bonneville_Dam
      gas_theta   10.0
      k_entrain   0.00
      nsat_day_equation 30
            parameter 0 17.2 0 34.4
            parameter 1 -30.9 -61.8 0
            parameter 2 -0.03070 -0.0614 0
            parameter 3 0 0 0
            parameter 4 400 0 800
      end  nsat_day_equation
      nsat_night_equation 30
            parameter 0 17.2 0 34.4
            parameter 1 -30.9 -61.8 0
            parameter 2 -0.03070 -0.0614 0
            parameter 3 0 0 0
            parameter 4 400 0 800
      end  nsat_night_equation
      nsat_backup_equation 12
            parameter 0 0 0 0
            parameter 1 0.085 0 0.17
            parameter 2 100 0 200
      end  nsat_backup_equation
end dam (Bonneville_Dam)

dam The_Dalles_Dam
      gas_theta   10.0
      k_entrain   0.05
      nsat_day_equation 30
            parameter 0 19.9 0 39.8
            parameter 1 -19.1 -38.2 0
            parameter 2 -0.01850 -0.037 0
            parameter 3 0 0 0
            parameter 4 400 0 800
      end  nsat_day_equation
      nsat_night_equation 30
            parameter 0 19.9 0 39.8
            parameter 1 -19.1 -38.2 0
            parameter 2 -0.01850 -0.037 0
            parameter 3 0 0 0
            parameter 4 400 0 800
      end  nsat_night_equation
      nsat_backup_equation 30
            parameter 0 25.75 0 51.5
            parameter 1 -4.319 -8.638 0
            parameter 2 -0.002965 -0.00593 0
            parameter 3 0 0 0
            parameter 4 1000 0 1000
      end  nsat_backup_equation
end dam (The_Dalles_Dam)

dam John_Day_Dam
      gas_theta   0.0
      k_entrain   0.00
      nsat_day_equation 30
            parameter 0 24.1 0 48.2
```

```
            parameter 1 -21.4 -42.8 0
            parameter 2 -0.01350 -0.027 0
            parameter 3 0 0 0
            parameter 4 400 0 800
      end  nsat_day_equation
      nsat_night_equation 30
            parameter 0 24.1 0 48.2
            parameter 1 -21.4 -42.8 0
            parameter 2 -0.01350 -0.027 0
            parameter 3 0 0 0
            parameter 4 400 0 800
      end  nsat_night_equation
      nsat_backup_equation 12
            parameter 0 22 0 44
            parameter 1 0.015 0 0.03
            parameter 2 10 0 20
      end  nsat_backup_equation
end dam (John_Day_Dam)

dam McNary_Dam
      gas_theta   1.5
      k_entrain   0.20
      nsat_day_equation 30
            parameter 0 23.8 0 47.6
            parameter 1 -17.8 -35.6 0
            parameter 2 -0.00987 -0.01974 0
            parameter 3 0 0 0
            parameter 4 400 0 800
      end  nsat_day_equation
      nsat_night_equation 30
            parameter 0 23.8 0 47.6
            parameter 1 -17.8 -35.6 0
            parameter 2 -0.00987 -0.01974 0
            parameter 3 0 0 0
            parameter 4 400 0 800
      end  nsat_night_equation
      nsat_backup_equation 30
            parameter 0 38.292 0 76.584
            parameter 1 -38.7853 -77.5706 0
            parameter 2 -0.009525 -0.01905 0
            parameter 3 0 0 0
            parameter 4 1000 0 1000
      end  nsat_backup_equation
end dam (McNary_Dam)

dam Ice_Harbor_Dam
      gas_theta   3.5
      k_entrain   0.10
      nsat_day_equation 30
            parameter 0 36.3 0 72.6
            parameter 1 -36.3 -72.6 0
            parameter 2 -0.00837 -0.01674 0
            parameter 3 0 0 0
            parameter 4 200 0 400
      end  nsat_day_equation
      nsat_night_equation 30
            parameter 0 36.3 0 72.6
            parameter 1 -36.3 -72.6 0
```

