State, Federal and Tribal Fishery Agencies Joint Technical Staff Memorandum

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SUBJECT: Technical Considerations for Adaptive Management to Improve Survival of Listed Columbia and Snake River Salmon and Steelhead during Low Flows in 2015

DATE: May 6, 2015

Based on data and analyses contained in the 2014 Supplemental Biological Opinion (NOAA, 2014) and the 2013 Comprehensive Evaluation (Action Agencies, 2013), the predicted 2015 river migration conditions and ocean conditions (NOAA, 2015) present a significant risk to downstream migrating ESA-listed salmon and steelhead. In addition, drum gate maintenance at Grand Coulee Dam resulted in drafting nearly thirty feet below the April 10th reservoir elevation for 2015 run-off volume conditions, further reducing migration flows. The projected low runoff volume, together with the drafting of Grand Coulee Reservoir, means that Biological Opinion flow objectives at Priest Rapids, Lower Granite, and The Dalles dams will not be met for either the spring or summer migration period.

Juvenile migration conditions are predicted to be worse than have occurred in recent decades, and combined with expectations for poor ocean conditions, the following technical review concludes that there are opportunities available to mitigate the expected adverse impacts on salmon and steelhead and improve juvenile survival and subsequent adult returns. Implementation of additional spill (to the gas cap) at the lower Snake River projects (Lower Granite, Little Goose, Lower Monumental, Ice Harbor), and at McNary Dam provides an opportunity to improve juvenile salmon and steelhead survival and adult returns. Although there are no similar opportunities to improve the predicted poor ocean conditions, maximizing juvenile survival through the hydrosystem will increase the number of fish that reach the ocean and improve their survival to adult return. The available opportunities to improve juvenile salmon and steelhead survival in 2015 also provide a unique opportunity to learn within the construct of adaptive management. The monitoring and data management structures to support adaptive management implementation of the operational opportunities to improve survival (while accounting for ocean conditions) are in place, are operating, and have been identified as important for improving management (ISAB 2014).

Technical Review

The following technical review is based upon the migration conditions that are predicted to occur, and the current body of scientific analyses and data regarding juvenile salmon and steelhead migration conditions relative to survival, subsequent adult returns, and river operations conditions. Present dissolved gas waiver limits were also included. The unique opportunity to gain additional knowledge (about the effects of increased spill levels during low flow conditions) provided by these circumstances was also considered.

1. Juvenile Migration Flows for 2015

Flows throughout the Columbia Basin are expected to be below average throughout the Columbia River Basin during the spring and summer juvenile salmon migration period. Very low flows are expected to occur in the lower Snake River and the middle Columbia River. As of April 12, 2015, the predicted runoff volume at the Lower Granite Dam (LGR) is estimated to be 68% (5-day QPF ESP) of the 30-year average (1981–2010). According to the April 13, 2015, STP Forecast, flows at LGR are expected to average approximately 61.6 Kcfs for the period of April 3 to June 20, 2015 (using actual LGR flows April 3–13 and STP flows April 14–June 20). This average flow level is below the Biological Opinion flow objective of 85 Kcfs for the spring period, and is the 19th lowest flow out of the past 21 years (Table 1). The only lower years in the period were 2007 with a similar average flow of 61.2, and the extreme drought year of 2001.

The runoff volume at McNary Dam (April–July) is predicted to be 79% of average (April 15th 5-day QPF ESP), with an average flow of 177.3 Kcfs predicted during the Biological Opinion flow period using actual McNary flows April 10–13 and April 13, 2015 STP flows April 14–June 30. This average flow is ranked 20th out of the past 21 years (Table 1), with only the drought year of 2001 having a lower flow for the period.

The Upper Columbia flows at Priest Rapids Dam are expected to average 115.6 Kcfs (using April 10–13 actual flows and April 13, 2015, STP flows April 14–June 30). The drafting of Grand Coulee for drum gate maintenance (at or below 1,255 ft.) had a negative impact on upper and middle Columbia River flows. Without the drum gate maintenance draft, Grand Coulee would have been at 1,283.3 feet for Flood Control on April 10th; instead Grand Coulee was at an elevation of 1,253.4 feet on April 10th, 2015—a difference of 2,136 AF. By having to refill an extra 2,136 Kaf this year, flows at Priest Rapids will effectively be reduced in comparison to a situation where Grand Coulee was at its April 10th Flood Control elevation. This additional water would have increased upper and middle Columbia flows at Priest Rapids and McNary Dam by 13.1 Kcfs over the spring flow periods. This additional water would have brought the average flow at Priest Rapids to 129 Kcfs; a level closer to the flow objective of 135 Kcfs. Flows at McNary Dam would have averaged 190 Kcfs, a level closer to the BiOp flow objective of 220 Kcfs, if the drum gate maintenance had not been conducted this year.

Table 1. Average flows for the Biological Opinion flow period at Lower Granite and McNary dams and the rank among the 1995 to present period. Averages in 2015 use actual flows recorded through April 13, 2015, and flows through the remainder of the spring flow periods predicted by the April 13, 2015, STP.

		Rank 21 years		Rank 21 years
	LGR	LGR	MCN	MCN
	Apr3-June 20	Apr3-June 20	apr10-June 30	apr10-June 30
1995	96.5	10	241.8	14
1996	134.3	3	353.7	3
1997	155.9	1	430.1	1
1998	110.8	6	269.1	10
1999	113.7	5	291.2	6
2000	84.1	13	244.9	13
2001	47.5	21	123.9	21
2002	83.4	14	269.3	9
2003	90.0	12	231.4	16
2004	70.1	16	203.2	18
2005	66.3	18	195.7	19
2006	125.3	4	325.4	5
2007	61.2	20	239.6	15
2008	98.7	9	286.7	7
2009	110.3	7	268.1	11
2010	78.1	15	225.7	17
2011	137.8	2	377.4	2
2012	107.9	8	342.4	4
2013	67.9	17	261.9	12
2014	91.8	11	286.3	8
2015	61.6	19	177.3	20

2. Juvenile Transportation

Maximizing juvenile transportation has been the management strategy used during poor migration conditions. In the past the proportion of fish transported in some years was close to 100%. From 1983 until 1994 there was no voluntary spill at Lower Granite and Little Goose Dam, regardless of flow conditions, and from 1995 to 2006 there was no spill during low flow years (low flow was defined as less than 100 Kcfs from 1995 to 1997, less than 85 Kcfs from 1998 to 2004, and less than 70 Kcfs in 2005). Lower Monumental Dam implemented no spill operations in 1993, and then operated the same as the upper Snake dams beginning in 1995. Estimated proportions transported since 1998 are presented in Table 2 (estimates taken from Fish Passage Center Annual Reports 1998–2013). From the table it is apparent that prior to the Court Ordered Spill program in 2006, most juvenile migrants from the Snake River were transported. In the 2001 low flow year an estimated 96%–98% of all fish were transported. Following the 2007 ISAB review, the management strategy emphasized using transportation with spill operations such that risk was spread between the two operations while more information could be collected to understand the role of each alternative in improving migration success.

Table 2. Annual percentages of the Snake River smolt population that were transported from the transportation collector projects. (From 1999 to 2004, the transport percentages were estimated for the combined population of hatchery and wild fish).

	Yearling Chinook		**Steelhead**		**Subyearling Chinook**	
	Wild	**Hatchery**	**Wild**	**Hatchery**	**Wild**	**Hatchery**
1998	66-81	69-77	69-83	72-85	91	
1999	78	86	83		87	
2000	71		81		93	
2001	98		97		96	
2002	68		68		93	
2003	63		67		90	
2004	87		96		97	
2005	92		94		81	
2006	58	61	79	76	56	52
2007	17	24	49	47	36	36
2008	49	49	45	41	46	58
2009	40	36	48	46	45	51
2010	40	24	42	39	49	56
2011	40	42	48	36	42	46
2012	20	20	28	24	41	41
2013	38	37	48	32	61	30

The results from implementation of maximum transportation to mitigate for the effects of hydrosystem operation and development have not been encouraging. The clearest evidence is the ESA listing of all Snake River salmon and steelhead after years of maximizing juvenile transportation. The recent body of scientific data and analyses begins to elucidate the mechanisms contributing to the inability of smolt transportation to adequately mitigate for the development and operation of the hydro system.

The evidence for delayed mortality associated with the collection and transportation of smolts is expanding. Fish that were transported as smolts do not incur the direct mortality that in-river migrants experience while migrating through the hydrosystem. However, the injuries and stresses associated with the collection systems at the transport dam, including the crowding and potential exposure to pathogens in holding raceways and barges, and altered estuary arrival timing (Budy et al. 2002; Van Gaest et al. 2011) all could have an impact on transported fish survival. The existing data suggest that barged fish have additional mortality after release as a result of these factors (Budy et al. 2002; Schaller and Petrosky 2007; Tuomikoski et al. 2011). It has been shown that upon release there is a differential delayed mortality between in-river and barged fish that can reduce the post-hydrosystem survival smolt-to-adult survival rate (SAR) of barged fish, which is often lower than that of in-river migrants, and is sometimes low enough to offset the survival benefit of barging through the hydrosystem (Petrosky and Schaller 2010 and Schaller et al. 2014).

Recent years of life-cycle monitoring data indicates that transportation of smolts results in increased straying and decreased adult upstream migration success. In addition, increasing transportation percentage for Snake River stocks increases the straying rate for the returning adults (Keefer et al., 2008; Keefer and Caudill, 2012 and Tuomikoski, 2011). Snake River steelhead that strayed tended to enter the Deschutes and John Day river basins which have small spawning populations as compared to the returning Snake River hatchery steelhead population. Lastly, as in-river survival increases, the effectiveness of transportation decreases.

Adult return rates of in-river migrant Snake River fall Chinook have been shown to be higher than transported fish when survival from LGR to BON exceeds approximately 0.50 (McCann et al., 2014). Based on analyses presented in McCann et al. (2014) subyearling Chinook, that typically migrate out of the Snake River from late May to mid-July in-river, more often return at a higher rate than transported fish.

There are many years of data and analyses of the results of maximization of smolt transportation. NOAA Fisheries has recognized the limitations of the smolt transportation program to mitigate the effects of the hydrosystem in the 2014 Biological Opinion. According to the 2014 Supplemental Biological Opinion, NOAA Fisheries views recent transport operations as

> "…an ISAB-supported, adaptive management operation. Given annual variations in both the freshwater and marine environments, and the continual annual installation of structures to improve survival rates at the mainstem dams, NOAA Fisheries expects that additional years of data will be needed to better understand how, whether, and to what extent (or during which parts of the migration season) transport or in-river migration strategies are preferable given current dam configurations and relatively stable spill operations."

Prior implementation of maximized juvenile transportation strategies have not resulted in adequate mitigation for the impact of the development and operation of the hydrosystem, particularly in low flow years. The SAR data do not provide promising results to support increasing transportation during low flow years.

3. Spill

The available scientific data and analyses indicate that increasing spill to the gas caps at the Snake River FCRPS projects and McNary Dam is a viable option to reduce the impact of the anticipated low flows and ocean conditions in 2015. The use of spill to the gas caps as a tool to improve juvenile survival has precedence. To assess the effects of spill levels on fish passage characteristics, the available monitoring information regarding the benefits of spill for fish passage through the Columbia and Snake rivers was reviewed. Observations of juvenile fish passage characteristics developed through annual monitoring of downstream passage in the Smolt Monitoring Program and SARs from life-cycle monitoring efforts conducted through the Comparative Survival Study (CSS) were considered. In particular, the observations from monitoring and the results of various analyses regarding the effects of spill for fish passage were considered. The CSS has conducted analyses to evaluate the effects of spill levels on juvenile fish survival. An extensive review of analyses that documented the benefits of increased spill proportions on juvenile survivals and fish travel times was provided by the Fish Passage Center in a memo dated July 14, 2011 (attached). The primary conclusions from this review were:

- Increasing the proportion of spill provided for fish passage at hydroelectric projects has resulted in higher juvenile spring/summer Chinook, fall Chinook, sockeye and steelhead survival and faster juvenile fish travel time through the FCRPS.
- Increasing spill proportion provides mitigation for low flows through the hydrosystem. In observations of years with similar flow and water travel time, juvenile fish survival and fish travel time are improved in years with higher average spill.
- Spill proportion and water travel time (i.e., flow) are correlated with smolt-to-adult return rates. Increasing spill proportion and faster water travel time (i.e., higher flow) result in higher smolt-to-adult return rate.
- Fresh water passage conditions affect early ocean survival. Spill proportion and water travel time affect ocean survival of Chinook and steelhead.
- Increasing spill proportion allows a higher proportion of downstream migrants to avoid power house passage. Powerhouse passage through juvenile bypass systems decreases smolt-to-adult return rates. Direct estimates of project survival do not capture the delayed mortality effect of project passage and therefore underestimate project impact on juvenile survival and adult return.
- Model simulations indicate that juvenile survival could be significantly increased and juvenile fish travel time could be decreased by increasing spill proportion in low flow periods.

More recent analyses (Schaller et al., 2014) indicated that a high percentage (76%) of Snake River juvenile salmon that survived the FCRPS subsequently died in the marine environment as a result of their outmigration experience. Through this and previous studies, it is evident that delayed hydrosystem mortality increases with the number of powerhouse passages and decreases with the speed of outmigration. Therefore, a promising conservation approach would be to explore management experiments that evaluate these relationships by increasing managed spill levels at the dams during the spring migration period.

4. Model Simulations for 2015

The CSS survival and fish travel time models were used to estimate juvenile survivals (LGR-to-MCN) and fish travel times of in-river migrating salmonids under three spill scenarios in 2015. These spill scenarios were: (1) spill under the 2015 Fish Operations Plan (FOP), (2) spill under the 2015 FOP at McNary and spill to current 115%/120% TDG constraints at Snake River Projects (here-in referred to as GC), and (3) spill under the current 115%/120% TDG constraints at all Snake River projects and McNary (here-in referred to as GC+MCN).

a) Modeling Spill

To assess the three spill scenarios, daily average spill proportions at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, and McNary were modeled for each scenario. All three scenarios relied on actual daily average flows from April 1 to April 12, 2015, and the predicted daily average flows from the April 13, 2015, STP model run through July 31, 2015. Table 3 is provided below to illustrate the different spill volumes that were used under the three scenarios. Spill caps for all three scenarios were assumed from the April 1, 2015, Spill Priority List at the 115%/125% TDG levels (http://www.nwd-wc.usace.army.mil/tmt/documents/ops/spill/priority/Spill-Priority-List_2015_0401.pdf). At low flows, many of the spill volumes in Table 2 are not possible due to powerhouse minimum requirements. Modeled spill proportions for both scenarios accounted for powerhouse minimums at each project, which were assumed to be 12.0 Kcfs at LGR and LMN, 11.5 Kcfs at LGS, 10.5 Kcfs at IHR, and 55 Kcfs at MCN.

Table 3. Spill levels and powerhouse minimum flows used for modeling daily spill proportions under the 2015 FOP, FOP/Spill to Gas Cap, and GC+MCN scenarios at Snake River projects and McNary Dam.

