Exposure of migrating salmon populations in the Columbia/Snake River basins to environmental factors

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Introduction

Salmonids in the Columbia and Snake River basins are exposed to a variety of environmental conditions that vary with year, day of year, and management actions. The impact on them varies with their developmental stage and individual behaviors. The effects of some of these factors have been studied in the laboratory and to a limited extent in the field but the influence of these on the survival of salmonids in a large river system is complex. Simple monitoring of in-river conditions, regardless of the spatial and temporal resolution of the data is insufficient for understanding the impact on the life-history of the fish in the river.

In the 2000 FCRPS Biological Opinion (Bi-Op) the action agencies were directed to maintain certain in-river environmental conditions within specific tolerances. Management actions can then be evaluated in terms of how well they performed in meeting criteria for temperature, spill, flow, total dissolved gas, and other physical conditions or properties of hydrosystem operations. However, these are important only because of their biological impact and therefore it is vital that we be able to estimate the exposure of the fish to the physical conditions.

In this paper, the exposures of salmon and steelhead groups to selected river conditions were quantified with two measures and Exposure Index (EI), which is a measure of the average conditions experienced by a group of fish during passage, and a Percent Exposure (PE,) which quantifies the percent of the groups that experienced a physical property beyond a critical level (c). Together these measures characterize the conditions individual groupings of fish experience during hydrosystem passage.

Methods

The exposure measures for this report were developed from the website Columbia Basin Performance Measures - Fish Exposure to River Conditions at Hydroelectric Projects (See http://www.cbr.washington.edu/perform/). The calculation of the exposure measures used real time river properties and fish passage information available at the

DART data site (www.cbr.washington.edu/dart/dart.html). Note the information contained in DART is archived from daily downloads of information from the Fish Passage Center; the U.S. Army Corps of Engineers; and from the Pacific States Marine Fisheries Commission.

Exposure estimates can be made at any dam where water properties and fish passage were measured. Thus, the exposure of both juvenile and adult fish salmonids and steelhead to a number of water properties can be determined. This report evaluates the exposure of juvenile salmon and steelhead to four hydrosystem properties: temperature, flow, spill and total dissolved gas. Figure 1 graphically illustrates the calculation for the exposure of Snake River subyearling chinook to temperature at Lower Granite Dam. To calculate the exposure index daily temperature and fish passage numbers are used in the equation

$$EI = \frac{\sum_{i=start}^{i=end} n_i \theta_i}{\sum_{i=start}^{i=end} n_i} \tag{1.1}$$

where n_i is the number of fish passing the dam at day i and θ_i is the temperature on day i. For Figure 1 $EI = 19.43^{o}$ C. The summation is over all passage dates at the dam. The percent exposed PE defines the number of fish that passed when temperatures were above a critical value, which was set at 18^{o} C in this example. For Figure 1 $PE = 61.3\%$.

When any data were missing for any part of a calculation the data was omitted from the estimation of EI and PE. The entire grous was excluded from an analysis when greater than 10% of passage dates had missing data. This results in missing years in the results tables.

A vast number of queries are possible for various combinations of fish populations, locations, factors and critical values. In this analysis we used critical values consistent with 2000 Bi-Op targets or other critical values related to the biology of the fish and examined populations of interest. We tracked the exposure of multiple ESU groups including subyearling/yearling Snake River chinook, and Snake/Columbia steelhead to spill, flow, total dissolved gas, and temperature. We also examined the exposure of transported fish to temperature conditions.