```
            parameter 2 -0.00837 -0.01674 0
            parameter 3 0 0 0
            parameter 4 200 0 400
      end  nsat_night_equation
      nsat_backup_equation 12
            parameter 0 30 0 60
            parameter 1 0 0 0
            parameter 2 10 0 20
      end  nsat_backup_equation
end dam (Ice_Harbor_Dam)

dam Lower_Monumental_Dam
      gas_theta   2.0
      k_entrain   0.10
      nsat_day_equation 30
            parameter 0 57.0 0 114
            parameter 1 -48.6 -97.2 0
            parameter 2 -0.00589 -0.01178 0
            parameter 3 0 0 0
            parameter 4 200 0 400
      end  nsat_day_equation
      nsat_night_equation 30
            parameter 0 57.0 0 114
            parameter 1 -48.6 -97.2 0
            parameter 2 -0.00589 -0.01178 0
            parameter 3 0 0 0
            parameter 4 200 0 400
      end  nsat_night_equation
      nsat_backup_equation 12
            parameter 0 30 0 60
            parameter 1 0 0 0
            parameter 2 100 0 200
      end  nsat_backup_equation
end dam (Lower_Monumental_Dam)

dam Little_Goose_Dam
      gas_theta   1.0
      k_entrain   0.05
      nsat_day_equation 30
            parameter 0 33.1 0 66.2
            parameter 1 -26.2 -52.4 0
            parameter 2 -0.01260 -0.0252 0
            parameter 3 0 0 0
            parameter 4 200 0 400
      end  nsat_day_equation
      nsat_night_equation 30
            parameter 0 33.1 0 66.2
            parameter 1 -26.2 -52.4 0
            parameter 2 -0.01260 -0.0252 0
            parameter 3 0 0 0
            parameter 4 200 0 400
      end  nsat_night_equation
      nsat_backup_equation 12
            parameter 0 26.365 0 52.73
            parameter 1 0 0 0
            parameter 2 100 0 200
      end  nsat_backup_equation
end dam (Little_Goose_Dam)
```

```
dam Lower_Granite_Dam
      gas_theta   0.0
      k_entrain   0.00
      nsat_day_equation 30
            parameter 0 38.8 0 77.6
            parameter 1 -37.2 -74.4 0
            parameter 2 -0.01220 -0.0244 0
            parameter 3 0 0 0
            parameter 4 200 0 400
      end  nsat_day_equation
      nsat_night_equation 30
            parameter 0 38.8 0 77.6
            parameter 1 -37.2 -74.4 0
            parameter 2 -0.01220 -0.0244 0
            parameter 3 0 0 0
            parameter 4 200 0 400
      end  nsat_night_equation
      nsat_backup_equation 12
            parameter 0 37 0 74
            parameter 1 0 0 0
            parameter 2 100 0 200
      end  nsat_backup_equation
end dam (Lower_Granite_Dam)

dam Priest_Rapids_Dam
      gas_theta   10.0
      k_entrain   0.05
      nsat_day_equation 30
            parameter 0 22.3 0 44.6
            parameter 1 -20.4 -40.8 0
            parameter 2 -0.01960 -0.0392 0
            parameter 3 0 0 0
            parameter 4 200 0 400
      end  nsat_day_equation
      nsat_night_equation 30
            parameter 0 22.3 0 44.6
            parameter 1 -20.4 -40.8 0
            parameter 2 -0.01960 -0.0392 0
            parameter 3 0 0 0
            parameter 4 200 0 400
      end  nsat_night_equation
      nsat_backup_equation 12
            parameter 0 25 0 50
            parameter 1 0.015 0 0.03
            parameter 2 0.030 0 0.06
      end  nsat_backup_equation
end dam (Priest_Rapids_Dam)

dam Rock_Island_Dam
      gas_theta   0.0
      k_entrain   0.40
      nsat_day_equation 30
            parameter 0 19.4 0 38.8
            parameter 1 -19.4 -38.8 0
            parameter 2 -0.07750 -0.155 0
            parameter 3 0 0 0
            parameter 4 200 0 400
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```
      end  nsat_day_equation
      nsat_night_equation 30
            parameter 0 19.4 0 38.8
            parameter 1 -19.4 -38.8 0
            parameter 2 -0.07750 -0.155 0
            parameter 3 0 0 0
            parameter 4 200 0 400
      end  nsat_night_equation
      nsat_backup_equation 12
            parameter 0 40 0 80
            parameter 1 0 0 0
            parameter 2 100 0 200
      end  nsat_backup_equation
end dam (Rock_Island_Dam)

