MEMORANDUM

TO: Eric Merrill, NPCC

FROM: Michele DeHart

DATE: February 28, 2020

SUBJECT: Chapter 2 of the Comparative Survival Study (CSS) Annual Report for 2019

Attached is Chapter 2 of the CSS Annual Report for 2019. In response to requests from the federal agencies, the CSS Oversight Committee applied CSS life cycle and cohort models to evaluate federal CRSO-EIS operation alternatives. Most of the CSS analytical work in 2019 was focused on CRSO-EIS analyses. The federal agencies required a non-disclosure agreement for this process. Analytical results could not become public until the Draft CRSO-EIS was released for public review. For this reason Chapter 2 was not included in the 2019 CSS Draft Annual Report. The draft CRSO-EIS was released for public review today.

Please contact us if you have additional questions.
CHAPTER 2
LIFE CYCLE EVALUATIONS OF FISH PASSAGE OPERATIONS ALTERNATIVES FROM THE COLUMBIA RIVER SYSTEMS OPERATIONS, ENVIRONMENTAL IMPACT STATEMENT

Abstract

At the request of the Federal Action Agencies, the CSS used the Grande Ronde Life Cycle Model and the cohort-specific model to analyze six federal operational alternatives for the Columbia River Systems Operations (CRSO) Environmental Impact Statement (EIS), using the 80-year water record. These six operational alternatives included the No Action Alternative (NAA), Multi-Objective Alternatives 1-4 (MO1, MO2, MO3, and MO4), and the Preferred Alternative (PA). In 2017, the CSS modeled several operational scenarios that were analogous to those developed for the CRSO-EIS. The CRSO-EIS federal alternatives included a power focused alternative (MO2) as a “bookend” but did not include a SAR focused alternative. The 2017 CSS scenario of breach of the Lower Snake River dams and spill to the 125% tailrace TDG levels in the Middle Columbia River can be considered a SAR focused “bookend”. Therefore, to provide this SAR focused “bookend” in the context of the CRSO-EIS scenarios, the CSS added a seventh alternative (MO34) to these analyses, also using the 80-year water record.

There were several important findings from the CSS model analyses. For both CSS models, the non-federal MO34 alternative demonstrated the greatest expected improvements across all biological response metrics, compared to all of the federal CRSO-EIS alternatives. On average, the non-federal MO34 alternative exceeded the 4% average SAR regional goal. The lower end of the predicted SAR range for MO34 was above 1% for both Chinook and steelhead, indicating that further population decline would be avoided.

Among the federal alternatives, MO3 (the four dam breach alternative with spill to the 120% tailrace TDG in the Middle Columbia River) resulted in the highest SARs and in-river survivals, followed by MO4 (the spill to the 125% tailrace TDG alternative). These two alternatives, among the federal alternatives, resulted in the highest likelihood of meeting the 4% average SAR regional goal. The lower end of the predicted SAR range for MO3 was also above 1% for both Chinook and steelhead but for MO4, the lower end of the predicted SAR was slightly below 1%, indicating greater risk of further population decline. The other federal alternatives (NAA, MO1, MO2, and the PA) did not meet the regional 4% SAR goal and the lower end of the predicted SAR ranges were well below 1%, indicating greater risk of further population decline under each of these alternatives. For all fish survival metrics, the PA resulted in only slightly better performance than the NAA and MO1, and had lower performance than both MO3 and MO4. Because the modeled datasets provided by the federal agencies used daily averages, the CSS results for the PA are likely overestimates.


**Introduction**

Beginning in 2013 the Comparative Survival Study (CSS) workgroup began developing life cycle models for the purpose of examining survival at specific life stages, which is a critical component of NOAA’s Biological Opinion on the operation of the Federal Columbia River Hydrosystem. CSS life cycle modeling initiatives have pursued integrated assessments of tributary smolt production, mainstem passage survival, ocean survival, and smolt to adult return rates. In 2017, the CSS Annual Report presented Grande Ronde life cycle model analyses of multiple spill scenarios for fish passage operations and dam breaching of the four lower Snake River hydrosystem projects (McCann et al. 2017). In addition, the CSS completed a synthesis of within-season, cohort-specific models for evaluating hydrosystem operations and their predicted impact on Snake River salmon and steelhead populations, which was submitted to the Independent Scientific Advisory Board (ISAB) on May 12, 2017 (CSSOC 2017).

Late in 2018, the Federal Action Agencies requested that the CSS evaluate hydrosystem alternatives proposed by the Columbia River Systems Operations (CRSO) Fish and Wildlife Technical Team in its preparation of the Environmental Impact Statement (EIS) as part of the National Environmental Policy Act (NEPA) process pursuant to Endangered Species Act Section 7(a)(2). These CSS analyses for the CRSO-EIS were a large part of the focus of CSS work in 2019 and represents one of the primary products developed by CSS in 2019. These analyses were not included in the version of the 2019 CSS Annual Report that was released in December 2019 because the Federal Action Agencies required a non-disclosure agreement which precluded distribution of these analyses prior to the release of the draft CRSO-EIS for public review. With the distribution of the draft CRSO-EIS for public review, this chapter has now been included in this 2019 CSS Annual Report.

In response to requests from the Federal Action Agencies developing the Columbia River system Operations Environmental Impact Statement (CRSO-EIS), the CSS Oversight Committee and the Fish Passage Center submitted model analyses on April 29, 2019, which predicted survival rates for each of the CRSO-EIS operations alternatives selected by the federal agencies (FPC 2019b). The CSS model analyses of operation alternatives utilized both the Grand Ronde wild spring Chinook life cycle model based on the tributary abundance and production data sets (1966-2010 migration years) and the CSS cohort-specific models, based upon the historical PIT-tag data set (1998-2015 migration years). Detailed documentation of life cycle model methods are included in Chapter 2 of each of the 2014, 2015, 2016, and 2017 CSS Annual Reports (McCann et al. 2014, McCann et al. 2015, McCann et al. 2016, and McCann et al. 2017), and are not included in this chapter. Detailed model documentation and model coefficients for the CSS cohort-specific models are included in “Documentation of Experimental Spill Management: Models, Hypothesis, Study Design and response to the ISAB”, submitted to the ISAB on May 12, 2017 (CSSOC 2017). Model documentation for both of these models have been available to the public, reviewed by the ISAB, and are posted on the Fish Passage Center web site.

On September 5, 2019 the CSS received a request for an additional model run of MO3, utilizing only wild Chinook and wild steelhead. Since the Grand Ronde life cycle model already utilizes wild fish only, additional analyses were not required. In response to this request, wild-only CSS cohort-specific models were developed and results from these wild only models were submitted to the federal and cooperative agencies on October 25, 2019 (FPC 2019c). Those results are also presented in this chapter. On December 19, 2019, the Federal Action Agencies
requested CSS analyses of their CRSO-EIS Preferred Alternative (PA). The Federal Action Agencies provided the data set for their CRSO-EIS Preferred Alternative on December 19, but did not provide a written description of the alternative until January 3, 2020. In response to this request, the CSS Oversight Committee and the Fish Passage Center submitted results from CSS model analyses of the PA on January 24, 2020 (FPC 2020).

In the 2017 CSS Annual Report (McCann et al. 2017), an analysis of four operations alternatives were presented: 1) the Biological Opinion spill levels, 2) 115% forebay/120% tailrace spill levels 24 hours per day, 3) 120% tailrace spill levels 24 hours per day, and 4) 125% tailrace spill levels 24 hours per day. Each of these alternatives were also analyzed with breach of the four Lower Snake River dams. The 125% spill at the Middle Columbia projects with breach of the four Lower Snake River dams was not included in the federal CRSO-EIS alternatives, but it was included in the 2017 CSS Annual Report (McCann et al. 2017). Federal parties expressed their concern that the 2017 CSS alternatives were not based on the full 80-year water record, and so they would not be applicable to the CRSO-EIS analyses. Results from the 2017 CSS alternatives were similar to the federal NAA, MO1, MO3, and MO4 alternatives, in terms of relative benefits. In order to present the 2017 CSS analyses in the same context as the recent CRSO-EIS alternatives, the 125% tailrace spill levels in the Middle Columbia with breach of the four Lower Snake River dams (herein referred to as MO34) is presented in this chapter. This alternative uses the 80-year water record, in the same analytical framework as the previous CSS alternatives and the CRSO-EIS alternatives.

The objective of these analyses was to present an evaluation of the federal CRSO-EIS operations alternatives on salmon and steelhead using the CSS models, which were submitted to the federal and cooperating agencies during the development of the CRSO-EIS in 2019 and early 2020 (FPC 2019b, FPC 2019c, and FPC 2020). With the issuance of the draft EIS, resulting memoranda to the federal and cooperating agencies are now posted on the FPC website (http://www.fpc.org/documents/CSS.html) and include predicted metrics of abundance, juvenile passage metrics, and SARs under each operational alternative put forward in the CRSO-EIS. The CSS metrics are important reference points for salmon conservation and recovery, and have a long history within the Columbia Basin.

The results of the CSS analyses of all seven alternatives (NAA, MO1-MO4, PA, and MO34) are presented together in this chapter, so that the expected results can be evaluated relative to each other and relative to the regional SAR goals for rebuilding of listed Snake River populations of salmon and steelhead. The Northwest Power and Conservation Council (NPCC 2003, 2009, 2014) adopted a goal of achieving overall SARs (including jacks) in the 2%-6% range (4% average; 2% minimum) for federal ESA-listed Snake River and upper Columbia River salmon and steelhead. The NPCC (2009) Fish and Wildlife Program objectives for unlisted populations or listed populations downstream of the Snake River and Upper Columbia River basins are to “significantly improve the smolt-to-adult return rates (SARs) for Columbia River Basin salmon and steelhead, resulting in productivity well into the range of positive population replacement.” The 2017 CSS Annual Report included analyses of SARs and productivity for Snake River spring/summer Chinook and Snake River steelhead (McCann et al. 2017, Chapter 5). Results from these analyses indicated that population declines for spring/summer Chinook and steelhead were associated with brood year SARs less than 1% and increased life-cycle productivity occurred when SARs exceeded 2%. These results are generally consistent with the NPCC 2-6% SAR objectives. It is important to keep these NPCC SAR goals and the minimum
1% SAR necessary to avoid further population decline in mind when assessing SAR results from the various CRSO-EIS alternatives. Finally, it is important to carefully consider the lower end of the predicted ranges of biological response metrics, as anticipated consequences of climate change suggest poor river or ocean conditions may occur more frequently, which would mean that the lower end of the predicted ranges is likely to occur more often.

Methods

Operational Alternatives Modeled by the CSS

Below is a brief description of each of the alternatives that were provided for CRSO-EIS modeling (NAA, MO1-MO4, and PA). As mentioned above, one additional alternative was added for CSS modeling (MO34). This alternative (MO34) was added in order to present CSS 2017 analyses in the same context as recent CRSO-EIS alternatives, using the same analytical framework. More detailed information on the spring spill operations for each of these alternatives is available in the Supplemental Materials section, at the end of this chapter.

