2003 Evaluation of Juvenile Fall Chinook Salmon Stranding in the Hanford Reach of the Columbia River

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Executive Summary

The Washington Department of Fish and Wildlife (WDFW) in cooperation with the Grant County Public Utility District (GCPUD) and Pacific Northwest National Laboratory (PNNL) performed the 2003 Evaluation of Juvenile Fall Chinook Salmon (*Oncorhynchus tshawytscha*) Stranding in the Hanford Reach of the Columbia River. The 2003 evaluation was the seventh year of a multi-year study to assess the impacts of water fluctuations from Priest Rapids Dam on rearing juvenile fall chinook salmon, other fishes, and in previous years macroinvertebrates, of the Hanford Reach.

The objectives of the 2003 evaluation were to: determine if start and end dates for implementation of the juvenile fall chinook salmon protection operations meet observed emergence and susceptibility to entrapment and stranding; estimate the number of juvenile fall chinook salmon stranded (mortalities) and entrapped in isolated pools (at risk) due to reductions in discharge from Priest Rapids Dam within the designated sampling area during emergence and rearing; and to evaluate the effectiveness of operation guidelines (2003 Interim Protection Plan) on reducing mortality of fall chinook in the Hanford Reach.

A sampling plan to estimate the total number of juvenile fall chinook salmon killed or placed at risk due to flow fluctuations was designed by PNNL and WDFW prior to the 1999 field season and was implemented during the 1999 to 2001 evaluations. The plan was developed for the portion of the Hanford Reach defined by the SHOALS bathymetry data (Rkm 571.3 to Rkm 606.9) along the shorelines exposed by flows of 40 kcfs to 400 kcfs. The study area was reduced in 2002 and 2003 to the area from Locke Island (Rkm 600.2) to Hanford Slough (Rkm 584.5).

Emergence of naturally spawned juvenile fall chinook salmon in 2003, as calculated under the terms of the Vernita Bar Settlement Agreement, was estimated to start February 20 and end April 27. The 2003 Interim Protection Program began February 28 and ended June 5, when 400ºC temperature units were accumulated following the estimated end of emergence. Random sampling to assess the effectiveness of the 2003 Interim Protection Program began March 20 and ended June 14.

Hourly discharge from Priest Rapids Dam averaged 117.0 kcfs during the period the 2003 Juvenile Fall Chinook Interim Protection Plan was in effect. Hourly discharge ranged from 70.4 kcfs to 229.9 kcfs. Mean daily flow fluctuation from Priest Rapids Dam during the this period was 33.3 kcfs with 32 days of relatively stable flows (fluctuations < 20 kcfs), 54 days with flow fluctuations between 20 kcfs and 60 kcfs, and 12 days with flow fluctuations greater than 60 kcfs.

A total of 193 random plots encompassing 39,548 m^2 were sampled in 2003. Random plots contained 152 juvenile fall chinook salmon including 133 stranded and 19 entrapped individuals. Fish were first encountered in random plots on March 20 and last found on May 31, 2003. The estimated number of juvenile fall chinook salmon stranding and entrapment mortalities within the 2003 sample area was calculated to be 154,853 with a 95% confidence interval between 83,903 and 225,802. No additional mortalities were attributed to this estimate by re-visitation of entrapments. Juvenile fall chinook salmon placed at risk of mortality from stranding and entrapment was calculated to be 164,643 with a 95% confidence interval between 91,093 and 238,192. Of the chinook found stranded and entrapped, 44.7% were observed at flow levels between 50 and 120 kcfs though only 21.9% of the flow fluctuations occurred at these levels.

Sampling was only conducted on those days when a fluctuation was of sufficient magnitude and duration to dewater shorelines in the study area, 23 miles downstream, and during normal working hours (8:00am – 4:00pm). Sampling was conducted on 50 of the 87 days during the evaluation period (March 20 – June 14). During the 73 days from the first chinook encountered in random sampling (March 20) to the last chinook recorded (May 31), 38 days had flow fluctuations capable of producing fall chinook stranding and entrapment in the study area. There were 101 random plots sampled on 26 weekdays and 59 random plots sampled on 12 weekend days during this time frame. Stranded/entrapped chinook were found in 35.6% (21 of 59) of the plots sampled on the weekends and in 16.8% (17 of 101) of the random samples during weekdays. There were almost double the number of chinook recorded stranded/entrapped on the weekends (98) compared to the weekdays (54).

Juvenile fall chinook salmon collected in random plots had a mean fork length of 40.3 mm and ranged from 35 mm to 50 mm. These results are similar to data from previous years indicating that juvenile fall chinook salmon are less susceptible to stranding and entrapment with increased size. Minimum fork lengths for chinook sampled along nearshore areas in the Reach continued to be less than 40 mm through the final survey on June 23, however the composition of newly emergent fry (<42 mm) in the sample had decrease markedly by June 9 (7.2% of collection).

The 2003 Juvenile Fall Chinook Interim Protection Plan was in effect for 98 days during the emergence and rearing period for fall chinook in the Hanford Reach. Of the 84 operational constraints established by the plan, 49 targets were met with daily flow fluctuations below the maximum. There were 70 weekdays during the protection plan and 14 weekends. Weekday constraints were met on 43 (61%) days and weekend constraints were met on 6 (43%) of 14 weekends. Fluctuations were outside of target by less than 5 kcfs on 9 constraints, 5 weekdays and 4 weekends.

Rock Island previous weekday discharge was used to predict Priest Rapids discharge and to set constraints for weekdays. Weekend forecasts for Chief Joseph Dam plus side flows were used to predict weekend flows for Priest Rapids Dam and set weekend constraints. Use of previous day flows from Rock Island and weekend forecasts from Chief Joseph were used with the goal of accurrarately predicting daily mean discharge for Priest Rapids Dam and thus maintaining flow fluctuations in the Hanford Reach that will reduce stranding and entrapment. Overall, constraints set using these predictive methods accurately met or were more restrictive on 75 of the 84 targets (89%) during the protection plan in 2003. Constraints were identical on 55 predictions, more restrictive on 20 occassions, and were not restrictive enough on 9 occassions. Weekday constraint were accurately predicted on 45 (64%) days, 17 (24%) of the daily constraints were more restrictive, and 8 (11%) daily constraints were not restrictive enough based on Priest Rapids actual mean daily discharge. Chief Joseph weekend forecasts accurately predicted weekend flows for Priest Rapids on 10 (71%) of the weekends, 3 (21%) constraints were more restrictive than would have been using Priest Rapids Dam daily discharge to set constraint, and 1 (7%) constraint was not restrictive enough based on Priest Rapids actual.

Constraints were set in accordance with the 2003 Protection Plan based on predicted daily discharge at Priest Rapids Dam with the goal of maintaining daily fluctuations within the Hanford Reach at levels where mortality of juvenile fall chinook is reduced. There protection plan covered 98 days during emergence and rearing of juvenile fall chinook in 2003. During this period there were 27 days when fluctuations occurred above the target maximums. Fluctuations above these maximums most often occurred when mean daily flows were between 80 kcfs and 110 kcfs (34.8%), 110 kcfs and 140 kcfs (34.5%), and above 170 kcfs (100%) (Table 9). The number of days outside of target is less than the number of constraints outside of target for the protection plan due to the fact that constraints set by the protection plan used Rock Island prior weekday flows and Chief Joseph forecasts that were often more restrictive than the constraints would have been if based on actual Priest Rapids discharge for the day. Additionally, weekend constraints as set by the protection plan were set for a 48-hour period rather than individual weekend dates.

Fall chinook fry production on the Hanford Reach was estimated to provide a rough estimate of the population affected by flow fluctuations from Priest Rapids Dam. Fall chinook fry production on the Hanford Reach in 2003 was estimated to be between at 13.8 and 33.4 million emergent fry. The 2003 production estimate was based on year 2002 Hanford Reach adult fall chinook escapement, female composition of the escapement, fecundity of hatchery fall chinook salmon at Priest Rapids Hatchery, egg retention of fall chinook salmon in the Hanford Reach, and an egg to emergence survival rate of 30% (Healey 1998). An additional fry estimate was produced using aerial redd counts for fall chinook in the Hanford Reach conducted by PNNL.

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Introduction

In 2003, the Washington Department of Fish and Wildlife (WDFW) was contracted through Grant County Public Utility District (GCPUD) to evaluate impacts of water fluctuations from Priest Rapids Dam on emerging and rearing juvenile fall chinook salmon (*Oncorhynchus tshawytscha*) on the Hanford Reach of the Columbia River. This was the seventh year of a multi-year study to assess these impacts and evaluate the effectiveness of protection measures established to reduce mortality. This document provides the results of the 2003 field season and a brief summary of findings from previous years.

The 2003 Hanford Reach Juvenile Fall Chinook Salmon Interim Protection Program

The objectives for development of this program as proposed by the mid-Columbia hydroelectric operators are:

1. Provide a high level of protection for rearing fall chinook fry;
2. Maintain reasonable load following capability at all 7 projects;
3. Monitoring and evaluation that allows evaluation of the program relative to its effect on entrapment and stranding; and
4. A monitoring program that allows in-season changes of operations if substantial mortality is detected.
5. If possible, within the requirements of flood control, power generation, project operating constraints, and the BO, a goal of the program will be to incorporate the objective of releasing GCL weekly average discharge in a constant or steadily increasing manner.