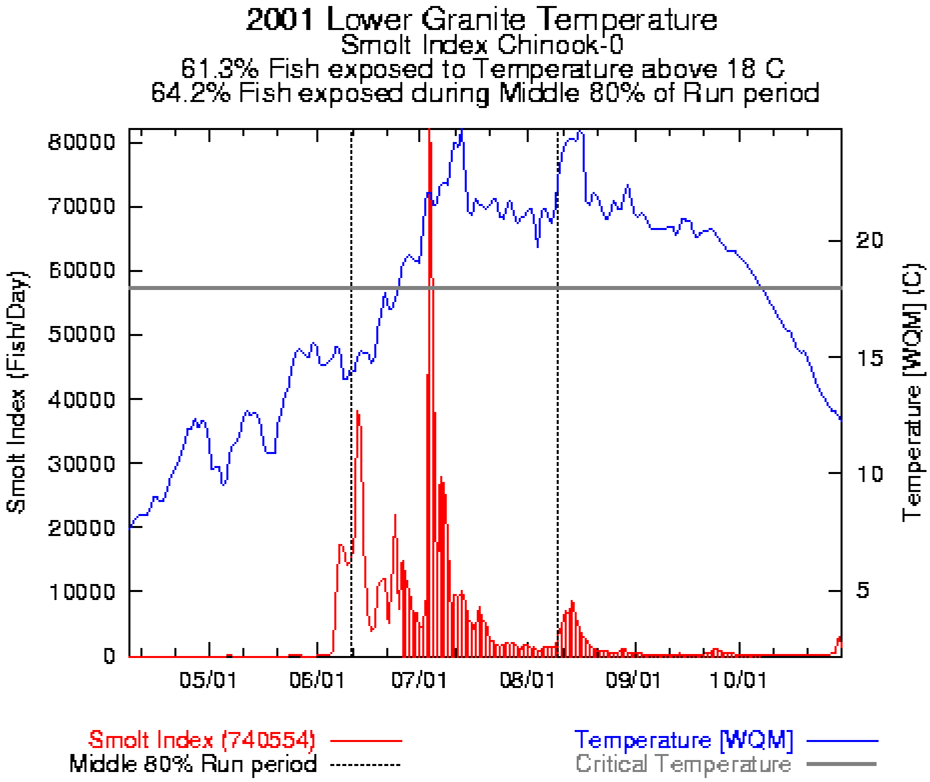

Figure 1. Exposure of subyearling fish to temperature at Lower Granite Dam.

The 2000 Bi-Op specified targets for flow, spill, TDG and temperature. Note that depending on the physical factor, "exposure" could be above or below the critical level. These are summarized in Table 1. This was pertinent for the computation of the proportion exposed. The intention was to compute the exposure to a hazardous condition such that if PE=1.0 then all fish in the population were exposed to the bad level of the factor.

Table 1. Summary of exposure critical values. Proportion of run was adjusted above or below the critical value based on the hypothesized risk to survival. Some targets were specified as ranges and in these cases the lower value was chosen.

Exposure factor	Critical value
Temperature	> 18 °C
Flow	< (Lower) Target Value
Spill	≤ (Lower) Target Value
TDG %	≥ 115%

Temperature

Temperature Exposure Index was computed for fish at Lower Granite and McNary. The Exposure Index was computed for four ESU populations. According to Oregon and Washington state water quality standards, in general, human activities must not raise surface temperatures in the areas of interest above 20 ºC. A benchmark of 18 ºC was evaluated because of its biological significance to migrating/rearing salmonids (EPA 2003).

Flow

Flow Exposure Index was determined for fish at Lower Granite and McNary dams. PIT-tagged ESU groups and corresponding Smolt Indices were analyzed for their exposure to spring and summer flows compared to the target ranges based on the criteria specified in the 2000 BiOP. Lower Granite Dam spring and summer targets are given in the tables below along with McNary spring targets.

Note that the flow targets change with season and the stocks span different seasons so the criteria may change during a population's passage. Exposures for Snake River subyearling chinook were therefore based on summer targets and the proportion that passed during the summer season was also reported. Other stocks' exposures were based on spring flow targets. The targets are described in the following tables.

Table 2. Lower Granite Dam Target Spring Flows for April 3 - June 20 based on the April Final Forecast for April to July Runoff Volumes as specified in the 2000 BiOP.

Year	Period of April Forecast	Forecasted Runoff Volume (MAF)	Flow Target (kcfs)
1995	Jan-Jul[1]	27.4	100.0
1996	Apr-Jul	21.9	100.0
1997	Apr-Jul	32.4	100.0
1998	Apr-Jul[2]	17.4	90.3
1999	Apr-Jul[2]	26.2	100.0
2000	Apr-Jul[2]	19.2	97.0
2001	Apr-Jul[2]	10.0	85.0
2002	Apr-Jul[2]	19.2	97.0

1. Forecast from FPC
2. Forecast from NWRFC.

Table 3. Lower Granite Dam Target Summer Flows for June 21 – August 31 based on the June Final Forecast for April to July Runoff Volumes as specified in the 2000 BiOP.

Year	Period of June Forecast	Forecasted Runoff Volume (MAF)	Flow Target (kcfs)
1995	Jan-Jul[1]	27.9	55.0
1996	Apr-Jul[1]	26.2	42.3
1997	Apr-Jul[1]	33.4	55.0
1998	Jan-Jul[1]	29.9	55.0
1999	Apr-Jul[2]	25.5	54.0
2000	Apr-Jul[2]	18.2	50.9
2001	Apr-Jul[2]	10.8	50.0
2002	Apr-Jul[2]	18.1	50.9

1. Forecast from FPC Weekly.
2. Forecast from NWRFC.

Table 4. McNary Dam Target Spring Flows for April 10 - June 30 based on the April Final Forecast at The Dalles Dam for April to August Runoff Volumes as specified in the 2000 BiOP. The Summer Flow Target for July 1 – August 31 at McNary Dam was set at 200 kcfs as specified in the 2000 BiOP (9-58).

