PERFORMANCE MEASURE INFORMATION SHEET #12

MID COLUMBIA RIVER: FISH HABITAT

Objective / Location	Performance Measure	Units	Description	MSIC
Fish Habitat/ Mid Columbia River	Average Monthly River Length	#km/month	Reports average monthly length of river that is not inundated as a result of backwatering of Arrow Reservoir. Represents food availability and serves as a proxy for habitat availability and energy requirements for key fish species.	1 km/ month
	Maximum Velocity Difference	m/sec	Represents energy requirements and displacement effects of flow changes on fish. Calculated as annual average of the maximum daily change in velocity.	10%
	Total Productive Area	Hectare-Days	Represents lower trophic productivity. Calculated as the annual average of the minimum area that is continuously wetted each month for a period of 21 days or more.	10%
	White Sturgeon Habitat Suitability	Weighted Useable Area (WUA) (m^2)	Reports on the minimum weighted useable area based on depth and velocity during the sturgeon spawning period (15 July – 15 August)	10%

Description

Discharge from Revelstoke Dam undergoes extreme fluctuations over short time periods. It is not uncommon for discharge to drop to zero during the middle of the night when power demand is low. During the day, discharge can exceed 1600 m^3/sec. These short-term or diel variations in flow are potentially harmful to white sturgeon, bull trout, rainbow trout, sculpin and dace that use the mid Columbia River (MCR) downstream of Revelstoke Dam. Predicting the effects of changes in depth, velocity and habitat area on fish populations is highly uncertain and controversial. A simple conceptual model shows how these physical factors could influence the somatic growth and survival rates of fish populations in the river (Figure 1). Diel variation in flow influences the inundation frequency of substrates at different elevations and very likely affects the productivity of lower trophic levels that provide food for fish. Previous efforts to find benthic invertebrates in the MCR for stable isotope analysis had limited success (D. Hunter, BC Hydro, Burnaby BC, pers. comm.); there is little doubt that the fluctuating flows in the MCR severely limit benthic invertebrate abundance, although the highly armoured riverbed could become a limiting factor if flow fluctuations were reduced. Higher discharges will increase the amount of wetted area by increasing river width, but this area may not be useable or of lesser value if velocities are very high, or if velocities and depths fluctuate over short time periods. These fluctuations increase energy expenditure because fish must constantly be moving to find suitable depth and velocity conditions. This movement also increases predation risk, especially for juvenile and small fish.

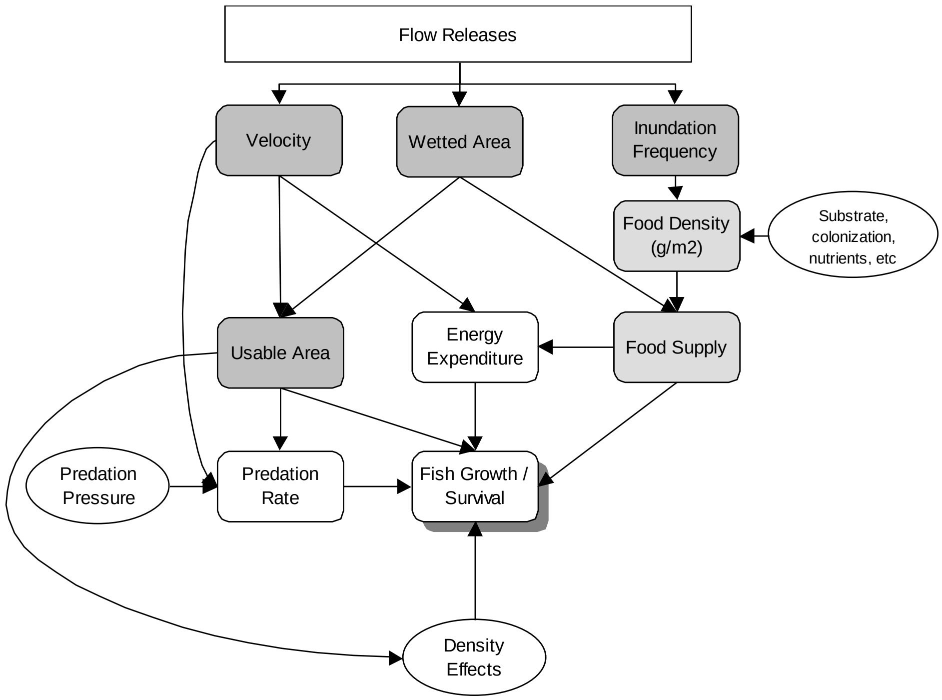

Figure 1. Conceptual Model of the Potential Relationships between Physical Factors affected by Discharge from Revelstoke Dam and Important Processes affecting Fish Populations in the MCR

