Gas Generation Equations for CRiSP 1.6

Theory

For CRiSP.1.6 new equations have been implemented for gas production from spill. As a part of the US Army Corps' Gas Abatement study, Waterways Experiment Station (WES) has developed these new equations as an improvement over GASPILL, which had been the predominantly used model for gas production.

The new equations are an empirical fit of spill data and monitoring data collected by the Corps. %TDG exiting the tailrace of a dam is predicted as a function of the amount of discharge in *kcfs*. This level of TDG is not necessarily the highest level of gas reached, but rather the level of gas in the spill water after some of the more turbulent processes have stabilized. The calibration for each dam was generally fit to the nearest downstream monitor, which is typically about a mile downstream of the dam.

For the 8 lower Snake and lower Columbia dams that were studied by WES, the gas production equation may take one of three forms: linear function of total spill, a bounded exponential function of total spill, and a bounded exponential function of the spill on a per spillbay basis. Work was then done, using CRiSP, to fit similar models for the mid-Columbia dams. See the calibration section below for more details.

Linear Saturation Equations.

$$\%TDG = m \cdot Q_s + b \qquad \text{(EQ 1)}$$

Here

- %TDG is the % total dissolved gas saturation, where 100% is equilibrium.
- Q_s is the total amount of spill in *kcfs*.
- *m*, *b* are the empirically fit slope and intercept parameters.

Bounded Exponential.

$$\%\text{TDG} = \text{a} + \text{b} \cdot \exp(c \cdot Q_s) \qquad \text{(EQ 2)}$$

OR

$$\%\text{TDG} = \text{a} + \text{b} \cdot \exp(c \cdot q_s) \qquad \text{(EQ 3)}$$

Here

- %TDG is the % total dissolved gas saturation, where 100% is equilibrium.

- Q_s is the total amount of spill in *kcfs*.
- q_s is the amount of spill through an individual spillbay.
- *a,b,c* are the empirically fit model parameters.

CRiSP is currently configured so that a separate spill pattern, and thus a separate gas production function, for night and for day can be set for each dam. This spill pattern specifies in particular which spill bays are used to discharge flow both in number and position. Once the number of spill gates, *n*, for a particular pattern is set Equation 3 is then convered into Equation 2 by the relation $q_s = Q_s/n$. This conversion formula assumes that the amount of spill is uniformly distributed among the open spill gates. The model parameters for the day and night gas production thus can be different for a given dam, due to a change in the number of gates open or because the positioning of the gates used changes the dynamics of gas production.

Calibration

For the most of the eight Lower Snake and Lower Columbia dams, the calibrations came from the work published by WES.

TABLE 1. Lower Snake and Lower Columbia Dams, WES gas production Curves

Project	%-TDG =		Reference
BON	$0.12 \cdot Q_s + 105.61$		WES Apr 1996
TDA	$124.3 - 9 \cdot \exp(-0.273 \cdot Q_s/12)$	juvenile pattern (night)	WES Feb 1997
	$124.3 - 9 \cdot \exp(-0.273 \cdot Q_s/23)$	adult pattern (day)	WES Feb 1997
JDA	$128.4 - 24.4 \cdot \exp(-0.024 \cdot Q_s)$	1998(with new deflectors)	Shaw 1998
	$0.203 \cdot Q_s + 108.5$	Before 1998 *	WES Feb 1997
MCN	$0.0487 \cdot Q_s + 114.9$		WES Feb 1997
IHR	$120.9 - 20.5 \cdot \exp(-0.023 \cdot Q_s)$	1998 (with 2 additional deflectors)	Shaw, 1998
IHR	$130.9 - 26.5 \cdot \exp(-0.022 \cdot Q_s)$	1997 (with new deflectors)	Shaw, 1997
IHR	$138.7 - 79 \cdot \exp(-0.0591 \cdot Q_s)$	Before 1997	WES Feb 1997
LGR	$138.0 - 35.8 \cdot \exp(-0.10 \cdot Q_s/6)$	(1996)	WES Feb 1997
	$138.0 - 35.8 \cdot \exp(-0.10 \cdot Q_s/8)$	(1995)	WES Feb 1997