Year	Period of April Forecast	Forecasted Runoff Volume (MAF)	Flow Target (kcfs)
1995	Jan-Jul[1]	99.6	260
1996	Apr-Sep[1]	104.0	260
1997	Apr-Sep[1]	133.0	260
1998	Apr-Sep[2]	82.1	227
1999	Apr-Sep[2]	119.0	260
2000	Apr-Sep[2]	98.2	260
2001	Apr-Sep[2]	52.6	220
2002	Apr-Sep[2]	92.8	260

1. Forecast from FPC Weekly.
2. Forecast from NWRFC.

Total Dissolved Gas

TDG Exposure Index was computed for fish at Lower Granite and McNary dams. EI was computed for four ESU populations. In general, hydroperations allowed the TDG levels to reach 120% (spill cap) in the local tailrace. It was believed that the TDG would then be reduced to 115% by the time the water and fish reached the forebay of the next project downstream. However, the long-term goal for hydrosystem operations is to keep the

TDG levels in the system below 110%. In this report we set the critical level at TDG = 115%.

Spill

Spill Exposure Index was computed for fish at Lower Granite and McNary dams. EI was computed for four ESU populations. Table 5 gives the spill targets identified in the 2000 Bi-Op .

Table 5. General guidelines for spill at Snake River and Lower Columbia projects.

Project	Spill target	Spill Hours	Limiting Factor
LWG until June 20	60 kcfs	6pm – 6am	gas cap
LGS until June 20	45 kcfs	6pm – 6am	gas cap
LMN until June 20	40 kcfs	24 h	gas cap
IHR	100 / 45 kcfs night / day	24 h	gas cap & adult passage (day)
MCN until June 20	120 – 150 kcfs	6pm – 6am	gas cap
JDA	85 – 160 kcfs	6pm – 6am	gas cap / percentage
TDA	40% of flow	24 h	Tailrace flow patterns
BON	90–150 / 75 kcfs night / day	24 h	gas cap / adult passage (day)

Note that for Snake river subyearling chinook passage spanned different seasons and the criteria change during the population's exposure. Exposure reporting for these stocks was therefore based on summer targets and the proportion that passed during the spring season was also reported.

Transport

The Transport Exposure Index is a special temperature exposure index for transported fish from Lower Granite Dam. The EI was computed for three smolt groups: Snake River steelhead, yearling chinook and subyearling chinook. The daily number of transported fish was computed as the sum of the fish barged and trucked from the facility on each day. Many fish are transported and the possible sites include Lower Granite Dam, Little Goose Dam, Lower Monumental Dam and McNary Dam.

Results

ESUs: Exposure Indices and Exposure Proportions

Each ESU stock is presented separately with summaries of PE and EI across four indices at two locations, McNary Dam (MCN) and Lower Granite Dam (LWG). To locate these results Table 6 cross-references their location.

Table 6. Exposure summary cross reference

	Analysis	LWG	MCN	Dam comparison
Snake River subyearling chinook W	Flow, Spill, °C, TDG	Table 7	Table 8	Table 9
Snake River yearling chinook	Flow, Spill, °C, TDG	Table 10	Table 11	Table 12
Snake River steelhead	Flow, Spill, °C, TDG	Table 13	Table 14	Table 15
Columbia River steelhead	Flow, Spill, °C, TDG	N / A	Table 16	N/A
Snake River transported Smolts	°C (Transport)	Table 18	N/A	N/A

Subyearling chinook exposures (Table 7) at Lower Granite Dam were highly variable for flow and spill yet more predictable for temperature and TDG.

- PE_{Flow} varied from 1% to 100%
- PE_{Spill} varied from 0% to 100%.
- PE_{Temp} varied from 44.3% to 86.2%.
- PE_{TDG} was always less than 1 for the years when it could be computed.

Subyearling chinook exposures (Table 8) at McNary Dam were not as variable for flow and spill as they were at Lower Granite Dam, but the temperature and TDG was more predictable.

- PE_{Flow} varied from near 30% to 89.8%
- PE_{Spill} had only one non-0 value during 2000 (34%)
- PE_{Temp} varied from 61.8% to 100%.
- PE_{TDG} was always less than 10 except during 2002 (29.6%).

Between years, there was no significant correlation (based on linear regression) between the LWG measures upstream and the MCN measures downstream. (Table 9)

Table 7. Snake River subyearling chinook exposures at Lower Granite Dam. N is the number of fish in the calculation

LWG (summer)	N	Fraction during Summer	Flow KCFS < 50*		Spill KCFS ≤ 30 *		Temperature °C > 18		TDG ≥ 115%	
			PE(%)	EI	PE(%)	EI	PE(%)	EI	PE(%)	EI
1995	474	0.942	52.1	54.7	100.00	16.63	78.50	19.44		
1996	141	0.892	50.9	51.1	0.00	73.16	68.80	18.79	0	103.5%
1997	124	0.891	1.0	77.7	0.00	78.96	57.30	17.86		
1998	666	0.955	11.2	63.7	21.40	52.03	82.30	19.91		
1999	559	0.830	42.9	64.8	0.00	53.10	61.40	17.91		
2000	329	0.891	96.0	38.4	36.30	29.18	77.30	18.97		
2001	195	0.931	100.0	26.1			86.20	21.34	1	107.1%
2002	493	0.961	59.2	54.1	42.10	36.84	44.30	18.22		
Average		0.912	51.7	53.8	28.54	48.56	69.51	19.06	0.5	105.3%

* Flow and spill targets varied by season and location.

