INDEPENDENT SCIENTIFIC ADVISORY BOARD

Review of the Proposed Spill Experiment

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for the Northwest Power and Conservation Council,
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and National Marine Fisheries Service
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Cover photo: McNary Dam spillway by Tony Grover.

ISAB Review of the Proposed Spill Experiment

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Review Charge

On December 16, 2013, the Northwest Power and Conservation Council requested that the ISAB review the spill experiment proposed by the State of Oregon, the Nez Perce Tribe, and others for inclusion in the Council's Fish and Wildlife Program. The Council asked that the ISAB consider the following questions:

1. Is the spill experiment proposal, and the postulated increases in fish survival, consistent with scientific methods?[1]

    (a) Does the experiment include an adequately researched hypothesis?
    (b) Is the experiment appropriately designed to test the hypothesis?
    (c) Is the proposed duration of the experiment sufficient?
    (d) Is it possible to isolate spill as the causative factor for changes in fish survival?

2. If not, what adjustments will ensure that the proposal is scientifically based?

3. What are the potential biological risks and/or benefits, particularly focusing on increased total dissolved gas effects on other aquatic species, associated with the proposal?

4. Is the proposed spill experiment likely to add to our existing knowledge regarding spill, juvenile dam passage survival, and adult fish returns (SARs)?

Background

The Council provided the following background information in their review request to the ISAB:

> As part of the Fish and Wildlife Program amendment process, the Council received recommendations, based on CSS studies, from Oregon Department of Fish and Wildlife (ODFW), the Nez Perce Tribe (NPT), the Pacific Fishery Management Council (PFMC), environmental and fishing groups, and individuals calling for implementation of an experimental spill management test. This proposal would increase spring spill levels at each mainstem federal Snake and Columbia River hydropower project up to 125% of total dissolved gas level in the tailrace of each dam or biological constraints, and then monitor survival effects over ten years compared to the current court-ordered spill program. Since 125% total dissolved gas exceeds the Clean Water Act water quality standard, modifications to the standard through regulatory processes by the states of Washington and Oregon would be required.

[1] The ISAB changed the wording of the Council's question from "the scientific method" to "scientific methods."

As proposed, the key elements of the experimental spill management would include:

1. Implementing voluntary spill levels greater than historical levels, particularly in lower flow years. Implementation is proposed to include these facets:

    - What: Increase spill to 125% of total dissolved gas level or biological constraints. As 125% total dissolved gas exceeds water quality criterion, criteria modifications through regulatory processes are required.

    - When: During spring operations (3 April through 20 June) for a period of 10 years with a comprehensive assessment after 5 years.

    - Where: At federal Lower Snake and Lower Columbia River Hydroelectric projects – Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles and Bonneville dams.

2. Utilizing the Comparative Survival Studies (CSS) PIT-tag monitoring framework.

3. Monitoring Smolt-to-Adult survival rates.

4. Comparing survival rates against both past survival rates and prospective model predictions.

5. Evaluating whether empirical observations are consistent with the predicted benefits of higher voluntary spill levels.

6. Inclusion of sideboards or “off-ramps” to ensure hydrosystem power generation viability as well as “on-ramps” that facilitate non-hydro renewable energy sources into the power system to offset impacts from increased spill levels.

Review Approach

To conduct the review, the ISAB received briefings and reviewed scientific documents explaining, supporting, and critiquing the spill study. On November 15, 2013, the Comparative Survival Study (CSS) team presented analyses related to the spill test to the ISAB. This presentation was part of the ISAB’s ongoing role in reviewing CSS and Fish Passage Center reports and analyses, primarily annual reports. This presentation occurred before the Council’s December 2014 review request but proved effective in introducing the ISAB to the spill study and supporting analyses. On January 17, 2014, the Bonneville Power Administration (BPA) and the U.S. Army Corps of Engineers (COE) briefed the ISAB on the performance standards, monitoring efforts, and study results related to dam and reach specific survival. Dr. John Skalski also briefed the ISAB on the results of his statistical analysis of the proposed spill test. The ISAB created a file accessible to the public containing the ISAB’s review materials. This proved effective in creating a dialogue and facilitating sharing of literature among the ISAB and entities involved in salmon passage studies, hydrosystem operations, and dissolved gas regulation. The ISAB greatly appreciates the briefings, literature shared, and robust exchange of information.