Daily operational constraints established for the protection program based on the 2003 Protection Plan were:

Mean Hourly Discharge (kcfs) [1]	**Operational Flow Constraint**[2]
Vernita Bar Agreement minimum and 80 kcfs[3]	maximum daily flow fluctuation ≤ 20 kcfs
80 kcfs and 110 kcfs	maximum daily flow fluctuation ≤ 30 kcfs
110 kcfs and 140 kcfs	maximum daily flow fluctuation ≤ 40 kcfs
140 kcfs and 170 kcfs	maximum daily flow fluctuation ≤ 60 kcfs
Greater than 170 kcfs	150 kcfs minimum hourly discharge at Priest Rapids

Monitoring under this program would consist of random sampling on an 8.5 mile subsection of the Hanford Reach (RM 364.5 to RM 373). This stretch runs from the upstream end of Locke Island downstream to Hanford Slough (Figure 1) . Crews would consist of a two person crew sampling seven days a week. Random samples will be taken within this 8.5 RM sampling area based on previously established protocols for selecting from a list of possible random sampling plots within each 10 kcfs flow band. Grant PUD will provide funding for this effort. If the field monitoring crew observes that a significant fall chinook mortality event is occurring or imminent, they will immediately notify the designated representative of the Washington Department of Fish and Wildlife (WDFW) and explain the situation. The WDFW representative will confirm whether a significant fall chinook mortality event is occurring or imminent and decide whether to request a modification of operations. If alteration of operations appears appropriate, the WDFW representative will notify Grant County PUD immediately to discuss a remedy. If Grant County PUD concurs that a significant fall chinook mortality event is occurring or imminent, it will consult, as necessary, with other operators and an operational remedy will be implemented.

[1] Mean discharge for determination of operational flow constraint for weekdays is defined as the previous weekday average (hourly) of Rock Island Dam. Weekend constraint is set as average weekend forecast for Chief Joseph Dam including side flows.
[2] Daily flow fluctuation (max-min) was calculated during the period from 1:00 am to midnight of each day
[3] Minimum discharge from Priest Rapids Dam during the 2003 fall chinook emergence was established at 60 kcfs according to the Vernita Bar Agreement. After the estimated end of emergence, minimum flows are restricted to 36 kcfs.

The 2003 Hanford Reach Juvenile Fall Chinook Salmon Interim Protection Program was developed from earlier programs and modified only slightly from the 2002 Interim Protection Plan. The primary changes were: use of previous days average flow from Rock Island Dam rather than a rolling 5-day average discharge from Priest Rapids to set the fluctuation limits for weekdays; and to manage flows for a single 48 hour weekend delta rather than separate Saturday and Sunday constraint. It is anticipated that using the previous weekday average from Rock Island Dam to determine the daily operational constraints will more accurately predict daily mean discharge at Priest Rapids Dam.

Prior to 2003, start of operational constraints under the protection plan would occur when a daily total of 50 or more sub-yearling chinook were sampled from six standardized index seining locations in the Hanford Reach. Index seining would begin one week prior to the calculated start of emergence under the Vernita Bar Agreement. Policy meetings to develop the 2003 Interim Protection Program were held on February 26 and 27, 2003. At the policy meeting, criteria for implementation of the annual Protection Plan was modified to begin on the estimated start of emergence established by the Vernita Bar Agreement. Estimated start of juvenile fall chinook emergence based on the Vernita Bar Agreement was February 20 in 2003. The Protection Plan went into effect on February 28, immediately following the initial policy meeting. The Protection Plan would continue to be in effect until 400 temperature units (°C) had accumulated following the end of emergence under the Vernita Bar Agreement.

Objectives

The objectives of the 2003 evaluation were:

1) Determine if start and end dates for implementation of the juvenile fall chinook salmon protection operations meet observed emergence and susceptibility to entrapment and stranding.

2) Estimate the number of juvenile fall chinook salmon A) stranded (mortalities) and B) entrapped in isolated pools (at risk) due to reductions in discharge from Priest Rapids Dam within the designated sampling area during emergence and rearing.

3) Evaluate the effectiveness of operation guidelines (2003 Interim Protection Plan) on reducing mortality of fall chinook in the Hanford Reach.

Methods

Objective 1, Determine if start and end dates for implementation of the juvenile fall chinook salmon protection operations meet observed emergence and fall chinook susceptibility to entrapment and stranding.

Nearshore seining at six standardized index seining locations will begin approximately one week prior to the start of chinook emergence as calculated by GCPUD staff as part of the Vernita Bar Settlement Agreement. Note that start of emergence as defined under the Vernita Bar Settlement Agreement is for protection of pre-emergent chinook at flow elevations of 36 kcfs (minimum project discharge) or greater. The one-week variance is to provide protection if emergence is earlier than predicted. WDFW staff will seine six predetermined index sites weekly to determine emergence, abundance, and susceptibility (based on forklength). WDFW staff will continue to seine the six index sites once per week through June 30.

Objective 2, Estimate the number of juvenile fall chinook salmon A) stranded (mortalities) and B) entrapped (at risk) due to reductions in discharge from Priest Rapids Dam within the designated sampling area during emergence and rearing.

A sampling plan to estimate the total number of juvenile fall chinook salmon killed or placed at risk due to flow fluctuations was designed by PNNL and WDFW prior to the 1999 field season. The plan was developed for the portion of the Hanford Reach defined by the SHOALS (Scanning Hydrographic Operational Airborne LIDAR (Light Detecting And Ranging) Survey) bathymetry data (Rkm 571.3 to Rkm 606.9) along the shorelines exposed by flows of 40 kcfs to 400 kcfs. In 2002, the sample area was reduced to approximately half the original study area (**Figure 1**). The reduced area was selected to include the section of the river where increased incidences of stranding and entrapment were observed in previous years. The sampling area monitored in 2002 and 2003 extends from Rkm 600.2 to Rkm 584.5.

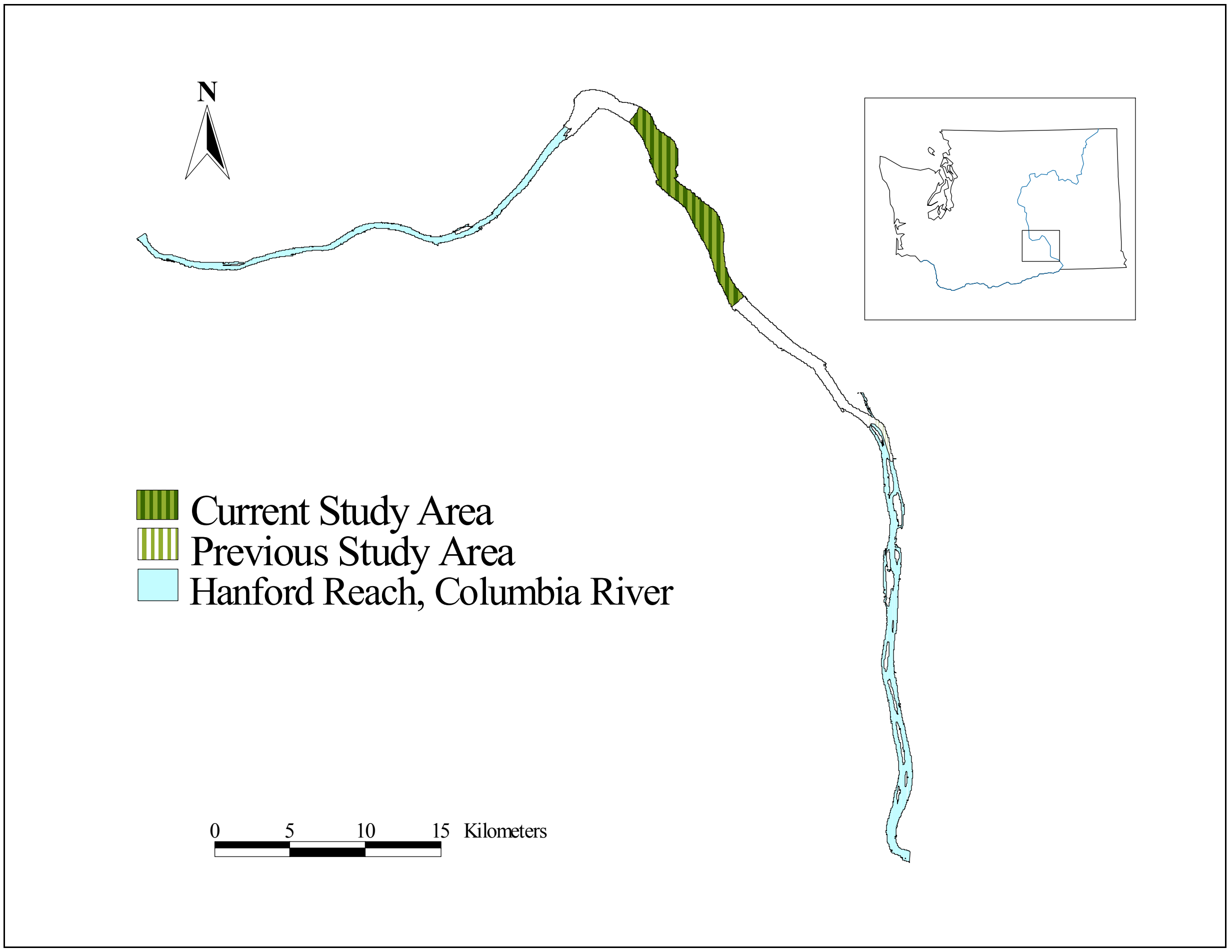

Figure 1. Modified study area on the Hanford Reach of the Columbia River, 2003.