Four performance metrics were developed to account for the dynamics of these hypotheses. Functional river length is computed as a measure of the average annual minimum length of large river habitat that is functional downstream of Revelstoke Dam. The average maximum daily velocity difference over the month is computed as a measure of potential energy expenditure and predation risk. The amount of productive habitat, defined as the area of substrate that is continuously submerged for more than 21 days, is computed as an index of the response of lower trophic levels (algae and benthic invertebrates) to flow variation. In addition, an index of sturgeon spawning habitat suitability was computed, as sturgeon are known to spawn near the confluence of the Jordan River in the MCR.

Calculations

The computation of MCR fish habitat performance measures in the Revelstoke Reach of Arrow Reservoir is based on results from the HEC-RAS 1-dimensional (1D) backwater hydraulic model. HEC-RAS is the official software released by the U.S. Army Corps of Engineers to perform both steady- and unsteady-state flow analyses in a river system. Such 1D hydraulic models are commonly used to predict the effects of discharge on wetted width, depth and average velocity at individual cross sections. The relationships between discharge and width, depth and velocity at particular cross-sections are referred to as hydraulic geometry. The effects of backwatering are considered in the HEC-RAS model, which is important as Arrow Reservoir water surface elevations have a large influence on width, depth, and velocity in the MCR.

The HEC-RAS model was run under a large range of discharges and downstream boundary conditions (Arrow Reservoir elevations) to generate a series of lookup-tables for water elevation, wetted width and average cross-sectional velocity. Flow scenarios consist of a series of hourly predictions of discharge from the BC Hydro GOM model and corresponding local inflows and reservoir elevations for each day. The flow and elevation data from these scenarios are used to find the appropriate water surface, width, and velocity estimates in the lookup tables for all cross-sections for each time step. These values are then used to compute the maximum daily velocity difference and the amount of productive and total wetted area.

Predictions of discharge at each cross-section for each time period form the basis of the computations. Discharges at each cross-section are assumed to be the same for a given 2-hour time step, except for the local inflows that are added at particular locations downstream of the dam. That is, the flow throughout the MCR varies spatially due to local inflows, but not temporally. In reality, even in the absence of local inflows, the discharge at an upstream cross-section at a particular time will be different than the discharge at a downstream location at that same time if releases from the dam are not constant. This temporal variation in discharge among cross-sections (unsteady flow) is controlled by the travel time of the discharge wave and the extent to which the wave gets attenuated.

The HEC-RAS model was developed from 245 cross-sections of the mid Columbia River from Revelstoke Dam to below the confluence of the Akolkolex River (about 37 km). The model was run under all combinations of 20 reservoir elevations ranging from 422-441 m.s.l. and 29 discharges ranging from 1-2832 m^3/sec. For each of these 580 runs, the predicted water surface elevation, wetted width and average velocity was saved for each of the 245 cross-sections. Lookup tables for each of these parameters consisted of 245 columns for the cross-sections and 580 rows for all the combinations of discharge and reservoir elevation.

Discharge at a cross-section is computed by,

$$Q_{cx} = Q_{\mathrm{Re}v} + Q_{Leak} + Q_{local} * Drain_{cx} \qquad [1]$$

where, Q_{cx} is the discharge at cross-section 'CX', Q_{Rev} is the total discharge released from Revelstoke Dam, Q_{Leak} is the assumed leakage from all components of the dam (assumed to be constant 300 ft^3/sec or 8 m^3/sec, L. Hildebrand, Golder and Associates, Castlegar, BC, pers. comm.), Q_{local} is the total local inflow to Arrow Reservoir, and $Drain_{cx}$ is the cumulative proportion of the local Arrow Reservoir watershed draining into cross-section 'CX'.

