# Gas Saturation and Sensitivity Analysis Using CRiSP

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## Introduction

The Army Corps of Engineers began the Gas Abatement Study in order to address the problem of gas and its effects on the Snake and Columbia Rivers. One important question is how much gas reductions caused by structural changes at a few or several of the dams would benefit fish survival. A gas sensitivity analysis was done using CRiSP to see how sensitive this model is to changes in gas levels and to get a preliminary idea of the effects of reducing gas at the region's top gas producing dams.

In this analysis, steelhead and yearling chinook were released above Lower Granite pool and followed through the tailrace of Bonneville Dam. The runs were done under two scenarios:

1) spill caps aimed at keeping the gas below 120-125% were set for the Snake and lower Columbia River dams and
2) spill fractions were set to meet an 80% FPE at each dam with no set spill caps.

The four most significant gas producing dams were identified and the levels of gas at these dams, two at a time, were reduced by 8-10% by adjusting the gas production characteristics of the dams. The measure used for rating the "significant" gas producers was the level of mortality in the downstream reservoir due to nitrogen exposure. This analysis was done for the years 1995-1993. 1994 data was used to represent a low flow year and 1993 data was used to represent a high flow year.

It is important to note that because the Gasspill equations used for modeling gas generation are nonlinear, gas levels can not be universally decreased by 8-10% just by adjusting equation coefficients. Instead, new coefficients were chosen at each dam so that the peak gas levels were reduced by 8-10%. Because of the nonlinearity of the equation, gas concentrations at other spill levels were sometimes reduced by different amounts. However, because of the broken stick nature of the gas mortality curve, with levels of gas above

120% having a much stronger mortality rate, decreases at the high levels have the largest effect and hence are the most important to decrease by the desired amount.

The broken stick mortality curve raises another issue concerning this analysis with regard to how one chooses the 4 worst dams. The dams which *generated* the most gas did not always coincide with the dams possessing the highest levels of gas *in the tailrace*. Bonneville Dam is a good example: when spilling large amounts, it increases supersaturation by about 10%, but because forebay gas levels were typically very low, the resulting gas level of the tailrace stayed under 120% saturation. Lower Monumental Dam on the other hand did not seem to increase the level of gas in the water, but forebay levels there were already elevated to about 130%. In light of this the dams were rated based on how significant an impact the gas in the downstream reservoir had on the fish, that is the worst gas producers were chosen based on which downstream reservoirs had the highest fish mortality due to nitrogen exposure.

The survival statistics presented in this report include: system survivals as the dams currently are, survivals with 2 dams' gas reduced by 10%, and survivals with 4 dams' gas reduced. These were presented for each scenerio, i.e. with spill caps and then with the 80% FPE, for the years 1993-1995, and with and without transportation. Reservoir specific mortality statistics are also given for the reservoirs immediately following the 4 dams having the biggest impact due to TDG. The reservoir specific statistics are presented for the in river fish only since transported fish are taken out of the river it is difficult to calculate the total impact of gas on these fish. A few other runs are done for comparison including: a run with 1995 conditions and the 50-year flow file from the SOR DFOP alternative and a run with Ice Harbor Dam taken out of the system.

# CRiSP Inputs

## 0. All runs were done with CRiSP version 1.5.3.

## I. Releases - taken from SOR releases

A. Snake River Spring Chinook

B. Dworshak (Hatchery) Steelhead

These releases were along the Snake River above Lower Granite Dam and span multiple days. They are the same releases from the upper Snake as were used in the SOR runs.

## II. Scenario 1: Spill caps

**TABLE 1. Spill Caps (kcfs) provided by Chris Pinney, COE**

| Project | Spill Cap (kcfs) |
|---|---|
| BON | 85 |
| TDA | 90 |
| JDA | 20 |
| MCN | 80 |
| IHR | 25 |
| LMN | 20 |
| LGS | 30 |
| LGR | 40 |
| DWK | 12 |
| HCD | 65 |
| mid-Columbia projects | 235 |

Maximum spills, in kcfs, were specified for each project as given in Table 1. If requested spill fractions exceeded spill caps, spills were held to the cap.