Overview

Potential Biological or Other Benefits

- Prospective modeling of the proposed spill test by the CSS team suggests that increasing spill levels up to 125% total dissolved gas may enable smolt-to-adult-return ratios (SARs) to reach the 4% biological goal for steelhead and approach the 4% goal for Chinook.
- Knowledge gained through experimental spill management could be generalized to inform operations at other dams.

Potential Biological or Other Risks

- The spill test may *not* result in increased SARs as the justification for the proposed test is based on correlative models that do not establish causality.
- There may be inadequate information gained to justify the cost due to study design limitations and lack of a detailed study and monitoring plan.
- The spill test could result in unintended consequences, including:
    - greater adverse gas bubble disease (GBD) effects on salmonids, native resident fish and/or aquatic life;
    - increased delay and/or predation of juvenile fish in tailraces;
    - increased fallback and/or passage delays of adult salmon at the dams;
    - difficulty in holding spill levels at desired levels, for example in a low water year;
    - increased spillway erosion problems;
    - possible navigation issues for commercial and juvenile fish transportation barges at dams;
    - possible effect on Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) operations or smolt transportation actions because increasing spill will reduce the number of fish collected for transportation;
    - future engineering changes to juvenile fish passage at dams could confound results from this spill test.

Additional Issues

- A detailed study plan needs to be developed by the proponents. The lack of details and lack of synthesis in the material presented leads the ISAB and others to raise questions (see unintended consequences listed above) that might have otherwise been addressed if a comprehensive study plan was developed.
- The Oregon and Washington water quality standards for total dissolved gas (TDG) would need to be modified with NOAA Fisheries concurring.
- Regional work and agreement would be needed on:
    - the study design including how long the test should run to provide convincing evidence of an increase in SARs that is due to increased spill;
    - an monitoring and evaluation plan for TDG, biological and physical parameters; and
    - changes to dam-specific spill patterns.

ISAB Answers to Council Questions

1. **Is the spill experiment proposal, and the postulated increases in fish survival, consistent with scientific methods?**

   (a) Does the experiment include an adequately researched hypothesis?

The spill experiment proposal does not provide enough evidence for the ISAB to conclude that the experiment includes an adequately researched hypothesis. A complete study design, including detailed hypotheses and review of the literature, was not presented to the ISAB. Additional effort is needed to fully vet the experimental spill hypotheses and methodology. An action of this importance requires development of a complete description of the study design that addresses issues presented in this ISAB review and those raised by other stakeholders in the region (Skalski et al. 2013; BPA/COE 2014 and Skalski 2014, presentations to the ISAB).

The effects on salmonids of passing through dam spillways, turbines, and fish bypass routes have been investigated for decades including analyses by CSS that are documented in annual reports and peer-reviewed publications, reach survival studies by NOAA Fisheries, and dam passage survival evaluations by the Corps of Engineers. The results of these studies need to be synthesized and integrated into a more complete proposal as a means to evaluate the regression analyses and modeling presented by the CSS.

In the proposed spill test, recent regression analyses (Haeseker et al. 2012) are used to support the hypothesis that an increased percentage of water spilled over dams leads to higher survival of in-river migrants. Presumably, the experimental spill hypothesis is that increasing spill targets up to 125% TDG will lead to higher SARs of spring-summer Chinook and steelhead compared with SARs observed in years leading up to the spill test period, after adjusting for confounding variables such as ocean conditions and other juvenile fish passage improvements at the dams. Simulation modeling, based on recent peer-reviewed models and assumptions within, suggests that increasing spill levels up to 125% TDG in each of the dam tailraces would lead to considerably higher SARs of spring-summer Chinook and steelhead compared with observed SARs and SARs estimated based on simulations of BiOp operations (see Fig. 1 below from Schaller PPT to ISAB, Nov 15, 2013). This modeling effort, based on existing data, should be used to establish specific quantitative hypotheses for testing. The model simulations should be updated with recent years of data prior to beginning the potential spill test. Furthermore, the degree to which the hypotheses rely on extrapolation should be discussed. For example, in the published modeling reports, how frequently were SAR estimates available when spills were at or near 125% TDG? Also, it may be worthwhile to compare model predictions with expectations from studies directly examining survival of salmonids passing through spill, turbines, and the bypass system (Muir et al. 2001, Marotz et al. 2007, WA Dept. of Ecology 2008). The extent to which results from the CSS simulation studies are consistent with the findings in other studies should be evaluated.