Table 8. Snake River subyearling chinook exposures at McNary Dam

MCN (summer)	N	Fraction during Summer	Flow KCFS < 200*		Spill KCFS ≤ 60 *		Temperature °C > 18		Gas TDG ≥ 115%	
			PE(%)	EI	PE(%)	EI	PE(%)	EI	PE(%)	EI
1995		1.000	87.3	159.8						
1996	21	1.000	30.0	198.6			100.0	20.15	0	108.6%
1997	18	1.000	46.7	219.1			83.4	19.27	5.5	108.6%
1998	349	0.850	72.1	182.4	0.0	149.19	82.3	20.46	4.8	109.9%
1999	128	0.871	29.7	227.1	0.0	150.32	61.8	18.63	1.5	111.0%
2000	226	0.607	89.8	170.6	34.0	62.75	56.2	18.09	0	108.7%
2001	57						86.0	19.94		
2002	375	0.855	37.0	209.0	0.0	152.73	69.4	18.73	29.6	112.8%
Average		0.898	61.6	195.2	8.5	128.75	77.0	19.32	6.9	109.9%

* Flow and spill targets varied by season and location.

Table 9. Correlation of Snake River subyearling chinook exposures at McNary Dam to exposures at Lower Granite Dam.

Performance Measure	Exposure factor	# years	R^2	p
EI_{Flow}	Flow	7	0.366	0.15
EI_{Spill}	Spill	4	0.568	0.246
EI_{Temp}	Temperature	7	0.294	0.208
PE_{Flow}	Flow	7	0.0831	0.531
PE_{Spill}	Spill	4	0.162	0.597
PE_{Temp}	Temperature	7	0.0407	0.665

Yearling chinook exposures (Table 10) at Lower GraniteDam were highly variable for flow and spill, but the temperature and TDG seeweremore predictable.

- PE_{Flow} varied from near <2% to 95.2%
- PE_{Spill} varied from 1% to 100%
- PE_{Temp} varied from 1.3% to 10%.
- PE_{TDG} was always < 4%.

Yearling chinook exposures (Table 11) at McNary Dam were much less variable for flow and spill than at Lower Granite Dam. The temperature exposure was very low and stable but the TDG was much greater than at Lower Granite Dam and compared to the Chin-0 exposures.

- PE_{Flow} varied from near 0% to 47%
- PE_{Spill} varied from 0% to 15%
- PE_{Temp} varied from 1% to 7%.
- PE_{TDG} varied from 10.2% to 76%.

Table 10. Snake River yearling chinook exposures at Lower Granite Dam

LWG	N	Fraction during Summer	Flow KCFS < 85*		Spill KCFS ≤ 30 *		Temperature °C > 18		TDG ≥ 115%	
			PE(%)	EI	PE(%)	EI	PE(%)	EI	PE(%)	EI
1995	11289	0.116	44.6	92.9	100.00	9.77	6.70	11.85		
1996	2853	0.080	1.7	131.3	21.40	50.68	4.90	10.01	3.5	106.4%
1997	1316	0.130	10.2	151.8	30.30	48.41	6.60	10.55		
1998	9406	0.128	44.4	94.5	64.40	22.99	10.00	12.14		
1999	9966	0.091	8.0	118.5	1.00	42.56	5.20	11.11		
2000	9484	0.113	21.5	94.5	91.90	24.39	9.30	12.02		
2001	19517	0.015	95.2	54.4			1.30	11.97	0	103.0%
2002	6953	0.164	47.3	88.2	69.40	29.80	4.50	11.04		
Average		0.105	34.1	103.2	54.06	32.66	6.06	11.34	1.75	104.7%

* Flow and spill targets varied by season and location.

Between years, there was a significant correlation (based on linear regression) between the LWG measures upstream and the MCN measures downstream for some of the exposure indices (Table 12) most notably, the Flow and Temperature exposure indices and the proportion exposed to flows. This relationship was similar to that of the Snake River steelhead (Table 15).