**No Action Alternative (NAA)** – Spring spill operations for the NAA followed the 2016 Fish Operations Plan (Table 2.S1). Under the NAA, transportation was to begin on May 1st. In addition, the NAA included the addition of “fish friendly turbines” at Ice Harbor and McNary dams but did not include any Powerhouse Surface Passage routes (PSPs).

**Multi-Objective 1 (MO1)** – Spring spill operations for MO1 followed a block design, where two different operations were conducted in a single season. These two “treatments” were: 1) spill to performance standards levels and 2) spill to the Gas Cap (115%/120% Total Dissolved Gas (TDG) standard) (Table 2.S2). Under the block design, the order of the two “treatments” would alternate from year to year. Under MO1, transportation was to begin on April 15th. MO1 included the addition of “fish friendly turbines” at Ice Harbor, McNary, and John Day dams and the installation of PSPs at Ice Harbor and McNary dams. Finally, MO1 included several measures at high head reservoir projects that may have led to decreases in flows in the Mid-Columbia River. It is unclear whether these changes were incorporated in the Action Agencies’ modeling of the 80-year water record.

**Multi-Objective 2 (MO2)** – Spring spill operations for MO2 were outlined as Gas Cap spill (to a 110% TDG standard) at all eight FCRPS projects (Table 2.S3). Under MO2, transportation was to begin on April 25th. MO2 included the addition of “fish friendly turbines” at Ice Harbor, McNary, and John Day dams and the installation of Powerhouse Surface Passage structures (PSPs) at Ice Harbor, McNary, and John Day dams. Finally, MO2 included several measures that may affect flows and Water Transit Times (WTT), including: 1) changes at high head reservoir projects that may have led to decreases in flows in the Mid-Columbia River, 2) removal of ramping rate restrictions, which may affect flows to be shaped for power production, and 3) Snake River projects and John Day Dam operate within full reservoir operating range, which may lead to changes in WTT. It is unclear whether these changes were incorporated in the Action Agencies’ modeling of the 80-year water record.

**Multi-Objective 3 (MO3)** - MO3 included breach of the four Lower Snake River dams, which means there is no spill operation at these projects. The spring spill operation at all
four Middle Columbia River dams was spill to the 120% TDG standard levels (Table 2.S4). Since MO3 involved breach of the Lower Snake projects, there is no transportation under this scenario. MO3 included the installation of PSPs at McNary Dam. Finally, MO3 included several measures that may affect flows and WTT, including: 1) changes at high head reservoir projects that may have led to decreases in flows in the Mid-Columbia River, 2) John Day Dam operates within full reservoir operating range, which may lead to changes in WTT, and 3) turbines operate within and above the 1% peak efficiency during the spill season, which may result in higher powerhouse capacities. It is unclear whether these changes were incorporated in the Action Agencies’ modeling of the 80-year water record.

**Multi-Objective 4 (MO4)** - Spring spill operations for MO4 were outlined as spill to the 125% TDG levels at all eight FCRPS projects (Table 2.S5). Under MO4, the spring spill operation of 125% TDG spill begins on March 1st and continues into the summer until August 31st. Transportation was to begin on April 25th. MO4 included the addition of “fish friendly turbines” at Ice Harbor, McNary, and John Day dams and the installation of PSPs at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, and John Day dams. Finally, MO4 included several measures that may affect flows and WTT, including: 1) changes at high head reservoir projects that may have led to decreases in flows in the Mid-Columbia River, 2) reservoir drawdown to MOP, which may affect WTT, and 3) turbines operate within and above the 1% peak efficiency during the spill season, which may result in higher powerhouse capacities. It is unclear whether these changes were incorporated in the Action Agencies’ modeling of the 80-year water record.

**Preferred Alternative (PA)** – The spring spill operation under the PA was for 16 hours of spill to the 125% TDG levels and 8 hours of lower performance standard spill at each of the four Lower Snake River projects and McNary Dam in the Middle Columbia River. At John Day, the PA called for 16 hours of spill to the 120% TDG levels and 8 hours of lower performance standard spill. At The Dalles, the PA called for 24 hours of 40% spill. Finally, at Bonneville, the PA called for 16 hours of spill to 150 Kcfs and 8 hours of lower performance standard spill (Table 2.S6). Transportation was to begin on April 20th. The PA included the addition of “fish friendly turbines” at Ice Harbor, McNary, and John Day dams but no PSPs were identified. Finally, MO4 included several measures that may affect flows and WTT, including: 1) changes at high head reservoir projects that may have led to decreases in flows in the Mid-Columbia River, 2) John Day Dam operates a full reservoir operating range, which may affect WTT, and 3) turbines operate within and above the 1% peak efficiency during the spill season, which may result in higher powerhouse capacities. It is unclear whether these changes were incorporated in the Action Agencies’ modeling of the 80-year water record.

**Non-federal MO34** – MO34 included breach of the four Lower Snake River dams, which means there is no spill operation at these projects. The spring spill operation at all four Middle Columbia River dams was spill to the 125% TDG levels (Table 2.S7). Since MO3 involved breach of the Lower Snake projects, there is no transportation under this scenario. Under MO34, would include the addition of “fish friendly” turbines at John Day Dam and the installation of PSPs at McNary and John Day dams. Finally, MO34 would include several measures that may affect flows and WTT, including: 1) changes at high head reservoir projects that may have led to decreases in flows in the Mid-Columbia
River, 2) John Day Dam operates within full reservoir operating range, which may lead to changes in WTT, and 3) turbines operate within and above the 1% peak efficiency during the spill season, which may result in higher powerhouse capacities. It is unclear whether these changes were incorporated in the Action Agencies’ modeling of the 80-year water record.

All CSS analyses of CRSO-EIS operations alternatives utilized results from Action Agencies’ hydro-modeling of flow, spill, and reservoir elevations, over the 80-year water record. The results from the Action Agencies’ hydro-modeling were summarized for input into the CSS models. The inputs for the CSS models include Water Transit Time (WTT), the number of powerhouse passage events (PITPH), and the proportion transported. For the Grande Ronde life cycle model, the summaries of the alternatives consisted of annual estimates of each input metric (i.e., PITPH, WTT, and transport proportion). For the cohort-specific models, the summaries consisted of four, cohort-specific estimates of each input metric (i.e., PITPH, WTT), per year. Where applicable, CSS modeling of CRSO-EIS Alternatives, and MO34, included PSPs with assumed efficiencies of 0%, 10%, 20%, and 30%, which would result in reduced PITPH. However, even at 30% efficiency, the installation of PSPs had very little effect on modeling results. Here, we only present model results with no PSPs installed (i.e., 0% efficiency). Estimates of PITPH were generated based on the coefficients provided in Appendix J of the 2015 CSS Annual Report (McCann et al. 2015).

CSS Grande Ronde Life Cycle Model

Detailed methods for the CSS Grande Ronde life cycle model are documented in a series of CSS Annual Reports (McCann et al. 2014, McCann et al. 2015, McCann et al. 2016, and McCann et al. 2017). The CSS life cycle model was statistically validated with historical spawner abundance data, smolt abundance data, and empirically derived migration survival data, using a predictive model that complied with harvest rates and environmental variables that explained variability in survival (McCann et al. 2017). Model validation resulted in estimates of the magnitude of influence of variables that affect variation in survival (e.g., how many percentage points higher survival do we expect to see when powerhouse passage is reduced by a certain amount). The model validation involved comparing predictions against empirical data until the best fitting model satisfied criteria that ensured the best fit across all abundance and survival data. The results included estimates of the amount of variability in the magnitude of influence of environmental variables (e.g., a range in the number of percentage points increase in survival expected with powerhouse passage reduction).

A further validation step was made to assure that the model was capable of predicting reasonable values beyond the limited data range used to calibrate predictions, i.e., we asked the question "what does the model predict when conditions go beyond what we have recently observed". This is a reassuring step to take, because the intention of this analysis is to examine if affecting fish passage with hydrosystem operational alternatives has the potential to have a strong impact on survival. It is important to think about the range of conditions that affected migrating fish. To explore this concept, we set the PITPH value to zero, which approximates no powerhouse encounters, and we set the WTT value to 3 days, which approximates a free-flowing river. The rationale behind doing so is that we should be verifying if the model is capable of approximating survival in a free-flowing river. Three days travel from Lower Granite to
Bonneville without any powerhouse encounters is a reasonable approximation of a free-flowing river, with the exception that the reservoirs would still be in place. That said, the CSS life cycle model implicitly estimates a base survival value separate from any portion of survival accounted for by PITPH or WTT, so the "reservoir effect" is implicit in the estimated base survival rate. The CSS life cycle model predicts approximately 79% survival for in-river migrating salmon under those assumptions. This means that any reservoir effect independent of the PITPH or WTT is implicit in the 79%, and if the reservoir effect is negative, than survival would be higher than 79% in a true free-flowing river without "reservoir effects". Conversely, the CSS life cycle model predicts in-river survivals roughly in the 45%-55% range when PITPH falls in the range 2-3 and WTT falls in the range 15-25, i.e., average recent conditions, which is consistent with empirical data used to validate the model. Figure 2.1 shows the relative expected benefit to in-river survival across a range of conditions. The CSS life cycle model predictions for a free-flowing river are also consistent with empirical in-river survival estimates from wild spring Chinook from the John Day River, which averaged 81% during 2000-2012.

Figure 2.1. Mean relative prediction of in-river survival across ranges of PITPH and WTT. The red box is the approximate range of recently observed in-river conditions. The blue box is the approximate range of conditions of more aggressive spill options.
In the 2017 CSS Annual Report (McCann et al. 2017), the CSS life cycle model was used to estimate spawner abundance and SARs over several operational scenarios using three years with distinct hydrograph flow conditions (i.e., a high flow year, an average flow year, and a low flow year). The operational scenarios included in the 2017 Annual Report included: 1) the status quo BiOp spill levels (i.e., 2014 BiOp), 2) spill to 115% TDG limit at the forebay and 120% at the tailrace, 3) spill to 120% TDG levels in the tailrace, and 4) spill to 125% TDG levels in the tailrace. In addition, each of these scenarios was modeled with and without breach of the four Lower Snake River dams.

Examining the CRSEI multiple objective alternatives was essentially a reapplication of the CSS Life Cycle model using inputs analogous to the scenarios in the McCann et al. (2017) analysis, but differing in the fact that the CRSEI data inputs generated long time series of PITPH, WTT and transportation values instead of three static values for low, average, and high flow. Another difference between this CRSEI modeling and the 2017 CSS analysis (McCann et al. 2017) is that the 2017 CSS analyses used a fixed value of 0.20 for the proportion transport input metric. For CRSEI modeling, the proportion transport input metric was calculated for each year, based on the cumulative PITPH at the three transportation projects, the transportation start date at Lower Granite Dam, and the transportation start date at Little Goose Dam for each of the CRSEI alternatives.

\[ \text{Logit}(Pr\text{Trans}) = 1.086 + (1.683 \cdot \text{PITPH}) - (0.184 \cdot \text{LGRDate}) + (0.150 \cdot \text{LGSDate}) \]

Finally, SARs and return abundances for CRSEI modeling were calculated slightly differently from the methods in McCann et al. (2017). In the CRSEI analyses, the two metrics were averages over a random 10 year period in the 80-year simulations for each simulated outcome. This is in contrast to always taking the average of the last 10 years in the 2017 CSS Annual Report (McCann et al. 2017).