Historical inflows show strong seasonality, which is driven by snowmelt. Local inflows used in the scenario analysis correspond to inflows estimated for the 1964/65 to 1973/74 water years.

The computations for the three fish habitat performance measures for the MCR are described below.

Average Monthly Maximum Daily Velocity Difference

- Discharge for each cross-section every 2 hours for each day is computed from Eqn. 1.
- Based on the 2-hour discharge estimates and hydraulic geometry generated from the HEC-RAS model, the maximum and minimum average cross-sectional velocities are computed for each day and cross-section;
- The difference between maximum and minimum velocities at each cross-section are computed for each day and averaged over the month;
- A weighted average across all cross-sections that make up the riverine portion of the modeled area is used to compute the river-wide average maximum velocity difference for each month. The weighting is based on the length of river each cross-section represents;

- If multiple years of hydrology are used in the analysis, monthly values are averaged across years. The standard deviation of the performance measure for any month is computed from the variability across years.

Productive Habitat Area

- The amount of area at 0.25m elevation increments for each cross-section is computed;
- The minimum daily discharge for each day over the month is used to determine which of the 0.25m elevation 'slices' for each cross-section are wet;
- An elevation slice is considered productive when it has been continuously wetted for 21 days or more. The number of productive days for each slice-cross-section combination over each month is computed. An estimate of 21 days was used as the minimum time required for a significant benthic community to develop following inundation;
- The monthly productive area for each slice-cross section combination is the product of the number of productive days times the area that the slice represents. The sum of these products across all cross-sections that are riverine in nature (average daily velocity >=0.2 m/sec) is used to compute the productive area statistic, which is in units of Hectare-Days.

Functional River Length

- The average cross-sectional velocity for each day at each cross-section given flow and reservoir elevations is computed.
- The distance between each cross-section is considered to be functional river if the average velocity exceeds a minimum criterion of 0.2 m/sec.
- The sum of those functional lengths is the functional length of river for each day.
- The average functional length over each month is then computed from the daily values.

Sturgeon Spawning Habitat

A small subset of these cross-sections (5) was used to model the hydraulic geometry in the area that is used for spawning by white sturgeon. This smaller model area extends 300 m upstream and downstream of the confluence with the Jordan River. Predictions of velocity for a given discharge were used to compute spawning habitat suitability based on published sturgeon spawning habitat suitability relationships (Parsley et al. 2000, Parsley and Beckman 1994). Water surface profiles computed by HEC-RAS for each NTSA scenario on a bi-hourly time step for the 10-year record (1964-1973) were used to predict depth and velocity at individual vertical cells (20 per cross-section averaging 10-12 m in width) for each modeled cross-section. Predictions of velocity for each cell were translated into suitability values ranging from 0 to 1. Weighted-useable-area (WUA) for each time step was computed as the sum of the product of the cross-sectional area for each cell (A_i) and its suitability value for velocity. Time-specific results were summarized by computing the percentage of time WUA was above 200 m^2 when summed across cross-sections over the spawning and rearing period (July 15-August15).

Results

Average Monthly Maximum Daily Velocity Difference

There is very little difference among the NTS scenarios for the maximum daily velocity difference measure (Figure 2, Table 1). The exception to this is Scenario D, which on average performs worse during the months of September and October (i.e., a greater daily velocity difference).