Table 11. Snake River yearling chinook exposures at McNary Dam

MCN	N	Fraction during Summer	Flow KCFS < 220*		Spill KCFS ≤ 60 *		Temperature °C > 18		TDG ≥ 115%	
			PE(%)	EI	PE(%)	EI	PE(%)	EI	PE(%)	EI
1995	12759	0.067	23.7	243.2	4.40	96.79	7.40	12.88	16.10	110.8%
1996	2160	0.024	0.0	346.9	0.00	180.05	2.30	9.97	76.00	116.8%
1997	279	0.085	0.0	427.7	0.00	258.94	6.90	11.43	74.90	116.3%
1998	6672	0.076	27.8	265.8	0.40	111.68	7.50	13.20	29.60	113.1%
1999	12391	0.016	2.4	283.3	2.30	127.63	1.00	11.07	17.30	112.2%
2000	14843	0.032	13.2	263.3	2.30	108.17	3.30	12.52	17.70	112.4%
2001	8637						2.30	14.71		
2002	11556	0.039	47.0	239.2	15.00	88.98	3.00	11.82	10.20	111.9%
Average		0.042	26.8	295.6	3.49	138.89	4.21	12.20	34.54	113.4%

* Flow and spill targets varied by season and location.

Table 12. Correlation of Snake River yearling chinook exposures at McNary Dam to exposures at Lower Granite Dam.

Performance Measure	Exposure factor	# years	R^2	P
EI_{Flow}	Flow	7	0.931	0.000429
EI_{Spill}	Spill	7	0.567	0.0506
EI_{Temp}	Temperature	8	0.745	0.00577
PE_{Flow}	Flow	7	0.853	0.00295
PE_{Spill}	Spill	7	0.114	0.459
PE_{Temp}	Temperature	8	0.335	0.133

Snake River steelhead exposures (Table 13) at Lower Granite Dam were highly variable for flow and spill. The temperature and TDG exposures were very low and stable.

- PE_{Flow} varied from 1.1% to 92.9%
- PE_{Spill} varied from ~0% to 100%
- PE_{Temp} was always <1%
- PE_{TDG} was <7%

Snake River steelhead exposures (Table 14) at McNary Dam were less variable for flow and spill than at Lower Granite Dam. The temperature exposure was low and stable but TDG exposures were very variable like chinook.

- PE_{Flow} varied from 0% to 31.5%
- PE_{Spill} varied from 0% to 12.6%
- PE_{Temp} was always <1%
- PE_{TDG} varied from 19.5% to 80.4%

Table 13. Snake River steelhead exposures at Lower Granite Dam

LWG	N	Fraction during Summer	Flow KCFS < 85*		Spill KCFS ≤ 30 *		Temperature °C > 18		TDG ≥ 115%	
			PE(%)	EI	PE(%)	EI	PE(%)	EI	PE(%)	EI
1995	2987	0.002	31.3	95.3	100.00	12.02	0.10	10.59		
1996	1788	0.001	2.0	132.0	32.40	45.88	0.00	9.44	7.00	107.8%
1997	2435	0.001	1.1	165.2	9.10	50.07	0.10	9.26		
1998	4971	0.001	28.6	105.7	55.90	27.72	0.10	11.48		
1999	3535	0.000	5.4	114.5	0.10	39.69	0.00	10.66		
2000	7986	0.001	23.7	93.5	95.30	23.67	0.10	10.98		
2001	13624	0.005	92.9	61.2			0.50	11.48	0.00	102.0%
2002	5347	0.005	45.4	89.1	69.60	28.98	0.10	9.65		
Average		0.002	28.8	107.1	51.77	32.58	0.12	10.44	3.50	104.9%

* Flow and spill targets varied by season and location.

Table 14. Snake River steelhead exposures at McNary Dam

MCN	N	Fraction during Summer	Flow KCFS < 220*		Spill KCFS ≤ 60 *		Temperature °C > 18		TDG ≥ 115%	
			PE(%)	EI	PE(%)	EI	PE(%)	EI	PE(%)	EI
1995	863	0.005	23.3	238.0	11.00	94.67	0.50	12.18	21.20	111.4%
1996	541	0.000	0.0	346.9	0.00	177.34	0.00	9.85	80.40	116.9%
1997	459	0.000	0.5	427.6	0.40	258.76	0.00	10.26	80.10	117.0%
1998	1447	0.000	8.4	305.4	2.80	141.06	0.10	12.61	24.00	112.8%
1999	2717	0.000	5.1	286.2	5.00	129.35	0.00	11.42	36.70	113.2%
2000	6892	0.000	3.0	282.7	0.00	121.47	0.10	11.15	19.50	112.5%
2001	2602	0.000					0.30	14.81		
2002	6224	0.001	31.5	251.3	12.60	101.21	0.20	11.10	21.80	112.6%
Average		0.001	21.5	305.4	4.54	146.27	0.15	11.67	40.53	113.8%

* Flow and spill targets varied by season and location.

Between years, there was a significant correlation (based on linear regression) between the LWG measures upstream and the MCN measures downstream for some of the exposure indices (Table 15) most notably, the Flow and Temperature exposure indices and the proportion exposed to flows. This relationship was similar to that of the wild yearling chinook (Table 12).

Table 15. Correlation of Snake River steelhead exposures at McNary Dam to exposures at Lower Granite Dam.