CSS Cohort-specific Models

The CSSOSC has established models and metrics for assessing environmental variables such as spill and flow on juvenile fish migration and smolt to adult return rates (CSSOC 2017). The models utilized both hatchery- and wild-origin spring/summer Chinook salmon and steelhead from the Snake River basin PIT-tagged upstream of Lower Granite Dam. We developed separate models for spring/summer Chinook salmon and for steelhead. The CSSOC utilized these models to evaluate the effects of the CRSEI operations alternatives on juvenile fish travel time, juvenile fish survival, TIR, ocean survival, and smolt-to-adult return rate (SAR). Operations data at each project, across the 80-year water record, were used to generate WTT and PITPH inputs for the models. For each cohort and water year, 10,000 random simulations were generated using the parameters described in the models presented in CSSOC (2017). A brief description of those models is provided below.

Juvenile Fish Travel Time Models

We developed models similar to those described in McCann et al. (2015) for characterizing associations between environmental conditions and juvenile fish travel time (FTT). In this application, juvenile fish travel time was defined as the number of days between detection at Lower Granite Dam and subsequent detection at Bonneville Dam. Similar to
Haeseker et al. (2012), we grouped individuals based on their juvenile detection date at Lower Granite Dam into two-week cohorts for analysis: April 8 – April 21, April 22 – May 5, May 6 – May 19, and May 20 – June 2. Data from juvenile outmigration years 1998-2011 were used in these analyses. Models described in McCann et al. (2015) have consistently shown that juvenile fish travel time is primarily a function of water transit time (WTT), proportion spill, and seasonal effects (Julian day). Based on regional review suggestions (Marmorek et al. 2011), we replaced the proportion spill variable with estimates of the total number of powerhouse passage events using the PITPH variable (McCann et al. 2015, Appendix J). Preliminary analyses indicated that mixed-effects models with migration year as a random effect (i.e., random intercept) improved model fit based on the Deviance Information Criterion (DIC).

The model for characterizing the effects of environmental and management factors on FTT for steelhead was of the form:

$$\log_e(FTT_{i,y}) = \beta_0 + \beta_1 \cdot Day_{i,y} + \beta_2 \cdot WTT_{i,y} + \beta_3 \cdot PITPH_{i,y} + \tau_y + \epsilon_{i,y},$$

where $\beta_0, \beta_1, \ldots, \beta_3$ are estimated parameters, $i$ and $y$ are the indexes for release cohort and year, $\tau_y$ is a random effect of migration year with $\tau_y \sim N(0, \sigma^2_\tau)$ and $\epsilon_{i,y} \sim N(0, \sigma^2_\epsilon)$. For yearling Chinook salmon, the model was of the form:

$$\log_e(FTT_{i,y}) = \beta_0 + \beta_1 \cdot Day_{i,y} + \beta_2 \cdot Day^2 + \beta_3 \cdot WTT_{i,y} + \beta_4 \cdot PITPH_{i,y} + \tau_y + \epsilon_{i,y},$$

where $\beta_0, \beta_1, \ldots, \beta_4$ are estimated parameters, $i$ and $y$ are the indexes for release cohort and year, $\tau_y$ is a random effect of migration year with $\tau_y \sim N(0, \sigma^2_\tau)$, and $\epsilon_{i,y} \sim N(0, \sigma^2_\epsilon)$. Previous analyses have shown that yearling Chinook salmon FTT has a seasonal pattern that is best characterized using both a linear and quadratic effect of Julian day (McCann et al. 2015).

**Juvenile Survival Models**

We developed models similar to those described in Haeseker et al. (2012) for characterizing associations between environmental conditions and juvenile survival ($S_R$). The Cormack-Jolly-Seber (CJS) model was used to estimate juvenile survival from Lower Granite Dam to Bonneville Dam using methods described by McCann et al. (2015). Similar to Haeseker et al. (2012), we grouped individuals based on their juvenile detection date at Lower Granite Dam into two-week cohorts for analysis: April 8 – April 21, April 22 – May 5, May 6 – May 19, and May 20 – June 2. Data from juvenile outmigration years 1998-2015 were used in these analyses. Models described in Haeseker et al. (2012) found that juvenile survival was primarily a function of water transit time (WTT), proportion spill, and seasonal effects (Julian day). Based on regional review suggestions (Marmorek et al. 2011), we replaced the proportion spill variable with estimates of the total number of powerhouse passage events using the PITPH variable (McCann et al. 2015, Appendix J).

The model for characterizing the effects of environmental and management factors on juvenile survival was:

$$logit(S_{R,i,y}) = \beta_0 + \beta_1 \cdot Day_{i,y} + \beta_2 \cdot WTT_{i,y} + \beta_3 \cdot PITPH_{i,y} + \epsilon_{i,y},$$

where $\beta_0, \beta_1, \ldots, \beta_3$ are estimated parameters, $i$ and $y$ are the indexes for release cohort and year, and $\epsilon_{i,y} \sim N(0, \sigma^2_\epsilon)$. Preliminary analyses indicated that mixed-effects models with migration year as a random effect (i.e., random intercept) did not improve model fit based on the Deviance Information Criterion (DIC).
Information Criterion (DIC), and therefore random effects were not included in subsequent analyses.

**Ocean survival models**

We developed models similar to those described in Haeseker et al. (2012) for characterizing associations between environmental conditions and ocean survival ($S_O$). Following the methods described in Haeseker et al. (2012), estimates of ocean survival were calculated as the Smolt-to-Adult Return rate (SAR) divided by the juvenile survival rate from Lower Granite Dam to Bonneville Dam. The SAR was calculated as the number of adults detected at Bonneville Dam divided by the number of smolts detected at Lower Granite Dam. Therefore the ocean survival rate measures survival from the time that smolts pass Bonneville Dam until the time that adults return to Bonneville Dam. The Cormack-Jolly-Seber (CJS) model was used to estimate juvenile survival from Lower Granite Dam to Bonneville Dam using methods described by McCann et al. (2015) and SARs were calculated using methods described by Haeseker et al. (2012) except that adults were enumerated at Bonneville Dam rather than Lower Granite Dam for these analyses. Similar to Haeseker et al. (2012), we grouped individuals based on their juvenile detection date at Lower Granite Dam into two-week cohorts: April 8 – April 21, April 22 – May 5, May 6 – May 19, and May 20 – June 2. Data from juvenile outmigration years 1998-2013 were used in these analyses.

Models described in Haeseker et al. (2012) found that ocean survival was associated with seasonal, freshwater, and ocean variables. Seasonal and freshwater variables considered for this analysis included Julian day, WTT, and PITPH. Ocean variables considered for this analysis included the average of monthly values for the Pacific Decadal Oscillation (PDO) during May through August, the sum of monthly coastal upwelling anomalies during April and May, and a recently-developed index of winter ichthyoplankton biomass (Daly et al. 2013). The ichthyoplankton index reflects the biomass of late-larval- and early-juvenile-stage fish taxa that spawn in winter and constitute the majority of the diets of juvenile salmon (Daly et al. 2009). In preliminary analyses, models that included the upwelling and ichthyoplankton biomass indices had the lowest AICc values compared to models with other combinations and therefore these two variables were retained in subsequent analyses.

The model for characterizing the effects of environmental and management factors on ocean survival was:

$$\logit(S_{O,i,y}) = \beta_0 + \beta_1 \cdot \text{Day}_{i,y} + \beta_2 \cdot \text{WTT}_{i,y} + \beta_3 \cdot \text{PITPH}_{i,y} + \beta_4 \cdot \text{UP}_{y} + \beta_5 \cdot \text{ICH}_{y} + \tau_{y} + \varepsilon_{i,y},$$

where $\beta_0, \beta_1, \ldots, \beta_5$ are estimated parameters, $i$ and $y$ are the indexes for release cohort and year, $\text{UP}_{y}$ is the upwelling anomaly index for year $y$, $\text{ICH}_{y}$ is the winter ichthyoplankton biomass index for year $y$, $\tau_{y}$ is a random effect of migration year with $\tau_{y} \sim N(0, \sigma^2_{\tau})$, and $\varepsilon_{i,y} \sim N(0, \sigma^2_{\varepsilon})$. Preliminary analyses indicated that mixed-effects models with migration year as a random effect (i.e., random intercept) improved model fit based on the Deviance Information Criterion (DIC), and therefore a random effect of migration year was included in the analyses.
Smolt-to-Adult Return (SAR) models

We developed models similar to those described in Haeseker et al. (2012) for characterizing associations between environmental conditions and Smolt-to-Adult Return rates (SARs). The SARs were calculated as the number of adults detected at Bonneville Dam divided by the number of smolts detected at Lower Granite Dam. Consistent with Haeseker et al. (2012), we grouped individuals based on their juvenile detection date at Lower Granite Dam into two-week cohorts: April 8 – April 21, April 22 – May 5, May 6 – May 19, and May 20 – June 2. Data from juvenile outmigration years 1998-2013 were used in these analyses.

Based on regional review comments (ISAB 2014-2), additional statistical considerations (Kéry and Schaub 2012), and the need to account for changes in sample sizes (i.e., the number of PIT tagged fish detected as juveniles at Lower Granite Dam) that would be expected under an experimental spill management program, we incorporated several refinements to the SAR models that were developed for this analysis compared to those described in Haeseker et al. (2012). First, to account for potential correlations among cohorts released within the same year and non-independence due to latent states, we considered mixed effects models that included migration year as a random effect (ISAB 2014-2, Thorson and Minto 2015). Second, because the SARs represent a binomial process defined by a number of successes (i.e., adult returns) for a given number of trials (i.e., number of smolts detected within a timing cohort), a binomial Generalized Linear Model (GLM) was applied. Third, to account for potential overdispersion in the data beyond that which is assumed under a binomial GLM, we allowed for and evaluated whether there was evidence of overdispersion, a common feature of ecological data (Kéry & Schaub 2012). Incorporating these issues, the model considered in this analysis would be classified as a binomial Generalized Linear Mixed Model with overdispersion.

The model for characterizing the effects of environmental and management factors on SARs was defined using the following relationships:

\[
SAR_{i,y} = \frac{Adults_{i,y}}{Smolts_{i,y}}
\]

\[
Adults_{i,y} \sim \text{Binomial}(Smolts_{i,y}, p_{i,y})
\]

\[
\text{logit}(p_{i,y}) = \beta_0 + \beta_1 \cdot \text{Day}_{i,y} + \beta_2 \cdot \text{WTT}_{i,y} + \beta_3 \cdot \text{PITPH}_{i,y} + \beta_4 \cdot \text{UP}_{y} + \beta_5 \cdot \text{ICH}_{y} + \tau_{y} + \epsilon_{i,y},
\]

where \(\beta_0, \beta_1, \ldots, \beta_5\) are estimated parameters, \(i\) and \(y\) are the indexes for release cohort and year, \(\text{UP}_{y}\) is the upwelling anomaly index for year \(y\), \(\text{ICH}_{y}\) is the winter ichthyoplankton biomass index for year \(y\), \(\tau_{y}\) is a random effect of migration year with \(\tau_{y} \sim N(0, \sigma^2_{\tau})\), and \(\epsilon_{i,y} \sim N(0, \sigma^2_{\epsilon})\). The \(\epsilon_{i,y}\) account for any extra variability (i.e., overdispersion) in survival beyond that which is expected from a binomial process (Kéry & Schaub 2012).