The SHOALS data was broken into 344.4 m^2 (3600 ft^2) plots. Plot size was based on the mean size of entrapments found in the 1998 Hanford Stranding Study (Nugent *et al*, 1998). Sample plots that crossed the line between designated 40 kcfs flow bands were included in the flow band that contained at least 50% of the cell. Cells that did not include a majority of one 40 kcfs flow band were removed from consideration. A list of all cells contained within the study area was compiled and cells were randomly selected to use in daily field sampling activities. Daily sampling targeted wetted flow bands identified in the previous 48-hour flow history.

Prior to 2002, two field teams comprised of WDFW and GCPUD personnel collected data daily during the fall chinook salmon emergence and rearing period when wetted shorelines were visible. In 2002 and 2003, only one crew was used to sample in the reduced study area.

River flows from the previous 48 hours were downloaded every morning prior to sampling. Sites were randomly selected within 10 kcfs flow bands that should have been dewatered based on the previous 48-hour flow history. Coordinates of randomly selected sites were entered into a Trimble TSCI global positioning system (GPS). The TSCI is capable of sub-meter accuracy. Jet boats were used to navigate to sites aided by GPS. If a randomly selected site had not been wetted from the previous 48-hour flow band, the site was not sampled and returned to the pool of available sites. Sites that were sampled were removed from the sampling pool.

An eight pound mushroom anchor attached to an incrementally marked cable was placed at the center of each sample plot to delineate the circular boundary of the plot. Entrapments encountered within the sample area were assessed to determine the percentage of the entrapment contained within the sample area. Entrapments with a surface area of 50% or greater within the circle were sampled in their entirety, including the entrapment area outside the circular sample plot area. Entrapments with a surface area greater than 50% outside of the circle were not sampled. If portions of the plot were dry (had not been wetted by the previous 48-hour flow history) or covered by the river, the marked cable was used to estimate the wetted area within the sample plot. A scaled drawing was produced to calculate the proportion of the plot that was affected by flow fluctuations within the previous 48 hours.

The number of juvenile fall chinook salmon and other fish species found within the sample plot were counted and classified as alive or dead. Fork lengths were recorded on all fish sampled that were not desiccated or deteriorated. Methods for calculating the estimated total number of juvenile fall chinook salmon mortalities and at risk due to stranding and entrapment are provided in Appendix B.

Additional data collected at the sites included bird activity (i.e., tracks, droppings), entrapment water temperatures, dominant and subdominant substrate size (classified according to a modified Wentworth code, Platts et al. 1983), substrate embeddedness as outlined in Platts et al. (1983), and vegetation density. Vegetation density was recorded as absent, sparse, medium, or dense (Appendix A).

Objective 3,Evaluate the effectiveness of operation guidelines (2003 Interim Protection Plan) on reducing mortality of fall chinook in the Hanford Reach.

Assessment of the impacts of fluctuations of project discharge on juvenile fall chinook survival and evaluation of the 2003 Juvenile Fall Chinook Interim Protection Plan is based on comparative results of 2003 chinook mortalities and at risk to estimated losses in prior years. Chinook mortality and at risk was determined through random sampling of the flow fluctuation zones from daily operations as discussed in Objective 2.

2003 Hanford Reach Flows and Meteorological Conditions

With the exception of November 2002, flows in the Hanford Reach were lower than normal during the incubation, emergence, and rearing period in 2003 (Table 1). January through June river flows were 5.1 kcfs (April) to 52.6 kcfs (Feb) lower than the 10-year mean. Air and river temperatures in the Hanford Reach were warmer than average through March and in June; and near normal in April and May. Precipitation was above average in January and April, near normal in February and March, and below average in May and June. Solar radiation was below average for the months of January, March, April, and May; and above average in February and June.

Table 1. Comparison of 2003 monthly mean river flow, river temperature, air temperature, precipitation, and solar radiation levels to past years on the Hanford Reach of the Columbia River.

River Flows[1] (Kcfs)												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.[02]	Nov.[02]	Dec.[02]
2003	80.8	73.8	83.7	113.1	138.2	142.9	-	-	-	82.4	100.5	99.9
Mean (1993-2002)	121.7	126.5	109.0	118.3	158.6	178.5	140.7	110.9	83.3	83.5	96.0	115.1
Departure	-40.9	-52.6	-25.2	-5.1	-20.5	-35.6	-	-	-	-1.1	4.5	-15.2
River Temperatures[2] (°C)												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.[02]	Nov.[02]	Dec.[02]
2003	5.4	5.0	5.8	7.5	10.3	14.8	-	-	-	15.7	11.9	8.0
Mean (1993- 2002)	3.8	2.9	4.3	7.1	10.5	13.7	-	-	-	15.4	11.2	7.1
Departure	1.7	2.1	1.5	0.4	-0.2	1.1	-	-	-	0.3	0.7	0.9
Air Temperature[3] (°C)												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2003	3.3	4.4	9.5	11.2	16.1	22.5	-	-	-	-	-	-
Mean (1945-2002)	-0.6	3.2	7.3	11.6	16.6	20.7	24.7	23.9	19.0	11.6	4.5	0.3
Departure	3.9	1.3	2.1	-0.4	-0.5	1.8	-	-	-	-	-	-
Precipitation[3] (cm)												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2003	4.7	2.1	0.7	5.7	0.2	0.0	-	-	-	-	-	-
Mean (1947-2002)	2.3	1.6	1.3	1.1	1.3	1.4	0.6	0.6	0.8	1.4	2.3	2.6
Departure	2.4	0.5	-0.6	4.5	-1.1	-1.4	-	-	-	-	-	-
Solar Radiation[3] (Langleys)												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2003	57.3	195.9	261.1	395.3	482.5	610.1	-	-	-	-	-	-
Mean (1995-2002)	89.8	175.3	285.7	405.9	501.4	563.1	596.4	512.3	373.0	230.6	107.6	64.5
Departure	-32.4	20.6	-24.6	-10.6	-18.9	47.0	-	-	-	-	-	-

[1]Data from USGS Gauging Station 12472800 below Priest Rapids Dam

[2]Data from Vernita Bar Annual Monitoring Reports (1992-2001) and WDFW Temperature Probes at Rkm 594

[3] Data from Hanford Meteorological Station, PNNL

Mean hourly discharge during the primary period of susceptibility (March – June) have been variable during the five years a protection plan has been instituted for emerging and rearing fall chinook in the Hanford Reach (Figure 2). In 1999, flow conditions were excellent with moderate flows from March through June. In 2003, flows were lower than ideal in March and April but increased in May and June.

Mean daily fluctuations in discharge for mid-March through May were relatively stable in 1999. Daily fluctuations for the past two years reflect the change in the protection plan that allows greater fluctuations to coincide with increasing discharge (Figure 3).

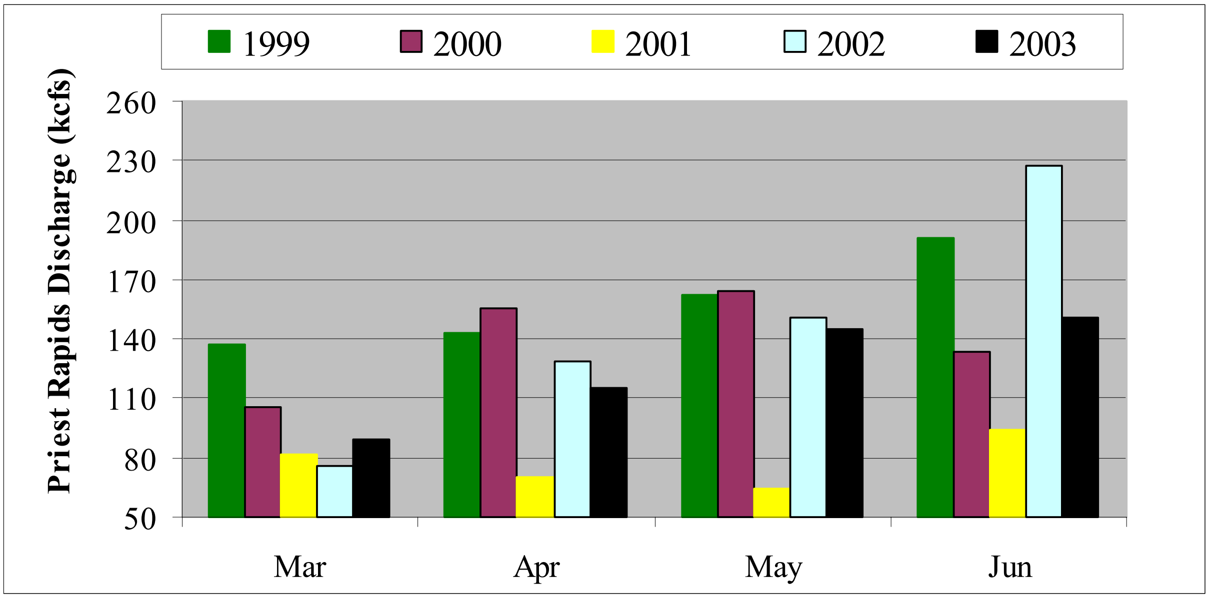

Figure 2. Mean monthly discharge (kcfs/hr) at Priest Rapids Dam during fall chinook emergence and rearing, 1999 – 2003.

