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MEMORANDUM

TO: Bob Heinith, CRITFC

FROM: FPC Staff

DATE: August 17, 2009

RE: WTT and Fish Survival and the 1 Maf of Supplemental Canadian Storage

In response to your request, we have estimated the impact of the 1 Maf of Supplemental Canadian Treaty storage water on Columbia River Water Transit Times (WTT) and the resultant impact on migrating juvenile fish survival. For this analysis, we utilized the actual release accounting of the 1 Maf of flow augmentation released at Arrow Dam provided by BPA for 2008 (April 1st, 2008 to July 31st, 2008). We then modified these Arrow outflows into three additional scenarios:

1. Actual 2008 1 Maf Release
2. Estimations of Columbia River flows had the 1 Maf not been provided in 2008
3. Reshaping the 1 Maf to maximize releases in May and June
4. Reshaping the 1 Maf to maximize releases in July

The following plot shows each scenario described above.

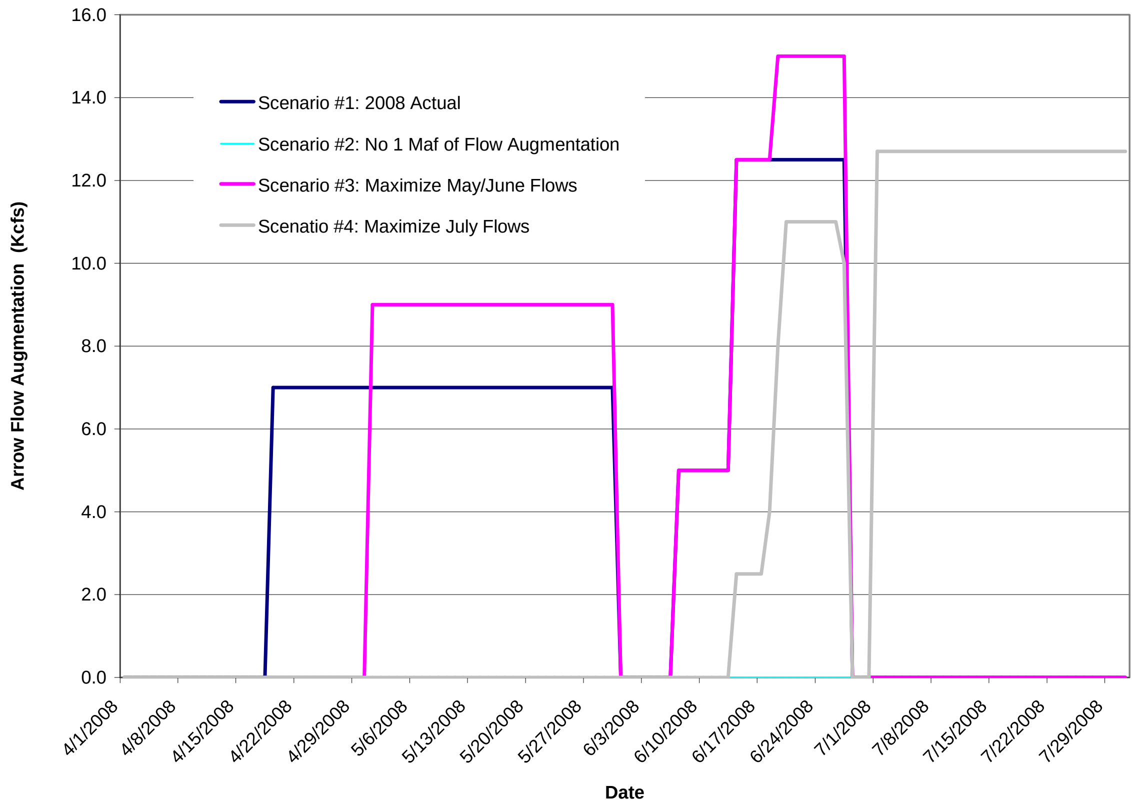

Figure 1. Four scenarios for the 1 Maf of flow augmentation used in this analysis.

For each scenario, FPC staff used actual river discharge data from April 1, 2008 to July 31, 2008 at the following projects that would be impacted by the 1 Maf of flow Augmentation from Canadian Storage: Rocky Reach, Rock Island, Wanapum, Priest Rapids, McNary, and John Day. It was assumed that changes in the 1 Maf of flow augmentation would have immediate impacts at projects downstream. For example, for Scenario #2 Columbia River flows without all the 1 Maf of flow augmentation, actual daily river discharges at each mentioned project were decreased in accordance with the actual values released in 2008. Also, BPA personnel informed us of several limitations to outflows at Arrow Dam that were accounted for in Scenarios 3 and 4 that reshaped the 1 Maf of flow augmentation. These limitations are that the 1 Maf must be released from Arrow between April 15th and July 31st and total Arrow outflows could not exceed 30 Kcfs (personal communication BPA staff).