These spill caps were chosen to keep the gas produced at these dams below 120%. Note, however, that the amount of water spilled alone cannot control the gas produced at the dams. Flow and the amount of water spilled both have a large impact on gas production. The fraction of flow spilled is a confounding factor. As the spill fraction changes the fraction of water spilled changes and hence the fraction of water that becomes supersaturated changes. Thus, gas levels will change with a fixed flow by changing the fraction of spill at a dam. Another condition affecting gas production is the amount of gas coming into the dam, which varies. It is not clear whether these spill caps were meant to apply to all conditions, ie all spill fractions, gate settings, forebay gas levels, flow conditions, etc.

The spill caps provided for this analysis were based upon the TDG from the overgeneration operation from 1993 and the Emergency Spill Operation from 1994. With CRiSP's current calibration these spill caps do not always keep the gas below 120% as was intended. This could potentially be due to one of the following reasons:

1) the conditions that led to the higher levels of gas were different than those found in the spill data used to set these caps and hence the caps don't apply, or

2) the nitrogen generation function in CRiSP needs to be recalibrated.

Some evidence supporting the first reason is that in order for these spill caps to keep gas under 120% for conditions seen in 1993-1995, the gas production function in CRiSP had to be changed to significantly reduce gas. As a result overall gas levels were radically changed and hence potentially unrealistic compared to the monitoring data on TDG. The conditions under which these caps were tested need to be made explicit before an evaluation of whether CRiSP needs to be recalibrated can be made. For these reasons I left the CRiSP calibration for nitrogen generation as is and accepted that these spill caps *generally* kept spill gas below 120%.

## III. Scenario 2: 80% FPE spill fractions

Spill fractions were changed to accommodate spring chinook and steelhead during:

| | |
|---|---|
| April 10 (100) to June 20 (171) | Along the Snake River dams<br>IHR, LMN, LGO, LGR |
| April 20 (110) to June 30 (181) | Along the Columbia River dams<br>BON, TDA, JDA, MCN. |

An 80% FPE ensures that at most 20% of the target stock would pass through the turbines at each project. Spill fractions guaranteeing 80% FPE were calculated for both chinook and steelhead. The maximum value of the two was then chosen to guarantee 80% for both species. Since steelhead FGE is always greater than chinook FGE, the resulting spill fractions used were those that produced 80% FPE for chinook (and higher FPE for steelhead). Both spill fractions are given in Table 2 below.

**TABLE 2. Spill fractions required to achieve 80% FPE at each project for yearling chinook and steelhead**

| Project | Chinook FPE spill | Steelhead FPE spill |
|---|---|---|
| LGR | 60% | 17% |
| LGS | 61% | -- |
| LMN | 49% | 38% |
| IHR | 53% | 13% |
| MCN | 58% | 47% |
| JDA | 52% | 28% |
| TDA | 35% | 34% |
| BON | 71% | 43% |

Note that steelhead FGE at Little Goose Dam is 81%, thus requiring no spill to achieve 80% FPE.

The formula for the spill fraction S needed to obtain a given FPE is given by:

$$\mathrm{FPE} = S \times E + (1 - S \times E) \times \mathrm{FGE}$$

where

- S = Spill Fraction as a percentage (e.g. 0.2)
- E = Spill Efficiency, assumed to be 1:1 except at TDA: E=2:1 and LMN: E=1.2:1
- FGE = Fish Guidance Efficiency

# Results: Survival to Bonneville Tailrace

The first group of tables in sections I, II, and III present the system survival through Bonneville Dam's tailrace for each species. For these tables, gas production was first reduced at the two dams with the highest mortality due to gas, and then gas was reduced at the dams with the four highest mortalities due to gas. To obtain the mortality due to gas from a dam the mortality due to gas exposure in the downstream reservoir was looked at. The dams which caused the most mortality on average over both scenarios and all three years were chosen. IHR and LGO were the top two dams. That is the MCN reservoir following IHR and LMN reservoir following LGO had the highest gas mortalities. LMN and

MCN were the next two highest. That is IHR reservoir, following LMN, and the JDA reservoir, following MCN had the next highest mortalities due to gas exposure.