Project	2015 FOP	
	Spring[A]	**Summer[B]**
LGR	20 Kcfs/20 Kcfs	18 Kcfs/18 Kcfs
LGS	30%/30%	30%/30%
LMN[C]	28 Kcfs/28 Kcfs	17 Kcfs/17 Kcfs
IHR[D]	45 Kcfs/95 Kcfs and 30%/30%	45 Kcfs/95 Kcfs and 30%/30%
MCN	40%/40%	50%/50%
	GC	
LGR	41 Kcfs/41 Kcfs	41 Kcfs/41 Kcfs
LGS	40 Kcfs/40 Kcfs	40 Kcfs/40 Kcfs
LMN[C]	36 Kcfs/36 Kcfs	36 Kcfs/36 Kcfs
IHR[D]	75 Kcfs/95 Kcfs	75 Kcfs/95 Kcfs
MCN	40%/40%	50%/50%
	GC+MCN	
LGR	41 Kcfs/41 Kcfs	41 Kcfs/41 Kcfs
LGS	40 Kcfs/40 Kcfs	40 Kcfs/40 Kcfs
LMN[C]	36 Kcfs/36 Kcfs	36 Kcfs/36 Kcfs
IHR[D]	75 Kcfs/95 Kcfs	75 Kcfs/95 Kcfs
MCN	146 Kcfs/146 Kcfs	146 Kcfs/146 Kcfs

[A] Snake River sites (April 3-June 20), McNary (April 10-June 15)

[B] Snake River sites (June 21-July 31), McNary (June 16-July 31)

[C] 2015 FOP assumed Gas Cap under Bulk spill pattern (28 Kcfs). GC+MCN assumed Gas Cap under the Uniform pattern (36 Kcfs).

[D] 2015 FOP scenario assumed modified spill schedule from April 8, 2015 FPOM meeting.

A summary of the results from the spill modeling exercises are presented below in Table 4. The estimated daily average flow and spill proportions from this modeling were then used to generate flow and spill variables for input into the CSS survival and fish travel time models. For each fish species (hatchery yearling Chinook, wild yearling Chinook, steelhead, sockeye and subyearling hatchery Chinook) fish travel times were developed for simulated cohorts that matched the seasonal cohorts for those species in Chapter 3 of the CSS report. Simulated travel times were generated for each species and cohort using the average fish travel times from cohorts from the recent low flow years of 2001, 2005, 2007 and 2010. Once fish travel times were assembled for the simulated 2015 migration year, the spill modeled data were assigned to each cohort using the methods described in Chapter 3 of McCann et al., (2014). In their analysis, McCann et al. (2014) use those average fish travel times generated from low flow years, to assigned flow and spill data to each cohort. Temperature data for each cohort for each species were assigned based on the average river temperature for those same cohorts from the years 2001, 2005, 2007 and 2010. The same temperature data was used for all the spill model scenarios. For each species and cohort, the inputs of fish travel time, flow, and temperature were the same for each modeled spill scenario. Only spill volumes (and consequently) spill proportions changed between scenarios. Spill inputs for each of the species and model scenarios can be found in Appendix A.

Table 4. Seasonal average spill proportions from modeling of spill under the 2015 FOP, GC, and GC+MCN scenarios at Snake River projects and McNary Dam. Ranges in daily spill proportions are provided in parentheses)

Project	**2015 FOP**	
	Spring	**Summer**
LGR	0.34 (0.24-0.48)	0.50 (0.42-0.60)
LGS	0.30 (0.30-0.30)	0.30 (0.30-0.30)
LMN	0.47 (0.34-0.69)	0.49 (0.42-0.58)
IHR	0.61 (0.30-0.81)	0.49 (0.30-0.71)
MCN	0.40 (0.40-0.40)	0.50 (0.50-0.50)
	GC	
LGR	0.65 (0.50-0.77)	0.53 (0.42-0.70)
LGS	0.64 (0.49-0.78)	0.55 (0.45-0.71)
LMN	0.59 (0.44-0.74)	0.53 (0.42-0.70)
IHR	0.82 (0.74-0.87)	0.59 (0.50-0.74)
MCN	0.40 (0.40-0.40)	0.50 (0.50-0.50)
	GC+MCN	
LGR	0.65 (0.50-0.77)	0.53 (0.42-0.70)
LGS	0.64 (0.49-0.78)	0.55 (0.45-0.71)
LMN	0.59 (0.44-0.74)	0.53 (0.42-0.70)
IHR	0.82 (0.74-0.87)	0.59 (0.50-0.74)
MCN	0.69 (0.65-0.72)	0.64 (0.57-0.68)

b) Results from CSS Survival and Fish Travel Time Model Simulations

McCann et al. (2014) conducted and presented analyses on the effects of several environmental and management factors on juvenile survival, fish travel time, and instantaneous mortality rates of yearling Chinook salmon, steelhead, sockeye, and subyearling Chinook salmon. These models were shown to accurately capture the juvenile responses to changes in those environmental and management factors. Because these models were effective in explaining the juvenile responses to historical variability in environmental and management factors, they serve as a useful tool for forecasting the expected responses to various future management options, such as changes in spill volumes. Although some factors are largely beyond management control (e.g., low snowpack, which reduces runoff volumes), spill volumes can be managed to improve juvenile fish passage, particularly during years with low runoff volumes while still remaining below total dissolved gas limits (Hall and Marmorek 2013).

To evaluate expected juvenile responses to spill management options, we applied the models developed by McCann et al. (2014) to three spill management scenarios using current projections of low runoff volume (i.e., FOP, GC, and GC+MCN). Across all three scenarios, current runoff volume and timing projections were used to calculate water transit times. Water temperatures were estimated using historical average water temperatures during low runoff years (i.e., 2001, 2005, 2007, 2010).

The models developed by McCann et al. (2014) utilize temporally defined cohorts for calculating survival, fish travel time, and instantaneous mortality rates. These models capture how juvenile responses vary over the migration season in addition to the environmental and management factors that are experienced during the outmigration. We defined temporal cohorts identical to McCann et al. (2014) and calculated the water transit time (Figure 1), average spill levels (Figure 2), number of dams with surface passage structures, and water temperatures for each cohort within each of the three spill management scenarios considered. Because of the later migration timing of subyearling (fall) Chinook salmon and the lower flows expected to occur during their migration, the projected water transit times for subyearling Chinook salmon are nearly double those of other species (Figure 1). Application of the McCann et al. (2014) models to the environmental and management factor data resulted in predictions of the fish travel times (Figure 3), instantaneous mortality rates (Figure 4), and survival probabilities (Figure 5). For simplicity, the average juvenile survival, travel time, and mortality rate across cohorts are reported.

Results showed that fish travel times were predicted to be fastest under the GC+MCN spill management scenario, followed by the GC and FOP spill management scenarios (Figure 3). This result was consistent across all species. The GC+MCN spill management scenario was predicted to reduce fish travel times by 1.4 (SOX-HW) to 2.3 (CH0-H) days relative to the FOP spill management scenario. The GC spill management scenario was predicted to reduce fish travel times by 0.7 (STH-HW) to 1.9 (CH0-H) days relative to the FOP spill management scenario.

For all species except hatchery and wild steelhead, the average instantaneous mortality rates were predicted to remain relatively similar across spill management scenarios (Figure 4). However, the average instantaneous mortality rates for hatchery and wild steelhead were predicted to decline for both the GC and the GC+MCN spill management scenarios relative to the FOP spill management scenario. Instantaneous mortality rates approximate the daily fraction of the population that dies per day (see McCann et al. 2014 for details).

For all species, survival probabilities were predicted to be highest under the GC+MCN spill management scenario, followed by the GC and FOP spill management scenarios (Figure 5). The GC+MCN spill management scenario was predicted to increase survival probabilities by 2.9% (CH0-H) to 9.3% (STH-HW) relative to the FOP spill management scenario. The GC spill management scenario was predicted to increase survival probabilities by 2.1% (CH1-W) to 6.6% (STH-HW) relative to the FOP spill management scenario. The large improvements in predicted survival were the result of both faster travel times and lower instantaneous mortality rates under the GC+MCN and GC spill management scenarios relative to the FOP spill management scenario.

Under recent configuration of the hydropower system, spill management decisions have been shown to partially mitigate the detrimental effects of low runoff volumes. McCann et al. (2014) provides data on 2 years (2004 and 2013) that had low runoff volumes similar to those expected this year, but with very different spill management decisions (Table 1). In 2004, voluntary spill was eliminated at Lower Granite, Little Goose, and Lower Monumental dams but did occur at Ice Harbor and McNary dams, resulting in 32% average spill across the dams. However, voluntary spill was provided at all of those projects in 2013, resulting in 43% average spill across the dams. In addition, each of the dams were equipped with surface passage structures, which have shown some benefit in terms of reducing powerhouse passage for steelhead (Hall and

Marmorek 2013). Despite similar water transit times in 2004 and 2013, the increased levels of spill in 2013 resulted in improved fish travel time and increased survival relative to 2004 (Table 1). In 2015, water transit times are projected to be near those levels observed in 2004 and 2013, and there are few management options available to increase water volumes. However, spill management options are available to hydrosystem operators, and analyses indicate that these options can improve juvenile fish passage despite the expected detrimental effects of low runoff volumes (Figures 2–5, Table 5).

Table 5. Summaries of average water transit time (WTT), percent spill, fish travel time (FTT), and survival for hatchery and wild steelhead during 2004 and 2013, along with projected WTT (bold) and the range of percent spill, FTT, and survival that may occur in 2015 (grey shaded cells).

Year	WTT (d)	Spill	FTT (d)	Survival
2004	11.4	32%	12.2	42%
2013	11.4	43%	7.6	63%
2015	**12.7**	42% - 66%	9.2 - 8.1	66% - 75%

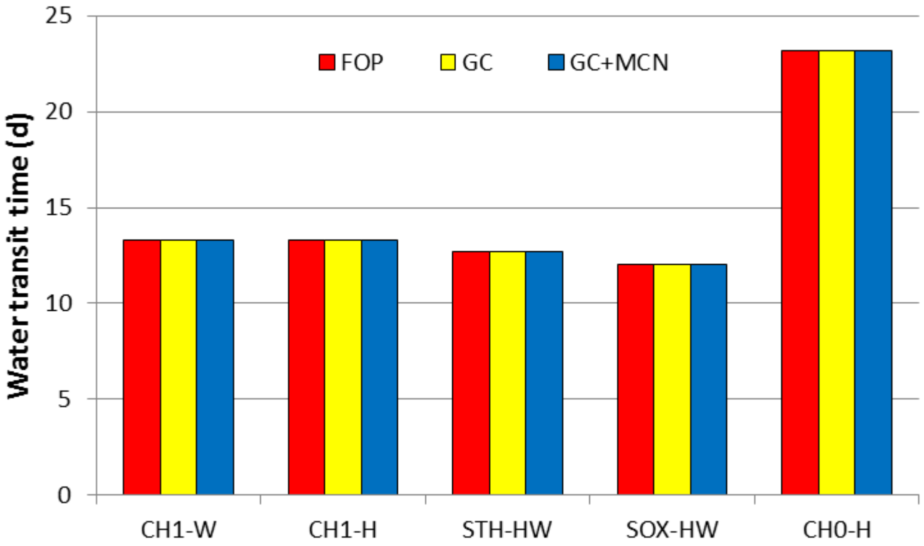

Figure 1. Water transit times from Lower Granite Dam to McNary Dam used in models for hatchery yearling Chinook salmon (CH1-H), wild yearling Chinook salmon (CH1-W), hatchery and wild steelhead (STH-HW), hatchery and wild sockeye salmon (SOX-HW), and hatchery subyearling (fall) Chinook salmon (CH0-H). The FOP, GC, and GC+MCN scenarios are represented by red, yellow, and blue bars, respectively.

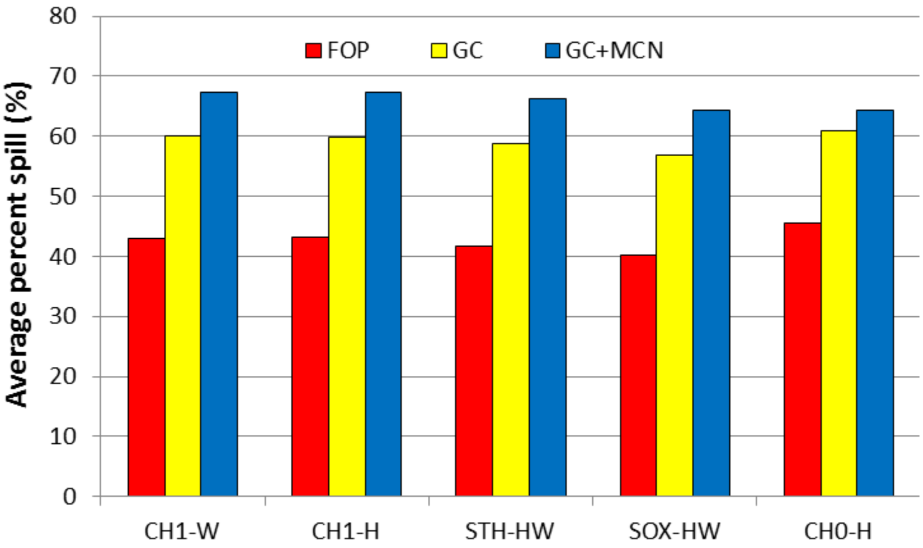

Figure 2. Average percent spill across Little Goose, Lower Monumental, Ice Harbor, and McNary dams for each species and spill management scenario. See Figure 1 caption for a description of the species abbreviations.

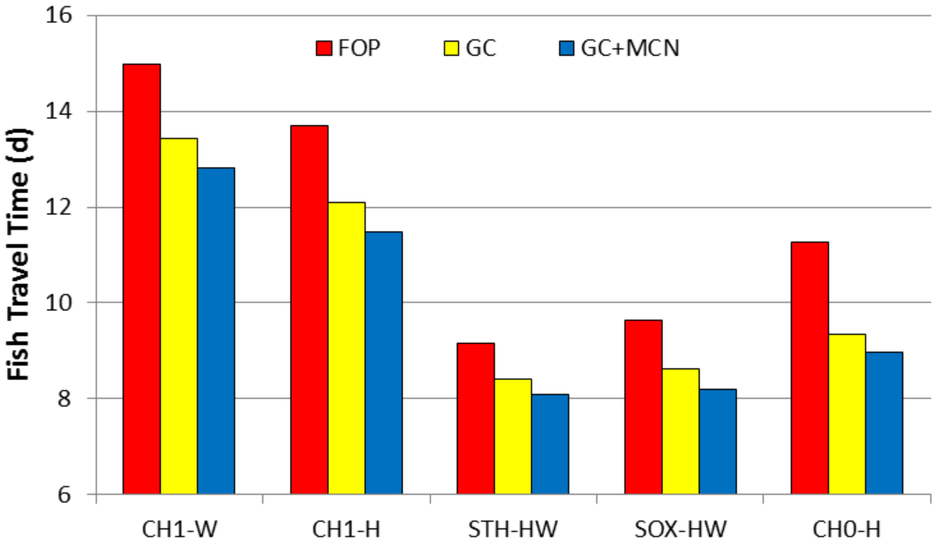

Figure 3. Predicted average fish travel times from Lower Granite Dam to McNary Dam for each species and spill management scenario. See Figure 1 caption for a description of the species abbreviations.