Further scrutiny of the analyses and interpretation of the data and models used to justify the spill test is warranted. The spill test was generated primarily in response to regression models that showed that changes in spill percentage were correlated with increases in SARs. There is a potential problem in using the results of a regression equation as the basis for an experiment, especially if sample sizes are small. Regression models based on small sample sizes often overfit the data so the resulting relationships are not applicable to other sets of data. Selection of explanatory variables for multiple regressions must be carefully considered (Skalski et al. 2013) and the resulting models should be interpreted with caution. That said, six freshwater and marine variables examined by Haeseker et al. (2012) – water transit time (WTT), spill, date of migration, upwelling, sea surface temperature (SST), and Pacific Decadal Oscillation (PDO) – had all been identified as important in other studies, so the choice of these variables has support in the literature (Muir et al 2001, Scheuerell and Williams 2005, Schaller and Petrosky 2007, Petrosky and Schaller 2010). Nevertheless, to address alternative hypotheses additional candidate variables need to be evaluated, for example, biological measures of top-down (predation) and bottom-up (primary and secondary productivity) forcing, individual fish (age, growth, and condition), density-dependent effects, and anthropogenic forcing (habitat, harvest, and hatchery).

Some of the explanatory variables in the model operate at the year level (e.g., PDO, upwelling and SST) whereas others operate at the week or period of release level. A more complex model including multiple random effects is likely needed to fully account for the internal correlation structure. By ignoring the multi-level variation, estimates of residual error are likely underestimated, which also may lead to errors in model predictions.

It is assumed that the survival rate experienced by each release group within a year was independent of survival rates experienced by other groups within the same year. However, in reality, survival rates are likely correlated among groups within the same year, as well as autocorrelated over time. Such correlations reduce the effective sample sizes in tests of statistical significance, and failure to account for these effects will increase the uncertainty of the model predictions. The Durbin-Watson test is not appropriate to evaluate autocorrelation as it fails to account for the two levels of explanatory variables needed in the model.

Despite these concerns with the statistical analyses used to support implementation of the spill test, it appears that the increased spill hypothesis stands as a possible candidate for testing. Other changes to hydrosystem operations have so far been inadequate to meet SAR targets required to conserve endangered salmon populations, even with structural changes that have been made at the dams such as surface spill weirs. It appears that increasing the amount of water spilled at lower Columbia and Snake River dams has merit as a hypothesis to test, but additional review of literature and analysis of data would be worthwhile.

Increasing spill is expected to allow a greater proportion of migrants to avoid the powerhouse intakes and speed their migration through forebays. It is uncertain if the proportion of fish that avoid powerhouse intakes continues to increase as spill increases, and how this proportion is affected by changes in flow. That is, how does each project's spill efficiency change with changing flow conditions, and is there a point of diminishing returns in terms of spill and percentage of fish passed over the spillway?

Hypotheses should be developed for how increasing spill levels will affect returning adult salmonids, downstream-migrating steelhead repeat spawners (kelts), adult and juvenile lamprey, and sturgeon that may be influenced by TDG and changes in hydraulic flow patterns at the dams. The level of effort to monitor gas and adult migration effects would depend on a review of the literature and resulting uncertainty about potential adverse effects. The CSS and others presented the ISAB with some ongoing review of TDG effects, but this information should be summarized and presented in the proposal. As well, the spill test should consider whether effects from the proposed increase in spill might compromise the results from other ongoing studies in the basin.