Sections I and II present the results for the spill cap runs and 80% FPE runs respectively. Section III presents an example of what happens to the system if gas is reduced by 5% instead of 10%.

## I. Spill Cap Runs

**TABLE 3. Chinook Survival (%) with % increase relative to original survival**

| | | Original System Survival | Survival after 10% decrease at 2 dams | Survival after 10% decrease at 4 dams |
|---|---|---|---|---|
| **In River** | **1995** | 38.1 | 38.3 (+0.52%) | 38.4 (+0.79%) |
| | **1994** | 27.3 | 28.2 (+3.3%) | 28.4 (+4.0%) |
| | **1993** | 38.0 | 38.1 (+0.26%) | 38.2 (+0.53%) |
| **w/Transport** | **1995** | 64.5 | 64.6 (+0.16%) | 64.6 (+0.16%) |
| | **1994** | 57.6 | 57.9 (0.52%) | 58.0 (0.69%) |
| | **1993** | 62.4 | 62.4 (+0.0%) | 62.4 (+0.0%) |

**TABLE 4. Steelhead Survival (%) with % increase relative to original survival**

| | | Original System Survival | Survival after 10% decrease at 2 dams | Survival after 10% decrease at 4 dams |
|---|---|---|---|---|
| **In River** | **1995** | 30.0 | 30.6 (+2.0%) | 30.9 (+3.0%) |
| | **1994** | 16.3 | 17.6 (+8.0%) | 18.2 (+11.7%) |
| | **1993** | 31.0 | 31.4 (+1.3%) | 31.7 (+2.3%) |
| **w/Transport** | **1995** | 74.0 | 74.1 (+0.14%) | 74.1 (+0.14%) |
| | **1994** | 66.6 | 66.7 (+0.15%) | 66.8 (+0.30%) |
| | **1993** | 74.1 | 74.1 (+0.0%) | 74.2 (+0.13%) |

## II. 80% FPE Runs

**TABLE 5. Chinook Survival (%) with % increase relative to original survival**

| | | Original System Survival | Survival after 10% decrease at 2 dams | Survival after 10% decrease at 4 dams |
|---|---|---|---|---|
| **In River** | **1995** | 33.2 | 38.5 (+16.0%) | 40.0 (+20.5%) |
| | **1994** | 21.9 | 28.1 (+28.3%) | 29.3 (+33.8%) |
| | **1993** | 30.5 | 35.3 (+15.7%) | 37.1 (+21.6%) |

**TABLE 5. Chinook Survival (%) with % increase relative to original survival**

| | Original System Survival | Survival after 10% decrease at 2 dams | Survival after 10% decrease at 4 dams |
|---|---|---|---|
| **In River 1995** | 33.2 | 38.5 (+16.0%) | 40.0 (+20.5%) |
| **w/Transport 1995** | 50.0 | 53.2 (+6.4%) | 54.1 (+8.2%) |
| **1994** | 42.8 | 46.6 (+8.9%) | 47.3 (+10.5%) |
| **1993** | 46.1 | 49.4 (+7.2%) | 50.5 (+9.5%) |

**TABLE 6. Steelhead Survival (%) with % increase relative to original survival**

| | Original System Survival | Survival after 10% decrease at 2 dams | Survival after 10% decrease at 4 dams |
|---|---|---|---|
| **In River 1995** | 14.3 | 21.7 (+34.1%) | 24.5 (+71.3%) |
| **1994** | 6.0 | 12.3 (+105%) | 14.4 (+140%) |
| **1993** | 12.1 | 18.9 (+56.2%) | 21.7 (+79.3%) |
| **w/Transport 1995** | 49.7 | 53.0 (+6.6%) | 54.1 (+8.8%) |
| **1994** | 42.3 | 45.7 (+8.0%) | 46.6 (+10.2%) |
| **1993** | 48.3 | 51.8 (+7.3%) | 53.0 (+9.7%) |

# III. 5% Reduction in Gas

Because the gains in survival for the 1994 FPE runs were so high, the same runs were done with gas reduced by only 4-5% at the top worst dams. Even with the 5% decrease there is still a noticeable gain in survival for the two species. The results are listed in Table 7. A similar benefit after a 4-5% reduction in gas is also expected in the other in river 80% FPE runs where the survival exceeded 60% for the 10% gas reduction.