TABLE 1. Lower Snake and Lower Columbia Dams, WES gas production Curves

Project	%-TDG =	Reference
LMN	$131.0 - 26.9 \cdot \exp(-0.0256 \cdot Q_s)$ juvenile pattern (night)	WES Feb 1997
	$0.67 \cdot Q_s + 105.62$ adult pattern (day)*	WES Apr 1996
LGS	$131.3 - 37.0 \cdot \exp(-0.01985 \cdot Q_s)$ juvenile pattern (night)	WES Feb 1997
	$0.53 \cdot Q_s + 100.5$ adult pattern (day)*	WES Apr 1996
LGR	$138.0 - 35.8 \cdot \exp(-0.10 \cdot Q_s/6)$ (1996)	WES Feb 1997
	$138.0 - 35.8 \cdot \exp(-0.10 \cdot Q_s/8)$ (1995)	WES Feb 1997

* In CRiSP an upper bound of roughly 145% was added to these equations.

For LGR and TDA the Feb 97 WES reference gave the production curve in the terms of q_s = discharge/spillbay. Here qs was converted to Q_s/n assuming the total discharge, Q_s, was uniformly distributed between the number, n, of spillbays. In addition, the number of spillbays in use for Lower Granite was different for 1995 and 1996. In general, because of possible construction or repairs at a dam, the number of spill bays will have to be set separately for each year.

In the cases where the older reference was used, there was no new recommendation in the 97 documentation; the authors in fact felt that there was not a good fit available. The equations given in the older reference were nevertheless taken as a starting point for the new gas production model.

For the mid-Columbia dams, the "best" fitting of the three empirical gas production equations was chosen based on available hourly tailwater TDG data, with the exception of Wells Dam. For Wells Dam, tailwater TDG data was simulated using the CRiSP1.6 TDG distribution model and observed data for RRH forebay. The results of this calibration is shown below.

TABLE 2. Mid-Columbia Dams and Dworshak

Project	%-TDG =
PRD	$130.4 - 25.2 \cdot \exp(-0.01045 \cdot Q_s)$
WAN	$139.4 - 26.9 \cdot \exp(-0.00915 \cdot Q_s)$
RIS	$141.1 - 26.9 \cdot \exp(-0.00874 \cdot Q_s)$
RRH	$137.6 - 21.4 \cdot \exp(-0.00733 \cdot Q_s)$
WEL	$143.3 - 19.5 \cdot \exp(-0.0338 \cdot Q_s)$

TABLE 2. Mid-Columbia Dams and Dworshak

Project	%-TDG =
CHJ	$140.1 - 34.8 \cdot \exp(-0.0241 \cdot Q_s)$
DWR	$135.9 - 71.1 \cdot \exp(-0.4787 \cdot Q_s)$

NOTE: All gas production curves break down when spill gets to be only a few *kcfs*. In this case the gas of the tailwater is that of the forebay.

Also NOTE: there was no data for Hells Canyon Dam and so a “generic” set of coefficients was used for this dam. The bounded exponential model, the one predominantly used for the other dams, was chosen and the coefficients were set for moderate gas production.

HCY	$138 - 36 \cdot \exp(-0.02 \cdot Q_s)$

References

1. *Total Dissolved Gas Production at Spillways on the Snake and Lower Columbia Rivers. Memorandum for Record.* Waterways Experiment Station. February1997 (To be published in ACOE Dissolved Gas Abatement Study Phase II Report).

2. *Evaluation and Analysis of Historical Dissolved Gas Data from the Snake and Columbia Rivers*. ACOE Dissolved Gas Abatement Study Phase 1 Technical Report, Appendix K. April 1996.

3. *1996 Water Management Plan for FCRPS*. *Attatchment 1*. *List of Spill Caps*. Bolyvong Tanovan. Army Corps of Engineers North Pacific Division. May 30 1996.