Transported:In-River (TIR) models

Based on regional review suggestions (ISAB 2014-2), we developed models for characterizing associations between environmental conditions and the ratio of Smolt-to-Adult Return rates for Transported (SAR_{T0}) versus In-River migrants (SAR_{C0}), a ratio known as the TIR (McCann et al. 2015). Previous analyses have shown that the TIR declines as juvenile survival rates increase (McCann et al. 2015). Because juvenile survival rates, ocean survival
rates, and SARs for in-river migrants have been shown to be associated with freshwater environmental conditions (Haeseker et al. 2012), it is reasonable to expect that the TIR would also be associated with freshwater environmental conditions. In addition, the TIR incorporates the variable ocean conditions that both the in-river and transported migrants experience, potentially reducing the amount of residual variability in the ratio caused by variable ocean conditions. In contrast to the level of replication provided by the four, two-week cohorts defined in the analyses described above, the TIR is based on the annual SARs for the transported (T0) and in-river (C0) groups. However, eight release groups (i.e., individual hatcheries and aggregate wild groups) were available for both yearling Chinook and steelhead that provide eight replicates per year and per species for analysis. Preliminary analyses indicated that mixed-effects models with migration year as a random effect (i.e., random intercept) improved model fit based on AICc, and therefore a random effect of migration year was included in the analyses.

The model for characterizing the effects of environmental and management factors on TIRs was:

$$\log_e(TIR_{j,y}) = \text{Group}_j + \beta_1 \cdot WTT_y + \beta_2 \cdot PITPH_y + \tau_y + \epsilon_{j,y},$$

where $\text{Group}_j$ is the intercept for release group $j$, $\beta_1$ and $\beta_2$ are estimated parameters of the effects of WTT and PITPH, $\tau_y$ is a random effect of migration year $y$ with $\tau_y \sim N(0, \sigma^2_\tau)$, and $\epsilon_{j,y} \sim N(0, \sigma^2_\epsilon)$. Because the TIRs are annual estimates, the WTT and PITPH indices were calculated over the full, spring migration period from April 15 through May 30, consistent with Schaller et al. (2014).

**Influences of river and ocean variables on life-stage-specific survival**

The models described above characterize the influence of freshwater and marine factors on in-river, ocean, and smolt-to-adult return survival. To illustrate the influence of these factors on survival at each life stage, we summarized the parameter estimates and their associated confidence bounds from the survival models. Prior to fitting the models, the freshwater and marine indices were standardized to have a mean value of zero and a standard deviation of one by subtracting the mean and dividing by the standard deviation.

At each life stage, there was evidence of negative effects of WTT and PITPH on survival (Figure 2.2). That is, increases in WTT and PITPH were associated with reductions in in-river survival, ocean survival, and smolt-to-adult return survival. There was evidence of positive effects of ichthyoplankton biomass and upwelling on ocean survival and smolt-to-adult return survival. Seasonal effects were also apparent, as evidenced by negative effects of Julian Day at Lower Granite Dam on survival at each life stage. These results illustrate that the WTT and PITPH factors are not only important for explaining patterns of variation in survival while in the freshwater environment, but are also important for explaining patterns of variation in survival in the ocean and the overall smolt-to-adult return rate for both spring/summer Chinook salmon and steelhead.
Figure 2.2. Estimated coefficients (with 95% confidence intervals) for cohort-specific models of in-river survival (top row), ocean survival (middle row), and Smolt-to-Adult Return (SAR, bottom row) for steelhead (left column) and yearling Chinook salmon (right column). The variables include Julian Day at Lower Granite Dam (Day), Water Transit Time (WTT), the number of powerhouse passage events (PITPH), winter ichthyoplankton biomass (ICH), and upwelling during April and May (UP).

Results
Summary of Input Metrics from Operational Alternatives

Below, we provide a summary of results of some of the CSS model input values that were derived from the CRSO-EIS modeled alternatives, and MO34.
PITPH

It is important to note that PITPH is an index that is used as a covariate in the CSS life cycle and CSS cohort-specific models to describe the effects of spill, which incorporates the operation of spillway surface passage structures. Analyses of relative variable importance have shown that the combination of PITPH, water transit time, and seasonality are important factors for explaining variation in juvenile survival and juvenile travel time. Analyses of relative variable importance have also shown that combinations of PITPH, water transit time, seasonality, and ocean indices are important factors for explaining patterns of variation in SARs. The PITPH index by itself, without consideration of the other factors, provides an incomplete characterization of the biological impacts of hydrosystem operations on juvenile survival and SARs. Recognizing these issues, we summarize the seasonal average estimates of PITPH from the CRSO-EIS alternatives and MO34 (Figure 2.3, Table 2.1). It is important to note that these are the seasonal average PITPH estimates that were utilized by the CSS life cycle model (Chinook only). The cohort-specific models used similar estimates, only those estimates were specific to each cohort in the analysis. Furthermore, separate estimates of cohort-specific PITPH were generated for Chinook and steelhead.

From this summary, a few obvious patterns emerge. First, MO2 always resulted in higher estimates of cumulative PITPH. Second, MO34 consistently resulted in the lowest estimates of cumulative PITPH, followed closely by MO3 and MO4. Finally, cumulative PITPH under the PA was lower than the NAA and MO1 but higher than each of MO34, MO3, and MO4. Patterns described above for seasonal average PITPH were similar in the cohort-specific estimates of PITPH.
Table 2.1. Mean seasonal average PITPH (95% confidence intervals) for spring/summer Chinook and steelhead over the 80-year water record for each CRSO-EIS Alternative, and MO34, used in the CSS modeling. Values presented assume no additional powerhouse surface passage structures.

<table>
<thead>
<tr>
<th>Modeled Alternative</th>
<th>Chinook</th>
<th>Steelhead</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAA</td>
<td>2.15 (2.06-2.23)</td>
<td>1.96 (1.85-2.06)</td>
</tr>
<tr>
<td>MO1</td>
<td>1.85 (1.72-1.97)</td>
<td>1.69 (1.56-1.83)</td>
</tr>
<tr>
<td>MO2</td>
<td>3.90 (3.82-3.98)</td>
<td>3.65 (3.55-3.75)</td>
</tr>
<tr>
<td>MO3</td>
<td>0.62 (0.57-0.67)</td>
<td>0.47 (0.42-0.52)</td>
</tr>
<tr>
<td>MO4</td>
<td>0.45 (0.40-0.50)</td>
<td>0.36 (0.31-0.42)</td>
</tr>
<tr>
<td>PA</td>
<td>0.98 (0.89-1.07)</td>
<td>0.88 (0.78-0.97)</td>
</tr>
<tr>
<td>MO34</td>
<td>0.25 (0.23-0.27)</td>
<td>0.15 (0.13-0.17)</td>
</tr>
</tbody>
</table>

Water Transit Time

Below are the seasonal average estimates of water transit time (WTT) from the CRSO-EIS alternatives, and MO34 (Figure 2.4). It is important to note that the results presented below are the seasonal average WTT estimates that were utilized by the CSS life cycle model. The cohort-specific models used similar estimates, only those estimates were specific to each cohort in the analysis. From this summary, one obvious pattern emerges. Water transit time is nearly identical for most of the alternatives modeled, except MO3 and MO34. This is because these two alternatives are the only two that involve breach of the four Lower Snake River dams and, thus, significantly reduces WTT.
Figure 2.4. Annual estimates of water transit time (WTT) (days) derived from predicted hydrosystem conditions under CRSO-EIS modeled alternatives, and MO34.

Transport Proportions

Below are the seasonal average estimates of transport proportions from the CRSO-EIS alternatives, and MO34 (Figure 2.5, Table 2.2). It is important to note that these estimates of transport proportions were only utilized by the CSS life cycle model. The cohort-specific models do not use transport proportions as an input. From this summary, two obvious patterns emerge. First, because MO3 and MO34 both involve breaching of the four Lower Snake River dams, the estimated transport proportion for these two scenarios was 0.0. Second, MO2 always resulted in the highest estimates of transport proportions.
Figure 2.5. Annual estimates of transport proportions derived from predicted hydrosystem conditions under CRSO-EIS modeled alternatives, and MO34.

Table 2.2. Mean estimates of transport proportions (95% confidence intervals) for Chinook over the 80-year water record for each CRSO-EIS Alternative, and MO34, used in the CSS Life Cycle modeling. Values presented assume no additional powerhouse surface passage structures.

<table>
<thead>
<tr>
<th>Model Alternative</th>
<th>Transport Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAA</td>
<td>0.192 (0.176-0.208)</td>
</tr>
<tr>
<td>MO1</td>
<td>0.265 (0.243-0.288)</td>
</tr>
<tr>
<td>MO2</td>
<td>0.338 (0.314-0.363)</td>
</tr>
<tr>
<td>MO3(^A)</td>
<td>---</td>
</tr>
<tr>
<td>MO4</td>
<td>0.075 (0.071-0.079)</td>
</tr>
<tr>
<td>PA</td>
<td>0.102 (0.093-0.111)</td>
</tr>
<tr>
<td>MO34(^A)</td>
<td>---</td>
</tr>
</tbody>
</table>

\(^A\) With breach, no transportation is provided under MO3 or MO34
CSS Grande Ronde Life-cycle Model

Results for the seven alternative operational scenarios, using CRSO-EIS simulated hydro data, are provided in Table 2.3 (predicted SARs) and Table 2.5 (predicted abundances). All values displayed are calculated using the median predictions. Consistent with the 2017 CSS Annual Report (McCann et al. 2017), predictions from the CSS Life Cycle Model cannot be considered as absolute values. Table 2.4 (SARs) and Table 2.6 (abundances) present the relative differences expected between the CRSO-EIS Alternatives, compared to the NAA. Examples of these relative comparisons are provided in Figure 2.6 (SARs) and Figure 2.7 (abundance).

The non-federal MO34 alternative demonstrated the greatest expected improvements in both SARs and abundance, compared to all of the federal CRSO-EIS alternatives. Among the federal alternatives MO3 resulted in the highest relative performance in SARs and abundance, followed by MO4. In terms of relative performance, MO1 was nearly identical to the NAA for both SARs and abundance while MO2 was substantially lower than the NAA. Finally, the relative performance of the PA was higher than the NAA but lower than MO3, MO4 and MO34.