**TABLE 7. 1994 Steelhead and Chinook Survival (%) with % increase relative to original survival**

| | Original System Survival | Survival after 5% decrease at 2 dams | Survival after 5% decrease at 4 dams |
|---|---|---|---|
| **Chinook In River** | 21.9 | 24.7 (+12.8) | 25.2 (+15.1%) |
| **w/Transport** | 42.8 | 44.6 (+4.2%) | 44.9 (+4.9%) |
| | | | |
| **Steelhead In River** | 6.0 | 8.3 (+38%) | 8.9 (+48%) |
| **w/Transport** | 42.3 | 43.9 (+3.8%) | 44.1 (+4.2%) |

## IV. Reservoir Mortality Statistics

The next group of tables presents reservoir specific mortality tables. These are presented for the reservoirs with the highest mortality rates, which as explained above are LMN, IHR, MCN, JDA. The survivals are then looked at after gas in two of these and then all four of these reservoirs is reduced. The reservoir mortality presented in these tables, as calculated in CRiSP, is caused by two things: nitrogen exposure and predation. The predation component is unchanged by changes in nitrogen levels, hence the observed decreases in mortality are due solely to the decreased levels of gas.

### A. Spill Cap Runs

**TABLE 8. LMN Reservoir**

| | | Reservoir Mortality in Original System | Reservoir Mortality after 10% decrease at 2 dams | Reservoir Mortality after 10% decrease at 4 dams |
|---|---|---|---|---|
| **Chinook** | **1995** | 4.97 | 4.87 | 4.87 |
| | **1994** | 10.18 | 9.47 | 9.47 |
| | **1993** | 5.35 | 5.31 | 5.31 |
| **Steelhead** | **1995** | 7.90 | 7.58 | 7.58 |
| | **1994** | 16.85 | 15.61 | 15.61 |
| | **1993** | 8.38 | 8.15 | 8.15 |

**TABLE 9. IHR Reservoir**

| | | Reservoir Mortality in Original System | Reservoir Mortality after 10% decrease at 2 dams | Reservoir Mortality after 10% decrease at 4 dams |
|---|---|---|---|---|
| **Chinook** | **1995** | 4.60 | 4.55 | 4.54 |
| | **1994** | 7.85 | 7.37 | 7.14 |
| | **1993** | 4.78 | 4.76 | 4.74 |
| **Steelhead** | **1995** | 7.55 | 7.29 | 7.23 |
| | **1994** | 16.21 | 15.12 | 14.50 |
| | **1993** | 8.37 | 8.17 | 8.06 |

**TABLE 10. MCN Reservoir**

| | | Reservoir Mortality in Original System | Reservoir Mortality after 10% decrease at 2 dams | Reservoir Mortality after 10% decrease at 4 dams |
|---|---|---|---|---|
| **Chinook** | **1995** | 5.55 | 5.28 | 5.24 |
| | **1994** | 9.29 | 7.54 | 7.11 |
| | **1993** | 5.22 | 5.10 | 5.06 |
| **Steelhead** | **1995** | 10.34 | 9.55 | 9.45 |
| | **1994** | 19.62 | 15.83 | 14.79 |
| | **1993** | 10.03 | 9.48 | 4.39 |

**TABLE 11. JDA Reservoir**

| | | Reservoir Mortality in Original System | Reservoir Mortality after 10% decrease at 2 dams | Reservoir Mortality after 10% decrease at 4 dams |
|---|---|---|---|---|
| **Chinook** | **1995** | 7.49 | 7.45 | 7.41 |
| | **1994** | 8.94 | 8.90 | 8.83 |
| | **1993** | 6.57 | 6.55 | 6.51 |
| **Steelhead** | **1995** | 16.74 | 16.49 | 16.00 |
| | **1994** | 21.27 | 20.98 | 20.26 |
| | **1993** | 14.09 | 13.90 | 13.47 |