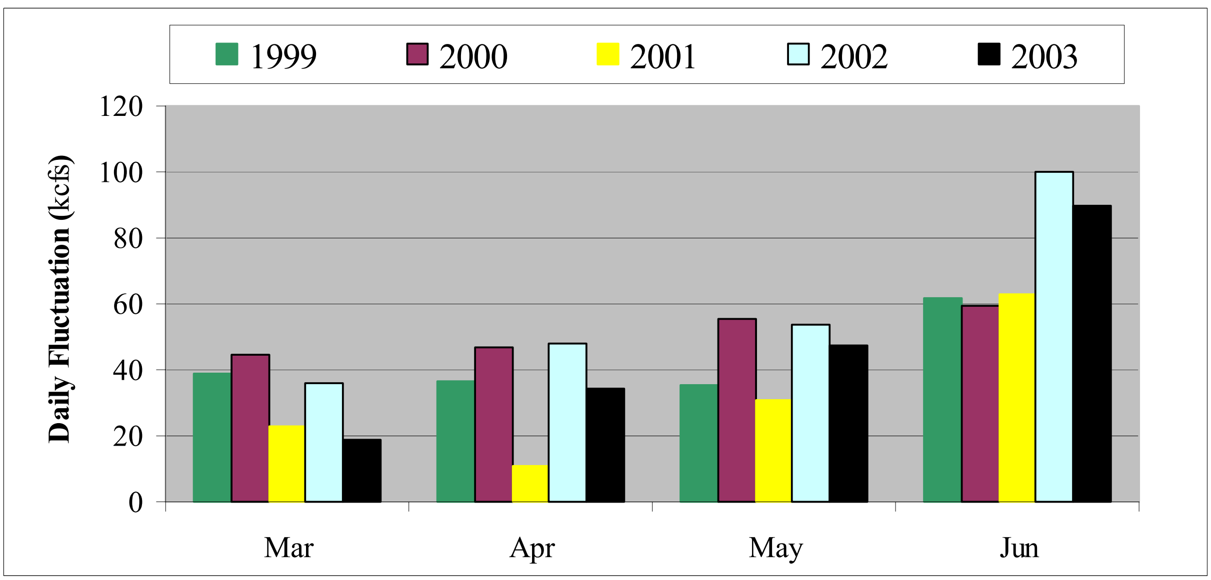

Figure 3. Mean daily fluctuation in discharge (max-min) at Priest Rapids Dam during fall chinook emergence and rearing, March 15 – June 15, 1999 – 2003.

Fall Chinook Salmon Fry Production Estimate

Fall chinook fry production on the Hanford Reach was estimated to provide a rough estimate of the population affected by flow fluctuations from Priest Rapids Dam. Fall chinook fry production on the Hanford Reach in 2003 was estimated to be between at 13.8 and 33.4 million emergent fry (Table 2). The 2003 production estimate was based on 2002 Hanford Reach adult fall chinook escapement, female composition of the escapement, fecundity of hatchery fall chinook salmon at Priest Rapids Hatchery, egg retention of fall chinook salmon in the Hanford Reach, and an egg to emergence survival rate of 30% (Healey 1998). An additional fry estimate was produced using aerial redd counts for fall chinook in the Hanford Reach conducted by PNNL.

Fall chinook escapement and harvest in the Hanford Reach are calculated annually by WDFW. The total fall chinook escapement for the Hanford Reach in 2002 was estimated at 84,509, with an adult escapement of 69,117 salmon (Appendix D). This was the fourth largest adult escapement recorded since 1964. Of the 1,442 adult chinook sampled during the 2002 Hanford Reach fall chinook sport fishery the female composition was 40.4% (Appendix C). Fecundity rates have not been determined for naturally spawning fall chinook salmon on the Hanford Reach. For this estimate, fecundity estimates of fall chinook salmon sampled at Priest Rapids Hatchery were used. In 2002, estimated eggs per female of fall chinook returning to the hatchery was 4,003. No studies have been conducted on egg to emergence/fry/smolt mortality rates of naturally spawned fall chinook salmon in the Hanford Reach. Healey (1998) reported under natural conditions, 30% or less of the potential eggs deposited resulted in emergent fry or fry and fingerling migrants in the systems studied. For purposes of this estimate, an egg to fry survival rate of 30% was used.

A second estimate of fry production was produced using aerial redd counts from PNNL, fecundity from Priest Rapids Hatchery, and an egg to emergent fry survival rate of 30%. Peak redd counts for the Hanford Reach in 2002 was 8,041 (memo, PNNL). For purposes of this estimate the redd count was expanded using an assumed visibility of 70% of the total redd production. Increased escapement of fall chinook into the Hanford Reach in 2002 led to high densities of redds located in the high use areas and redd counts may have been conservative. Expanded redd counts were estimated at 11,487 with a fecundity of 4,003 eggs per female, and an egg to fry survival rate of 30%.

Table 2. Calculation of the 1999-2003 fall chinook salmon fry production estimate for the Hanford Reach of the Columbia River.

			Emergence Year		
Method 1	**2003**	**2002**	**2001**	**2000**	**1999**
Adult Fall Chinook Escapement	69,117	44,140	36,027	27,012	29,410
Female (%)	40.4%	36.5%	54%	46%	46%
Fecundity	4,003	4,418	4,794	4,371	4,200
# of spawning females	27,923	16,111	19,455	12,426	13,646
Potential eggs	111,776,842	71,178,840	93,265,257	54,311,948	57,314,208
Egg Retention	0.50%	0.50%	0.50%	0.50%	0.50%
Total eggs deposited	111,217,958	70,822,946	92,798,930	54,040,388	57,027,637
Egg to fry survival @ 30%	**33,365,387**	**21,246,884**	**27,839,679**	**16,212,116**	**17,108,291**
Method 2					
PNNL Aerial Redd count	8,041	6,248	5,507	6,086	5,368
Expansion (70% of redds observed)	11,487	8,926	7,867	8,694	7,669
Fecundity	4,003	4,418	4,794	4,371	4,200
Potential eggs	45,983,033	39,433,806	37,715,083	38,002,723	32,208,000
Egg to fry survival @ 30%	**13,794,910**	**11,830,142**	**11,314,525**	**11,400,817**	**9,662,400**
Mean of Two Estimates	**23,580,149**	**16,538,513**	**19,577,102**	**13,806,467**	**13,385,346**
Hatchery Releases of Fall Chinook in the Hanford Reach and Yakima River	**12,255,089**	**10,913,482**	**11,976,344**	**12,293,934**	**11,870,800**
Subyearling Passage Index at McNary	**10,561,371**[1]	**8,372,688**	**10,782,663**	**10,667,690**	**7,643,679**

[1] Smolt monitoring at the McNary fish facility was discontinued early in 2003 (Oct 1) and sampling occurred on an every other day basis from April 1 through June 28. Passage was doubled for the period of alternate day sampling to allow comparisons between years.

Hatchery releases of subyearling chinook into the Hanford Reach and Yakima River for the period from 1999 to 2003 have varied from 10.9 to 12.3 million annually. Subyearling chinook passage indices for McNary Dam for the same years have ranged from 7.6 to 10.8 million. These numbers would indicate significant mortality occurs to fall chinook for both hatchery and wild fish. Hatchery released juvenile fall chinook are typically large enough (>60 mm) that it is unlikely significant mortality would occur from fluctuations from hydroelectric operations at Priest Rapids Dam.

Results

Implementation Timing and Operation of the 2003 Hanford Reach Juvenile Fall Chinook Salmon Interim Protection Program

Emergence timing during the past five years has begun as early as February 20 (2003) and as late as April 1 (2001). The period of emergence since the Protection Plan went into effect, calculated under the Vernita Bar Agreement as 1,000 accumulated temperature units Celcius (ATU) from the initiation of spawning to 1,000 ATU from the end of spawning, has lasted from 40 days in length (2001 and 2002) to 67 days in 2003 (Table 3). Chinook fry have been found, typically in low numbers, in the nearshore areas prior to the estimated start of emergence for all five years of this study. The annual protection plan has started, based on nearshore presence of chinook, prior to or within four days of the estimated emergence date for the four years prior to 2003.

Emergence of juvenile fall chinook salmon in 2003, as calculated under the terms of the Vernita Bar Settlement Agreement, began February 20 (Figure 4). Under the criteria adopted for implementation in 2003, the Protection Plan would coincide with emergence. Sampling to assess juvenile fall chinook emergence, abundance, and fish size began on February 19, one day prior to the estimated start of emergence. A total of 33 chinook fry ranging in length from 37 mm to 44 mm were collected from six nearshore locations in the Hanford Reach indicating that fall chinook were emerging. The number of chinook collected was relatively low as would be expected during the early period of emergence. Lengths greater than 40 mm would further indicate that at least a minimum number of chinook had emerged in the weeks prior to February 20. Newly emergent fall chinook salmon collected on the Hanford Reach often possess ventral slits (unbuttoned), a physical characteristic of the late stage of yolk sac absorption. Fork lengths of these unbuttoned fall chinook salmon range up to 44 mm but are most often found in salmon at or below 42 mm in length. The criteria for the start of emergence for 2000 to 2002 was the collection of 50 chinook from the six designated index locations. This target was reached on March 12 with the collection of 182 chinook but would likely have been reached earlier under the prior standard protocol of daily sampling as opposed to weekly sampling conducted in 2003.