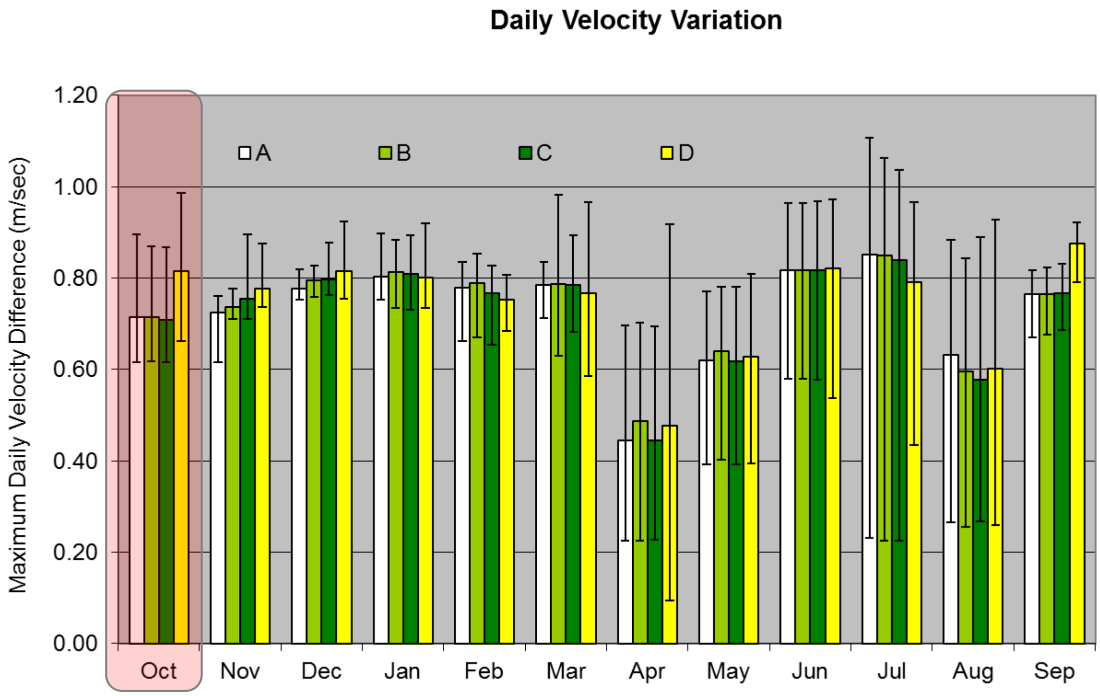

Figure 2. The Average of the Maximum Difference in Velocity over a day in the Revelstoke Reach by Month between 1964 and 1973 across the Four NTSA Scenarios. Error bars show the minimum and maximum values over the 10 simulation years. Red-shaded results carried forward into Consequence Table.

Table 1. Statistics on the Maximum Difference in Velocity over the Day in Revelstoke Reach across Four NTSA Scenarios by month

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Average												
A	0.71	0.72	0.78	0.80	0.78	0.79	0.45	0.62	0.82	0.85	0.63	0.76
B	0.72	0.74	0.79	0.81	0.79	0.79	0.49	0.64	0.82	0.85	0.59	0.76
C	0.71	0.75	0.80	0.81	0.77	0.78	0.45	0.62	0.82	0.84	0.58	0.77
D	0.82	0.78	0.82	0.80	0.75	0.77	0.48	0.63	0.82	0.79	0.60	0.88
Median												
A	0.66	0.73	0.77	0.80	0.78	0.79	0.40	0.61	0.87	0.92	0.66	0.78
B	0.67	0.73	0.79	0.81	0.80	0.78	0.46	0.64	0.90	0.88	0.60	0.78
C	0.67	0.73	0.79	0.80	0.77	0.79	0.40	0.61	0.87	0.92	0.56	0.78
D	0.82	0.77	0.81	0.79	0.75	0.77	0.46	0.63	0.89	0.86	0.57	0.89
Minimum												
A	0.62	0.61	0.75	0.75	0.66	0.71	0.23	0.39	0.58	0.23	0.27	0.67
B	0.62	0.71	0.76	0.73	0.67	0.63	0.22	0.40	0.58	0.22	0.26	0.68
C	0.62	0.71	0.76	0.73	0.65	0.68	0.23	0.39	0.58	0.22	0.27	0.69
D	0.66	0.74	0.75	0.73	0.68	0.59	0.09	0.39	0.54	0.43	0.26	0.79
Maximum												
A	0.89	0.76	0.82	0.90	0.84	0.83	0.70	0.77	0.96	1.11	0.88	0.82
B	0.87	0.78	0.83	0.88	0.85	0.98	0.70	0.78	0.96	1.06	0.84	0.82
C	0.87	0.90	0.88	0.89	0.83	0.89	0.69	0.78	0.97	1.04	0.89	0.83
D	0.99	0.88	0.92	0.92	0.81	0.97	0.92	0.81	0.97	0.97	0.93	0.92
10th Percentile												
A	0.62	0.62	0.75	0.75	0.67	0.72	0.23	0.41	0.58	0.28	0.28	0.67
B	0.62	0.71	0.76	0.74	0.68	0.64	0.23	0.42	0.59	0.28	0.27	0.68
C	0.62	0.71	0.76	0.73	0.66	0.69	0.24	0.41	0.58	0.27	0.28	0.69
D	0.66	0.74	0.76	0.74	0.69	0.59	0.11	0.41	0.55	0.44	0.28	0.79
90th Percentile												
A	0.89	0.76	0.82	0.89	0.83	0.83	0.69	0.77	0.96	1.10	0.88	0.81
B	0.87	0.77	0.83	0.88	0.85	0.97	0.70	0.78	0.96	1.06	0.84	0.82
C	0.86	0.89	0.87	0.89	0.83	0.89	0.69	0.78	0.97	1.03	0.88	0.83
D	0.98	0.87	0.92	0.91	0.81	0.95	0.90	0.80	0.97	0.96	0.92	0.92