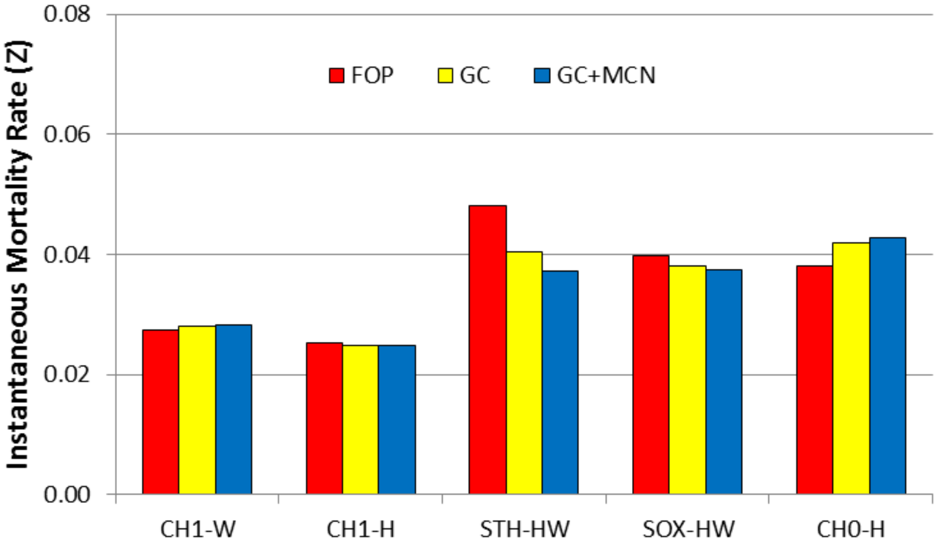

Figure 4. Predicted average instantaneous mortality rates from Lower Granite Dam to McNary Dam for each species and spill management scenario. See Figure 1 caption for a description of the species abbreviations.

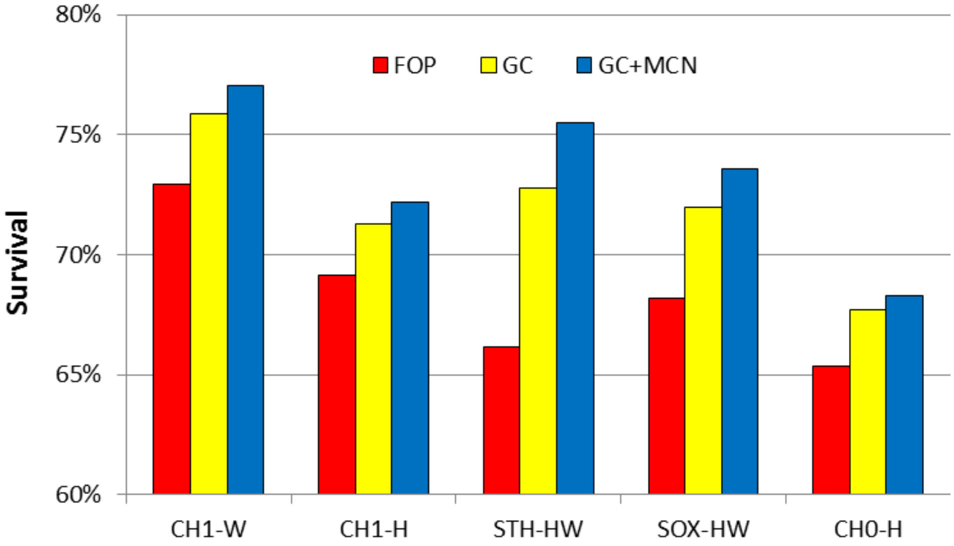

Figure 5. Predicted average survival probability from Lower Granite Dam to McNary Dam for each species and spill management scenario. See Figure 1 caption for a description of the species abbreviations.

c) *Results from CSS Smolt-to-Adult Survival Model Simulations*

To evaluate the effects of spill management options on SARs, we utilized the SAR models that were developed for the 2013 Comparative Survival Study Workshop (Hall and Marmorek 2013). These models account for the effects of release timing (Julian day), water transit time, spill proportions, surface passage structures, and variable ocean conditions as indexed by the Pacific Decadal Oscillation (PDO) to explain patterns of variation in SARs. To forecast the expected

SARs for the 2015 outmigration, we applied these models using projections of the low flow volumes that are expected in 2015, along with a range of spill management options that could be implemented in 2015. We used the most recent projections of flow volumes to project water transit times in 2015 for each of the four release cohorts, along with the project-specific spill proportions at each project under the Fish Operations Plan (FOP) scenario, a Gas Cap (GC) scenario, and a Gas Cap with McNary Dam (GC+MCN) scenario. Recent estimates (Figure 6) of the PDO have indicated that water temperatures in the northeastern Pacific Ocean are in a warm phase, which has been associated with low survival for Columbia Basin salmonids (Haeseker et al. 2012, Schaller et al. 2014). To account for expected ocean conditions in 2015, we identified ten, historical, analog years that had similar March PDO values as the month of March 2015. These ten analog years were used to represent the range of ocean conditions that may be experienced by 2015 outmigrants and the SARs that may result for each of the three spill management options.

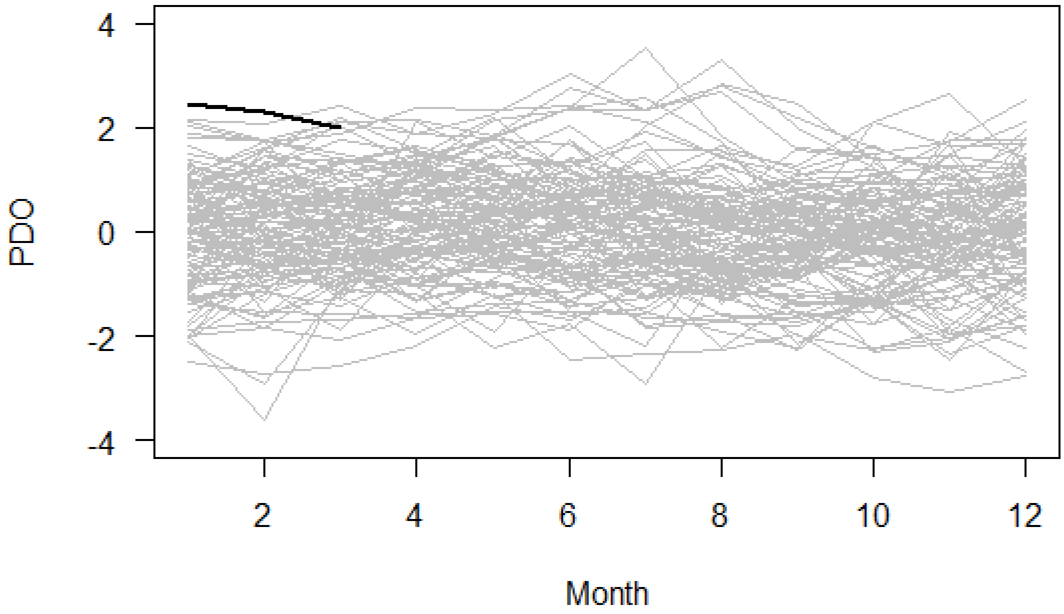

Figure 6. Monthly estimates of the Pacific Decadal Oscillation (PDO) 1900–2014 (grey lines) and January–March monthly estimates for 2015 (black line). Data were downloaded from [http://research.jisao.washington.edu/pdo/PDO. latest on April 30](http://research.jisao.washington.edu/pdo/PDO.latest), 2015.

Because of expected warm-phase PDO conditions, projected SARs are expected to be low for both yearling Chinook salmon and steelhead (Figure 7, Table 6). However, the GC+MCN spill scenario is projected to have the highest SARs for both yearling Chinook salmon and steelhead. For steelhead, mean SARs are projected to be 0.76%, 0.95%, and 1.03% under the FOP, GC, and GC+MCN scenarios, respectively. Relative to the mean SAR under the FOP, the GC scenario represents a 25% improvement and the GC+MCN scenario represents a 36% improvement in the mean SAR for steelhead. For yearling Chinook salmon, mean SARs are projected to be 0.32%, 0.40%, and 0.48% under the FOP, GC, and GC+MCN scenarios, respectively. Relative to the mean SAR under the FOP, the GC scenario represents a 25% improvement and the GC+MCN represents a 50% improvement in the mean SAR for Chinook salmon. McCann et al. (2014)

presented analyses that showed SARs less than 1% are associated with productivity levels below replacement for spring Chinook salmon populations, therefore SARs less than 1% are useful as a measure of conservation risk. To evaluate the risk of SARs less than 1%, we quantified the proportion of the simulations where projected SARs were less than 1% for both species. For yearling Chinook salmon, 100% of the simulated SARs were less than 1% under the FOP and GC scenarios, compared to 90% for the GC+MCN scenario (Table 6). For steelhead, the proportion of SARs less than 1% was 75% under the FOP scenario, 62% under the GC scenario, and 57% under the GC+MCN scenario. For both species, the risk of SARs less than 1% was lowest under the GC+MCN spill management scenario, indicating that the GC+MCN spill management option is most likely to minimize conservation and productivity risk to Chinook salmon and steelhead in this year of expected poor ocean conditions.

Table 6. Mean SARs and proportion of SARs less than 1% for the FOP, GC, and GC+MCN spill management scenarios for Chinook salmon and steelhead.

Species	Metric	FOP	GC	GC+MCN
Chinook Salmon	Mean SAR	0.32%	0.40%	0.48%
Chinook Salmon	SAR < 1%	100%	100%	90%
Steelhead	Mean SAR	0.76%	0.95%	1.03%
Steelhead	SAR < 1%	75%	62%	57%

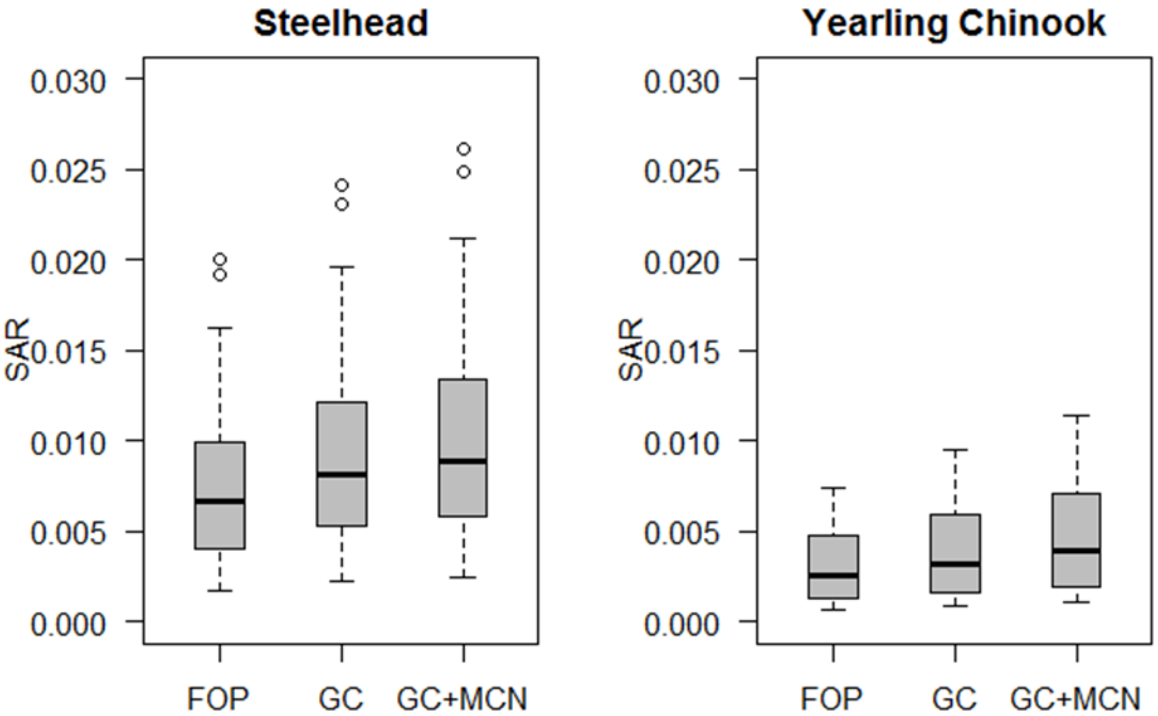

Figure 7. Boxplots of simulated SARs under the FOP, GC, and GC+MCN spill management options for steelhead and yearling Chinook salmon. Simulations represent range of analogous years of warm-phase PDO conditions that may occur this year.

5. Adult fallback and adult passage concerns

Adult fallback and adult passage at hydroelectric projects is a function of several variables including, but not limited to: project unit priority operations, ladder criteria, temperature blockages, TSW or RSW operations, spill patterns, and possibly spill volumes. It is likely that the relation between adult passage and spill volumes will be raised as an issue of concern when increasing spill volumes. In the summer of 2005 the first court-ordered spill at dams in the FCRPS was implemented. Coincident with that implementation, adult passage was impeded at Little Goose Dam. Subsequently, spill volumes were decreased, and the implementation of spill operations since that time has been limited to spilling no more than 30% of river flow. This operation has been reviewed by the Fish Passage Center in several memorandums dated July 7, 2005, July 26, 2006, November 6, 2009, and December 9, 2011. All of these memorandums suggest that there is no relation between spill and a reduction in the adult conversion rate through the Snake River, past Little Goose Dam. For example, during 2011 daily spill proportions ranged as high as 97% of river flow and analyses conducted found no evidence of impacts on conversion rates, with regard to LGS spill operations. Conversion rates for PIT-tagged adult Chinook remained high throughout the entire voluntary spill season (Apr. 3 to Aug. 31), even when LGS spill percent was high.

Given these reviews conducted on data collected since 2005, it is unlikely that the increased spill proportions for improvements in juvenile survival and SARs considered here would impact adult river passage and conversion rates. However, it is important to note that there is a real-time monitoring program in place, and that this adaptive spill management alternative would be a “**voluntary**” operation that, if implemented, could be changed in response to real-time monitoring information.