The 2003 Interim Protection Program began February 28 following the annual policy meeting and eight days after the estimated start of emergence. Monitoring of stranding/entrapment in the Hanford Reach to estimate losses began on March 20, one month after the estimated start of emergence (Table 4). The first stranded/entrapped chinook was recovered on March 23, three days after monitoring began.

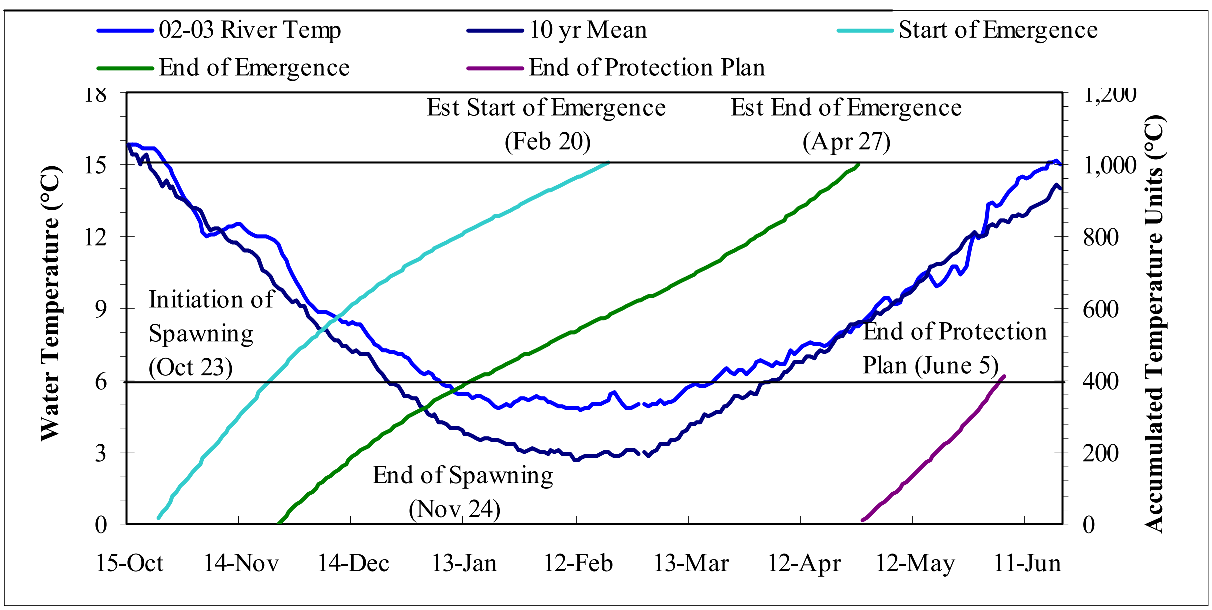

Figure 4. Mean daily river temperatures on the Hanford Reach of the Columbia River and estimated timing of fall chinook salmon emergence based on accumulated temperature units (ATU).

Table 3. Summary of emergence timing and chinook presence in nearshore areas and encountered in random sampling, 1999 – 2003.

Year	Nearshore Sampling First Chinook	Estimated Emergence		Begin Protection Plan	Stranded/Entrapped		
		Start	End		Begin Monitoring	1st Chinook	Last Chinook
2003	Feb 19	Feb 20	April 27	Feb 28	March 20[1]	March 23	May 31
2002	March 1	March 17	April 25	March 21	March 22	March 23	June 9
2001	March 15	April 1	May 10	March 26	March 26[2]	April 13	June 24
2000	March 13	March 20	May 2	March 21	March 24	March 24	June 2
1999	March 5	March 8	May 11	March 10	March 20	March 20	June 12

Table 4. Fall chinook spawning and fry emergence timing in the Hanford Reach as established through the Vernita Bar Agreement, 1991 – 2003.

Year	Critical Elevation	Initiation of Spawning		End of Spawning	Start of Emergence	End of Emergence
		<50 kcfs	>50 kcfs			
2002-03	70	10/23/02	10/30/02	11/24/02	2/20/03	4/27/03
2001-02	50	11/31/01	---	11/18/01	3/17/02	4/25/02
2000-01	65	10/25/00	10/25/00	11/19/00	4/1/01	5/10/01
1999-2000	60	10/27/99	10/27/99	11/21/99	3/20/00	5/2/00
1998-99	60	10/28/98	11/11/98	11/29/98	3/8/99	5/11/99
1997-98	65	10/22/97	10/22/97	11/23/97	3/12/98	5/4/98
1996-97	65	10/23/96	10/23/96	11/24/96	4/30/97	6/4/97
1995-96	65	10/18/95	10/25/95	11/19/95	5/28/96	6/22/96
1994-95	60	10/26/94	11/2/94	11/20/94	5/6/95	5/28/95
1993-94	50	10/27/93	---	11/21/93		
1992-93	55	10/21/92	10/28/92	11/22/92	4/18/93	5/24/93
1991-92	70	10/23/91	10/23/91	11/24/91	2/20/92	4/21/92
1990-91	65	10/24/90	10/24/90	11/18/90	4/13/91	5/23/91
1989-90	70	10/18/89	10/25/89	11/19/89	3/5/90	4/29/90
1988-89	70	10/19/88	10/26/88	11/20/88	4/3/89	5/14/89

Monitoring of juvenile fall chinook mortality during the five years of this evaluation has been variable and has typically began after the estimated start of emergence. In all years, except 2001, the first stranded/entrapped chinook was recorded within three days of implementation of monitoring and on the same day in 1999 and 2000. Monitoring in 2003, as in 1999, began one month after estimated emergence. The first chinook mortality was recorded four days after monitoring began in 2003 and on the first day of monitoring in 1999. In 2000 and 2002, the first chinook mortality during random sampling was recovered within six days of emergence. In 2001, the first chinook was recovered 12 days after emergence after the first significant fluctuation in discharge occurred.
The 2003 Interim Protection Program ended June 5, 400 ATU after the estimated end of emergence as determined by the Vernita Bar Agreement. This end date criteria was established and implemented beginning with the 2001 Interim Protection Plan. Length frequency data from nearshore sampling further indicated a reduction in chinook in nearshore areas, an increase in mean fork length over 50mm, and reduced presence of newly emergent fry (<42mm) at 400 ATU. In 2003, the last chinook was recovered during random sample monitoring on May 31, 344 ATU. In 1999 and 2000, the final chinook recovered during monitoring (random sampling) was 374 ATU in 1999 and 358 ATU in 2000. In 2001 and 2002, fall chinook were found stranded and entrapped beyond 400ATU but in low numbers. In a similar study in 2003, chinook were found in entrapments as late as June 20.

Random sampling to recover fall chinook mortalities in the Hanford Reach in 2003 concluded June 14. On June 9, four days after the end of the protection plan, 1,253 fall chinook fry were collected in nearshore abundance sampling indicating the continued presence of relatively large numbers of chinook in the nearshore areas though no chinook were recovered during sampling after May 31 (Table 5). Numbers of chinook inhabiting nearshore areas did not decrease to under 10% of peak abundance until June 23 when 236 (4.0% of peak abundance) were collected on the final nearshore survey of the season. Newly emergent fry were sampled in the catch on the final survey.

Table 5. Summary of chinook fork length and abundance at the end of the protection plan, 1999 – 2003.

Year	2003	2002	2001	2000	1999
Protection Plan End Date	June 5	June 4	June 10	June 26	June 30
Index Sample Date	June 9	June 5[1]	June 13	June 26	June 30
Chinook in Index Sample	1,253[2]	8	182	26	66
% of Peak Abundance	21.5%	0.5%	2.5%	3.0%	3.6%
Mean Fork length	48.5 mm	49.9 mm	50.4 mm	65.1 mm	73.9 mm
Minimum Fork length	33.0 mm	37.0 mm	37.0 mm	46.0 mm	46.0 mm

[1] On June 19, 111 chinook were sampled (17.9% of peak abundance)
[2] Nearshore seining was conducted at 15 locations in 2003, only 6 sites were seined in previous years

Mean Daily Flows and Fluctuations in the Hanford Reach

Hourly discharge from Priest Rapids Dam averaged 117.0 kcfs during the period the 2003 Juvenile Fall Chinook Protection Plan was in effect, February 28 – June 5 (Figure 5). Hourly discharge ranged from 70.4 kcfs to 229.9 kcfs. Mean daily flow fluctuation from Priest Rapids Dam during the this period was 33.3 kcfs with 32 days of relatively stable flows (fluctuations < 20 kcfs), 54 days with of flow fluctuations between 20 kcfs and 60 kcfs, and 12 days with flow fluctuations greater than 60 kcfs (Table 6 & Figures 6 & 7). The daily fluctuation was calculated during the period from 1:00 am to midnight of each day. A 17 kcfs fluctuation in discharge equates to a vertical change in river elevation of approximately 0.3 m (1.0 ft). Comparisons of mean daily fluctuations during the annual interim protection programs is provided in Table 6.