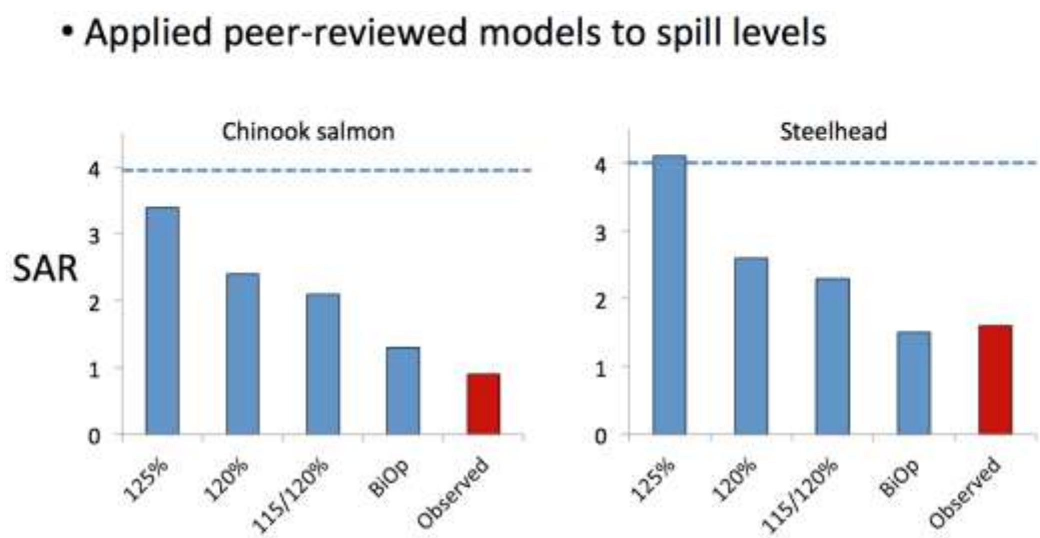

Fig. 1. Modeled SAR estimates of spring Chinook and steelhead in relation to spill levels, based on recent publications by CSS members. Source: Schaller PPT to ISAB, Nov 15, 2013. These charts presumably describe the spill hypothesis. Values in these charts should be updated with the latest data.

(b) Is the experiment appropriately designed to test the hypothesis?

Details of the proposed experiment are not adequately described or documented in a written proposal, so it is premature for the ISAB to determine if the study design is appropriate. First, as discussed above, the specific hypotheses to be tested are not adequately described. Second, due perhaps to practical limitations in devising controls for treatments, what is proposed is not a rigorous experiment but a test of a management action whose effects, ideally, will be evaluated.

It is not clear why a more rigorous experiment with controls has not been proposed. The proposed action is limited to levels of spill at each dam which result in 125% TDG in the tailrace rather than to vary the spill more systematically or consider designing a regime of alternating high/low spill years. This proposal does not discuss the merits of alternative designs, for example varying the level of spill in some years or split-spill studies where only some dams have increased spill. Such a discussion would illustrate the constraints under which such experiments operate and why some may not be feasible. If these and other experimental designs have been considered and discarded, then these efforts should be noted and the reasons for dismissing them identified.

A problem in comparing SARs during the experimental period (with spill targets set at 125% TDG) to SARs during the pre-spill test period is that the pre-spill test period may not be an adequate control because ocean and environmental conditions are likely to be considerably different. Ocean conditions have a major impact on SARs beyond in-river factors. The models attempt to account for ocean effects with independent variables such as the PDO, but considerable variability undoubtedly remains, which will lower the power and reliability of the test. The CSS may be aware of this, but it would be worthwhile to discuss the issue in a proposal and justify the use of SARs to assess results and testing hypotheses in a realistic time frame. Presumably, in-river survival also will be measured, as in past CSS studies. In-river survival estimates are more direct measures of the spill effect, though they cannot detect changes in delayed mortality.

Multiple lines of evidence based on different approaches should be considered. SARs for John Day, Mid-Columbia, and Snake populations could be compared to better estimate the magnitude of the effect of higher spill on reach survivals and SARs. SARs for John Day River populations (passing 3 dams) and Snake River populations (passing 8 dams) were previously compared to infer the deleterious effects of dams. Although this historical comparison was potentially confounded by other factors associated with location in the basin and stock differences, an experimental contrasting manipulation of spill levels that changed SARs in the predicted direction would provide some evidence of the influence of spill. In addition, other modeling approaches should be considered such as using the ratio of SAR for transported fish to SAR for in-river fish (TIR). Although transported fish are influenced by in-river conditions upstream of the transportation collection site and below Bonneville Dam that are positively correlated with percentage spill, most of these fish do not directly experience any spillway passage.