Table 2.3. Median predicted SARs, with no powerhouse surface passage structures, using the CSS Life-Cycle Model. CC=Catherine Creek, GR=Grande Ronde, IMN = Imnaha, LOS=Lostine, MIN=Minam, and WEN=Wenaha

<table>
<thead>
<tr>
<th>Population</th>
<th>NAA</th>
<th>PA</th>
<th>MO1</th>
<th>MO2</th>
<th>MO3</th>
<th>MO4</th>
<th>MO34</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>0.0275</td>
<td>0.0378</td>
<td>0.0279</td>
<td>0.0177</td>
<td>0.0487</td>
<td>0.0436</td>
<td>0.0510</td>
</tr>
<tr>
<td>GR</td>
<td>0.0277</td>
<td>0.0389</td>
<td>0.0280</td>
<td>0.0178</td>
<td>0.0492</td>
<td>0.0434</td>
<td>0.0537</td>
</tr>
<tr>
<td>IMN</td>
<td>0.0276</td>
<td>0.0391</td>
<td>0.0279</td>
<td>0.0177</td>
<td>0.0493</td>
<td>0.0435</td>
<td>0.0531</td>
</tr>
<tr>
<td>LOS</td>
<td>0.0278</td>
<td>0.0385</td>
<td>0.0281</td>
<td>0.0177</td>
<td>0.0494</td>
<td>0.0437</td>
<td>0.0525</td>
</tr>
<tr>
<td>MIN</td>
<td>0.0276</td>
<td>0.0385</td>
<td>0.0278</td>
<td>0.0176</td>
<td>0.0495</td>
<td>0.0439</td>
<td>0.0531</td>
</tr>
<tr>
<td>WEN</td>
<td>0.0277</td>
<td>0.0374</td>
<td>0.0279</td>
<td>0.0177</td>
<td>0.0493</td>
<td>0.0435</td>
<td>0.0532</td>
</tr>
</tbody>
</table>

Table 2.4. Performance of SARs relative to the NAA, with no powerhouse surface passage structures, using the CSS Life Cycle Model. Values greater than 1 indicate an increase over the NAA. CC=Catherine Creek, GR=Grande Ronde, IMN = Imnaha, LOS=Lostine, MIN=Minam, and WEN=Wenaha

<table>
<thead>
<tr>
<th>Population</th>
<th>NAA</th>
<th>PA</th>
<th>MO1</th>
<th>MO2</th>
<th>MO3</th>
<th>MO4</th>
<th>MO34</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>1.00</td>
<td>1.38</td>
<td>1.01</td>
<td>0.64</td>
<td>1.77</td>
<td>1.59</td>
<td>1.86</td>
</tr>
<tr>
<td>GR</td>
<td>1.00</td>
<td>1.41</td>
<td>1.01</td>
<td>0.64</td>
<td>1.77</td>
<td>1.57</td>
<td>1.94</td>
</tr>
<tr>
<td>IMN</td>
<td>1.00</td>
<td>1.42</td>
<td>1.01</td>
<td>0.64</td>
<td>1.79</td>
<td>1.58</td>
<td>1.93</td>
</tr>
<tr>
<td>LOS</td>
<td>1.00</td>
<td>1.38</td>
<td>1.01</td>
<td>0.64</td>
<td>1.77</td>
<td>1.57</td>
<td>1.89</td>
</tr>
<tr>
<td>MIN</td>
<td>1.00</td>
<td>1.39</td>
<td>1.01</td>
<td>0.64</td>
<td>1.79</td>
<td>1.59</td>
<td>1.92</td>
</tr>
<tr>
<td>WEN</td>
<td>1.00</td>
<td>1.35</td>
<td>1.01</td>
<td>0.64</td>
<td>1.78</td>
<td>1.57</td>
<td>1.92</td>
</tr>
</tbody>
</table>
Table 2.5. Median predicted abundances, with no powerhouse surface passage structures, using the CSS Life-Cycle Model. CC=Catherine Creek, GR=Grande Ronde, IMN = Imnaha, LOS=Lostine, MIN=Minam, and WEN=Wenaha

<table>
<thead>
<tr>
<th>Population</th>
<th>NAA</th>
<th>PA</th>
<th>MO1</th>
<th>MO2</th>
<th>MO3</th>
<th>MO4</th>
<th>MO34</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>232</td>
<td>375</td>
<td>239</td>
<td>103</td>
<td>560</td>
<td>450</td>
<td>599</td>
</tr>
<tr>
<td>GR</td>
<td>258</td>
<td>484</td>
<td>278</td>
<td>91</td>
<td>764</td>
<td>600</td>
<td>821</td>
</tr>
<tr>
<td>IMN</td>
<td>2549</td>
<td>3926</td>
<td>2577</td>
<td>1395</td>
<td>5297</td>
<td>4537</td>
<td>6068</td>
</tr>
<tr>
<td>LOS</td>
<td>742</td>
<td>1148</td>
<td>764</td>
<td>374</td>
<td>1650</td>
<td>1391</td>
<td>1897</td>
</tr>
<tr>
<td>MIN</td>
<td>1140</td>
<td>1673</td>
<td>1162</td>
<td>621</td>
<td>2385</td>
<td>2054</td>
<td>2719</td>
</tr>
<tr>
<td>WEN</td>
<td>1193</td>
<td>2026</td>
<td>1205</td>
<td>442</td>
<td>3241</td>
<td>2662</td>
<td>3888</td>
</tr>
</tbody>
</table>

Table 2.6. Abundances relative to the NAA, with no powerhouse surface passage structures, using the CSS Life Cycle Model. Values greater than 1 indicate an increase over the NAA. CC=Catherine Creek, GR=Grande Ronde, IMN = Imnaha, LOS=Lostine, MIN=Minam, and WEN=Wenaha

<table>
<thead>
<tr>
<th>Population</th>
<th>NAA</th>
<th>PA</th>
<th>MO1</th>
<th>MO2</th>
<th>MO3</th>
<th>MO4</th>
<th>MO34</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>1.00</td>
<td>1.62</td>
<td>1.03</td>
<td>0.45</td>
<td>2.42</td>
<td>1.94</td>
<td>2.59</td>
</tr>
<tr>
<td>GR</td>
<td>1.00</td>
<td>1.88</td>
<td>1.08</td>
<td>0.35</td>
<td>2.97</td>
<td>2.33</td>
<td>3.19</td>
</tr>
<tr>
<td>IMN</td>
<td>1.00</td>
<td>1.54</td>
<td>1.01</td>
<td>0.55</td>
<td>2.08</td>
<td>1.78</td>
<td>2.39</td>
</tr>
<tr>
<td>LOS</td>
<td>1.00</td>
<td>1.55</td>
<td>1.03</td>
<td>0.50</td>
<td>2.22</td>
<td>1.87</td>
<td>2.56</td>
</tr>
<tr>
<td>MIN</td>
<td>1.00</td>
<td>1.47</td>
<td>1.02</td>
<td>0.55</td>
<td>2.09</td>
<td>1.80</td>
<td>2.38</td>
</tr>
<tr>
<td>WEN</td>
<td>1.00</td>
<td>1.70</td>
<td>1.01</td>
<td>0.37</td>
<td>2.72</td>
<td>2.23</td>
<td>3.26</td>
</tr>
</tbody>
</table>
Figure 2.6. Life cycle model results of relative performance of SARs across six CRSO alternatives, and MO34. Relative performance data displayed are the average across all six of the sub-populations presented in Table 4. Values of relative performance that are greater than 1.0 indicate higher predicted SARs than the NAA and values less than 1.0 indicate lower predicted SARs than the NAA.

Figure 2.7. Life cycle model results of relative performance of abundance across six CRSO alternatives, and MO34. Data displayed are for the Imnaha population only, as presented in Table 6. Values of relative performance that are greater than 1.0 indicate higher abundance than the NAA and values less than 1.0 indicate lower abundance than the NAA.
CSS Cohort-specific Model

Detailed results under each CRSO alternative, for both Snake River spring/summer Chinook and steelhead, are provided in Table 2.7 (juvenile survival), Table 2.8 (juvenile fish travel time), Table 2.9 (ocean survival rates), Table 2.10 (SARs), and Table 2.11 (Transport:In-river Ratios). These results are also provided in Figures 2.8 and 2.9 (juvenile survival), Figures 2.10 and 2.11 (juvenile fish travel time), Figures 2.12 and 2.13 (ocean survival rates), Figures 2.14 and 2.15 (SARs), and Figures 2.16 and 2.17 (Transport:In-river Ratios), along with the relative performance of each alternative to the NAA.

Across all of the biological response metrics, the non-federal MO34 alternative demonstrated the greatest improvements relative to the NAA, followed by the federal MO3 alternative. The federal MO4 alternative also demonstrated substantial improvements in biological response metrics relative to the NAA, but responses were somewhat less than MO3. The patterns in model results were similar to what was observed in the CSS life cycle model. Average SARs from the CSS cohort-specific model for the non-federal MO34 alternative exceeded the regional 4% average SAR goal for both spring/summer Chinook and steelhead. The lower end of the predicted SAR range for the non-federal MO3 alternative was greater than 1% for both species.

For all biological response metrics, the federal PA resulted in only slightly better performance than the NAA and MO1, and had lower performance than MO34, MO3, and MO4. Average SARs from the CSS cohort-specific model for the PA did not meet the regional 4% average SAR goal for either spring/summer Chinook or steelhead. The lower end of the predicted SAR range for the PA was less than 1% for both species, which is below the minimum to avoid population decline.

Among the federal alternatives, MO3 demonstrated the greatest expected improvements, compared to the NAA. This was true across all biological response metrics. Average SARs from the CSS cohort-specific model for MO3 consistently met the regional 4% average SAR goal for both spring/summer Chinook and steelhead. The lower end of the predicted SAR range for MO3 was 1.3% for spring/summer Chinook and 1.6% for steelhead. It is important to note that MO3 was the only federal alternative that resulted in significantly faster water travel times.

Second among the federal alternatives was MO4, which demonstrated large expected improvements compared to the NAA but these improvements were less than those predicted under MO3. Average SARs from the CSS cohort-specific model were 3.4% for spring/summer Chinook and 3.0% for steelhead. The lower end of the predicted SAR range for MO4 was 0.9% for both species, which is below the minimum to avoid population decline.

The federal MO1 alternative demonstrated similar performance compared to the NAA, across all biological response metrics. Average SARs from the CSS cohort-specific model were 2.1% for spring/summer Chinook and 1.8% for steelhead under MO1. The lower end of the predicted SAR range for MO1 was 0.6% for spring/summer Chinook and 0.5% for steelhead, which are both below the minimum to avoid population decline.

The federal MO2 alternative demonstrated substantial reductions in biological performance metrics, compared to the NAA. Average SARs from the CSS cohort-specific model were 1.2% for both spring/summer Chinook and steelhead under MO2. The lower end of
the predicted SAR range for MO2 was 0.3% for both species, which is below the minimum to avoid population decline.

To further characterize the probability of population declines (i.e., SARs less than 1%) and the probability of population increases (i.e., SARs greater than 2%) expected under each alternative, we summarized the proportion of the simulated SARs that were less than 1% and the proportion of the SARs that were greater than 2% under each alternative (Figure 2.18, Table 2.12). The MO34 alternative had the lowest probabilities of SARs less than 1% and the greatest probabilities of SARs greater than 2%. The second-best performance was from the MO3 alternative followed by the MO4 alternative. The MO2 alternative showed the greatest probabilities of population declines and the lowest probabilities of population increases, followed by the NAA and MO1 alternatives. Under the PA alternative 36-39% of the simulated SARs were less than 1%. In contrast, under the MO34 alternative only 8-15% of the simulated SARs were less than 1%.