6. Adaptive Management

The region has emphasized the importance of using current available science when developing adaptive management approaches aimed at improving juvenile migration conditions, and that adding to the current state of knowledge should be emphasized when there is a need to implement new adaptive management approaches. To date, dry year management has occurred using a maximum transport strategy and a mix of transport with spill. The results of both have demonstrated that higher proportional spill equalizes the observed difference between strategies such that benefits are less apparent. Given both strategies do not differ greatly, an adaptive change during this dry water year may provide additional information that yields a management approach that better demonstrates results of implementing higher proportional spill to improve juvenile migration success. More recently, regional groups identified that maximizing juvenile transport management was not achieving a desired result, and thus adapted to implement a mix of transport with spill while learning (ISAB 2008). Given that these past assessments of transport management have not resulted in statistically significant improvements during dry water years, identifying and monitoring an adaptive spill management approach may be a viable next step in understanding the efficacy of improving juvenile migration success during poor migration conditions. The option of voluntarily increasing spill proportions for fish passage to current total dissolved gas constraints has not been implemented in these conditions. A new alternative strategy using higher voluntary proportional spill volumes, a condition to date that has only occurred during opportunistic or involuntary operational conditions, has yet to be empirically tested under a controlled study design. To conclude, implementing a new approach under current dry water year conditions fits the conceptual framework defined for adaptive management. Given the current state of the science, a change seems justifiable, and if implemented may provide the information needed to support a regionally accepted strategy that achieves a consistent and effective juvenile migration success and achieves regional SAR goals.

cc: Ritchie Graves, NOAA National Marine Fisheries Service

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Appendix A
Model Spill Percentage Inputs for Three Spill Scenarios

Table A1. Average Spill Percentages under the 2015 FOP spill scenario assigned to hatchery yearling Chinook cohorts.

		Average Spill Percentage Assigned to Cohorts				
Species	**LGR dates**	**All Dams**	**LGS**	**LMN**	**IHR**	**MCN**
ch1h	4/1 to 4/7	45.6	30	47.6	64.8	40
ch1h	4/8 to 4/14	46.875	30	47.3	70.2	40
ch1h	4/15 to 4/21	46.925	30	47.5	70.2	40
ch1h	4/22 to 4/28	48.05	30	45.9	76.3	40
ch1h	4/29 to 5/5	39.975	30	40.3	49.6	40
ch1h	5/6 to 5/12	40.275	30	36.8	54.3	40
ch1h	5/13 to 5/19	36.7	30	34.5	42.3	40
ch1h	5/20 to 5/26	40.75	30	35.3	57.7	40

Table A2. Average Spill Percentages under the FOP/Spill to the Gas Cap spill scenario assigned to hatchery yearling Chinook cohorts.

		Average Spill Percentage Assigned to Cohorts				
Species	**LGR dates**	**All Dams**	**LGS**	**LMN**	**IHR**	**MCN**
ch1h	4/1 to 4/7	63.5	70.6	61.2	82.2	40
ch1h	4/8 to 4/14	62.725	67.7	60.8	82.4	40
ch1h	4/15 to 4/21	62.9	68.1	61.1	82.4	40
ch1h	4/22 to 4/28	62.675	68.3	59.0	83.4	40
ch1h	4/29 to 5/5	59.8	62.3	51.8	85.1	40
ch1h	5/6 to 5/12	57.425	55.9	47.4	86.4	40
ch1h	5/13 to 5/19	55.25	49.6	44.3	87.1	40
ch1h	5/20 to 5/26	55.325	49.7	45.4	86.2	40

Table A3. Average Spill Percentages under the Spill to the Gas Cap spill scenario assigned to hatchery yearling Chinook cohorts.

		Average Spill Percentage Assigned to Cohorts				
Species	**LGR dates**	**All Dams**	**LGS**	**LMN**	**IHR**	**MCN**
ch1h	4/1 to 4/7	70.275	70.6	61.2	82.2	67.1
ch1h	4/8 to 4/14	69.625	67.7	60.8	82.4	67.6
ch1h	4/15 to 4/21	69.75	68.1	61.1	82.4	67.4
ch1h	4/22 to 4/28	69.75	68.3	59.0	83.4	68.3
ch1h	4/29 to 5/5	67.55	62.3	51.8	85.1	71.0
ch1h	5/6 to 5/12	65.225	55.9	47.4	86.4	71.2
ch1h	5/13 to 5/19	62.875	49.6	44.3	87.1	70.5
ch1h	5/20 to 5/26	63.175	49.7	45.4	86.2	71.4

Table A4. Average Spill Percentages under the 2015 FOP spill scenario assigned to wild yearling Chinook cohorts.

		Average Spill Percentage Assigned to Cohorts				
Species	**LGR dates**	**All Dams**	**LGS**	**LMN**	**IHR**	**MCN**
ch1w	4/1 to 4/7	45.55	30	47.3	64.9	40
ch1w	4/8 to 4/14	46.925	30	47.5	70.2	40
ch1w	4/15 to 4/21	45.575	30	47.6	64.7	40
ch1w	4/22 to 4/28	48.05	30	45.9	76.3	40
ch1w	4/29 to 5/5	40.15	30	41.0	49.6	40
ch1w	5/6 to 5/12	40.475	30	37.6	54.3	40
ch1w	5/13 to 5/19	36.35	30	34.4	41.0	40
ch1w	5/20 to 5/26	41.425	30	36.0	59.7	40

Table A5. Average Spill Percentages under FOP/Spill to the Gas Cap spill scenario assigned to wild yearling Chinook cohorts.

		Average Spill Percentage Assigned to Cohorts				
Species	**LGR dates**	**All Dams**	**LGS**	**LMN**	**IHR**	**MCN**
ch1w	4/1 to 4/7	63.4	70.6	60.8	82.2	40
ch1w	4/8 to 4/14	62.9	68.1	61.1	82.4	40
ch1w	4/15 to 4/21	62.825	67.8	61.2	82.3	40
ch1w	4/22 to 4/28	62.675	68.3	59.0	83.4	40
ch1w	4/29 to 5/5	60.375	63.7	52.7	85.1	40
ch1w	5/6 to 5/12	57.65	55.9	48.3	86.4	40
ch1w	5/13 to 5/19	55.225	49.6	44.2	87.1	40
ch1w	5/20 to 5/26	55.45	49.7	46.3	85.8	40

Table A6. Average Spill Percentages under the Spill to the Gas Cap spill scenario assigned to wild yearling Chinook cohorts.

		Average Spill Percentage Assigned to Cohorts				
Species	**LGR dates**	**All Dams**	**LGS**	**LMN**	**IHR**	**MCN**
ch1w	4/1 to 4/7	70.175	70.6	60.8	82.2	67.1
ch1w	4/8 to 4/14	69.725	68.1	61.1	82.4	67.3
ch1w	4/15 to 4/21	69.675	67.8	61.2	82.3	67.4
ch1w	4/22 to 4/28	69.825	68.3	59.0	83.4	68.6
ch1w	4/29 to 5/5	68.125	63.7	52.7	85.1	71.0
ch1w	5/6 to 5/12	65.45	55.9	48.3	86.4	71.2
ch1w	5/13 to 5/19	62.85	49.6	44.2	87.1	70.5
ch1w	5/20 to 5/26	63.25	49.7	46.3	85.8	71.2

Table A7. Average Spill Percentages under the 2015 FOP spill scenario assigned to hatchery and wild steelhead cohorts.

		Average Spill Percentage Assigned to Cohorts				
Species	**LGR dates**	**All Dams**	**LGS**	**LMN**	**IHR**	**MCN**
sthw	4/17 to 4/23	48.525	30	47.3	76.8	40
sthw	4/24 to 4/30	46.4	30	45.2	70.4	40
sthw	5/1 to 5/7	39.425	30	39.7	48.0	40
sthw	5/8 to 5/14	39.7	30	36.2	52.6	40
sthw	5/15 to 5/21	37.375	30	34.3	45.2	40
sthw	5/22 to 5/28	39.2	30	36.9	49.9	40

Table A8. Average Spill Percentages under the FOP/Spill to the Gas Cap spill scenario assigned to hatchery and wild steelhead cohorts.

		Average Spill Percentage Assigned to Cohorts				
Species	**LGR dates**	**All Dams**	**LGS**	**LMN**	**IHR**	**MCN**
sthw	4/17 to 4/23	62.8	67.8	60.8	82.6	40
sthw	4/24 to 4/30	62.45	68.0	58.1	83.7	40
sthw	5/1 to 5/7	59.35	60.9	51.1	85.4	40
sthw	5/8 to 5/14	57.025	54.9	46.5	86.7	40
sthw	5/15 to 5/21	55.15	49.4	44.1	87.1	40
sthw	5/22 to 5/28	55.575	50.0	47.4	84.9	40

Table A9. Average Spill Percentages under the Spill to the Gas Cap spill scenario assigned to hatchery and wild steelhead cohorts.

		Average Spill Percentage Assigned to Cohorts				
Species	**LGR dates**	**All Dams**	**LGS**	**LMN**	**IHR**	**MCN**
sthw	4/17 to 4/23	69.75	67.8	60.8	82.6	67.8
sthw	4/24 to 4/30	69.675	68.0	58.1	83.7	68.9
sthw	5/1 to 5/7	67.175	60.9	51.1	85.4	71.3
sthw	5/8 to 5/14	64.75	54.9	46.5	86.7	70.9
sthw	5/15 to 5/21	62.8	49.4	44.1	87.1	70.6
sthw	5/22 to 5/28	63.175	50.0	47.4	84.9	70.4

Table A10. Average Spill Percentages under the 2015 FOP spill scenario assigned to hatchery and wild sockeye cohorts.

		Average Spill Percentage Assigned to Cohorts				
Species	**LGR dates**	**All Dams**	**LGS**	**LMN**	**IHR**	**MCN**
sohw	5/8 to 6/4	40.3	30	37.7	53.5	40

Table A11. Average Spill Percentages under the FOP/Spill to the Gas Cap spill scenario assigned to hatchery and wild sockeye cohorts.

		Average Spill Percentage Assigned to Cohorts				
Species	**LGR dates**	**All Dams**	**LGS**	**LMN**	**IHR**	**MCN**
sohw	5/8 to 6/4	56.825	53.2	48.5	85.6	40

Table A12. Average Spill Percentages under the Spill to the Gas Cap spill scenario assigned to hatchery and wild sockeye cohorts.

		Average Spill Percentage Assigned to Cohorts				
Species	**LGR dates**	**All Dams**	**LGS**	**LMN**	**IHR**	**MCN**
sohw	5/8 to 6/4	64.4	53.2	48.5	85.6	70.3

Table A13. Average Spill Percentages under the 2015 FOP spill scenario assigned to hatchery subyearling fall Chinook cohorts.

		Average Spill Percentage Assigned to Cohorts				
Species	**LGR dates**	**All Dams**	**LGS**	**LMN**	**IHR**	**MCN**
choh	5/20 to 6/2	46.1	30	54.1	50.3	50
choh	6/3 to 6/16	46.425	30	53.9	51.8	50
choh	6/17 to 6/30	45.075	30	54.4	45.9	50
choh	7/1 to 7/14	44.925	30	51.2	48.5	50

Table A14. Average Spill Percentages under the FOP/Spill to the Gas Cap spill scenario assigned to hatchery subyearling fall Chinook cohorts.

		Average Spill Percentage Assigned to Cohorts				
Species	**LGR dates**	**All Dams**	**LGS**	**LMN**	**IHR**	**MCN**
choh	5/20 to 6/2	64.5	69.2	69.4	69.4	50
choh	6/3 to 6/16	66.675	72.5	69.4	74.8	50
choh	6/17 to 6/30	59.0	65.5	60.7	59.8	50
choh	7/1 to 7/14	53.4	55.1	51.2	57.3	50

Table A15. Average Spill Percentages under the Spill to the Gas Cap spill scenario assigned to hatchery subyearling fall Chinook cohorts.

		Average Spill Percentage Assigned to Cohorts				
Species	**LGR dates**	**All Dams**	**LGS**	**LMN**	**IHR**	**MCN**
choh	5/20 to 6/2	67.6	69.2	69.4	69.4	62.4
choh	6/3 to 6/16	70.05	72.5	69.4	74.8	63.5
choh	6/17 to 6/30	62.6	65.5	60.7	59.8	64.4
choh	7/1 to 7/14	57.375	55.1	51.2	57.3	65.9

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MEMORANDUM

TO: Dave Statler, NPT

Michele DeHart

FROM: Michele DeHart

DATE: July 14, 2011

RE: Benefits of spill for juvenile fish passage at hydroelectric projects

In response to your request, to assess fish passage characteristics with and without spill, the FPC staff has reviewed the available monitoring information regarding the benefits of spill for fish passage through the Columbia and Snake Rivers. The FPC has reviewed and summarized observations of juvenile fish passage characteristics developed through annual monitoring of downstream passage in the Smolt Monitoring Program and smolt-to-adult return rates from life cycle monitoring conducted through the Comparative Survival Study (CSS). In particular we have summarized the observations from monitoring and the results of various analyses regarding the benefits of spill for fish passage. We utilized the CSS developed model simulation analyses to address your question regarding juvenile fish survival with and without spill. Our primary conclusions from our review follow:

- Increasing proportion of spill provided for fish passage at hydroelectric projects has resulted in higher juvenile spring/summer Chinook, fall Chinook, sockeye and steelhead survival and faster juvenile fish travel time through the FCRPS.
- Increasing spill proportion provides mitigation for low flows through the hydrosystem. In observations of years with similar flow and water travel time, juvenile fish survival and fish travel time are improved in years with higher average spill.
- Spill proportion and water travel time (i.e.flow) are correlated with smolt-to-adult return rate. Increasing spill proportion and faster water travel time (i.e.higher flow) result in higher smolt-to-adult return rate.
- Fresh water passage conditions affect early ocean survival. Spill proportion and water travel time affect ocean survival of Chinook and steelhead.
- Increasing spill proportion allows a higher proportion of downstream migrants to avoid power house passage. Powerhouse passage through juvenile bypass systems decreases smolt-to-adult return rates. Direct estimates of project survival do not capture the delayed mortality effect of project passage and therefore underestimate project impact on juvenile survival and adult return.

- Model simulations indicate that juvenile survival could be significantly increased and juvenile fish travel time could be decreased by increasing spill proportion in low flow periods.

Increasing proportion of spill provided for fish passage at hydroelectric projects has resulted in higher juvenile Chinook, sockeye and steelhead survival and faster fish travel time through the FCRPS

In the Draft 2010 FPC Annual Report (Section IV), the FPC staff estimated the survival rates for weekly cohorts of Snake River wild Chinook, hatchery Chinook and combined hatchery and wild steelhead in the LGR-MCN reach using standard CJS methods over migration years 1998-2010. This report also provided seasonal survival rates for Snake River sockeye (combined hatchery and wild) in the LGR-MCN reach over 1998-2010. Finally, this report provided survival estimates of bi-weekly cohorts of Snake River hatchery sub-yearling Chinook over migration years 1998-2010.

As in annual reports from previous years, environmental variables associated with each of the above cohorts were generated based on fish travel time and conditions at each dam along the reaches. Among the environmental variables that were estimated were average spill percentage and median fish travel time. The spill percentage at downstream dams were averaged over a seven-day window around the median passage date at each dam, and the travel time to the next dam was used to adjust the start date of the calculations. For example, steelhead travel time from LGR to LGO for the earliest release cohort in 2005 (detected at LGR from 4/17 to 4/23) was estimated to be 5.0 days based on 378 detections. Average spill percentage over the time period of April 22 to April 28 at LGO was then calculated. At each downstream dam, average spill percentage was calculated in a similar manner. Since no PIT-tag detection data were available until 2005 at IHR, travel time to IHR was estimated as 43% of the total travel time from LMN to MCN (corresponding to the distance to IHR relative to the distance to MCN). The overall average spill percentage was the average of these dam-specific calculated values for spill percentage. Fish travel time estimates were the median fish travel time (LGR-MCN) for each cohort.