The proposed study offers an opportunity to use adaptive management that might improve SARs of threatened and endangered salmon ESUs and increase knowledge for future decisions. This situation seems to fit the criteria for true adaptive management, as outlined in papers like those by Kendall (2001), Runge (2011) and Tyre et al. (2011). First, there is certainty about the goal (increase SARs), but uncertainty remains about the ecological in-river and ocean survival processes that affect SARs. Therefore, the project should be designed to reduce critical uncertainties. Second, there are competing models that make contrasting predictions. Alternative actions could be identified and applied, and then the models updated periodically, using for example Bayesian analysis, leading to learning that feeds back to management.

(c) Is the proposed duration of the experiment sufficient?

The question of whether the study duration is sufficient to conclude that increased spill to the 125% TDG provides a meaningful increase in SARs for spring/summer Chinook and steelhead should be evaluated by the CSS in a study proposal. Existing data and hypothesized effects can be used to evaluate whether 10 years is adequate.

Ocean conditions are not controllable, so some estimate of the expected change in SARs due to increased spill under poor, average, or good ocean conditions is needed. For example, suppose that a warm phase of the PDO was to begin at the start of the test and last for many years. Or, what if a PDO regime shift occurs several times during the 10-year study period? Would this improve or hinder the chances of detecting effects after 10 years?

(d) Is it possible to isolate spill as the causative factor for changes in fish survival?

It is unlikely that overall changes in SARs can be isolated to conclude that spill is the causative factor for the system. The CSS approach uses correlations which do not by themselves determine cause and effect. There are many confounding factors and indirect effects of spill on fish survival including predation and other mortality in the reservoirs, deployment of new spillway weirs, delayed mortality, ocean conditions, habitat restoration activities, changes in toxic contaminants and other factors.

Nevertheless, multiple lines of evidence including correlations can help support or refute whether spill is a major factor affecting survival of salmonids. Experimental studies in the Basin provide additional information on survival of salmonids passing through spill versus turbines versus the turbine bypass (e.g., Muir et al. 2001). What do these experimental studies tell us and are differences in survival consistent with the CSS study results?

2. If not, what adjustments will ensure that the proposal is scientifically based?

The proponents should be encouraged to prepare a more complete and detailed proposal that addresses issues and concerns that have been put forward by the Action Agencies and stakeholders, partly because details of the study have yet to be described in a document. Several iterations of the proposal may be needed to fully vet issues while providing a rigorous scientific review. The main conceptual issues are 1) lack of an experimental control group, and 2) low statistical power to detect effects given empirical estimates of variation in survival estimates and the survival process itself.

The ISAB appreciates that some options for improving whole system survival cannot be tested with rigor because of practical limitations (they lack controls and sufficient power or sample size). However, such limitations should not, in principle, negate consideration of less rigorous tests. Regardless, proposed actions and monitoring opportunities should be thoroughly considered, with strong adherence to a strategy for adaptive management. Development of a detailed monitoring plan is recommended and needed, especially for areas of high uncertainty, such as the following:

(a) improving detection rates to get better estimates of smolt survival estimates through the hydropower dams and reservoirs. Estimates of the survival of juvenile fish passing the dams via spill or other passage routes are available through COE funded acoustic tag (JSATS) studies of dam passage survival, although dam performance standard studies are not conducted every year. Association of direct juvenile survival past dams with spill should be discernible with appropriately designed monitoring;

(b) monitoring to assess condition of juvenile fish after various passage options to see if the increased spill is having a detrimental effect on fish condition. The issue of possible selectivity of the bypass system whereby fish that enter the dam bypass facility may be injured or somehow weaker than those that pass dams through other passage routes should also be examined;

(c) monitoring of adult salmonids, steelhead kelts, and other fish and other aquatic life to determine the impact of a long period of increased spill and increased total dissolved gas;

(d) evaluation of the proportion of fish passing via spill and all other routes with increased spill;

(e) evaluation of the effect of increased levels of spill on upstream passage of adult fish. New spill patterns could be tested in the hydraulic scale models at Vicksburg and also monitored at the dams during the spill period. Advance testing of the effects of increased spill in hydraulic scale models would be useful not only for estimating impact on upstream fish passage but also for identifying paths that juvenile fish might prefer and to reduce predation risk to juvenile fish in downstream eddies and tailwaters;

(f) related to (d), monitoring predation risk of fish in relation to increased spill;

(g) at this time models probably cannot predict fish survival at 125% TDG levels since empirical data on such high spill levels over the 2.5 month spring migration period are not available. However, collecting appropriate data that can be used in models will enable predictions in the future.