Table 2.7. Predicted juvenile survival (LGR-BON) for yearling Chinook salmon and steelhead with inter-quartile ranges (parentheses) using the CSS cohort-specific model.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Yearling Chinook</th>
<th>Steelhead</th>
</tr>
</thead>
<tbody>
<tr>
<td>MO2</td>
<td>0.520 (0.420 - 0.623)</td>
<td>0.394 (0.251 - 0.525)</td>
</tr>
<tr>
<td>NAA</td>
<td>0.576 (0.485 - 0.675)</td>
<td>0.571 (0.455 - 0.700)</td>
</tr>
<tr>
<td>MO1</td>
<td>0.579 (0.488 - 0.678)</td>
<td>0.578 (0.463 - 0.707)</td>
</tr>
<tr>
<td>PA</td>
<td>0.605 (0.516 - 0.705)</td>
<td>0.645 (0.542 - 0.773)</td>
</tr>
<tr>
<td>MO4</td>
<td>0.632 (0.545 - 0.731)</td>
<td>0.729 (0.647 - 0.844)</td>
</tr>
<tr>
<td>MO3</td>
<td>0.680 (0.603 - 0.770)</td>
<td>0.829 (0.777 - 0.904)</td>
</tr>
<tr>
<td>MO3 (Wild)</td>
<td>0.722 (0.653 - 0.806)</td>
<td>0.807 (0.752 - 0.884)</td>
</tr>
<tr>
<td>MO34</td>
<td>0.702 (0.627 - 0.789)</td>
<td>0.866 (0.826 - 0.927)</td>
</tr>
</tbody>
</table>

Table 2.8. Predicted LGR-BON juvenile fish travel times (days) for yearling Chinook salmon and steelhead with inter-quartile ranges (parentheses) using the cohort-specific model.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Yearling Chinook</th>
<th>Steelhead</th>
</tr>
</thead>
<tbody>
<tr>
<td>MO2</td>
<td>18.3 (13.8 - 21.9)</td>
<td>17.6 (12.5 - 20.6)</td>
</tr>
<tr>
<td>NAA</td>
<td>15.8 (12.2 - 18.7)</td>
<td>16.2 (11.7 - 18.6)</td>
</tr>
<tr>
<td>MO1</td>
<td>15.7 (12.1 - 18.4)</td>
<td>16.3 (11.8 - 18.7)</td>
</tr>
<tr>
<td>PA</td>
<td>14.7 (11.3 - 17.2)</td>
<td>15.8 (11.4 - 18.1)</td>
</tr>
<tr>
<td>MO4</td>
<td>13.7 (10.6 - 16.1)</td>
<td>14.7 (10.7 - 16.9)</td>
</tr>
<tr>
<td>MO3</td>
<td>12.5 (9.8 - 14.7)</td>
<td>11.0 (8.7 - 12.6)</td>
</tr>
<tr>
<td>MO3 (Wild)</td>
<td>11.4 (8.9 - 13.2)</td>
<td>8.1 (6.4 - 9.3)</td>
</tr>
<tr>
<td>MO34</td>
<td>11.8 (9.3 - 13.9)</td>
<td>10.4 (8.3 - 11.9)</td>
</tr>
</tbody>
</table>
Table 2.9. Predicted ocean survival rates (BON-BON) for yearling Chinook salmon and steelhead with inter-quartile ranges (parentheses) using the cohort-specific model.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Yearling Chinook</th>
<th>Steelhead</th>
</tr>
</thead>
<tbody>
<tr>
<td>MO2</td>
<td>0.025 (0.007 - 0.027)</td>
<td>0.024 (0.014 - 0.039)</td>
</tr>
<tr>
<td>NAA</td>
<td>0.036 (0.010 - 0.041)</td>
<td>0.036 (0.016 - 0.044)</td>
</tr>
<tr>
<td>MO1</td>
<td>0.038 (0.011 - 0.043)</td>
<td>0.037 (0.016 - 0.045)</td>
</tr>
<tr>
<td>PA</td>
<td>0.047 (0.013 - 0.054)</td>
<td>0.039 (0.017 - 0.048)</td>
</tr>
<tr>
<td>MO4</td>
<td>0.055 (0.016 - 0.065)</td>
<td>0.042 (0.018 - 0.052)</td>
</tr>
<tr>
<td>MO3</td>
<td>0.059 (0.017 - 0.069)</td>
<td>0.046 (0.020 - 0.057)</td>
</tr>
<tr>
<td>MO3 (Wild)</td>
<td>0.075 (0.025 - 0.096)</td>
<td>0.049 (0.012 - 0.059)</td>
</tr>
<tr>
<td>MO34</td>
<td>0.067 (0.020 - 0.080)</td>
<td>0.049 (0.021 - 0.060)</td>
</tr>
</tbody>
</table>

Table 2.10. Predicted SARs (LGR-BON) for yearling Chinook salmon and steelhead with inter-quartile ranges (parentheses) using the cohort-specific model.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Yearling Chinook</th>
<th>Steelhead</th>
</tr>
</thead>
<tbody>
<tr>
<td>MO2</td>
<td>0.012 (0.003 - 0.013)</td>
<td>0.012 (0.003 - 0.013)</td>
</tr>
<tr>
<td>NAA</td>
<td>0.020 (0.005 - 0.022)</td>
<td>0.018 (0.005 - 0.022)</td>
</tr>
<tr>
<td>MO1</td>
<td>0.021 (0.006 - 0.022)</td>
<td>0.018 (0.005 - 0.022)</td>
</tr>
<tr>
<td>PA</td>
<td>0.027 (0.007 - 0.029)</td>
<td>0.023 (0.007 - 0.027)</td>
</tr>
<tr>
<td>MO4</td>
<td>0.034 (0.009 - 0.037)</td>
<td>0.030 (0.009 - 0.036)</td>
</tr>
<tr>
<td>MO3</td>
<td>0.042 (0.012 - 0.048)</td>
<td>0.050 (0.016 - 0.061)</td>
</tr>
<tr>
<td>MO3 (Wild)</td>
<td>0.053 (0.018 - 0.066)</td>
<td>0.078 (0.022 - 0.098)</td>
</tr>
<tr>
<td>MO34</td>
<td>0.051 (0.015 - 0.058)</td>
<td>0.060 (0.020 - 0.074)</td>
</tr>
</tbody>
</table>
Table 2.11. Predicted Transport: In-river Ratios (TIRs) for wild yearling Chinook salmon and steelhead with inter-quartile ranges (parentheses). No transportation would occur under MO3 or under the non-federal MO34.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Yearling Chinook</th>
<th>Steelhead</th>
</tr>
</thead>
<tbody>
<tr>
<td>MO2</td>
<td>1.29 (0.95 - 1.54)</td>
<td>2.51 (1.23 - 3.16)</td>
</tr>
<tr>
<td>NAA</td>
<td>0.86 (0.64 - 1.03)</td>
<td>1.41 (0.69 - 1.77)</td>
</tr>
<tr>
<td>MO1</td>
<td>0.69 (0.51 - 0.82)</td>
<td>1.09 (0.53 - 1.37)</td>
</tr>
<tr>
<td>PA</td>
<td>0.62 (0.46 - 0.75)</td>
<td>1.09 (0.53 - 1.37)</td>
</tr>
<tr>
<td>MO4</td>
<td>0.58 (0.42 - 0.69)</td>
<td>0.82 (0.40 - 1.04)</td>
</tr>
<tr>
<td>MO3</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>MO3 (Wild)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>MO34</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

Table 2.12. Predicted probabilities of SARs less than 1% and probabilities of SARs greater than 2% for yearling spring/summer Chinook salmon and steelhead under each of the alternatives analyzed.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Yearling Chinook</th>
<th>Steelhead</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 1%</td>
<td>&gt; 2%</td>
</tr>
<tr>
<td>MO2</td>
<td>0.67</td>
<td>0.15</td>
</tr>
<tr>
<td>NAA</td>
<td>0.47</td>
<td>0.27</td>
</tr>
<tr>
<td>MO1</td>
<td>0.46</td>
<td>0.29</td>
</tr>
<tr>
<td>PA</td>
<td>0.36</td>
<td>0.37</td>
</tr>
<tr>
<td>MO4</td>
<td>0.28</td>
<td>0.47</td>
</tr>
<tr>
<td>MO3</td>
<td>0.19</td>
<td>0.57</td>
</tr>
<tr>
<td>MO34</td>
<td>0.15</td>
<td>0.64</td>
</tr>
</tbody>
</table>
Figure 2.8. Yearling Chinook juvenile survival (top) and relative performance (bottom) using the cohort-specific model.

Figure 2.9. Steelhead juvenile survival (top) and relative performance (bottom) using the cohort-specific model.
Figure 2.10. Yearling Chinook Fish Travel Time (FTT, top) and relative performance (bottom) using the cohort-specific model.

Figure 2.11. Steelhead Fish Travel Time (FTT, top) and relative performance (bottom) using the cohort-specific model.
Figure 2.12. Yearling Chinook ocean survival (top) and relative performance (bottom) using the cohort-specific model.

Figure 2.13. Steelhead ocean survival (top) and relative performance (bottom) using the cohort-specific model.
Figure 2.14. Yearling Chinook SARs (top) and relative performance (bottom) using the cohort-specific model. The red dashed line in the upper panel represents the NPCC average SAR goal of 4%.

Figure 2.15. Steelhead SARs (top) and relative performance (bottom) using the cohort-specific model. The red dashed line in the upper panel represents the NPCC average SAR goal of 4%.
Figure 2.16. Wild Yearling Chinook Transport: In-River Ratios (TIRs, top) and relative performance (bottom) using the cohort-specific model. The red dashed line in the upper panel represents a TIR of one.

Figure 2.17. Steelhead Transport: In-River Ratios (TIRs, top) and relative performance (bottom) using the cohort-specific model. The red dashed line in the upper panel represents a TIR of one.
Figure 2.18. Probabilities of SARs less than 1% (top panel) and probabilities of SARs greater than 2% (bottom panel) for yearling spring/summer Chinook salmon (grey bars) and steelhead (blue bars) for each of the alternatives.

Discussion

CSS Life Cycle Analysis of Productivity, Abundance, and SARs

In 2017, the CSS used a life cycle model to compare predictions of in-river smolt survival, smolt to adult return rates (SARs), and long term predicted abundances of returning spawners of six Spring/Summer Chinook populations in the Grande Ronde / Imnaha major population group (MPG) (McCann et al. 2017). The analysis had been statistically validated against demographic and environmental trends, and characterized uncertainty in estimated population demographic rates. The model simulated future trends based on empirically estimated demographic rates and simulated future conditions. Results indicated that spilling to 125% tailrace total dissolved gas (TDG) limits predicts approximately a 2-2.5 fold increase in SARs and return abundances above BiOp spill levels, and up to 4 times higher SARs and return
abundances above BiOp levels if the lower four Snake River dams were breached as well as spilling to 125% TDG limits at the remaining four Middle Columbia River projects.