Survival: Increasing spill proportion has increased juvenile fish survival through the hydrosystem

Reach survival estimates and environmental variables for all cohorts will be available in a separate appendix of the Final 2010 Fish Passage Center Annual Report, which will be posted on the FPC web-site on August 31, 2011. Weighted regression analyses of average spill percentage and juvenile reach survival (LGR-MCN) were conducted for each species. Juvenile survival estimates were log-transformed ($\mathrm{Ln}(\mathrm{Surv}_{\mathrm{LGR\text{-}MCN}})$). In order to do weighted regressions with these log-transformed survival estimates, it was necessary to calculate the variance of a log-transformed variable. Weighting for these regressions was based on the inverse of this variance. For log normally distributed random variables, the variance of log (x) is (Blumenfeld 2001):

$$\mathrm{Var}[\log(x)] = \log(1 + [cv(x)]^2) \qquad (1)$$

Based on these weighted regression analyses, increasing spill percentage resulted in higher juvenile Chinook, sockeye, and steelhead survival through the FCRPS (Figures 1 through 6). Furthermore, for all species, it is evident that providing spill in a low flow year (e.g., 2007 and 2010) resulted in increased juvenile reach survival, when compared to low flow years with no spill (e.g., 2001) (Figures 1 through 6).

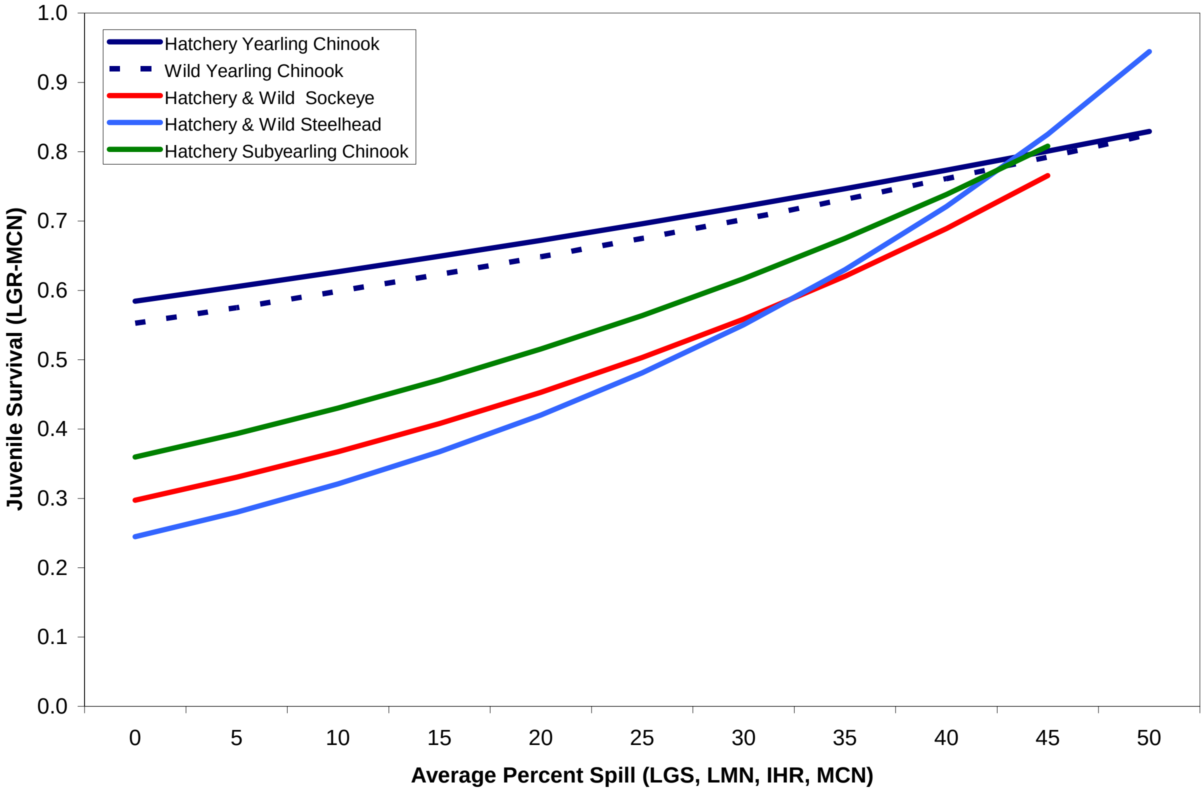


Figure 1. Weighted regression analyses of average spill percent and juvenile survival (LGR-MCN) for yearling Chinook, sockeye, steelhead, and subyearling Chinook (1998-2010).

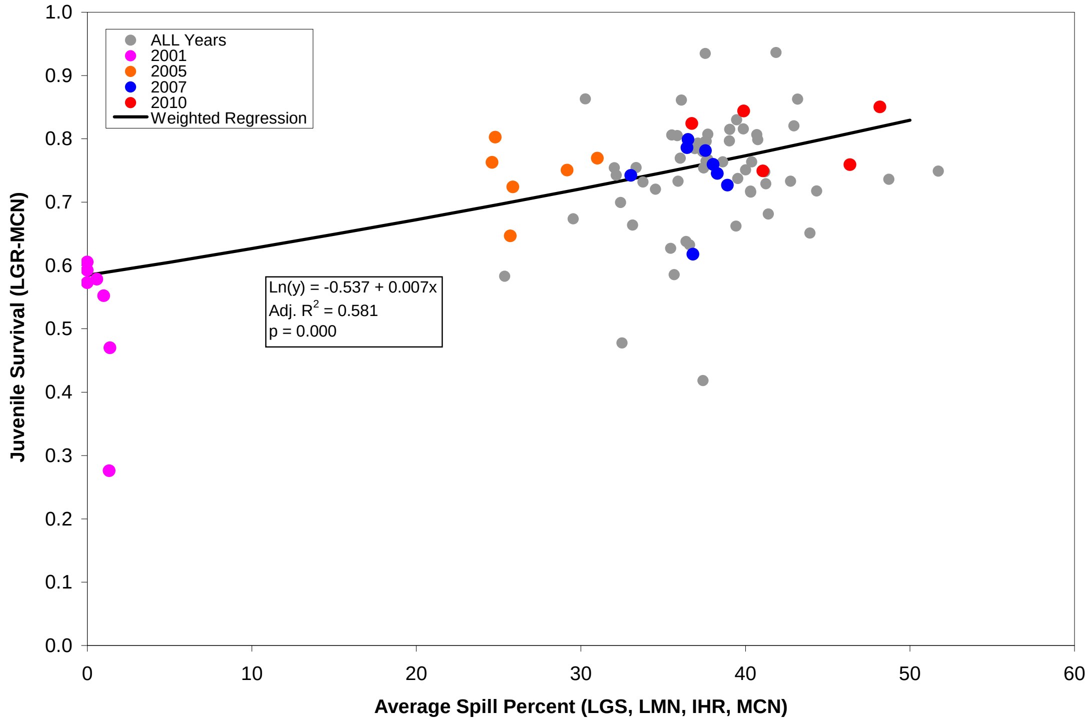


Figure 2. Weighted regression analysis of average spill percent and juvenile survival (LGR-MCN) for hatchery yearling Chinook. Weighted regression line is for all years (1998-2010).

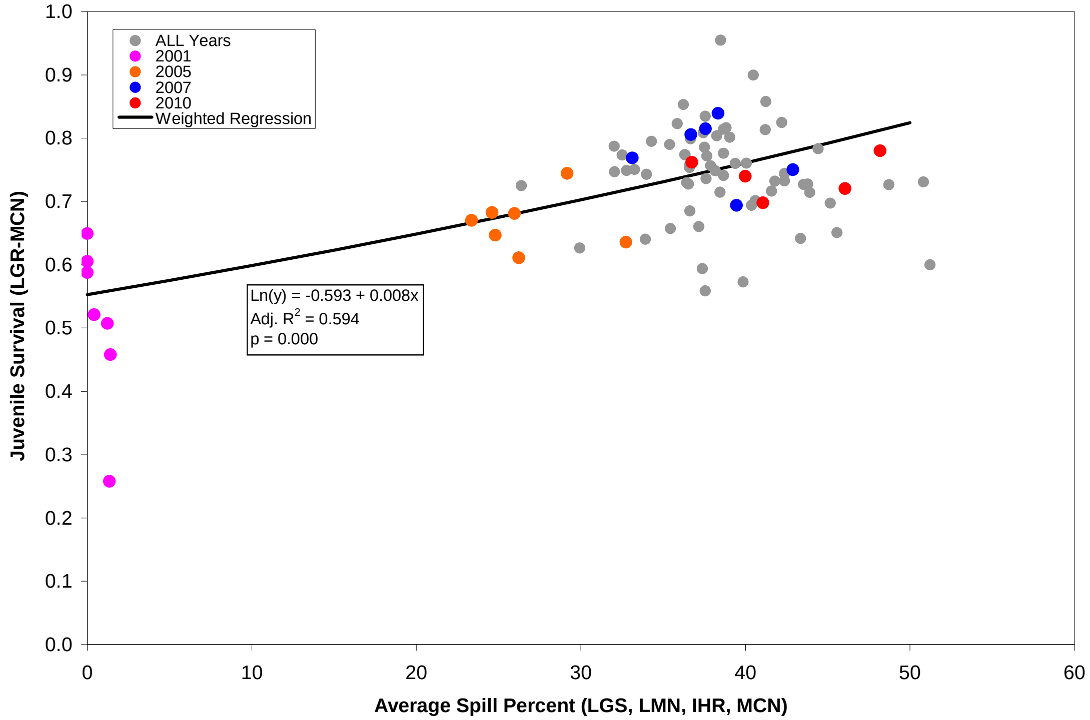


Figure 3. Weighted regression analysis of average spill percent and juvenile survival (LGR-MCN) for wild yearling Chinook. Weighted regression line is for all years (1998-2010).

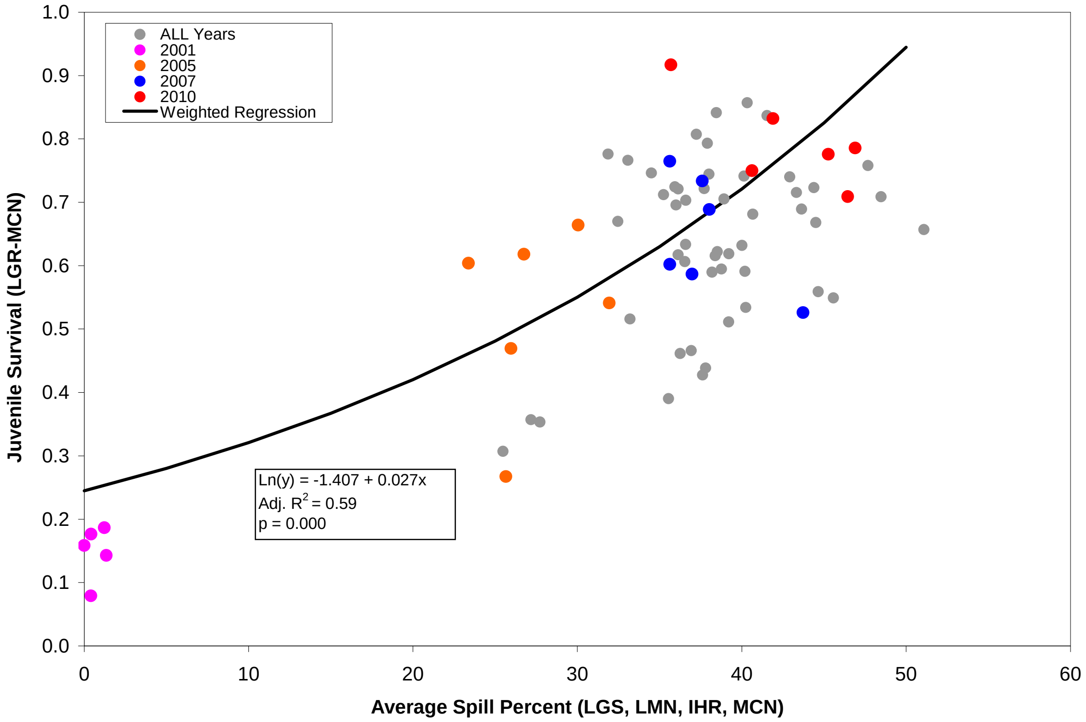


Figure 4. Weighted regression analysis of average spill percent and juvenile survival (LGR-MCN) for hatchery and wild steelhead. Weighted regression line is for all years (1998-2010).

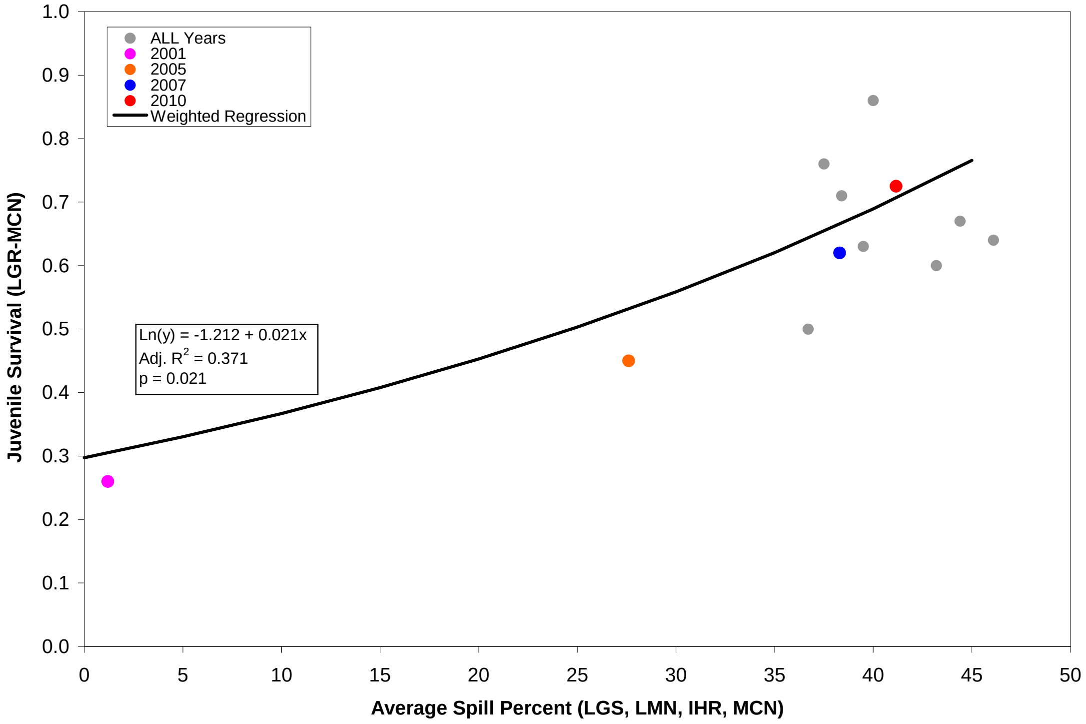


Figure 5. Weighted regression analysis of average spill percent and juvenile survival (LGR-MCN) for hatchery and wild sockeye. Weighted regression line is for all years (1998-2010, except 2004).