Productive Habitat Area

All of the “with NTS” scenarios perform similarly for the productive area measure (Figure 3, Table 2). However, Scenario D performs on average worse during the months of August through October, and better during the months of March and July.

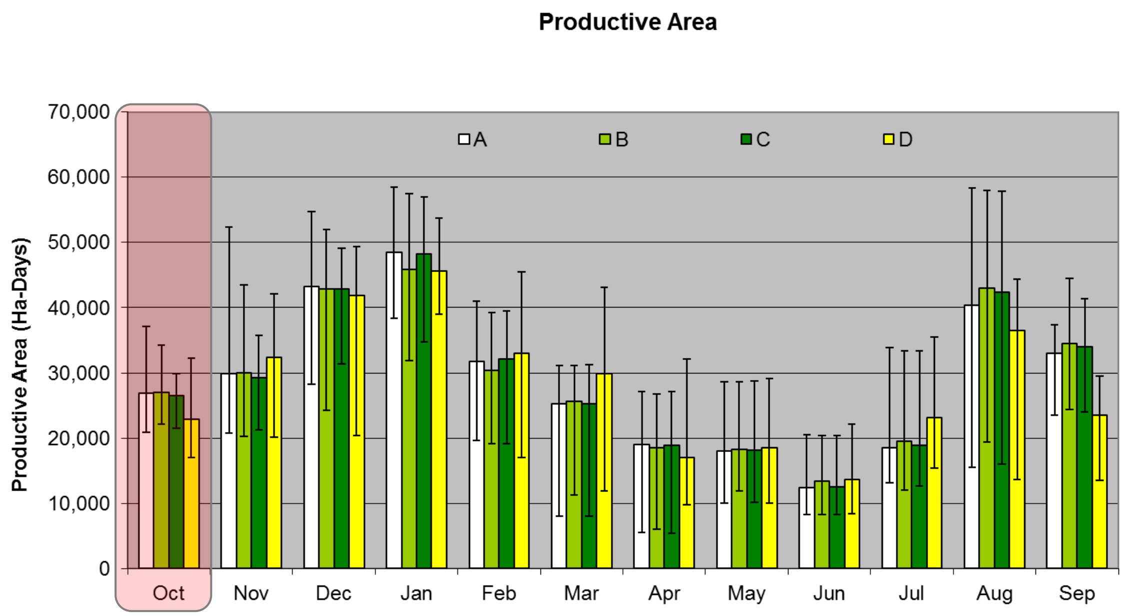

Figure 3. The Average of the Productive Area in the Revelstoke Reach by Month between 1964 and 1973 across the Four NTSA Scenarios. Error bars show the minimum and maximum values over the 10 simulation years. Red-shaded results carried forward into Consequence Table

Table 2. Statistics on the Productive Area (Ha-days) in the Revelstoke Reach across Four NTSA Scenarios by Month