3. What are the potential biological risks and/or benefits, particularly focusing on increased total dissolved gas effects on other aquatic species, associated with the proposal?

The proposed spill test should consider the potential impact on other species, such as fall Chinook and sockeye salmon, sturgeon, lamprey, and other aquatic life. Hypotheses should be developed on how spill maintained at 125% TDG for several months might affect each species and life stage, and a detailed biological monitoring plan should be developed to test the hypotheses.

Consideration of potential biological risks will not be easy because the effects of TDG are influenced by variables in the physical environment and the development and behavior of animals of concern. Foremost among these variables is the depth at which the organisms are exposed. Generally, one meter of depth protects aquatic organisms from the effects of 10% TDG via hydrostatic compensation (Weitkamp et al. 2003). For example, if TDG is 120% at the surface, fish at a depth of 2 m will experience 100% TDG. Backman et al. (2002) found that juvenile salmon collected from the forebays (where TDG was 115%) or tailraces (TDG = 120%)

of Columbia River dams had fewer signs of gas bubble disease (GBD) than did fish from the bypass systems of those dams. The authors attributed this disparity to the shallow water in the bypass systems. Steelhead kelts might be particularly affected as the majority passes FCRPS dams through traditional spill routes and spillway weirs (Colotelo et al. 2013). Fish depth behavior may protect them from adverse effects when they come to the surface. That is, time spent at depth protects fish from time spent at the surface (Knittel et al. 1980). This relation between GBD and depth also confounds interpretation of field and laboratory studies because most aquatic organisms are collected in shallow water (Weitkamp 2008) and, in order to control for the effects of hydrostatic compensation, most laboratory studies have been completed in shallow water tanks, for example depths of 0.25m (Mesa et al. 2000; Beeman et al. 2003).

Field studies can offer some insight into potential biological risks associated with high levels of TDG on aquatic organisms, especially fish. Field studies using cages in which fish were able to go to various depths attempt to approximate fish in the wild. Kokanee fry in 9-m deep cages suffered no mortalities even though TDG reached 125% (Weitkamp et al. 2000 cited in Weitkamp 2008, page 10). Schrank et al. (1997, 1998) held juvenile salmonids and several non-salmonid resident fish species in cages with various depths and found that even at TDG as high as 130 to 138%, GBD was low (~6%) in fish held 2 to 3 m deep for four days. Backman et al. (2002) looked at GBD in over 20,000 juvenile salmonids collected from the Snake and Columbia rivers and dams and regressed the incidence of GBD against TDG that varied from 100% to greater than 130%. Their regression suggests that at 125% one would see GBD in fewer than 5% of the fish. Backman and Evans (2002) examined over 8,000 adult steelhead, sockeye, and Chinook salmon below Bonneville Dam when TDG varied between 111% to greater than 130% and found less than 1% with GBD until TDG exceeded 126%. When TDG was between 126% and 130%, incidence of GBD increased in steelhead (~4%) and sockeye (~8%), but in Chinook salmon incidence of GBD stayed < 1%.

Uncontrolled spill at the high-head Libby Dam resulted in TDG between 124% and 131% (Martoz et al. 2007). Signs of GBD in five resident salmonid species and four non-salmonids increased to greater than 90% over the 19 days of spill. However, there were no differences in population estimates or growth of bull trout or *Oncorhynchus* spp. sampled two years before and a year after the high spill (Marotz et al. 2007). Weitkamp (2008) pointed out that, in most studies, signs of GBD are poorly correlated with rate of fish mortality. He points out, however, that historically when TDG has caused significant mortalities in the wild, dead fish were seen. In the Columbia River, a low proportion of fish have been observed with GBD, and it is unlikely that significant mortalities have occurred. However, it is possible that fish condition or health is compromised leading to increased predation.