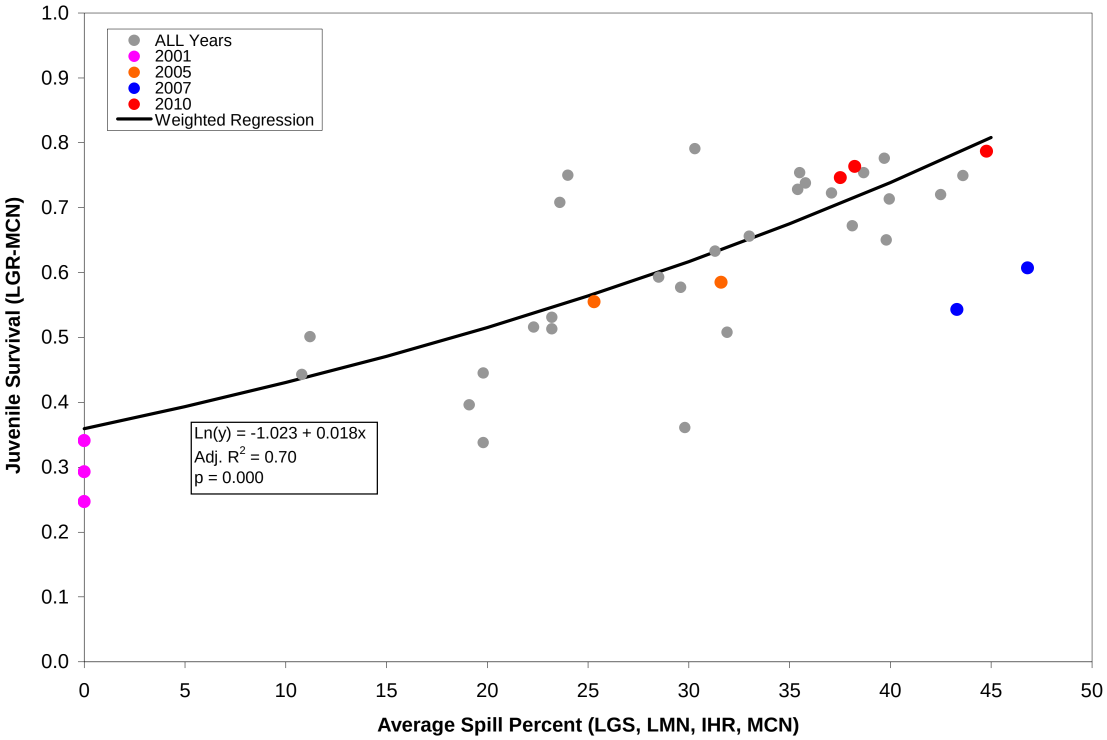


Figure 6. Weighted regression analysis of average spill percent and juvenile survival (LGR-MCN) for hatchery subyearling Chinook. Weighted regression line is for all years (1998-2010).

TRAVEL TIME

Increasing spill proportion at hydroelectric projects also decreased juvenile salmon and steelhead travel time through the Columbia and Snake Rivers FCRPS.

The following plots are the result of linear regression analyses of average spill percentage and median fish travel time for each species. There were not transformations of the variables in these regressions and no weighting. Based on these regression analyses, increasing spill percentage resulted in faster fish travel times for juvenile Chinook, sockeye and steelhead through the FCRPS (Figures 7 through 11). Furthermore, for all species it is evident that providing spill in a low flow year (e.g.2007 and 2010) resulted in decreased fish travel time, when compared to low flow years with no spill (e.g. 2001) (Figures 7 through 11).

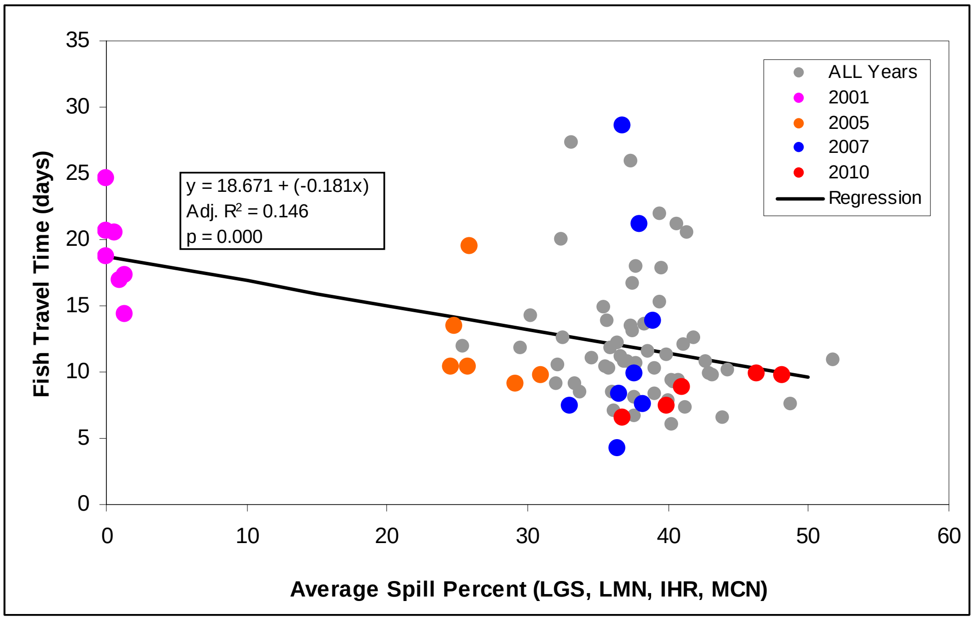


Figure 7. Linear regression analysis of average spill percent and fish travel time (LGR-MCN) for hatchery yearling Chinook for migration years 1998-2010.

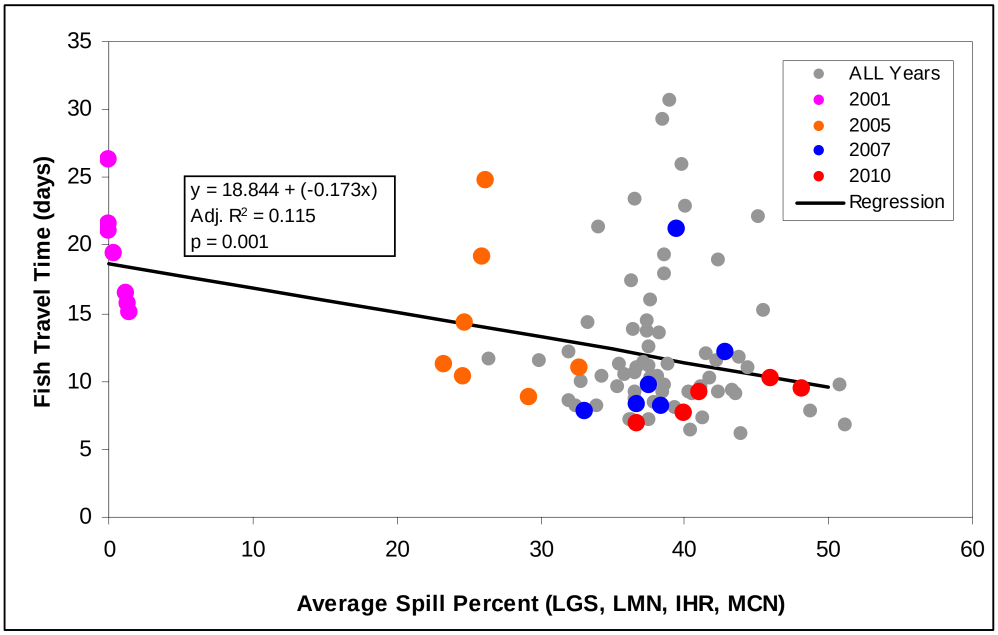


Figure 8. Linear regression analysis of average spill percent and fish travel time (LGR-MCN) for wild yearling Chinook for migration years 1998-2010.

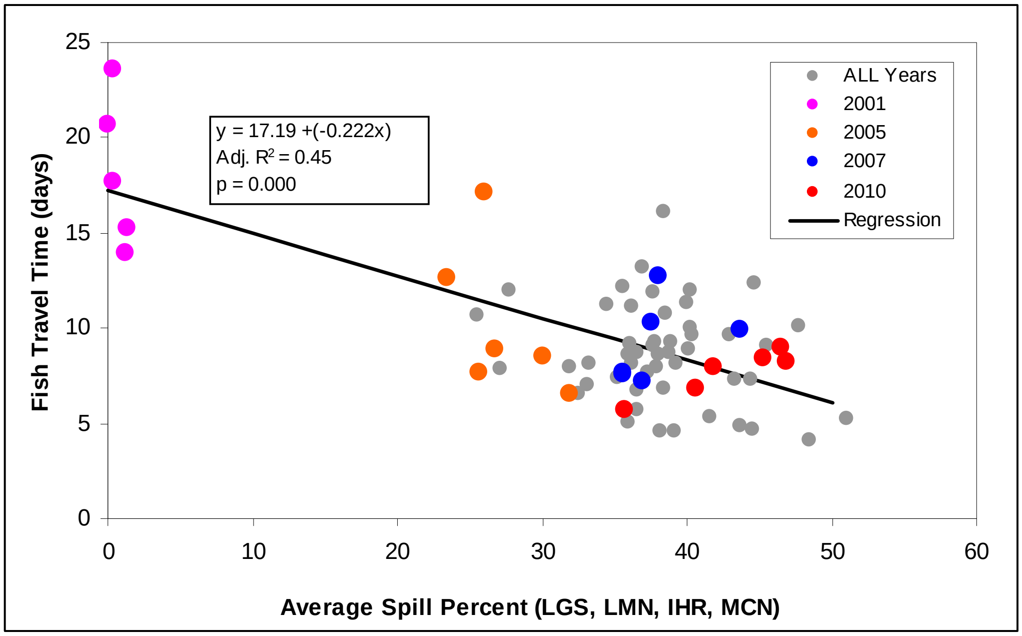


Figure 9. Linear regression analysis of average spill percent and fish travel time (LGR-MCN) for hatchery and wild steelhead for migration years 1998-2010.

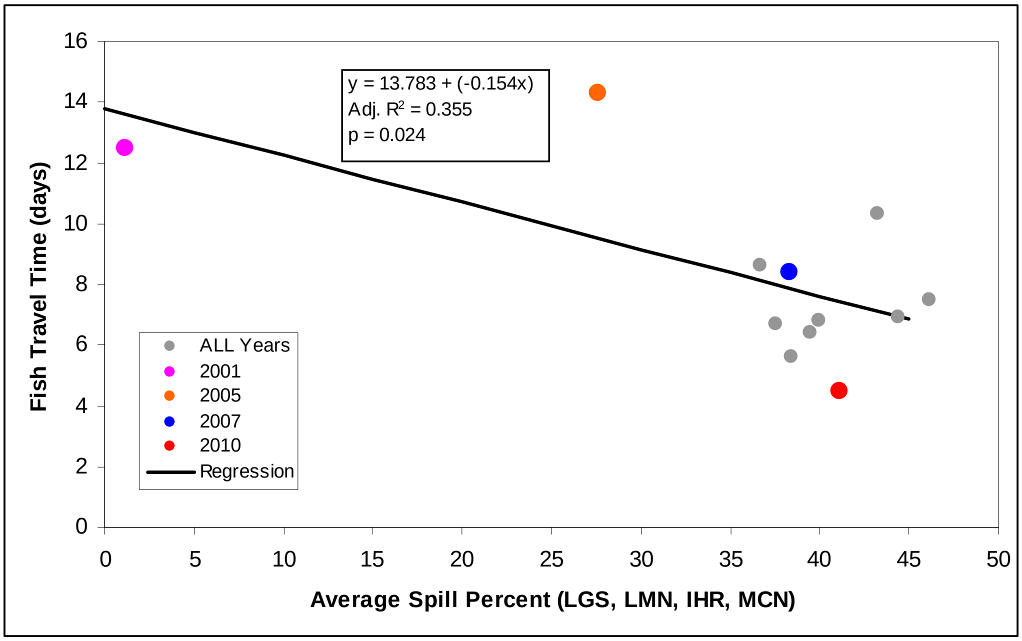


Figure 10. Linear regression analysis of average spill percent and fish travel time (LGR-MCN) for hatchery and wild sockeye for migration years 1998-2010 (excluding 2004).