Performance Measure	Exposure factor	# years	R^2	P
EI_{Flow}	Flow	7	0.92	0.000628
EI_{Spill}	Spill	7	0.674	0.0235
EI_{Temp}	Temperature	8	0.667	0.0134
PE_{Flow}	Flow	7	0.747	0.0121
PE_{Spill}	Spill	7	0.152	0.387
PE_{Temp}	Temperature	8	0.21	0.253

Columbia River steelhead exposures (Table 16) at McNary Dam were generally low for flow and spill except in 2002. The temperature exposure was low and stable but TDG exposures were variable like the Snake River steelhead and chinook.

- P_{Flow} varied from 0% to 47.6%
- P_{Spill} varied from 0% to 15.8%
- P_{Temp} was always ≤1%
- P_{TDG} varied from 7.1% to 93.3%

Table 16. Columbia river steelhead exposures at McNary Dam

MCN	N	Fraction during Summer	Flow KCFS < 220*		Spill KCFS ≤ 60 *		Temperature °C > 18		TDG (≥ 115%)	
			PE(%)	EI	PE(%)	EI	PE(%)	EI	PE(%)	EI
1995	144	0.000	9.8	259.9	0.60	111.49	0.70	14.16	56.20	114.4%
1996	116	0.000	0.0	343.0	0.00	184.42	0.00	10.53	88.70	117.9%
1997	75	0.000	0.0	441.0	0.00	269.20	0.00	11.13	93.30	118.6%
1998	108	0.000	1.9	316.2	0.00	150.30	0.00	12.79	37.00	113.4%
1999	5289	0.000	0.0	274.9	0.00	123.54	0.00	11.46	22.10	113.1%
2000	3100	0.000	13.3	252.5	0.00	102.76	0.00	12.75	13.50	112.0%
2001	186	0.010					0.00	15.12		
2002	210	0.001	47.6	237.3	15.80	86.45	1.00	11.79	7.10	112.3%
Average		0.000	21.6	303.5	2.34	146.88	0.21	12.47	45.41	114.5%

* Flow and spill targets varied by season and location.

Columbia River steelhead exposures at McNary Dam were generally the same as for the Snake River steelhead across years (Table 17). Most notably, all the EI measures were correlated ($p < .008$ and $R^2 > 0.78$).

Table 17. Correlation of exposure measures from Columbia River and Snake River steelhead at McNary Dam.

Performance Measure	Exposure factor	# years	R^2	P
EI_{Flow}	Flow	7	0.938	0.000337
EI_{Spill}	Spill	7	0.959	0.000117
EI_{Temp}	Temperature	8	0.817	0.00205
EI_{TDG}	TDG	7	0.785	0.00792
PE_{Flow}	Flow	7	0.667	0.025
PE_{Spill}	Spill	7	0.483	0.0829
PE_{Temp}	Temperature	8	0.35	0.122
PE_{TDG}	TDG	7	0.743	0.0126

Exposure of transported fish to temperature could be enumerated in a variety of ways. Fish may be transported from Lower Granite Dam (LWG), Little Goose Dam, Lower Monumental Dam, and McNary Dam (MCN). Presented here are Transport Temperature Exposure Index (EI_{TT}) and Proportion Exposed to 18°C (PE_{18}) results for LWG and MCN in (Table 18 and Table 19 respectively). Transported fish may include ESU fish but are generally hatchery fish (note the large numbers). Conditions along the Snake River were generally similar, so the EI_{TT} for the transported fish was comparable for fish from those transport sites. Fish transported from McNary may have had a significantly different exposure. The numbers of smolts within a species transported at a site varied over three orders of magnitude (chinook smolt transport at MCN declined from 1038133 smolts in 2001 to 912 smolts in 2002).

On average > 90% of all transported subyearling chinook smolts were transported from MCN. The EI_{TT} never varied by more than 1.6°C along the three Snake transport sites except during 1996 when it varied by 2.5°C. The MCN EI_{TT} never expanded the within-year range by more than 0.8°C. EI_{TT} at LWG varied from 17.2°C to 19.8°C, and PE_{18} was always over 50%. EI_{TT} at LWG varied from 17.2°C to 19.6°C, and PE_{18} varied from 31 to 97%.

On average < 5% of all transported yearling chinook smolts were transported from MCN. The EI_{TT} never varied by more than 1.1°C along the three Snake transport sites. However, the MCN EI_{TT} increased the range of exposures up to an additional 8.1°C. For example, during 1995, the EI_{TT}'s were 10.7, 11.4, and 11.3°C for the three Snake River sites LWG, LGS, and LMN respectively while the MCN EI_{TT} was 19.6°C. This was probably due to the significantly later arrivals of Columbia River yearling chinook at MCN than their Snake River counterparts. Transported yearling chinook smolts at LWG were essentially never exposed to temperatures over 18°C (PE_{18} always < 1%).