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Average												
A	26,912	29,926	43,282	48,415	31,690	25,240	19,044	18,071	12,469	18,475	40,347	32,981
B	27,050	30,015	42,910	45,858	30,430	25,589	18,567	18,273	13,455	19,552	42,957	34,457
C	26,465	29,301	42,891	48,199	32,128	25,300	18,838	18,162	12,479	18,858	42,387	33,984
D	22,949	32,334	41,882	45,625	33,057	29,925	17,055	18,542	13,594	23,091	36,451	23,510
Median												
A	26,867	28,443	45,141	48,580	32,098	25,988	19,906	16,744	10,718	16,945	42,771	33,426
B	26,997	30,003	45,458	45,293	30,548	26,387	19,392	16,496	11,283	20,200	45,095	34,099
C	27,153	30,453	45,458	49,493	32,674	26,554	20,033	16,726	10,716	16,507	46,013	34,276
D	22,987	35,202	45,702	43,755	34,198	30,275	14,471	17,325	11,593	23,684	39,572	24,743
Minimum												
A	20,836	20,787	28,238	38,410	19,673	8,028	5,491	9,994	8,304	13,139	15,567	23,458
B	22,190	20,293	24,248	31,904	19,099	11,241	5,993	11,889	8,300	12,061	19,342	24,430
C	21,514	21,234	31,428	34,712	19,139	8,055	5,440	10,136	8,297	12,636	16,017	23,999
D	16,997	20,096	20,352	39,002	16,967	11,928	9,725	10,081	8,425	15,363	13,693	13,468
Maximum												
A	37,098	52,300	54,767	58,467	40,934	31,137	27,093	28,660	20,512	33,849	58,319	37,322
B	34,259	43,541	51,985	57,505	39,238	31,135	26,710	28,667	20,452	33,386	57,949	44,508
C	29,908	35,797	49,063	57,019	39,549	31,246	27,124	28,741	20,436	33,395	57,784	41,325
D	32,308	42,140	49,352	53,690	45,450	43,137	32,116	29,101	22,104	35,442	44,410	29,493
10th Percentile												
A	20,851	21,202	28,720	38,435	20,363	9,596	6,338	10,360	8,333	13,142	16,654	24,162
B	22,307	20,700	25,388	32,541	19,829	12,484	6,758	12,064	8,329	12,144	20,095	25,011
C	21,719	21,296	31,734	35,126	19,974	9,674	6,297	10,490	8,327	12,770	17,071	24,625
D	17,021	20,115	21,073	39,206	17,701	12,542	9,888	10,399	8,500	15,378	15,312	14,066
90th Percentile												
A	36,773	50,376	54,275	58,256	40,506	31,110	26,965	28,228	20,397	32,709	57,313	37,278
B	33,846	42,627	51,698	57,066	39,149	31,111	26,434	28,359	20,426	32,457	57,765	43,994
C	29,882	35,666	48,993	57,017	39,422	31,238	26,828	28,348	20,348	32,367	57,234	41,101
D	31,684	41,972	49,347	53,614	45,069	42,922	31,679	28,863	21,956	34,596	44,287	29,166

Functional River Length

The functional river length measure showed poorer performance under Scenario D from August to January-February due to elevated reservoir elevation (Figure 4, Table 3).