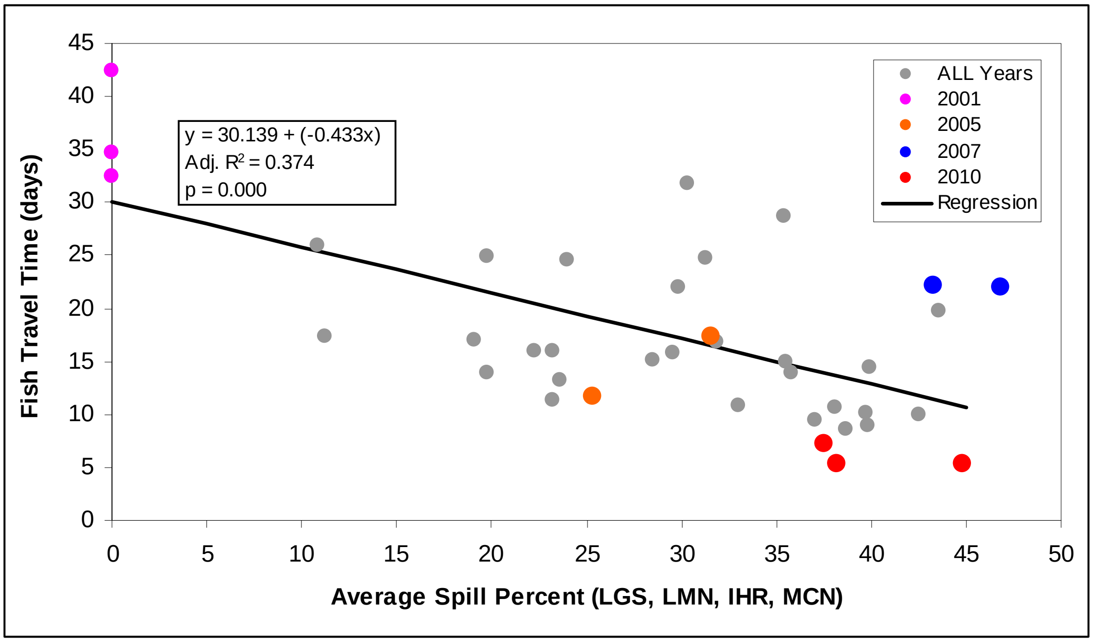


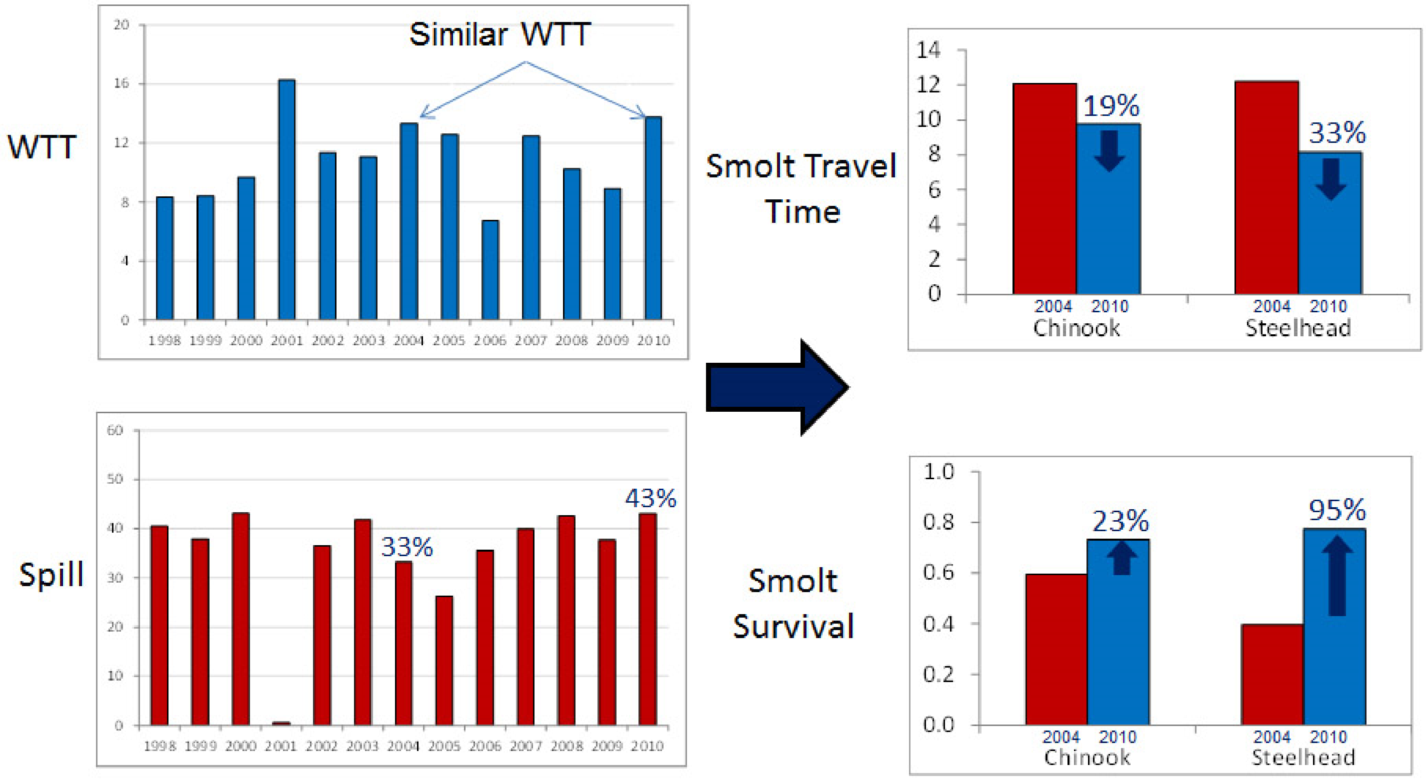
Figure 11. Linear regression analysis of average spill percent and fish travel time (LGR-MCN) for hatchery subyearling Chinook migration years 1998-2010.

In observations of similar flow and water travel time years, juvenile fish survival and travel time are improved in years with higher average spill.

Observations and comparison of of recent juvenile Chinook and steelhead downstream migration years with similar water transit times but different average spill levels indicate that for Chinook, sockeye and steelhead fish travel time is faster and juvenile fish survival is higher in years with higher average spill proportions. The following plots of observations of water transit time, average spill proportion and juvenile survival in the Lower Granite to McNary river reach illustrate two sets of comparisons of years with similar water transit time; 2005/2007 and 2004/2010.

In the 2005/2007 comparison water transit times were similar but average spill proportion was 27% in 2005 and 40% in 2007 (Figure 13). Chinook, steelhead and sockeye travel times were reduced in 2007 relative to 2005, while survival for all species was significantly increased in 2007 relative to 2005(Figure 13).

In the 2004/2010 comparisons water transit times were similar and slightly faster in 2004 than 2010. Average spill proportion was 33% in 2004 and was 43% in 2010 (Figure12). In addition, surface passage structures (RSWs and TSWs) were in place at all the intermediary dams in 2010 (LGS, LMN, IHR, MCN), but none were in place in 2004. The smolt travel time decreased 19% in 2010 relative to 2004 for Chinook and decreased 33% for steelhead in 2010 relative to 2004 (Figure 12). Chinook survival increased 23% in 2010 relative to 2004 and steelhead survival increased 95% in 2010 relative to 2004 (Figure 12).The vast majority of PIT-tagged sockeye were transported in 2004. Therefore it was not possible to estimate juvenile reach survival for sockeye in 2004.



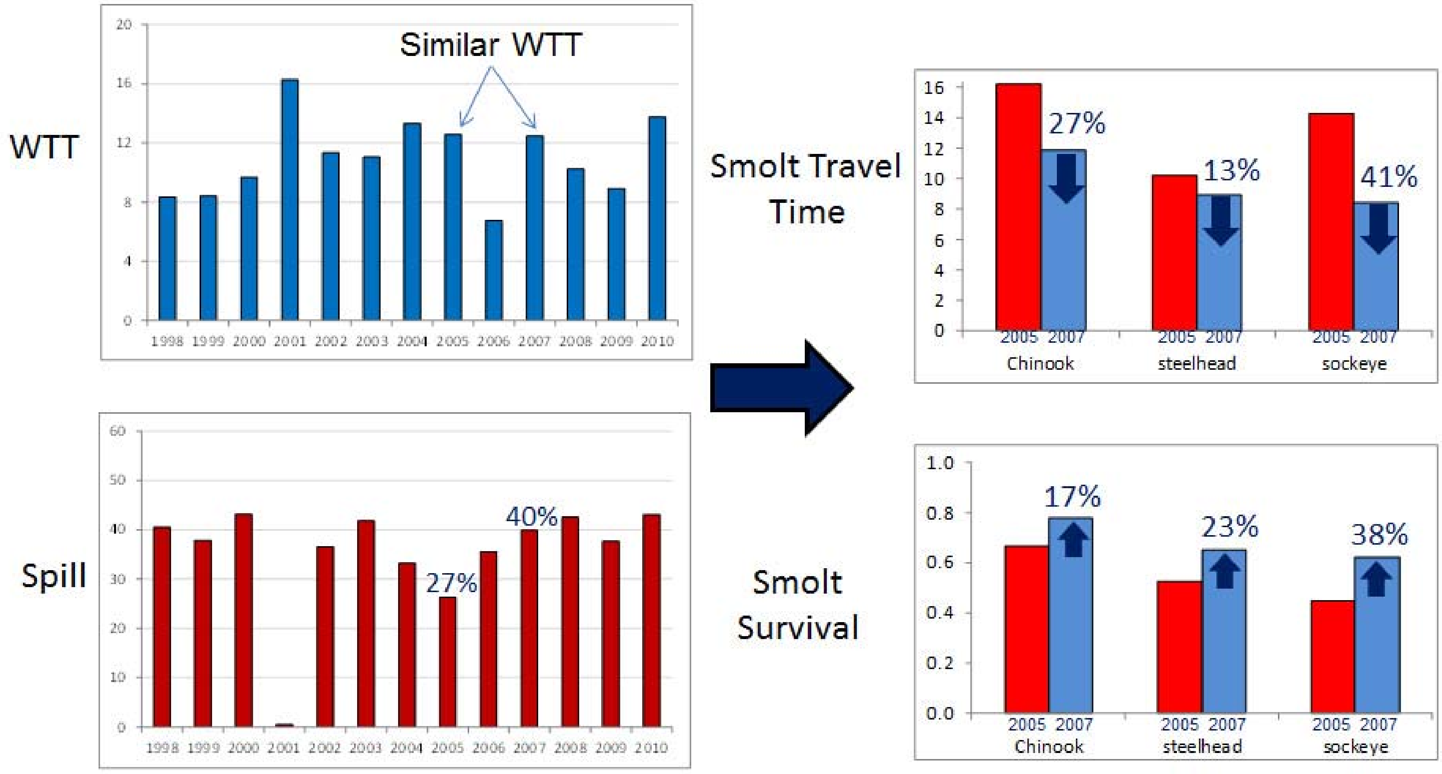


Figure 12.Lower Granite to McNary 1998-2010, Comparison of 2004 and 2010 (upper)
Figure 13. Lower Granite to McNary 1998-2010 Comparison of 2005/2007 (lower)

Model simulations indicate that juvenile survival in low flow periods such as the summer migration period and low run-off volume years, could be significantly increased and juvenile fish travel time could be decreased by increasing spill proportion in low flow years.

In order to address your question regarding a “with and without” spill condition, we relied on CSS analyses, presented in Chapter 3 of the Comparative Survival Study (CSS) Annual Report (Tuomikoski et al, 2010). The CSS has calculated smolt travel time and survival rate estimates using PIT-tagged spring/summer Chinook salmon and steelhead originating from the Snake River Basin. Using these estimates, along with measurements of the corresponding environmental conditions that occurred during smolt outmigration in each year, the CSS has developed models that characterize the effects of various spill levels and water transit times on smolt survival and travel time through the hydrosystem over the period of 1998-2010. In addition to explaining historic patterns of smolt survival and travel time, these models can also be used to simulate what could have occurred if different hydrosystem operations had been implemented.

To illustrate the effects of spill versus no-spill operations, we first used the CSS models to characterize the historic survival and travel time patterns during 2001, a low-flow year when hydrosystem operators elected to terminate spill at the outmigration dams. Figures 14 and 15 show that the CSS model predictions for survival and travel time in 2001 correspond well with the observed survival and travel time estimates for both yearling Chinook salmon and steelhead. To illustrate what could have occurred if different hydrosystem operations had been implemented, we simulated the juvenile travel times and juvenile survival rates that would be expected under a 50% spill operation at the outmigration dams, while maintaining the same flow conditions that occurred in 2001. The simulations indicate that despite the presence of low-flow conditions, survival rates in the river reach between Lower Granite Dam (LGR) and McNary Dam (MCN) could have been much higher if an aggressive spill operation had been implemented in 2001 (Figure 14). For steelhead, the simulated survival rates under a 50% spill operation were expected to be triple the observed survival rates under the no-spill operation that was implemented. Similarly, fish travel times under a 50% spill operation were expected to be 30-50% lower than the observed fish travel times under the no-spill operation that was implemented (Figure 15). These simulations demonstrate that spill is highly influential in determining smolt survival and travel time through the hydrosystem. In addition, these simulations indicate that spill can be an effective tool for mitigating for the effects of low-flow conditions.

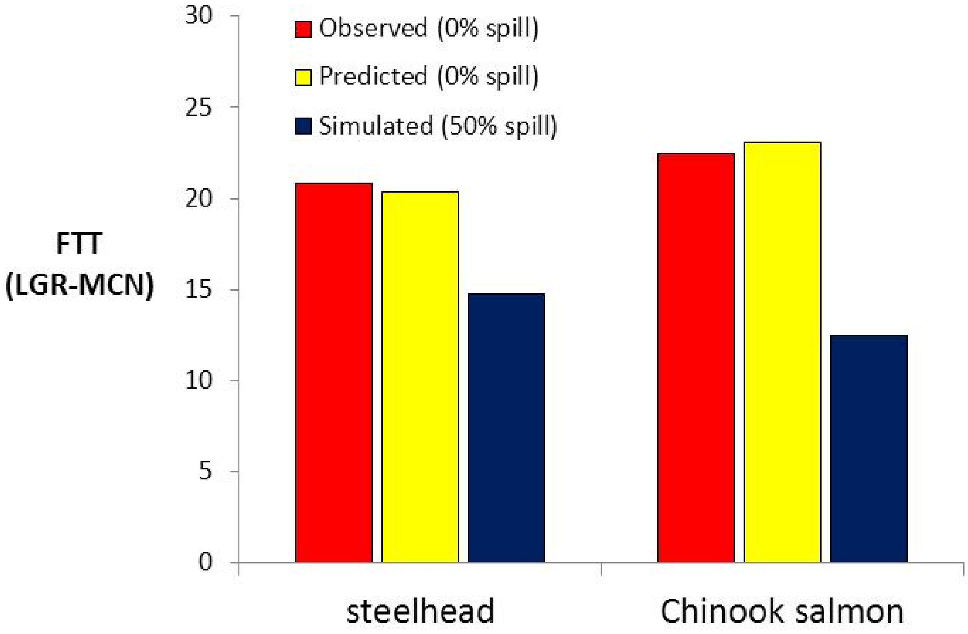


Figure 14. Average fish travel time (FTT, days) for hatchery and wild steelhead (left) and wild yearling Chinook salmon (right) in the LGR-MCN reach during 2001 (red bars), along with the CSS model predictions for average FTT under the 0% spill operation (yellow bars) that was implemented and expected FTT under a simulated 50% spill operation (blue bars) with the same low-flow conditions that occurred in 2001.

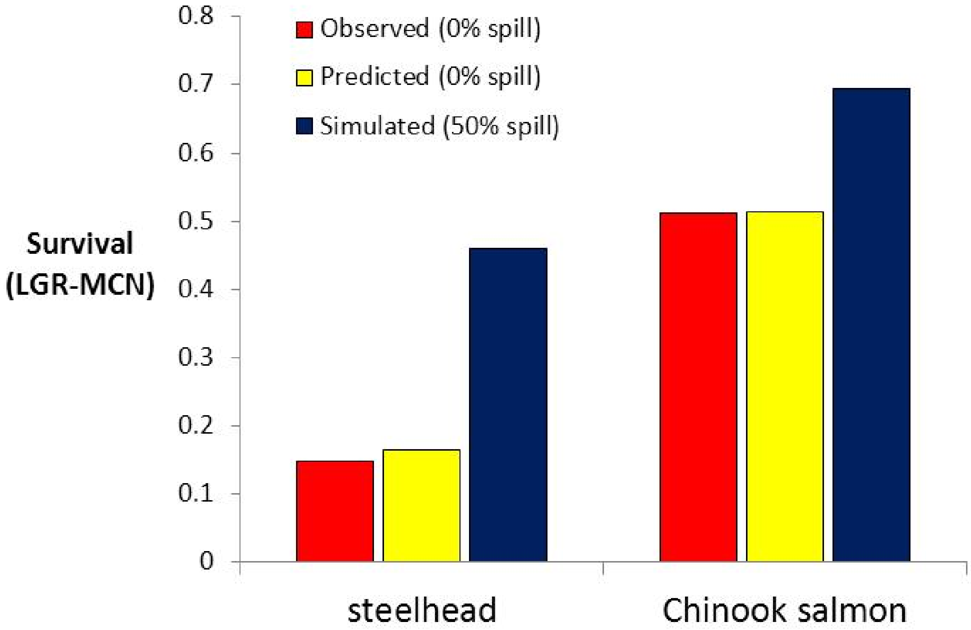


Figure 15. Average smolt survival for hatchery and wild steelhead (left) and wild yearling Chinook salmon (right) in the LGR-MCN reach during 2001 (red bars), along with the CSS model predictions for survival under the 0% spill operation (yellow bars) that was implemented and expected survival under a simulated 50% spill operation (blue bars) with the same low-flow conditions that occurred in 2001.