On average < 1% of all transported steelhead smolts were transported from MCN. The EI_{TT} never varied by more than 1.8°C within a year along the Snake River but the MCN EI_{TT} increased the range of exposures up to an additional 7.7°C. This was probably due to a similar timing phenomenon as the yearling chinook smolts. Transported steelhead smolts at LWG were essentially never exposed to temperatures over 18°C (PE_{18} always <3%).

Table 18. Transported Smolt exposures to temperature at Lower Granite Dam

LWG	Subyearling chinook Smolt °C > 18			Yearling chinook Smolt °C > 18			Steelhead Smolt °C > 18		
	N	PE(%)	EI	N	EI	PE(%)	N	PE(%)	EI
1995	28855	84.6	19.6	3494989	10.7	0.4	5529188	0.3	11.0
1996	15742	78.2	18.9	511896	9.3	0.2	4464286	0.3	9.2
1997	87012	77.4	18.7	276030	9.6	0.1	4180848	0.3	9.8
1998	78791	81.7	19.8	1491002	11.4	0.6	4953688	0.3	11.8
1999	254497	52.9	17.2	2044083	10.4	0.1	3087704	0.3	10.7
2000	678555	76.1	19.0	2331432	11.1	0.5	4812764	0.8	11.4
2001	736032	61.2	19.4	1874673	11.7	0.2	5307342	2.8	12.0
2002	624303	64.1	18.8	1495285	10.0	0.1	1631778	0.3	10.1

Table 19. Transported Smolt exposures to temperature at McNary Dam

MCN	Subyearling chinook Smolt °C > 18			Yearling chinook Smolt °C > 18			Steelhead Smolt °C > 18		
	N	PE(%)	EI	N	EI	PE(%)	N	PE(%)	EI
1995	5401928	97.2	19.6	19022	19.6	96.6	1125	83.4	19.3
1996	2877220	61.5	18.4	23620	14.6	4.5	9610	9.2	14.9
1997	5209575	45.3	17.9	26207	13.5	0.8	26417	1.8	13.6
1998	7948128	66.7	19.1	37341	15.9	11.5	10960	3.2	14.7
1999	3432467	31	17.2	3761	16.4	12.1	4975	25.0	16.9
2000	8484780	72.5	18.6	26011	17.9	50.4	10749	50.7	18.0
2001	10112402	68.4	18.9	1038133	15.4	3.5	239039	2.7	15.0
2002	2090815	97.2	19.6	912	18.9	90.9	1098	82.5	18.3

Discussion

This analysis illustrated there were significant differences in the exposure of different stocks in different years. Of particular significance was the difference in the spill exposure indices. In 1995, 100% of the Snake River ESU yearling chinook pass through the Snake River with spills below the spill target, while in 1999 only 1% of the fish were exposed to conditions below the target spill.

The largest difference between the ESU groups was in the exposure to temperature which was a factor that changed predictably over the season. The Snake River subyearling ESU migrated relatively late in the season and consequentially had EI > 18°C whereas the other stocks did not.

This report of ESU exposure to in-river physical conditions illustrates the variety and variability of conditions that fish may encounter in hydrosystem passage. Interpretation of these results will depend on the hypothesized impact of the exposures on the fish. Although further analysis on this is warranted this report provides a snapshot of the conditions experienced by salmon during their hydrosystem migration.