Analyses of the CRSO-EIS alternatives presented in this Chapter make use of the CSS life cycle model’s underlying structure to simulate predicted population trends when supplied with CRSO-EIS hydrosystem inputs that come from the specified hydrosystem multi-objective operational alternatives (See Methods and Supplemental Materials sections for more detail). The results of the analyses of CRSO-EIS alternatives, and MO34, show the same patterns as the McCann et al. (2017) results. Higher spill levels are predicted to result in higher in-river survival, higher SARs, and higher return abundances. In relative terms, the greatest benefits are seen when the four Lower Snake River dams are breached and the four Middle Columbia River projects spill to 125% TDG levels in the tailrace (i.e., MO34). With or without breach, higher spill levels resulted in higher survivals and abundances.

The insights gained from a comparison of CRSO-EIS scenarios using an 80-year water record are the same as the insights gained from the comparison of McCann et al. (2017) scenarios using three water years to represent low, average, and high flow conditions. In the case of the CRSO-EIS scenarios, a larger number of variable water years increased the range of predictions. However, similar patterns in relative performance were observed, indicating that the relationship between powerhouse passage and survival were not dampened by the year-to-year variation in flows.

**CSS Cohort-Specific Models of Biological Responses**

The results of the CSS cohort-specific models were consistent with the life cycle model results. In addition, the ranked performance of the alternatives was consistent across all of the biological response metrics. The non-federal MO34 alternative demonstrated the greatest expected improvements across all biological response metrics, compared to all of the federal CRSO-EIS alternatives. The non-federal MO34 alternative exceeded the 4% average SAR regional goal. The lower end of the predicted SAR range for MO34 was above 1% for both Chinook and steelhead, indicating that the probability of further population declines would be reduced. Among the federal alternatives, MO3 alternative resulted in the highest SARs and in-river survivals, followed by MO4. These two alternatives, among the federal alternatives, resulted in the highest likelihood of meeting the 4% average SAR regional goal. The lower end of the predicted SAR range for MO3 was also above 1% for both Chinook and steelhead but for MO4, the lower end of the predicted SAR was slightly below 1%, indicating greater risk of further population decline. The other federal alternatives (NAA, MO1, MO2, and the PA) did not meet the regional 4% SAR goal and the lower end of the predicted SAR ranges were well below 1%, indicating greater risk of further population decline under each of these alternatives. For all fish survival metrics, the PA resulted in only slightly better performance than the NAA and MO1, and had lower performance than both MO3 and MO4.
CRSO Actions with Highly Uncertain Benefits and Assumptions

Throughout the CRSO-EIS modeling process, the CSS documented serious concerns over the highly uncertain benefits assumed for two structural modifications that are specified for several of the federal alternatives. The concerns listed below were first brought to the attention of the CRSO-EIS Fish Technical Team in January of 2019 (FPC 2019a).

Powerhouse Surface Passage Structures

The first structural modification of concern is the addition of Powerhouse Surface Passage structures (PSPs) at FCRPS projects and the assumption that these structures will reduce powerhouse passage by 30%. Our review of the literature on similar structures indicates that there is considerable uncertainty surrounding the efficiency of powerhouse surface passage structures. A number of studies have looked at surface passage throughout the FCRPS with substantial variation in the results reported, as well as variability of passage effectiveness in relation to environmental and operational conditions (Adams and Rondorf 2007, McCann et al. 2015, Giorgi et al. 1995, Swan et al. 1997).

Adams and Rondorf (2007) reported an average corner collector efficiency of 30% for yearling Chinook at Bonneville Dam, however, efficiency varied widely between 40% during daytime, and 8% during night time hours. Similarly, steelhead passage through the corner collector ranged from averages of 20-80% as measured in the spring of 2005. However, in addition to diurnal treatments, these estimates also represent a wide range of flows (157.6-279.2 Kcfs) and spill volumes (65.1-105.4 Kcfs), as well as species specific diel behavior. Due to the large variance, and confounding treatments inherent in this study, the uncertainty associated with these estimates must be accounted for in any modeling scenario. Similar findings can be obtained when applying the route specific probability functions developed by McCann et al. (2015) from PIT-tag data at Bonneville Dam. When controlling for variable spill percentage, and river flow, the corner collection efficiency ranges from 6-33% of total fish passage at Powerhouse 2 (Table 2.13). While these data are not directly comparable to the aforementioned acoustic studies, they were derived from PIT-tag data spanning a wider range of flow/spill conditions and longer time series, and simply underscores the fact that modeling scenarios will need to account for changing surface passage probabilities as operational and environmental parameters change.
Table 2.13: Passage route probabilities for the Corner Collector (CC), the Spillway, and the Powerhouse (Turbine + Bypass) at Bonneville Dam as a function of percent spill and total river flow using equations presented in Appendix J of McCann et al. (2015).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>100</td>
<td>22%</td>
<td>0%</td>
<td>78%</td>
<td>22%</td>
</tr>
<tr>
<td>0%</td>
<td>200</td>
<td>12%</td>
<td>0%</td>
<td>88%</td>
<td>12%</td>
</tr>
<tr>
<td>0%</td>
<td>300</td>
<td>6%</td>
<td>0%</td>
<td>95%</td>
<td>6%</td>
</tr>
<tr>
<td>20%</td>
<td>100</td>
<td>22%</td>
<td>6%</td>
<td>72%</td>
<td>23%</td>
</tr>
<tr>
<td>20%</td>
<td>200</td>
<td>12%</td>
<td>7%</td>
<td>81%</td>
<td>13%</td>
</tr>
<tr>
<td>20%</td>
<td>300</td>
<td>6%</td>
<td>7%</td>
<td>86%</td>
<td>7%</td>
</tr>
<tr>
<td>40%</td>
<td>100</td>
<td>22%</td>
<td>35%</td>
<td>44%</td>
<td>33%</td>
</tr>
<tr>
<td>40%</td>
<td>200</td>
<td>12%</td>
<td>36%</td>
<td>52%</td>
<td>19%</td>
</tr>
<tr>
<td>40%</td>
<td>300</td>
<td>6%</td>
<td>38%</td>
<td>56%</td>
<td>10%</td>
</tr>
</tbody>
</table>

Bonneville is also unique among dams in the Columbia River, with three functionally separate routes of passage: Spillway, Powerhouse 1, and Powerhouse 2. It would be risky to assume surface passage will operate similarly at other dams in the Columbia or Snake Rivers with markedly different hydraulic conditions. While few studies have addressed surface passage directly at Snake River projects, Swan et al. (1997) attempted to quantify route specific surface passage probabilities with two modified spill bays at Ice Harbor Dam. This study found 53% of passage occurred in the sluiceway, however, this was spread across eight different treatments encompassing variable flow and spill conditions, confounding treatments between release sites, flow conditions, and diel behaviors. Inferences were based on combined spring and fall Chinook releases representing extremely small sample sizes of detected fish (n=1-28). As these fish were not actively migrating, they represented “fish naïve to riverine conditions, therefore, their behavior may not have been representative of in-river juvenile Chinook salmon.” It is unlikely that this study accurately addressed the natural passage distribution of migrating juvenile salmonids in this system, and any inference should be taken cautiously. Furthermore, we do not believe that all future powerhouse surface passage structures at FCRPS projects will behave analogously to those at Bonneville Dam, making any assumption surrounding their efficiency subject to significant uncertainty.

The literature on surface passage efficiency at FCRPS projects shows that there is a wide range of factors that regulate surface passage structures efficiency. While not all studies on the subject are directly comparable, combined they show the efficiency of surface passage structures is not static by any measure. There is also considerable uncertainty in these estimates based on the limited number of dams studied, and the inherent variability of these estimates. Any modeling scenario should account for this uncertainty in order to adequately evaluate the likelihood of outcomes informing the CRSO decision process. An assumed 30% efficiency for powerhouse surface passage structures is not supportable by the available literature, and would lead to unreliable estimates of CRSO alternatives effects on SARs. Therefore, the CSS used a range of values that reflected both the uncertainty in this estimate, as well as the variability in response to operational and environmental parameters. The results indicated that the PSPs, even
with 30% efficiency, had a very small effect on fish passage metrics and therefore it is unlikely that PSPs will have a meaningful effect on survival metrics (FPC 2019b). Since the predicted benefits were shown to be negligible (FPC 2019b), results on sensitivity to PSPs were excluded for this chapter.

**High-Capacity (i.e., “Fish-Friendly”) Turbines**

The second structural modification of concern is the installation of high-capacity (i.e., “fish friendly”) turbines, which is specified in several of the CRSO-EIS alternatives over a range of FCRPS projects. High-capacity turbines are designed to allow higher maximum flows through turbines and to increase power generation. The Federal Action Agencies’ assumption of increased survival through these high-capacity turbines is not supported by any available studies. Survival estimates of high-capacity turbines are, at best, equal to those of older turbine units (Skalski and Townsend 2005, Deng et al. 2019, Heisey et al. 2019). However, the higher flow through these turbines will cause higher absolute turbine passage, leading to lower overall dam survival and larger impacts of latent mortality.

There are few studies available to test the assumptions of increased turbine survival. In 2005, a comparison of turbine survival was done at Wanapum Dam, comparing one high-capacity turbine to a single turbine of the old design (Skalski and Townsend 2005). Results from this study indicate equal survival between the two turbine types, which does not lend support for the assumption of a significant reduction in mortality with high-capacity turbines. In 2019, sensor and balloon fish were deployed through the new turbine in Unit 2 of Ice Harbor Dam. The reports from these studies have not yet been made available, so a full review of their ability to address assumptions and interpretation of the results is not possible. However, the presentations at AFEP 2019 showed that severe shear or strike events were reduced only in two of four tested flows, and a reduction of 50% was only observed under one tested flow (Deng et al. 2019). Survivals of balloon-tagged fish were not significantly different under any of the tested conditions (Heisey et al. 2019). These studies indicate the increases in survival developed from bead strike studies and physical modelling efforts are overstated.

In “Turbine Improvement Assumptions Final”, the document used to justify increased survivals in CRSO-EIS modelling assumes that 50% fewer fish would experience mortality due to both low pressures and strike/shear. As reviewed above, this number is not based on any biological study, data, or other form of evidence. Any increase in turbine capacity will increase the total number of smolts passing via the powerhouse. powerhouse passage is also associated with delayed mortality, manifesting in the estuary or first year of ocean life (Haeseker et al. 2012, Petrosky and Schaller 2010, Tuomikoski et al. 2010, FPC 2010, FPC 2011a, FPC 2011b, and see Chapter 2). Modifications to the hydrosystem must be thought of in the context of the entire salmonid lifecycle, not just the concrete survival at each project. Even if the direct mortality of high-capacity turbines is shown to be no higher than that of the existing turbines, the increased turbine flow will lead to increase powerhouse passage of the run-at-large. This effect, compounded over multiple dams, will have a net negative impact on the smolt-to-adult returns. It is unclear whether higher powerhouse capacities associated with the installation of high-capacity turbines were incorporated in the Action Agencies’ modeling of the 80-year record. If they were not, the resulting increase in powerhouse passage would not be captured in the modeled datasets and, consequently, would be absent in the CSS modeling results.
**Preferred Alternative Considerations**

From a spill operation standpoint, the CRSO-EIS Preferred Alternative (PA) is the 2020 Flex Spill Agreement. This Flex Spill operation involved hourly changes in spill operations, where higher spill levels are provided for 16 hours and lower “performance spill” levels are provided for 8 hours. Both the higher and lower spill levels are provided during daytime and night time hours. When considering the CSS analyses of the PA, and specifically estimates of PITPH, it is important to recognize that these estimates likely underestimate. The CSS analyses of CRSO-EIS alternatives are based on the 80-year water record datasets generated by the federal agencies. The datasets present the PA in terms of daily average flow and spill, although the PA is implemented on an hourly, not daily average time step. Therefore the PITPH estimates generated on the basis of the federal dataset, does not reflect the higher PITPH that would result from implementing lower performance standard spill during evening and night time hours.