## B. 80% FPE Runs

**TABLE 12. LMN Reservoir**

| | | Reservoir Mortality in Original System | Reservoir Mortality after 10% decrease at 2 dams | Reservoir Mortality after 10% decrease at 4 dams |
|---|---|---|---|---|
| **Chinook** | **1995** | 10.2 | 7.6 | 7.6 |
| | **1994** | 18.10 | 12.9 | 12.9 |
| | **1993** | 11.26 | 8.8 | 8.8 |
| **Steelhead** | **1995** | 22.6 | 16.3 | 16.3 |
| | **1994** | 37.0 | 26.1 | 26.1 |
| | **1993** | 24.4 | 18.01 | 18.01 |

TABLE 13. IHR Reservoir

| | | Reservoir Mortality in Original System | Reservoir Mortality after 10% decrease at 2 dams | Reservoir Mortality after 10% decrease at 4 dams |
|---|---|---|---|---|
| **Chinook** | **1995** | 10.6 | 7.9 | 6.3 |
| | **1994** | 15.1 | 10.5 | 8.4 |
| | **1993** | 12.78 | 10.23 | 8.5 |
| **Steelhead** | **1995** | 23.6 | 17.5 | 13.5 |
| | **1994** | 36.1 | 25.4 | 19.5 |
| | **1993** | 28.05 | 21.81 | 17.64 |

TABLE 14. MCN Reservoir

| | | Reservoir Mortality in Original System | Reservoir Mortality after 10% decrease at 2 dams | Reservoir Mortality after 10% decrease at 4 dams |
|---|---|---|---|---|
| **Chinook** | **1995** | 16.2 | 8.6 | 7.1 |
| | **1994** | 20.9 | 9.7 | 7.9 |
| | **1993** | 19.47 | 12.12 | 10.10 |
| **Steelhead** | **1995** | 38.0 | 20.0 | 15.6 |
| | **1994** | 48.7 | 23.2 | 18.0 |
| | **1993** | 43.50 | 26.5 | 21.6 |

TABLE 15. JDA Reservoir

| | | Reservoir Mortality in Original System | Reservoir Mortality after 10% decrease at 2 dams | Reservoir Mortality after 10% decrease at 4 dams |
|---|---|---|---|---|
| **Chinook** | **1995** | 7.8 | 7.7 | 7.5 |
| | **1994** | 9.1 | 9.0 | 8.9 |
| | **1993** | 7.24 | 7.04 | 6.8 |
| **Steelhead** | **1995** | 18.7 | 18.1 | 17.1 |
| | **1994** | 22.2 | 21.7 | 20.6 |
| | **1993** | 17.15 | 16.4 | 15.4 |

## V. No Ice Harbor

Ice Harbor Dam had the largest mortality due to gas exposure in the downstream reservoir, thus to see exactly how much effect Ice Harbor has on fish mortality all mortalities attributed to this dam were zeroed out in the model. Hence the mortality due to dam passage at Ice Harbor was zeroed out and the nitrogen generation function was also set to zero. The results in Table 16 shows the system survivals as the rivers currently are as compared to those with Ice Harbor taken out of the system.

**TABLE 16. Chinook Survival to Bonneville Tailrace with and without dam passage mortality and gas production zeroed out at Ice Harbor Dam (with % increase relative to original survival)**

| Chinook | | Original System Survival | System Survival without IHR |
|---|---|---|---|
| **In River** | **1995** | 33.2 | 39.3 (+18.4%) |
| | **1994** | 21.9 | 26.8 (+22.4%) |
| | **1993** | 30.5 | 37.9 (+24.26%) |
| **With Transport** | **1995** | 50.0 | 50.9 (+1.8%) |
| | **1994** | 42.8 | 45.5 (+6.3%) |
| | **1993** | 46.1 | 53.4 (+15.8%) |

**TABLE 17. Steelhead Survival to Bonneville Tailrace with and without dam passage mortality and gas production zeroed out at Ice Harbor Dam (with % increase relative to original survival)**

| Steelhead | | Original System Survival | System Survival without IHR |
|---|---|---|---|
| **In River** | **1995** | 14.3 | 22.1 (+54.55%) |
| | **1994** | 6.0 | 10.3 (+71.67%) |
| | **1993** | 12.1 | 21.0 (+73.6%) |
| **With Transport** | **1995** | 49.7 | 52.6 (+5.8%) |
| | **1994** | 42.3 | 44.4 (+5.0%) |
| | **1993** | 48.3 | 52.2 (+8.1%) |

## VI. Monte Carlo Runs

CRiSP in monte carlo mode will produce a mean survival over multiple scenarios. The following table gives the mean survival and standard deviation for runs done over a 50 year flow archive. All other settings were done in accordance with 1995 conditions.