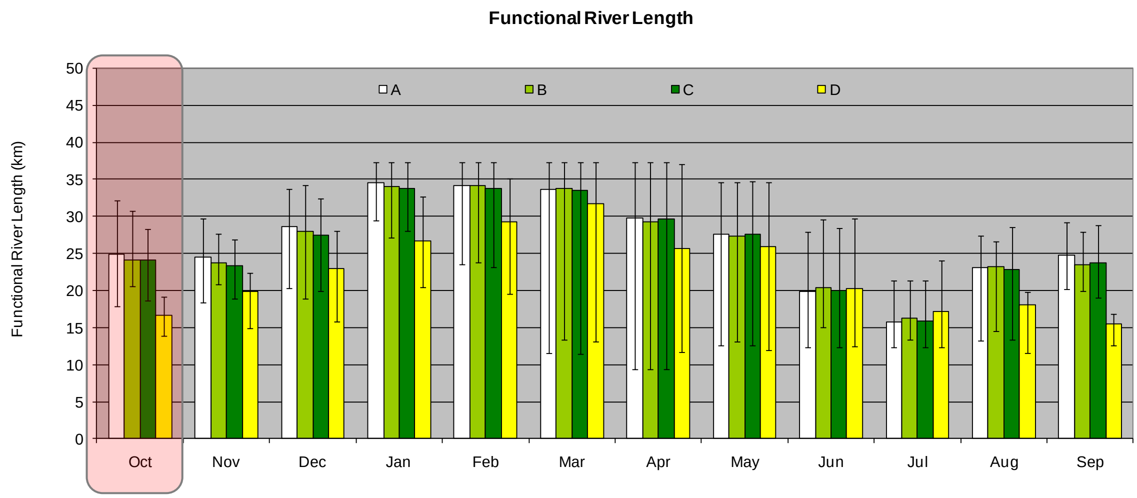

Figure 4. The Average Monthly Length of Large River Habitat in the Revelstoke Reach by Month between 1964 and 1973 across the Four NTSA Scenarios. Error bars show the minimum and maximum values over the 10 simulation years. Red-shaded results carried forward into Consequence Table

Table 3. Statistics on the Length of Functional River (Km) in the Revelstoke Reach of Arrow Reservoir across Four NTSA Scenarios by Month

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Average											
A	24.88	24.51	28.60	34.61	34.12	33.64	29.78	27.53	19.93	15.78	23.09
B	24.09	23.76	27.97	34.01	34.10	33.75	29.26	27.30	20.33	16.30	23.16
C	24.10	23.35	27.47	33.79	33.72	33.51	29.70	27.59	19.98	15.90	22.79
D	16.60	19.81	22.97	26.70	29.29	31.75	25.60	25.87	20.23	17.21	18.10
Median											
A	24.43	24.93	29.60	36.35	37.08	37.32	32.82	27.93	18.05	15.58	24.58
B	23.84	23.25	28.22	36.53	37.27	37.32	31.23	26.95	17.94	15.70	24.60
C	23.56	23.61	27.96	36.01	37.07	37.31	32.37	27.93	18.05	15.24	23.69
D	16.66	19.96	24.48	27.54	31.50	35.34	24.56	25.62	18.84	16.73	19.04
Minimum											
A	17.88	18.35	20.37	29.44	23.51	11.62	9.37	12.64	12.33	12.36	13.27
B	20.64	20.80	18.96	27.17	23.83	13.43	9.34	13.06	15.04	13.43	14.57
C	18.67	18.86	19.97	28.00	23.21	11.51	9.33	12.66	12.35	12.28	13.36
D	13.91	14.91	15.86	20.49	19.50	13.18	11.73	12.01	12.45	12.39	11.51
Maximum											
A	32.14	29.75	33.77	37.37	37.37	37.37	37.27	34.66	27.91	21.39	27.36
B	30.71	27.62	34.19	37.37	37.37	37.37	37.27	34.67	29.56	21.33	26.57
C	28.36	26.93	32.43	37.36	37.35	37.37	37.25	34.72	28.43	21.33	28.55
D	19.12	22.35	27.99	32.72	35.07	37.37	37.01	34.66	29.73	24.00	19.86
10th Percentile											
A	18.29	18.50	20.47	29.48	23.72	13.42	11.00	13.76	12.70	12.46	13.84
B	20.73	20.87	19.21	27.32	23.86	15.05	10.94	14.14	15.14	13.44	15.13
C	18.95	19.06	20.14	28.02	23.29	13.33	10.97	13.78	12.72	12.40	13.96
D	14.04	15.22	15.91	20.58	19.68	14.33	12.69	13.11	12.75	12.62	12.01
90th Percentile											
A	31.85	29.49	33.75	37.37	37.37	37.37	37.23	34.65	27.89	21.05	27.31
B	30.45	27.47	34.12	37.37	37.36	37.37	37.26	34.66	29.37	21.17	26.49
C	28.25	26.82	32.42	37.35	37.35	37.37	37.21	34.71	28.35	21.00	28.27
D	19.07	22.34	27.71	32.38	35.07	37.34	36.92	34.37	29.63	23.52	19.86

Sturgeon Spawning Habitat

Sturgeon spawning habitat increases with discharge from Revelstoke Dam because higher flows increase velocity (Figure 5). For a given flow, spawning habitat declines with increasing reservoir elevation because higher elevations result in lower velocities due to backwatering.