The 80-year water record dataset provided by the federal agencies was calculated on a daily average time step and, therefore, the hourly variation in lower “performance standard” spill is not captured and, as a result, is not captured in the CSS model analyses. This results in an overestimate of the benefits of the PA in the CSS analyses, because documented fish behavior shows that powerhouses are more efficient at catching fish at night than during daytime hours. This means that lower spill at night will increase PITPH. This is important because powerhouse passage (PITPH) is an input metric for CSS model analyses. This means that lower spill periods at night will increase PITPH. PITPH is an input variable for CSS analyses. The following example from analyses of acoustic tag data at John Day Dam (FPC 2020). This analysis demonstrated that PITPH was higher during night time hours than daytime hours, when the same spill and flow levels were provided (Figure 2.19). Using the relationship between spill proportion and powerhouse passage proportion, shown in Figure 2.18, we estimated that PITPH for steelhead would increase from 0.19 to 0.21 when Flex Spill was carried out only at night versus all daytime hours, at flows of 350 Kcfs. The magnitude of this increase may be different at different flows.
Figure 2.19. Powerhouse passage proportions at John Day Dam for yearling Chinook and steelhead as a function of spill proportion, at flows of 350 Kcfs. Figure is adapted from July 31, 2019 memorandum (FPC 2020).

**Literature Cited**


Petrosky CE and HA Schaller. 2010. Influence of river conditions during seaward migration and ocean conditions on survival rates of Snake River Chinook salmon and steelhead. 19:520-536


Supplemental Materials

Detailed Spring Spill Operations under the Different CRSO-EIS Operational Alternatives Modeled by the CSS

Table 2.S1. Spring spill operations at Lower Snake and Middle Columbia River projects under the No Action Alternative (NAA).

<table>
<thead>
<tr>
<th>Site</th>
<th>Spring Spill Operation</th>
<th>(Snake River Projects: April 3-June 20)</th>
<th>(Middle Columbia River Projects: April 10-June 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LGR</td>
<td>20 Kcfs (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LGS</td>
<td>30% (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LMN</td>
<td>115%/120% Gas Cap¹ (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IHR</td>
<td>April 3-28 – 45 Kcfs daytime/115%/120% Gas Cap¹ night time</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>April 28-June 20 – 30% (24-hour) vs. 45 Kcfs daytime/115%/120% Gas Cap¹ night time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MCN</td>
<td>40% (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JDA</td>
<td>April 10-April 28 – 30% (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>April 28-June 15 – 30% (24-hour) vs. 40% (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDA</td>
<td>40% (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BON</td>
<td>100 Kcfs (24-hour)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ Gas Cap spill under the NAA is to the standard of 120% total dissolved gas in the tailrace or 115% TDG in the next downstream forebay.

Table 2.S2. Spring spill operations at Lower Snake and Middle Columbia River projects under Multi-Objective 1 (MO1).

<table>
<thead>
<tr>
<th>Site</th>
<th>Spring Spill Operation</th>
<th>(Snake River Projects: April 3-June 20)</th>
<th>(Middle Columbia River Projects: April 10-June 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base Spill Operation</td>
<td>Test Spill Operation</td>
<td></td>
</tr>
<tr>
<td>LGR</td>
<td>20 Kcfs (24-hour)</td>
<td>115%/120% Gas Cap¹ (24-hour)</td>
<td></td>
</tr>
<tr>
<td>LGS</td>
<td>30% (24-hour)</td>
<td>115%/120% Gas Cap¹ (24-hour)</td>
<td></td>
</tr>
<tr>
<td>LMN</td>
<td>Gas Cap¹ (24-hour)</td>
<td>115%/120% Gas Cap¹ (24-hour)</td>
<td></td>
</tr>
<tr>
<td>IHR</td>
<td>30% (24-hour)</td>
<td>115%/120% Gas Cap¹ (24-hour)</td>
<td></td>
</tr>
<tr>
<td>MCN</td>
<td>48% (24-hour)</td>
<td>115%/120% Gas Cap¹ (24-hour)</td>
<td></td>
</tr>
<tr>
<td>JDA</td>
<td>32% (24-hour)</td>
<td>115%/120% Gas Cap¹ (24-hour)</td>
<td></td>
</tr>
<tr>
<td>TDA</td>
<td>40% (24-hour)</td>
<td>115%/120% Gas Cap¹ (24-hour)</td>
<td></td>
</tr>
<tr>
<td>BON</td>
<td>100 Kcfs (24-hour)</td>
<td>115%/120% Gas Cap¹ (24-hour)</td>
<td></td>
</tr>
</tbody>
</table>

¹ Gas Cap spill under MO1 is to the standard of 120% total dissolved gas in the tailrace or 115% TDG in the next downstream forebay.
Table 2.S3. Spring spill operations at Lower Snake and Middle Columbia River projects under Multi-Objective 2 (MO2).

<table>
<thead>
<tr>
<th>Site</th>
<th>Spring Spill Operation</th>
<th>(Snake River Projects: April 3-June 20)</th>
<th>(Middle Columbia River Projects: April 10-June 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LGR</td>
<td>110% Gas Cap(^1) (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LGS</td>
<td>110% Gas Cap(^1) (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LMN</td>
<td>110% Gas Cap(^1) (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IHR</td>
<td>110% Gas Cap(^1) (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MCN</td>
<td>110% Gas Cap(^1) (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JDA</td>
<td>110% Gas Cap(^1) (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDA</td>
<td>110% Gas Cap(^1) (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BON</td>
<td>110% Gas Cap(^1) (24-hour)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Gas Cap spill under MO2 is to a standard of 110% total dissolved gas.

Table 2.S4. Spring spill operations at Lower Snake and Middle Columbia River projects under Multi-Objective 3 (MO3).

<table>
<thead>
<tr>
<th>Site</th>
<th>Spring Spill Operation</th>
<th>(Snake River Projects: N/A)</th>
<th>(Middle Columbia River Projects: April 10-June 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LGR</td>
<td>N/A (Breach)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LGS</td>
<td>N/A (Breach)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LMN</td>
<td>N/A (Breach)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IHR</td>
<td>N/A (Breach)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MCN</td>
<td>120% Gas Cap(^1) (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JDA</td>
<td>120% Gas Cap(^1) (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDA</td>
<td>120% Gas Cap(^1) (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BON</td>
<td>120% Gas Cap(^1) (24-hour)</td>
<td>(not to exceed 150 Kcfs)</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Gas Cap spill under MO3 is to a standard of 120% total dissolved gas in the tailrace.

Table 2.S5. Spring spill operations at Lower Snake and Middle Columbia River projects under Multi-Objective 4 (MO4).

<table>
<thead>
<tr>
<th>Site</th>
<th>Spring Spill Operation</th>
<th>(Snake River Projects: March 1-June 20)(^1)</th>
<th>(Middle Columbia River Projects: March 1-June 15)(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LGR</td>
<td>125% Gas Cap(^2) (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LGS</td>
<td>125% Gas Cap(^2) (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LMN</td>
<td>125% Gas Cap(^2) (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IHR</td>
<td>125% Gas Cap(^2) (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MCN</td>
<td>125% Gas Cap(^2) (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JDA</td>
<td>125% Gas Cap(^2) (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDA</td>
<td>125% Gas Cap(^2) (24-hour)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BON</td>
<td>125% Gas Cap(^2) (24-hour)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Under MO4, summer spill volumes are the same as spring, which means that the 125% Gas Cap operation continues through August 31\(^{st}\).

\(^2\) Gas Cap spill under MO4 is to a standard of 125% total dissolved gas in the tailrace.
### Table 2.S6. Spring spill operations at Lower Snake and Middle Columbia River projects under the Preferred Alternative (PA).

<table>
<thead>
<tr>
<th>Site</th>
<th>Spring Spill Operation</th>
<th>Performance Standard Spill (8-hours/day)</th>
<th>Gas Cap Spill (16-hours per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LGR</td>
<td></td>
<td>20 Kcfs</td>
<td>125% Gas Cap¹</td>
</tr>
<tr>
<td>LGS</td>
<td></td>
<td>30%</td>
<td>125% Gas Cap¹</td>
</tr>
<tr>
<td>LMN</td>
<td></td>
<td>30 Kcfs</td>
<td>125% Gas Cap¹</td>
</tr>
<tr>
<td>IHR</td>
<td></td>
<td>30%</td>
<td>125% Gas Cap¹</td>
</tr>
<tr>
<td>MCN</td>
<td></td>
<td>48%</td>
<td>125% Gas Cap¹</td>
</tr>
<tr>
<td>JDA</td>
<td></td>
<td>32%</td>
<td>120% Gas Cap²</td>
</tr>
<tr>
<td>TDA</td>
<td></td>
<td>40% (24-hour)</td>
<td></td>
</tr>
<tr>
<td>BON</td>
<td></td>
<td>100 Kcfs</td>
<td>150 Kcfs</td>
</tr>
</tbody>
</table>

¹ Gas Cap spill at LGR, LGS, LMN, IHR, and MCN under the PA is to the standard of 125% total dissolved gas in the tailrace.

² Gas Cap spill at JDA under the PA is to the standard of 120% total dissolved gas in the tailrace.

### Table 2.S7. Spring spill operations at Lower Snake and Middle Columbia River projects under MO34.

<table>
<thead>
<tr>
<th>Site</th>
<th>Spring Spill Operation</th>
<th>Performance Standard Spill (8-hours/day)</th>
<th>Gas Cap Spill (16-hours per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LGR</td>
<td></td>
<td>N/A (Breach)</td>
<td></td>
</tr>
<tr>
<td>LGS</td>
<td></td>
<td>N/A (Breach)</td>
<td></td>
</tr>
<tr>
<td>LMN</td>
<td></td>
<td>N/A (Breach)</td>
<td></td>
</tr>
<tr>
<td>IHR</td>
<td></td>
<td>N/A (Breach)</td>
<td></td>
</tr>
<tr>
<td>MCN</td>
<td></td>
<td>125% Gas Cap¹ (24-hour)</td>
<td></td>
</tr>
<tr>
<td>JDA</td>
<td></td>
<td>125% Gas Cap¹ (24-hour)</td>
<td></td>
</tr>
<tr>
<td>TDA</td>
<td></td>
<td>125% Gas Cap¹ (24-hour)</td>
<td></td>
</tr>
<tr>
<td>BON</td>
<td></td>
<td>125% Gas Cap¹ (24-hour)</td>
<td></td>
</tr>
</tbody>
</table>

¹ Gas Cap spill under MO34 is to a standard of 125% total dissolved gas in the tailrace.