After determining the river flows for each project under each of the four scenarios listed above, Water Transit Times (WTT) were calculated. The Reservoir Replacement Method was used for calculating water transit times through each reservoir. This method is a calculation of the time needed to completely drain a reservoir of a known volume at a given discharge (or flow). This method is routinely used to calculate water transit times in reservoirs and was recommended by personnel from the US Army Core of Engineers (COE). The COE suggested using the storage replacement method for calculating Water Transit Time between respective pools based on the fact that the average water transit time is the same as the time that it takes to completely replace the volume of water contained in a reservoir. An "average" particle of water starting at the upstream end of the pool will "theoretically" exit at the downstream end when the volume of water that was in the pool has exited from the downstream end of the pool.

The formula for the calculation of Water Transit Time using the "storage replacement method" is:

$$WTT\ (s) = Reservoir\ Volume\ (ft^3) / Flow\ (ft^3/s)$$

The Hanford Reach (Priest Rapids to the Yakima River) in the Mid Columbia is a free-flowing section and, therefore, Water Transit Times were estimated using a different method. The Pacific Northwest National Laboratory provided estimates of water transit times at various discharges using their 1D unsteady flow model (MASS1) (Richmond, Perkins, Chien, 2002). Figure 2 displays the relationship between water transit times from Priest Rapids Dam to the confluence with the Yakima River (Hanford Reach) and flow through the reach as provided by the PNNL.

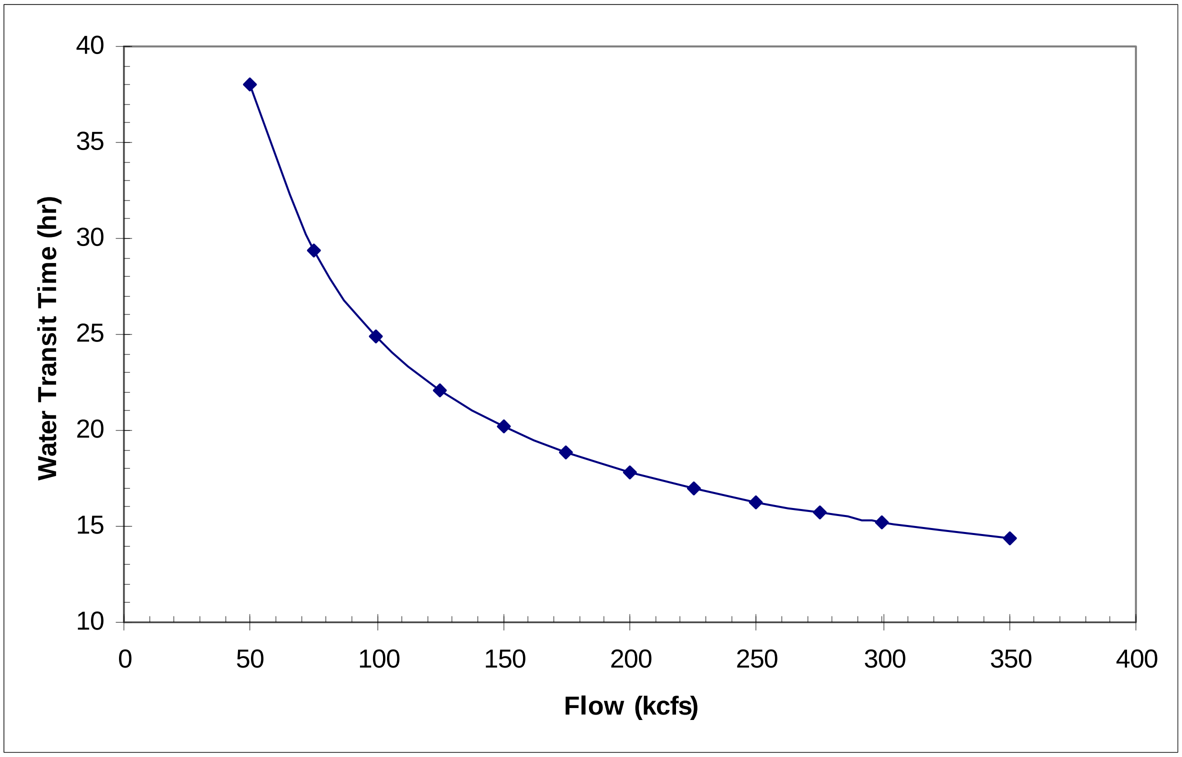

Figure 2. Water Transit Time from Priest Rapids Dam to the confluence with the Yakima River (Hanford Reach) versus flow through the reach estimated using MASS1 models provided by the PNNL.