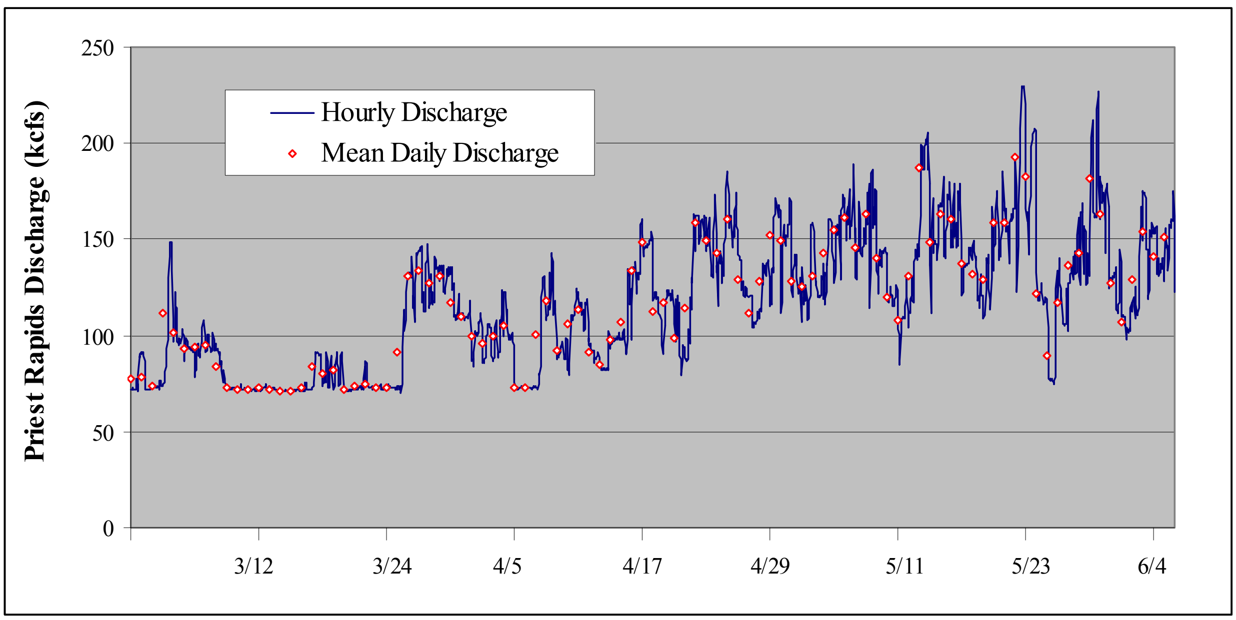

Figure 5. Hourly discharge and average daily flows from Priest Rapids Dam, February 28 – June 5, 2003.

Table 6. Summary of daily fluctuations in discharge from Priest Rapids Dam, during the Interim Protection Plans, 1999 - 2003.

Year	Protection Plan	Total # of Days	Mean Fluct. (kcfs)	Daily Fluctuation at Priest Rapids Dam				
				<20kcfs	20kcfs to 40kcfs	40kcfs to 60kcfs	60kcfs to 80kcfs	>80kcfs
2003	Feb 20-Jun 5	98	33.3	32	28	26	10	2
2002	Mar 21-Jun 4	76	47.1	19	9	26	11	11
2001	Mar 26-Jun 10	77	23.2	45	11	12	8	1
2000	Mar 21-Jun 26	98	50.0	9	30	34	13	12
1999	Mar 10-Jun 30	113	42.1[1]	13	51 (-1)	27 (-2)	12 (-1)	10 (-4)

[1] Protection plan called for rewetting of unwateed areas (8 days), average 39.5 with rewetting removed

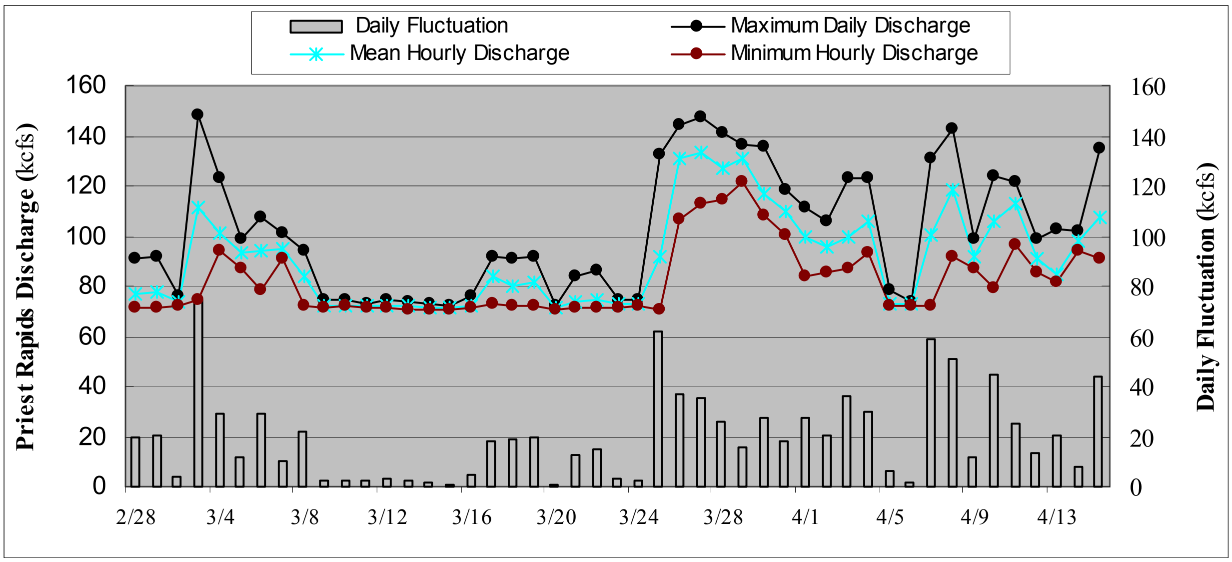

Figure 6. Mean, minimum, maximum hourly discharge, and daily fluctuation from Priest Rapids Dam, February 28 – April 15, 2003.

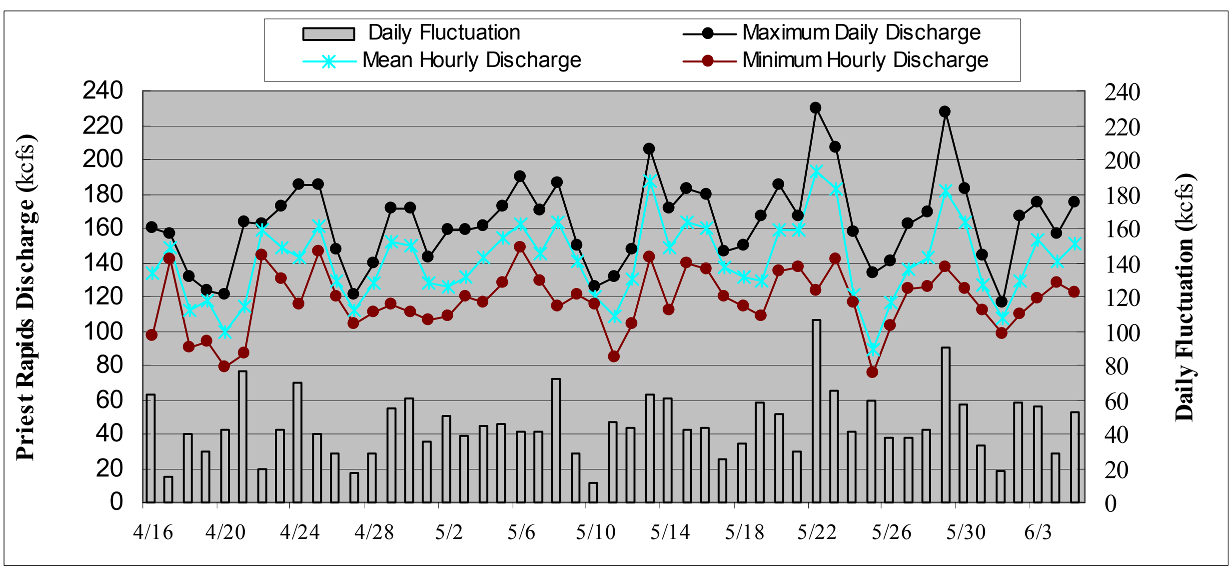

Figure 7. Mean, minimum, maximum hourly discharge, and daily fluctuation from Priest Rapids Dam, April 16 – June 5, 2003.

Estimates of Juvenile Fall Chinook Salmon Stranding and Entrapment

Juvenile Fall Chinook Mortality Estimate

The start of emergence of juvenile fall chinook salmon as calculated under the Vernita Bar Settlement Agreement has occurred between February 20 (2003) and April 1 (2001) during the five years of monitoring for stranding and entrapment. Emergence occurred earlier than typical in 2003 due to mild river temperatures during the incubation period. Emergence also occurred prior to policy discussions to establish protection plan criteria. Random sampling began on March 20, one month after the estimated start of emergence, and continued through June 14 in 2003.