Studies that have tracked fish depth using radio telemetry showed that juvenile salmonids emigrate at 1.5 to 3.2 m depth (Beeman and Maule 2006), adult salmonids immigrate greater than 2 m deep (Johnson et al. 2005) and a variety of resident fish were found between 2 to 6.8 m deep (Beeman et al. 2003). Thus, it appears that the migratory behavior of juvenile and adult salmonids will help protect them from adverse effects of TDG. There is, however, recent research conducted during uncontrolled spill in 2011, when water below Bonneville Dam had

TDG as high as 134%. The researchers used acoustic telemetry to examine survival of juvenile salmonids in two tests: (1) fish were collected, tagged and transported from Lower Granite Dam then released approximately 10 km below Bonneville Dam into water with TDG at about 115% (low exposure) or about 125% (high exposure); and (2) fish were collected, tagged and released at Bonneville Dam into water with TDG about 118% (low) or about 132% (high). In the Bonneville Dam comparison, daily mortality rate in the lower river was higher in fish when TDG was greater than 130%. In the transported groups, daily mortality rates did not differ in fish as they migrated in the lower river. Daily mortality rates of the high exposure groups were higher than that of the low exposure group in both tests during the fish’s migration in the Columbia River plume (Ian Brosnan, Cornell University, personal communication of unpublished data). While these data have not yet been published (they are in review for publication), they suggest that mortality of smolts exposed to TDG greater than 125% may lead to decreased survival beyond the Columbia River, that is, delayed mortality.

Few studies have considered the effects of TDG on amphibians, invertebrate species, or other fish species. Colt et al. (1984, 1987) studied effects of elevated TDG and reported no mortalities in tadpoles (*Rana catesbeiana*) held at about 122% TDG for 4 days. Adult bullfrogs suffered no mortalities at about 117% after 4 days, but 40% died after 1 day at about 132%. Several studies indicated that aquatic invertebrates are much less sensitive to high TDG than are fish (Nebeker et al. 1981; Schrank et al. 1997; Ryan et al. 2000). Ryan et al. (2000) collected over 5,400 invertebrates from the Columbia and Snake rivers at depths less than 0.6 m. They reported finding signs of GBD in only 7 (0.1%) individuals when TDG ranged from 120% to more than 135%. White et al. (1991, as cited in McGrath et al. 2006) found a shift in abundances of some invertebrate species before and after exposure to TDG. However, these effects could have been the result of increased water velocity or changing water temperature (White et al. 1991 as cited in Weitkamp 2008). There is also concern for larval/fry fish in shallow areas with elevated TDG. Studies have shown that bubbles formed in sturgeon larva (Counihan et al. 1998) and sucker fry (Schrank et al. 1998) and interfered with their buoyancy, which could lead to displacement in the habitat or increased vulnerability to predation. While it is assumed that lamprey migrate near the benthos, it is not clear if studies have documented the depth at which lamprey migrate and, thus, the degree to which hydrostatic compensation protects them from GBD.

4. **Is the proposed spill experiment likely to add to our existing knowledge regarding spill, juvenile dam passage survival, and adult fish returns (SARs)?**

It is likely that a spill test would enhance knowledge about spill, juvenile passage survival, and SARs. A spill test could also increase knowledge in other ways if appropriate monitoring is conducted. The ISAB agrees with the 2013 CSS Workshop conclusion that the experimental design and implementation should "focus on maximizing the amount of learning that can be achieved," where "learning" is the "likelihood of detecting a response." Here again, this situation seems to fit the need for true adaptive management as mentioned above. Alternative covariates and analytical approaches need to be identified and discussed. A preferred alternative action could be identified and applied, and then the models updated periodically, leading to learning that feeds back to management.

Currently, water quality standards and the desire to produce hydropower constrain the amount of water spilled over the dams. CSS annual reports and published papers, however, suggest that increased spill will lead to higher survival of spring Chinook and steelhead. This is a reasonable hypothesis. Nevertheless, as noted under Question 1.A., a detailed and adequately researched hypothesis for the spill experiment is needed, including consideration of alternative hypotheses. Given the potential importance of this study and concerns raised by the Action Agencies and a variety of stakeholders, further vetting of the study design and methodology in a study proposal would be worthwhile as a means to maximize knowledge gained by an experiment. Without a carefully designed experiment that reflects consideration of all possible alternative outcomes, an unexpected result might preclude drawing firm conclusions about the effect of increasing spill.

The ISAB cannot assess whether the ten-year study proposed by CSS is sufficient to detect a meaningful improvement in salmon survival because a detailed proposal has yet to be prepared. However, if adequate monitoring is implemented along with the spill, there should be increased knowledge regarding spill, juvenile salmonid dam passage survival, impacts on adult fish passage and other species, and total dissolved gas effects.

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