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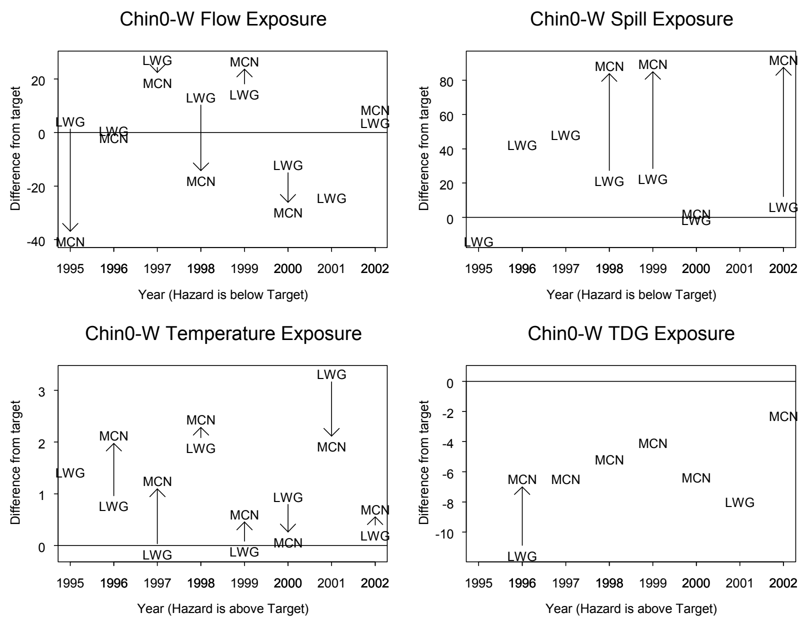
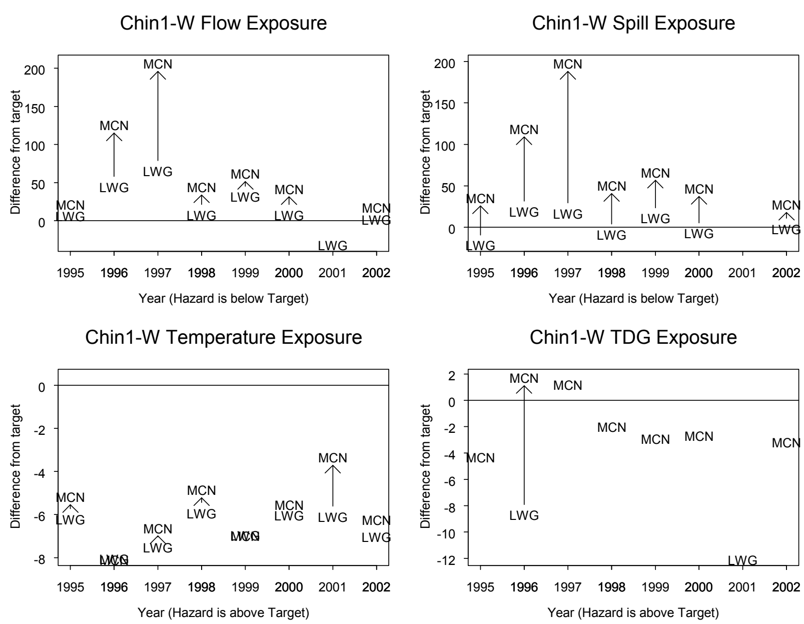
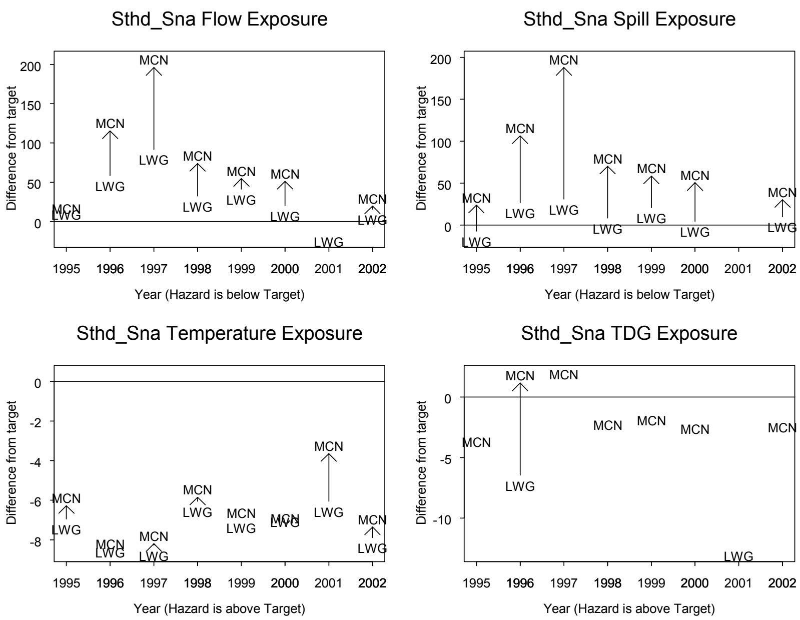
Appendix

The following graphs depict the Exposure Indices for the Snake River stocks across the eight years of study from 1995 to 2002 relative to the exposure target as they move from the upstream site at Lower Granite Dam ("LWG") to the downstream site at McNary Dam ("MCN"). For example, in almost all years the subyearling Temperature Exposure Index was above the target (18 °C) or very slightly below whereas the yearling Temperature Exposure Index was well below the target at both LWG and MCN. Arrows show the trend from upstream to downstream but are omitted if there was insufficent information or the difference was too small to depict.


Chin0-W Flow Exposure
Chin0-W Spill Exposure
Chin0-W Temperature Exposure
Chin0-W TDG Exposure
Difference from target
Year (Hazard is below Target)
Year (Hazard is above Target)
MCN
LWG


Chin1-W Flow Exposure
Chin1-W Spill Exposure
Chin1-W Temperature Exposure
Chin1-W TDG Exposure
Difference from target
Year (Hazard is below Target)
Year (Hazard is above Target)
MCN
LWG


Sthd_Sna Flow Exposure
Difference from target
Year (Hazard is below Target)
Sthd_Sna Spill Exposure
Difference from target
Year (Hazard is below Target)
Sthd_Sna Temperature Exposure
Difference from target
Year (Hazard is above Target)
Sthd_Sna TDG Exposure
Difference from target
Year (Hazard is above Target)
MCN
LWG
1995
1996
1997
1998
1999
2000
2001
2002