dam Rocky_Reach_Dam
      gas_theta   10.0
      k_entrain   0.00
      nsat_day_equation 30
            parameter 0 20.2 0 40.4
            parameter 1 -20.2 -40.4 0
            parameter 2 -0.03780 -0.0756 0
            parameter 3 0 0 0
            parameter 4 200 0 400
      end  nsat_day_equation
      nsat_night_equation 30
            parameter 0 20.2 0 40.4
            parameter 1 -20.2 -40.4 0
            parameter 2 -0.03780 -0.0756 0
            parameter 3 0 0 0
            parameter 4 200 0 400
      end  nsat_night_equation
      nsat_backup_equation 12
            parameter 0 30 0 60
            parameter 1 0.015 0 0.03
            parameter 2 0.03 0 0.06
      end  nsat_backup_equation
end dam (Rocky_Reach_Dam)

dam Wanapum_Dam
      gas_theta   10.0
      k_entrain   0.05
      nsat_day_equation 30
            parameter 0 26.6 0 53.2
            parameter 1 -21.8 -43.6 0
            parameter 2 -0.01140 -0.0228 0
            parameter 3 0 0 0
            parameter 4 200 0 400
      end  nsat_day_equation
      nsat_night_equation 30
            parameter 0 26.6 0 53.2
            parameter 1 -21.8 -43.6 0
            parameter 2 -0.01140 -0.0228 0
            parameter 3 0 0 0
            parameter 4 200 0 400
      end  nsat_night_equation
      nsat_backup_equation 12
            parameter 0 39.45 0 78.9
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```
            parameter 1 0 0 0
            parameter 2 100 0 200
      end  nsat_backup_equation
end dam (Wanapum_Dam)

dam Wells_Dam
      gas_theta   10.0
      k_entrain   0.05
      nsat_day_equation 30
            parameter 0 47.6 0 95.2
            parameter 1 -40.0 -80 0
            parameter 2 -0.00642 -0.01284 0
            parameter 3 0 0 0
            parameter 4 200 0 400
      end  nsat_day_equation
      nsat_night_equation 30
            parameter 0 47.6 0 95.2
            parameter 1 -40.0 -80 0
            parameter 2 -0.00642 -0.01284 0
            parameter 3 0 0 0
            parameter 4 200 0 400
      end  nsat_night_equation
      nsat_backup_equation 12
            parameter 0 39.43871 0 78.87742
            parameter 1 0 0 0
            parameter 2 100 0 200
      end  nsat_backup_equation
end dam (Wells_Dam)

dam Chief_Joseph_Dam
      gas_theta   4.0
      k_entrain   0.00
      nsat_day_equation 30
            parameter 0 21.4 0 42.8
            parameter 1 -21.4 -42.8 0
            parameter 2 -0.09130 -0.1826 0
            parameter 3 0 0 0
            parameter 4 100 0 200
      end  nsat_day_equation
      nsat_night_equation 30
            parameter 0 21.4 0 42.8
            parameter 1 -21.4 -42.8 0
            parameter 2 -0.09130 -0.1826 0
            parameter 3 0 0 0
            parameter 4 100 0 200
      end  nsat_night_equation
      nsat_backup_equation 12
            parameter 0 24.92 0 49.84
            parameter 1 0.06 0 0.12
            parameter 2 0.16 0 0.32
      end  nsat_backup_equation
end dam (Chief_Joseph_Dam)

dam Dworshak_Dam
      gas_theta   10
      k_entrain   .8
      nsat_day_equation 30
            parameter 0 51.5 0 103
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```
            parameter 1 -51.5 -103 0
            parameter 2 -0.04110 -0.0822 0
            parameter 3 0 0 0
            parameter 4 100 0 200
      end  nsat_day_equation
      nsat_night_equation 30
            parameter 0 51.5 0 103
            parameter 1 -51.5 -103 0
            parameter 2 -0.04110 -0.0822 0
            parameter 3 0 0 0
            parameter 4 100 0 200
      end  nsat_night_equation
      nsat_backup_equation 12
            parameter 0 34.5 0 69
            parameter 1 0.007248 0 0.014496
            parameter 2 0.03 0 0.06
      end  nsat_backup_equation
end dam (Dworshak_Dam)
```