Spill mitigates for low migration flow. Increasing spill proportion improves fish travel time in low flow periods such as low run-off volume years and the summer migration period. Increasing spill in low water periods can provide some mitigation for the impact of low migration flows on fish travel time. However, high flow and low spill would increase the proportion of fish passing through the power house, resulting in decrease in survival, increase in delayed mortality and decrease in smolt-to-adult return.
Historical observations through downstream migration monitoring has shown that faster water transit time (increasing flow and velocity) results in faster juvenile fish travel time during the downstream migration. The increase in spill proportion and duration that has occurred in recent years has resulted in faster fish travel times particularly in low flow years. Observations of similar flow year's show that the addition of spill improves fish travel time and survival. The following exercise illustrates the concept of increasing spill proportion as mitigation for low migration flows.

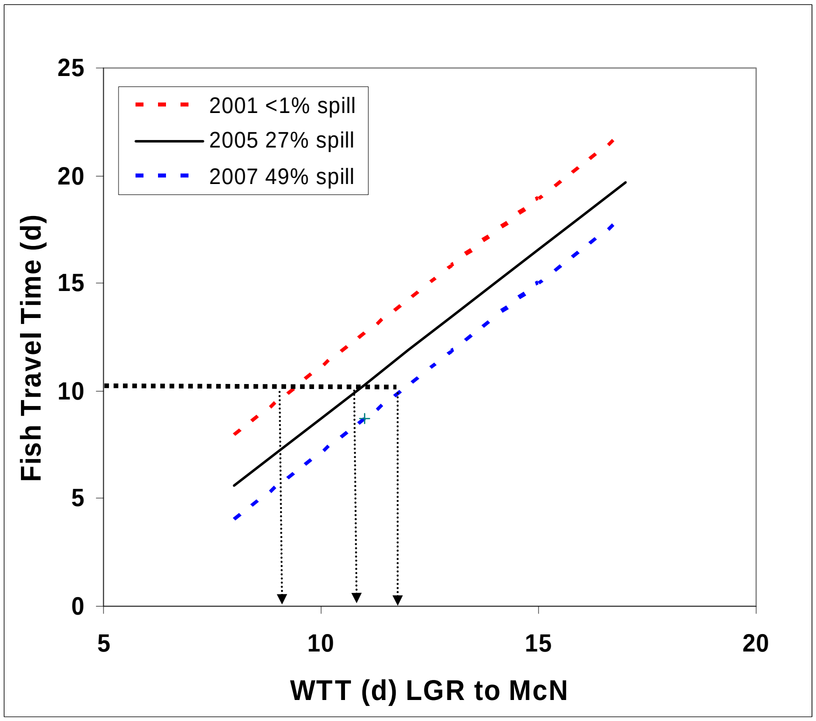


Figure 16. Steelhead Fish Travel Time versus Water Transit Time in the Snake River during low flow years with varying levels of spill in the reach. The relationship shown was a regression of the FTT and WTT for six release groups in each year. Two indicator variables were introduced to measure year effects.

From the regression shown in Figure 16 a conceptual spill benefit to steelhead travel time (FTT) could be derived. If the observed improvement in the relation between FTT and WTT were attributed to increased spill proportion from year to year then, given the common slope assumed for the three years, the improvement from spill would be expressed as a decrease in the WTT necessary to achieve the same FTT. For example to achieve a 10 day FTT in 2005 conditions it would have required a 10.8 day WTT (82 Kcfs in Snake River) while in 2007 the same FTT could have been achieved with 11.8 WTT (75 Kcfs) given the improved conditions in that year. For 2001, a year with almost no spill, the same 10 day FTT would have required a 9.3 day WTT or flows of 96 Kcfs in the Snake River. Given the difference in spill proportion in each of these low flow years, it is likely that the improvement in FTT in relation to WTT was largely due to the increased spill, particularly in 2007. Thus achieving a 10 day FTT for steelhead through the Lower Granite Dam to McNary Dam Reach during a low flow year would require either flows of 75 Kcfs with 40% spill or upstream reservoir releases to achieve flows of 96 Kcfs with no spill.

This conceptual exercise only considers fish travel time and does not consider fish survival. In a no spill situation additional upstream reservoir releases would be required to provide the flow to achieve the desired travel time, however fish survival would be lower because a larger proportion of downstream migrants would pass though powerhouse routes.

Spill proportion and water travel time (flow) are correlated with fish travel time and fish survival.
Life cycle monitoring through the Comparative Survival Study (CSS) has been conducted for the past thirteen years. The CSS Annual Report, Chapter 3, for 2010 (Tuomikoski et al 2010) included an analyses of the effects of the in-river environment on juvenile fish travel time, instantaneous mortality rates and juvenile survival. Linear regression techniques were used to evaluate the associations between the environmental variables and mean fish travel time and instantaneous mortality. The most important variables for the best fitting models for fish travel time were Water Transit Time (flow), spill, and Julian day. The most important variables for the best fitting models for instantaneous mortality were water transit time (flow), spill and Julian day. Instantaneous mortality was predicted to increase as Julian day increased and instantaneous mortality was predicted to decrease as spill increased.

Fresh water passage conditions affect early ocean survival. Spill proportion and water travel time affect ocean survival of Chinook and steelhead and smolt-to-adult return rate. Increasing spill proportion and faster water travel time (higher flow) result in higher smolt-to-adult return rate.
Past analyses have indicated that fresh water migration experience effect ocean survival and adult return. Budy et al. (2002) provide evidence that some estuary and early ocean mortality is related hydrosystem passage experience during downstream migration. This hydrosystem-related delayed mortality (Schaller and Petrosky 2007) is thought to be due to the cumulative effects of stress and its impacts on energetic condition, predation vulnerability, disease and physiology of migrating smolts, which eventually influences levels of delayed mortality. The same hydrosystem factors that cause direct mortality during downstream migration also impose stress on those fish that do survive, under the Budy et al. (2002) hypothesis mortality rates during downstream migration are expected to be positively correlated with mortality rates at later life stages.

Several recent analyses indicate that early ocean survival and fresh water migration passage conditions are correlated. Haeseker et. al. (In Press) concluded that freshwater and marine survival rates of Chinook and steelhead were correlated, indicating that a portion of the mortality expressed after leaving the hydrosystem is related to downstream migration conditions. Figure 17, below shows the relationships between in-river survival, environmental variables (average spill and water transit time), versus adult returns at various levels of ocean productivity. They concluded that across a range of marine conditions, improvements in life stage specific and smolt to adult returns may be achievable through increasing spill percentages and/or reducing water transit times during the juvenile out migration. Petrosky & Schaller (2010) found that survival rates during the smolt to adult and first year ocean life stages for Chinook and steelhead were associated with both ocean and river conditions. Best fit, simplest models indicate that lower survival rates for Chinook salmon are associated with warmer ocean conditions, reduced upwelling in the spring and with slower river velocity during the smolt migration or multiple passages through powerhouses at dams.

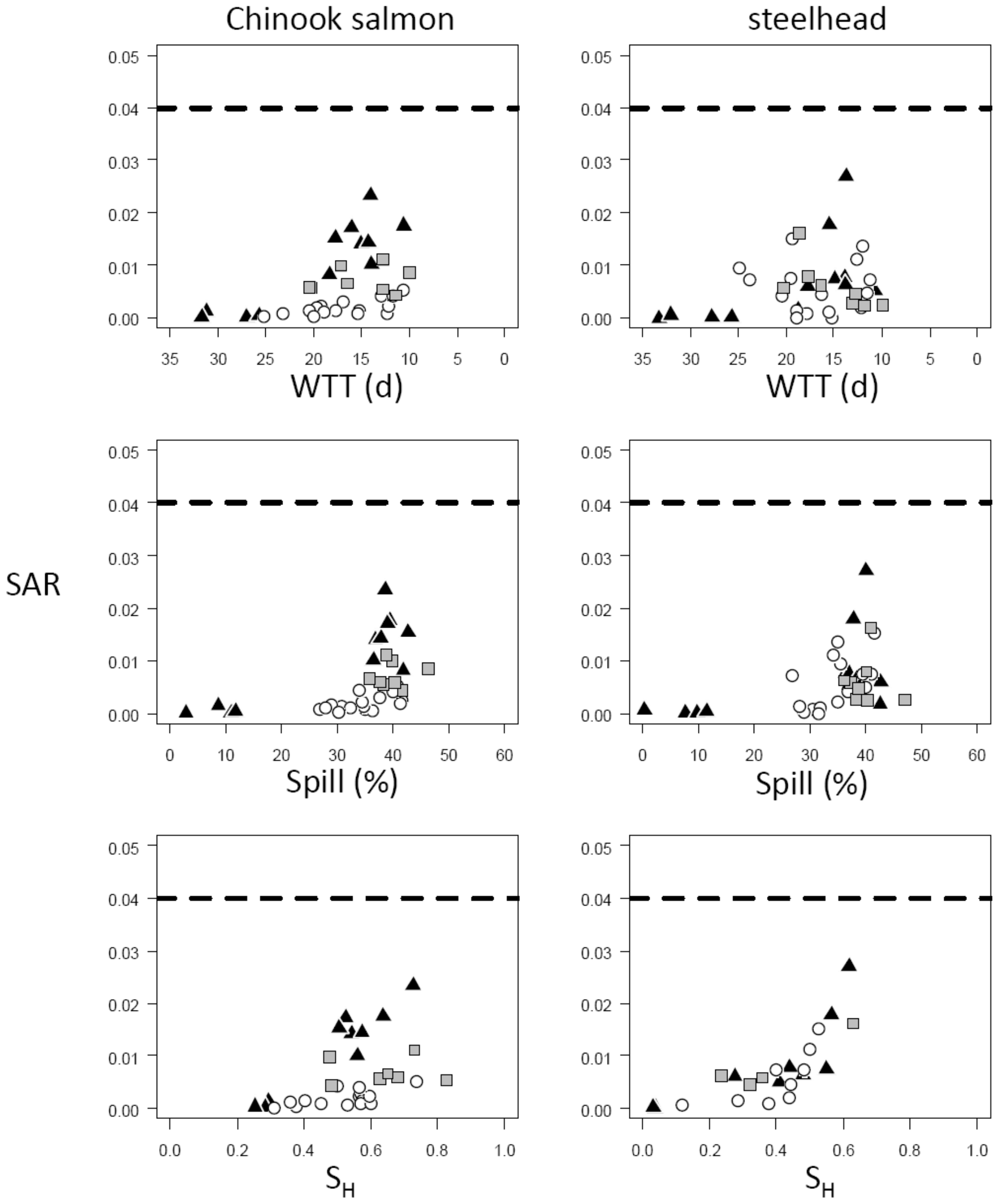


Figure 17. Bivariate plots from Haeseker et al (In Press) of *SAR* against water transit time (WTT), average percent spill (Spill) and juvenile outmigration survival (S_H) for Chinook salmon (left column) and steelhead (right column). Years with negative June-August Pacific Decadal Oscillations (PDO) are denoted by black triangles, years with neutral PDO values near zero are denoted by grey squares and years with positive PDO values are denoted by open circles. The horizontal dashed line at 4% denotes the Northwest Power and Conservation Council (2009) *SAR* objective.

Increasing spill proportion allows a higher proportion of downstream migrants to avoid power house passage. Powerhouse passage through juvenile bypass systems decreases smolt-to-adult return rate. Direct estimates of project survival such as those developed to evaluate performance standards, do not capture the delayed mortality effect of project passage and therefore underestimate project impact on juvenile survival and adult return.

Evidence from several independent analyses indicates that passage through powerhouse bypass systems results in significant delayed mortality of juvenile salmon and steelhead that reduces adult returns. (FPC memorandums; January 28, 2011, October 6, 2010, February 3, 2010, May 21, 2009, www.fpc.org) In addition to increasing levels of delayed mortality, passage through powerhouse bypass systems has also been shown to increase juvenile migration delay. Estimates of direct, route-specific survival do not account for delayed mortality effects that can be quantified with adult returns. Additionally, route-specific survivals do not incorporate the effects of migration delay in terms of decreased survival. Therefore, route-specific estimates underestimate the cumulative effects of powerhouse passage on life-cycle survival of salmon and steelhead. Based on these recent analyses, minimizing juvenile passage through powerhouses would reduce migration delay, reduce delayed mortality and improve adult return rates. Applying these results to project operations, increasing spill levels to dissolved gas limits would minimize juvenile passage through powerhouses and improve adult returns. The effects of bypass systems on juvenile salmon and steelhead travel times and smolt-to-adult return were analyzed in the Comparative Survival Study Annual Status Report for 2010. Three sets of analyses were conducted to evaluate:

1. The effects of bypass systems on fish travel time from Lower Granite Dam to Bonneville Dam.

2. The effects of bypass history on SARs from Bonneville outmigration as juveniles to adult return to Bonneville.

3 The effect of bypass passages during the juvenile outmigration, on Lower Granite outmigration as juveniles to adult return at Lower Granite.

The methods for these analyses are described in Chapter 7 of the CSS Annual Status Report for2010 which is available on the FPC website http://www.fpc.org/documents/CSS.html. The analyses of bypass passage on fish travel time identified significant migration delays for juvenile Chinook salmon and steelhead that were bypassed relative to non-bypassed fish. The average magnitude of the delay among the significant cases was 0.69 days (16.6 hours) for Chinook and 0.73 days (17.5 hours) for steelhead. Significant migration delays for bypassed fish were identified in the majority of the year-dam combinations for Chinook (67%) and a large proportion of the cases for steelhead (23-33%). The lower percentage of significant migration delay identified for steelhead was likely due to the smaller sample sizes available for steelhead. The analyses of effects of bypass on post-Bonneville smolt-to-adult return (SAR) indicated that post-Bonneville SARs are lower for bypassed Chinook and steelhead smolts than non-detected smolts. These analyses indicate that subsequent downstream passage experience may further influence smolt-to-adult return rate, with the smolts that pass undetected through the dams expected to have higher smolt-to-adult return rates than those smolts that are bypassed one or more times. Model estimates for Chinook salmon showed a 10% reduction in post-Bonneville SAR per bypass experience at upstream dams. Steelhead showed a 6% reduction in SAR per bypass experience at Snake River dams and a 22% reduction in post-Bonneville SARs per bypass experience at Columbia River dams. For Chinook estimates of bypass effects were similar across Columbia and Snake River dams. For steelhead bypass effects were more severe at McNary and John Day dams.

The third analyses of cumulative bypass effects showed that non-bypassed yearling Chinook LGR/LGR SARs averaged 52% higher, and non-bypassed steelhead SARs averaged 91% higher, than smolts that were bypassed at one or more of the collector facilities

The results of the CSS analyses indicate that route specific estimates of juvenile survival rate as defined from the forebay to tailrace of the projects, or from paired release studies to define project survival are likely to underestimate project impacts because they do not account for the mortality associated with migration delay or the latent mortality associated with project passage.

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