FPC staff used the forebay elevations and storage volumes displayed in Table 1 for all calculations of Water Transit Time in the analysis. Because forebay elevations (and volumes) remained constant for each project, changes in Water Transit Times between each of the four scenarios was entirely driven by the changes in flow through the reservoir under each of the scenarios.

Table 1. Forebay Elevations used in Water Transit Time estimations under all scenarios.

	Forebay Elevation (ft)	Storage at Forebay Elevation (ft^3)
Rocky Reach	706.0	16,473,311,712
Rock Island	612.6	5,617,860,019
Wanapum	569.8	24,504,123,917
Priest Rapids	486.9	8,309,265,846
McNary	338.7	56,710,764,000
John Day (MIP)	262.0	96,642,216,000

Previous FPC analyses were utilized to determine the relationship between Water Transit Time and juvenile survival (FPC 2008 Annual Report). Three groups of juvenile fish were utilized for survival estimates: Steelhead, yearling Chinook, and subyearling Chinook. Past FPC analyses utilized PIT-tagged yearling Chinook and Steelhead marked and released at Rock Island Dam in the years 1998 to 2007 and subyearling and hatchery releases from Wells NFH in the years 1998 to 2004. Three distinct detection groups were created for each year (except for subyearling Chinook) and survival estimates were generated for each group when sample sizes were adequate within the time periods, to estimate survival through the reach. For the yearling Chinook and Steelhead analysis, fish marked at Rock Island Dam bypass between April 21 and June 1 were included in three two-week release groups for subsequent analysis for the Rock Island Dam tailwater to McNary Dam reach. In contrast, subyearling Chinook were grouped in a single annual release for analysis of survival in the reach Wells Dam tailwater to John Day Dam tailwater.

Survival estimates were transformed using a logit transformation. Logit transformed survival was regressed against WTT using SYSTAT statistical software, and the resulting models are reported, including parameter coefficients, adjusted R square, and p values. These relationships were used to estimate the survival impact that changing water transit time conditions would have had upon fish in this reach under each scenario. The analysis used weighted regression because there was unequal confidence in the survival estimates based on the considerable difference in the variances of the estimates. The inverse relative variance was used to weight individual estimates (Burnham et al 1987). At the $\alpha = 0.05$ level, the FPC found a significant relationship between water transit time and juvenile reach survival for all species, reaches, and release dates analyzed, except for subyearling summer Chinook from Wells Hatchery. For these fish, the relationship between water transit time and juvenile reach survival was significant at the $\alpha = 0.1$ level ($p = 0.074$). Each of these relationships are reported in Appendix A.

Average river flow under each scenario was calculated based on 2008 fish travel time through each reach (2008 FPC Annual Report). Using the 2008 fish travel time for each group between dams, average flows were calculated for each scenario and each species (and where applicable, release group). Each average flow was an indicator of conditions each group experienced while passing through the reach. Conditions at downstream dams were averaged over two weeks and the fish travel time to the next dam was used to adjust the start date of the calculations. Since the Mid-Columbia dams do not have juvenile passage detections, fish travel time was calculated for the entire reach—Rock Island to McNary Dam. Fish travel time to dams between Rock Island and McNary dams was estimated based on the proportion of the total distance between dams that each dam represented. For example, in the reach Rock Island Dam to McNary Dam, for the earliest detection group in 1998 (marked from 4/21 to 5/4), travel time was estimated to be 7.6 days based on 20 detections. Travel time to Wanapum Dam, which is approximately 23% of the total distance from Rock Island to McNary, was calculated as the (total travel time * proportion of distance) or (7.6d * 0.23 = 1.8d). Based on this information, river flow at this site would have been averaged for the two week period April 23 to May 6. Similar two-week average values were generated for all river flows at all dams. Once an average discharge and forebay elevation (Table 1) at each dam were known, Water Transit Times could then be calculated using the methods explained above. The overall reach Water Travel Times were the sum of these calculated values for each project within the reach.

After Water Transit Times were calculated for each species and release group over each reach for each scenario, survivals were predicted based on the relationships explained above between Water Transit Time and juvenile survival. Again, these relationships are included in Appendix A.

Results:

The following tables display the results of this analysis. Table 2 displays the Water Transit Times for steelhead (ST), yearling Chinook (CH1), and subyearling summer Chinook (CH0) under each of the four scenarios presented. Table 3 displays the survivals for the same species over all four scenarios.

Table 2. Calculated WTT (days) under four Water Transit Time Scenarios based on 2008 water conditions for steelhead (ST), yearling Chinook (CH1), and subyearling summer Chinook (CH0).