Monitoring was conducted in shoreline areas corresponding to river elevations from 70 kcfs to 240 kcfs in discharge from Priest Rapids Dam. Random samples were combined into five 40 kcfs flow bands (40-80, 80-120, 120-160, 160-200, and 200-240 kcfs). The lowermost 40 kcfs flow band was truncated at 70 kcfs because no fluctuations occurred within the study area between 40 kcfs and 70 kcfs during the 2003 sampling season.

A total of 193 random plots were sampled in 2003. Random sites contained 152 juvenile fall chinook salmon (Table 7). Field crews recorded 133 direct mortalities (stranded) and 19 chinook at risk (entrapped). Juvenile fall chinook salmon were first encountered in random plots on March 20, the first day of random sampling, and the last chinook was found May 31. The majority of stranded/entrapped chinook were sampled during the months of April and May (Figure 8). One random site with an entrapment containing live juvenile fall chinook salmon was revisited during the following 24 hours to determine the fate of the chinook had they been left in the entrapment. Random site sampling protocol stated in the event an entrapment within a site drained or reached lethal temperatures (≥24ºC), fish would be recorded as mortalities. The entrapment continued to retain water at the time of revisit but recent rainfall may have refilled the entrapment. As in previous years, random sites sampled one week or more after the last fish was found were not included in the loss estimate (Appendix B).

Table 7. Weekly numbers of juvenile fall chinook salmon found in random plots on the Hanford Reach of the Columbia River in 2003.

Week	Total Sites Sampled	Stranded[1]	Entrapped	Total Mortalities (Stranded + Thermal)	Projected Mortalities Chinook Mortalities[2]	Total Chinook at Risk
Mar 17-23	5	1	0	1	1	1
Mar 24-30	10	0	0	0	0	0
Mar 31-Apr 6	18	18	19	18	18	37
Apr 7-13	22	25	0	25	25	25
Apr 14-20	8	24	0	24	24	24
Apr 21-27	16	5	0	5	5	5
Apr 28-May 4	12	6	0	6	6	6
May 5-11	23	29	0	29	29	29
May 12-18	13	1	0	1	1	1
May 19-25	24	22	0	22	22	22
May 26-Jun 1	13	2	0	2	2	2
Jun 2-8	15	0	0	0	0	0
Jun 9-15	14	0	0	0	0	0
Total	**193**	**133**	**19**	**133**	**133**	**152**

[1] All stranded fish were counted as mortalities

[2] Entrapments were revisited the next day to determine if fish would have died from drainage of entrapments of lethal temperatures (≥24°C).

Sampling was only conducted on those days when a fluctuation was of sufficient magnitude and duration to unwater shorelines in the study area 23 miles downstream, and during the normal working hours (8:00am – 4:00pm). Sampling was conducted on 50 of the 87 days during the evaluation period (March 20 – June 14). During the 73 days from the first chinook encountered in random sampling (March 20) to the last chinook recorded (May 31), 38 days had flow fluctuations capable of producing fall chinook stranding and entrapment in the study area. There were 101 random plots sampled on 26 weekdays and 59 random plots sampled on 12 weekend days during this time frame. Stranded/entrapped chinook were found in 16.8% (17 of 101) of the random samples during weekdays and in 35.6% (21 of 59) of the plots sampled on the weekends. There were almost double the number of chinook recorded stranded/entrapped on the weekends (98) compared to the weekdays (54).

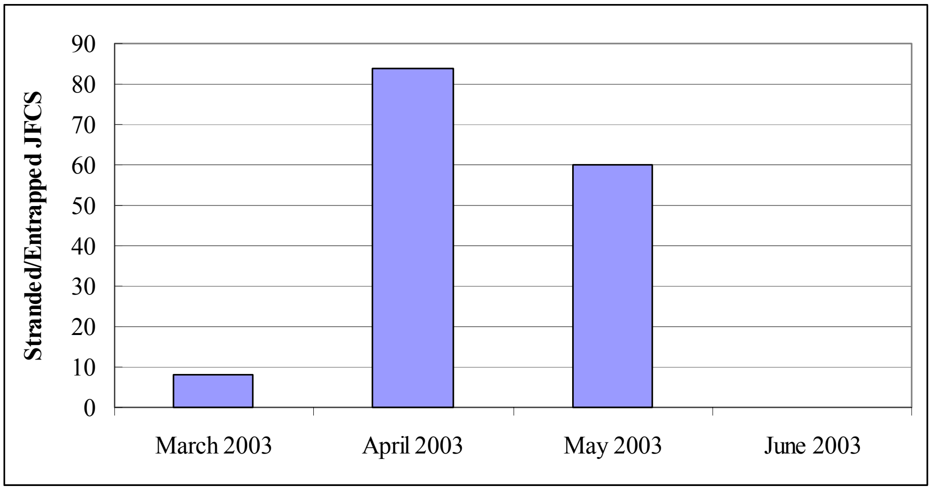

Figure 8. Monthly totals of juvenile fall chinook found stranded and entrapped, March 20-June 5, 2003.

A mean estimate of 154,853 juvenile fall chinook salmon mortalities due to stranding and entrapment occurred within the 8-mile study area between March 20 and May 31 in 2003 (Appendix B). Only eight fish other than chinook could be identified in random samples. These were comprised of seven sculpins (Cottus sp.) and one sucker (Catostomus sp.). Two entrapments contained large numbers of larval fish that were not identified. No additional mortality was determined through re-visitation of entrapments containing live chinook in 2003. Only a single entrapment containing live chinook was encountered within random sites in the 2003 field season. Juvenile fall chinook salmon at risk[4] of mortality due to stranding and entrapment was calculated to be 164,643. Impact and mortality estimates for the 8-mile sampling area for the 1999 through 2003 monitoring evaluations and are provided in Table 12 and Appendix B. These impacts should be considered minimum estimates for the 8-mile study area. Sampling efficiency is dependent upon substrate, vegetation, and predation. There were numerous citations of coyote and bird presence in sampling plots.

Size Susceptibility of Juvenile Fall Chinook Salmon

Juvenile fall chinook salmon collected in random plots had a mean fork length of 40.3 mm and ranged from 35 mm to 50 mm (Figure 9). These results are similar to data from previous years indicating that juvenile fall chinook salmon are less susceptible to stranding and entrapment with increased size. Chinook above 50 mm are rarely found in random plots and susceptibility to stranding diminishes almost completely by 60 mm.

On June 2, three days before the protection plan ended, fall chinook continued to be abundant in the nearshore areas with 2,402 chinook recovered during seining (41.1% of peak abundance) and fork length was 48.5 mm. By June 9, four days after the end of the Protection Plan, abundance in nearshore areas had declined to 21.5% of peak abundance and mean fork length of chinook had increased to 53.8 mm. Minimum fork lengths for chinook sampled along nearshore areas in the Reach continued to be less than 40 mm through the final survey on June 23, however the presence of newly emergent fry (<42 mm) in the sample had decrease markedly by June 9 (7.2% of collection) (Figure 10).

[4] At Risk estimates include fall chinook mortalities and expansion for live chinook recovered from entrapments

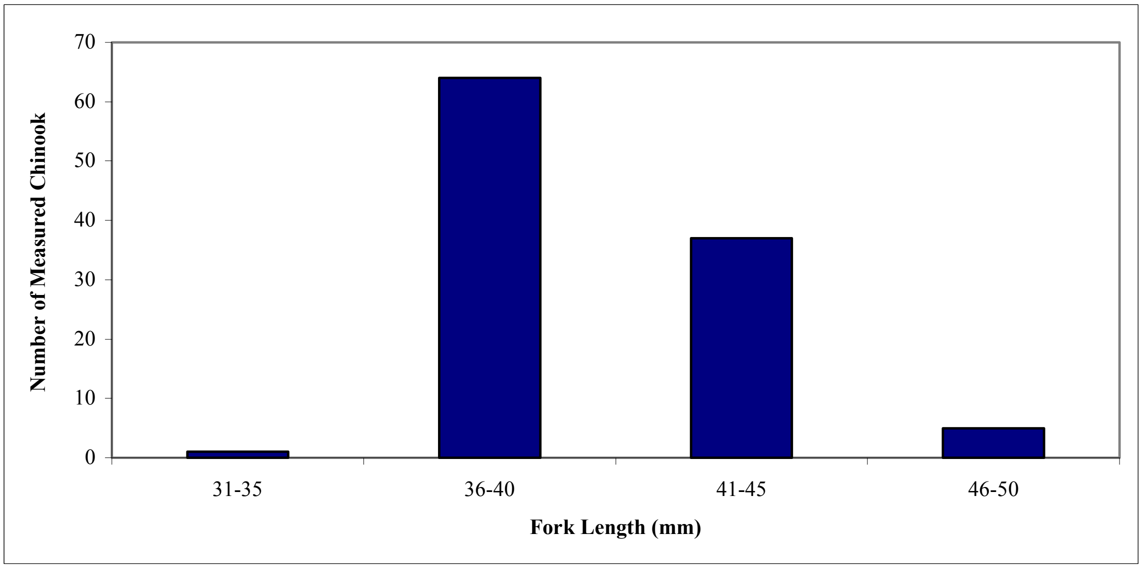

Figure 9. Fork length measurements of juvenile fall chinook salmon collected from random plots on the Hanford Reach of the Columbia River in 2003.