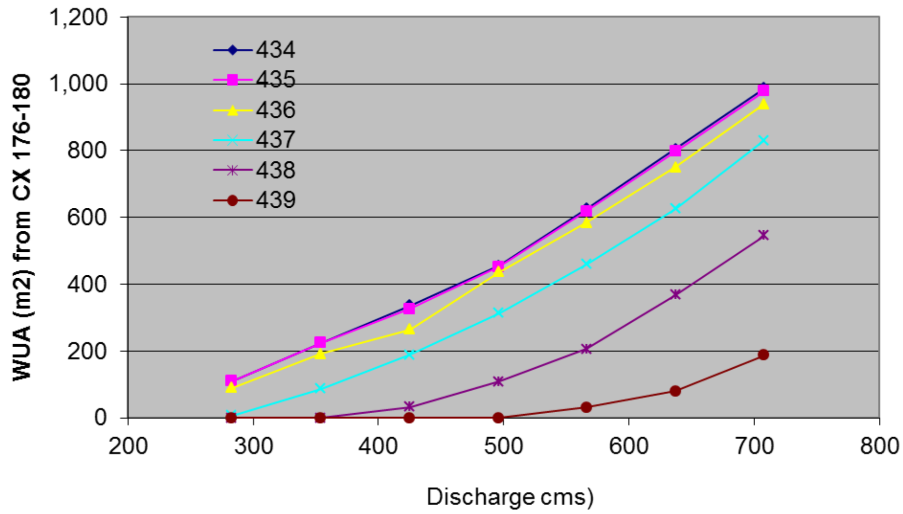

Figure 5. Relationships between Weighted-useable-area (WUA) for White Sturgeon Spawning Habitat and Discharge and Reservoir Elevations in the MCR near the Jordan River. Suitability increases with velocity, so WUA increases with discharge and decreases with reservoir elevation

Differences in the sturgeon spawning performance measure among the NTS scenarios are modest (Figure 6, Table 4). On average, Scenario D provides the highest sturgeon WUA values due to higher velocities during the July 15-August 15 period in most years.

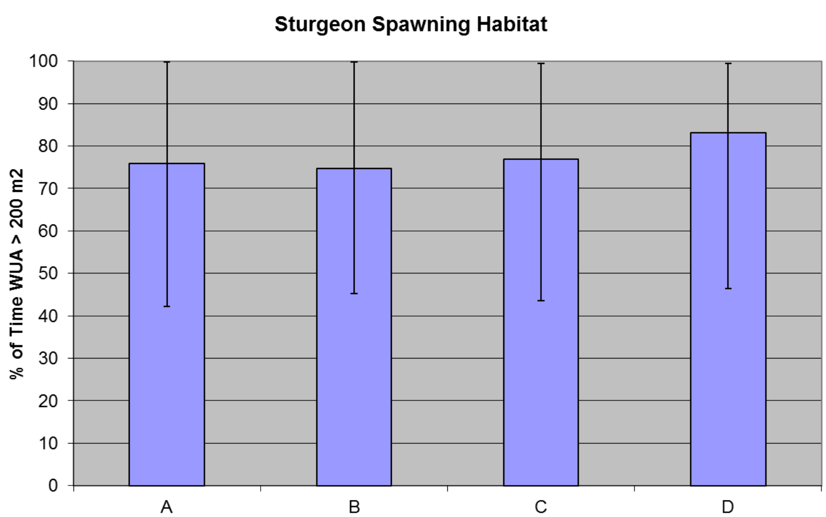

Figure 6. Average Percent of Time Weighted Useable Area for White Sturgeon Spawning Habitat in the Revelstoke Reach is Greater than 200 m^2 for the Four NTSA Scenarios between 1964 and 1973. The error bars show minimum and maximum values

Table 4. Statistics on the Percentage of Time White Sturgeon Spawning Habitat Weighted Useable Area exceeds 200 m^2

	Scenario			
	A	**B**	**C**	**D**
Mean	76	75	77	83
Median	77	77	79	87
Minimum	42	45	43	46
Maximum	100	100	99	99
10th Percentile	44	47	45	49
90th Percentile	99	98	99	99

References

Parsley, M.J. and L.G Beckman. 1994. White sturgeon spawning and rearing habitat in the Lower Columbia River. North American Journal of Fisheries Management 14:812-827.

Parley, M.J, and K.M. Kappenman. 2000. White sturgeon spawning areas in the Lower Snake River. Northwest Sciece 74:192-20.