				WTT Scenario			
Species	**Release Site**	**WTT Reach**	**Release Date(s)**	**1**	**2**	**3**	**4**
ST	RIS	RIS - MCN	4/21-5/4	7.3	7.7	7.4	7.7
			5/5-5/18	5.4	5.6	5.4	5.6
			5/19-6/1	4.1	4.1	4.0	4.1
CH1	RIS	RIS – MCN	4/21-5/4	6.8	7.1	6.8	7.1
			5/5-5/18	5.1	5.3	5.1	5.3
			5/19-6/1	4.1	4.1	4.0	4.1
CH0	WELH	WELH - JDA	6/16	14.0	14.2	14.1	13.4

Table 3. Predicted reach survival under four Water Transit Time Scenarios based on 2008 water conditions and travel times for steelhead (ST), yearling Chinook (CH1), and yearling summer Chinook (CH0).

				Survival Scenario			
Species	**Release Site**	**Surv. Reach**	**Release Date(s)**	**1**	**2**	**3**	**4**
ST	RIS	RIS - MCN	4/21-5/4	0.47	0.45	0.47	0.45
			5/5-5/18	0.61	0.59	0.61	0.59
			5/19-6/1	0.69	0.69	0.69	0.69
CH1	RIS	RIS – MCN	4/21-5/4	0.66	0.66	0.66	0.66
			5/5-5/18	0.71	0.70	0.71	0.70
			5/19-6/1	0.73	0.73	0.73	0.73
CH0	WELH	WELH – JDA	6/16	0.34	0.34	0.34	0.36

For all species, juvenile reach survival decreased as water transit time increased. Given this consistent relationship between water transit time and juvenile reach survival, we found that Scenarios 1 and 3 resulted in the highest overall estimates of juvenile reach survival (Table 3), although survival differences between scenarios were generally small. In all cases, scenarios 1 and 3 resulted in the same estimates of reach survival due to these two scenarios being very similar in terms of flows and resulting water transit times. Scenario #1 included releases of the 1 Maf of Canadian Supplemental storage as it actually occurred, which was generally focused on late April, May and early June (Figure 1). Scenario #3 was very similar, except focused more water in May and June (Figure 1). Finally, Scenario #2 and #4 nearly always resulted in the lowest estimates of juvenile reach survival, which is likely due to the fact that these scenarios consistently resulted in the highest estimates of Water Transit Time (Table 3, Figure 1). The lower survivals seen in scenario #2 and #4 appear to make sense as scenario #2 modeled flows without the 1 Maf of Canadian Supplemental storage and scenario #4 modeled flows if most of the 1 Maf of storage were focused in July. The focus on July releases in scenario #4 reduced water during the April to June time frame when most of the groups of fish used in this analysis were released (Tables 2 and 3). Scenario #4 did have the highest survival recorded in the latest migrating group of subyearling Chinook released on 6/16 from Wells hatchery to John Day Dam (Table 3).

Overall, the four scenarios that modeled different release scenarios for the 1 Maf of Supplemental Storage from Canadian releases did show small differences in survival between groups of migrating fish. This analysis does indicate that small survival benefits can be accomplished for steelhead and yearling chinook if releases are primarily focused on the late April-June time frame, where as slight survival benefits to sub-yearling chinook can be had if releases are focused primary in July. These survival benefits would be especially noticeable when coupled with other actions that benefit survival. It should be pointed out that the balance of releases is important, as focusing releases during one period may benefit one species but lead to decreases in survival to another species that tends to migrate at a different time.

APPENDIX A: Survival and WTT Relationships

Table A-1. Regression relation between steelhead reach survival Rock Island to McNary Dam and Water Transit time for the years 1998 to 2007. (R-squared 0.797)

Effect	Coefficient	Standard Error	Std. Coefficient	Tolerance	t	p-value
CONSTANT	1.9222	1.3539	0	.	1.4198	0.1691
WTT	-0.2756	0.029	-0.8926	1	-9.4958	0.000

Table A-2. Regression relation between yearling Chinook reach survival Rock Island to McNary Dam and Water Transit time for the years 1998 to 2007. (R-squared 0.669)

Effect	Coefficient	Standard Error	Std. Coefficient	Tolerance	t	p-value
CONSTANT	1.4987	17.8683	0	.	0.0839	0.934
WTT	-0.1202	0.0189	-0.8179	1	-6.3571	0.000

Table A-2. Regression relation between Subyearling Chinook reach survival Wells Hatchery to McNary Dam and Water Transit time for the years 1998 to 2004. (R-squared 0.503)

Effect	Coefficient	Standard Error	Std. Coefficient	Tolerance	t	p-value
CONSTANT	0.8707	1.4114	0	.	0.6169	0.5643
WTT	-0.1081	0.048	-0.7094	1	-2.2507	0.0742