**TABLE 18. In River Survival to the Bonneville Tailrace under 1995 conditions and the 50 year flow archive from the SOR DFOP alternative.**

| | | System Survival (with SD) |
|---|---|---|
| **Chinook** | **w/spill caps** | 38.07 (1.43) |
| | **80% FPE** | 44.62 (2.12) |
| | | |
| **Steelhead** | **w/spill caps** | 33.51 (2.73) |
| | **80% FPE** | 36.22 (3.49) |

# Observations

Decreasing TDG at the upstream dams as well as decreasing it at the dams with high TDG levels had the largest effect on survival. Decreasing gas at LGO and IHR were most effective in decreasing system mortality. Of the two schemes: 1) setting spill fractions to obtain an 80% FPE and 2) setting spill caps to limit gas production, the runs with the spill caps generated higher survivals. The runs without spill caps in turn gained the most from gas reduction at the two worst and four worst dams. Also of note is that survivals during the low flow year 1994 were lower than those in the high flow year 1993, and the relative increases in survival for 1994 were also higher than that for other years. A possible explanation for the larger benefit during a low flow year is that the river and hence the fish are moving slower thus increasing the fish's exposure time to higher levels of nitrogen where the mortality curve is the steepest.

Generally steelhead experienced greater survival increases with gas reduction at the worst dams. The most dramatic run was during the low flow year 1994 where the steelhead survival rates more than doubled when the gas levels were reduced by 10% at the two worst and four worst dams. For this run chinook had a 34% increase after gas was reduced at the 4 worst dams. For the high flow year 1993 the FPE runs also showed dramatic increases in survival. Steelhead had a 79% increase in survival whereas the chinook had only a 22% increase. With spill cap runs the gas reduction had significantly less of an impact. This is a reflection of the fact that the spill caps were for the most part keeping gas below lethal levels. The year 1994 once again experienced the greatest increases for the scenerio. Reducing the gas at the four worst dams in this case increased the steelhead's survival by 11.7% while increasing the chinook's survival by 4.0%.

The reservoir mortality tables, Tables 8-15, show how the decreases in gas affect each reservoir separately. As with the system survivals, the runs without spill caps showed the greater decreases in mortality. However in McNary's reservoir, there was a significant impact in further decreasing the gas in both scenarios, steelhead in particular were showing consistently noticeable decreases in mortality as gas was lowered in both scenarios. Looking at the reservoir mortality tables for the 80% FPE runs, one can see that reducing the gas produced at IHR, LMN, and LGO dams decreased mortality significantly in the downstream reservoirs. Decreasing the gas produced at MCN had much less of an effect, with the reservoir mortality in JDA's reservoir staying relatively the same.

From these statistics one can see that reducing gas production at IHR had the largest predicted impact on survival in the downstream reservoir. For the FPE runs mortality in the MCN reservoir was more than halved in most cases. For this reason separate runs were done keeping IHR completely out of the system. The results of these runs are shown in Tables 16-17. Comparing these figures to those found in Tables 5-6, one can see that in many cases the runs without IHR achieved increases in survival comparable to those found in the runs where gas was reduced at multiple dams by 10%. However eliminating the mortality at IHR alone did not yield as high of increases as achieved by reducing gas at the 4 worst dams.

## Summary

In the above analysis, reducing gas was more important for the in-river fish. Reducing the gas at IHR had the largest improvement on fish survivals. There were significant improvement in fish survivals after a 5 or 10% reduction in gas for the 80% FPE runs for all years and species. There was only slight improvement in survivals after the 10% reductions in gas for the spill cap runs, with this improvement being more pronounced in the low flow year 1994 and for steelhead. These results indicate that the spill caps were effective in limiting mortality due to gas exposure.