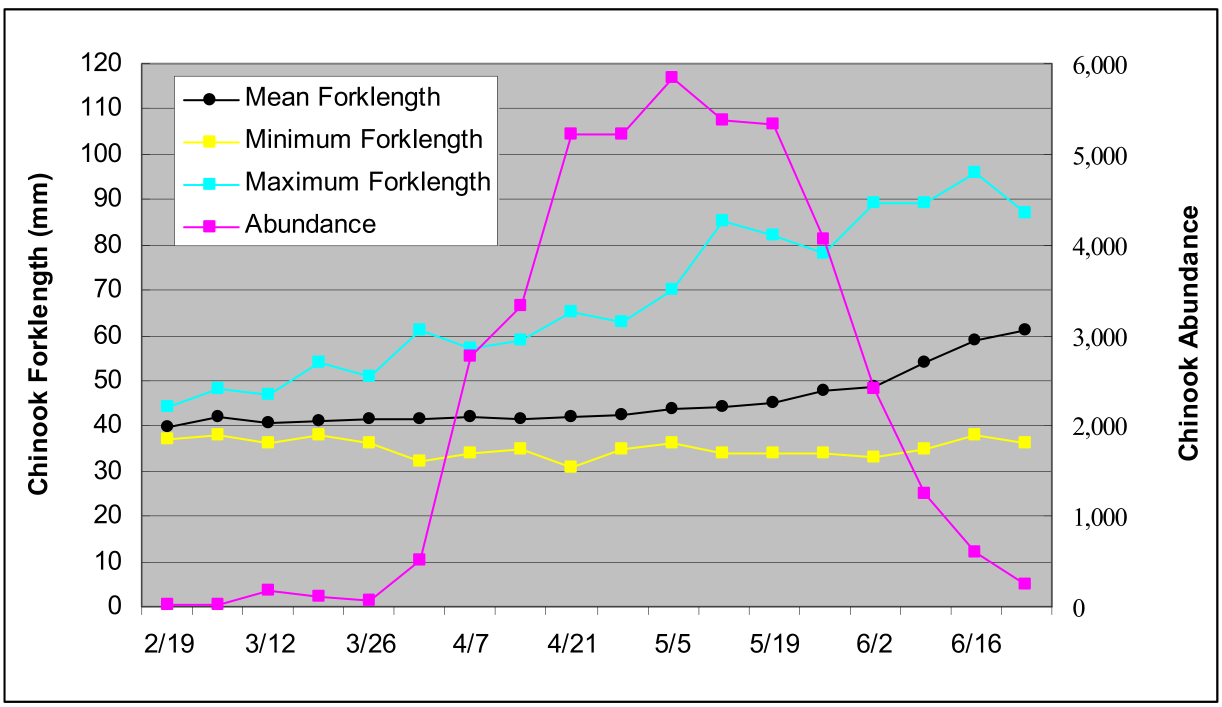

Figure 10. Nearshore abundance and fork length of juvenile fall chinook in the Hanford Reach, Feb 20 – June 23, 2003.

Distribution of Juvenile Fall Chinook Salmon

In 2002, the study area was reduced in size from 35.6 km (Rkm 571.3 to Rkm 606.9) to 15.7 km (Rkm 600.2 to Rkm 584.5). The reduced area represents the section of the river where the most frequent incidences of stranding and entrapment were observed in previous years. The reduced area was used again in 2003 to evaluate impacts on juvenile fall chinook survival. Juvenile fall chinook were found stranded/entrapped throughout the study area (Figure 11). Similar to previous years, impacts were greater at lower elevations. Of the chinook found stranded and entrapped in 2003, 44.7% were observed at flow levels between 50 and 120 kcfs though only 21.9% of the flow fluctuations occurred at these levels (Table 8).

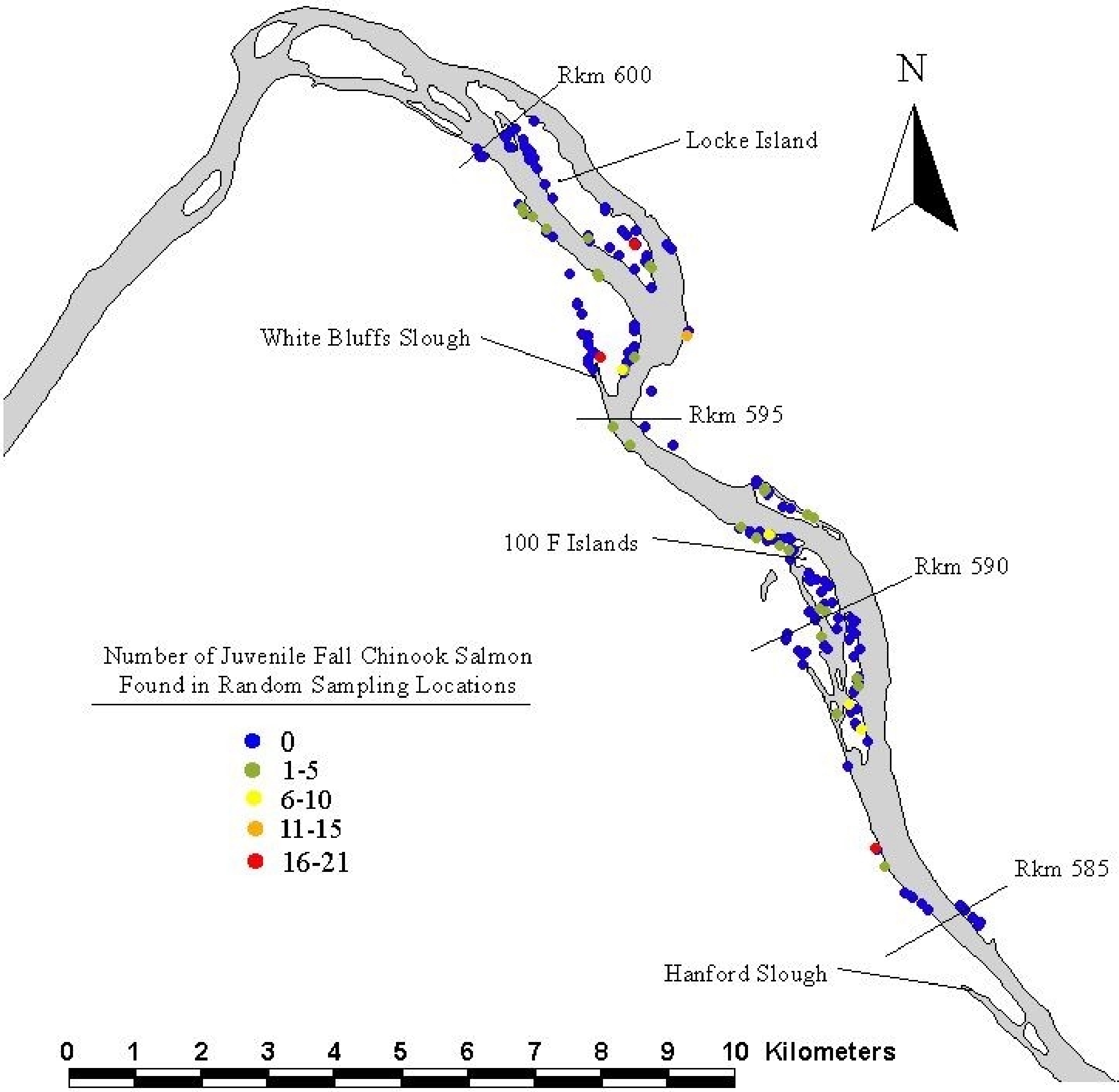

Figure 11. Number and location of stranded and entrapped juvenile fall chinook salmon found in random plots in the Hanford Reach of the Columbia River in 2003.

Table 8. Summary of shoreline exposed, fluctuations, and number of chinook at risk by flow band on the Hanford Reach of the Columbia River in 2003.

Flow Band (Kcfs)	Total Shoreline Within Study Area (hectares)	Number of Flow Fluctuations During Season	Shoreline Exposed During Season (hectares)	Number of Plots Sampled	Area Sampled (hectares)	Number of Plots with Chinook	Number of Chinook Found at Risk	Number of Chinook Found at Risk per Hectare
40-80	77.4	3.4	263.9	7	0.10	1	1	10.2
80-120	111.8	42.6	4,757.9	61	1.15	18	67	58.2
120-160	65.1	97.7	6,362.7	91	1.84	15	60	32.6
160-200	71.3	62.6	4,465.2	34	0.86	7	24	27.9
200-240	33.5	3.3	110.9	0	0.00	0	0	0.00
Total	359.1	209.6	15,960.6	193	3.95	41	152	128.7

Juvenile Fall Chinook Protection Plan

The 2003 Juvenile Fall Chinook Interim Protection Plan was in effect for 98 days during the emergence and rearing period for fall chinook in the Hanford Reach. Of the 84 operational constraints established by the plan, 49 targets were met with daily flow fluctuations below the maximum (Figure 12). There were 70 weekdays during the protection plan and 14 weekends. Weekday constraints were met on 43 (61%) days and weekend constraints were met on 6 (43%) of 14 weekends. Fluctuations were outside of target by less than 5 kcfs on 9 constraints, 5 weekdays and 4 weekends.

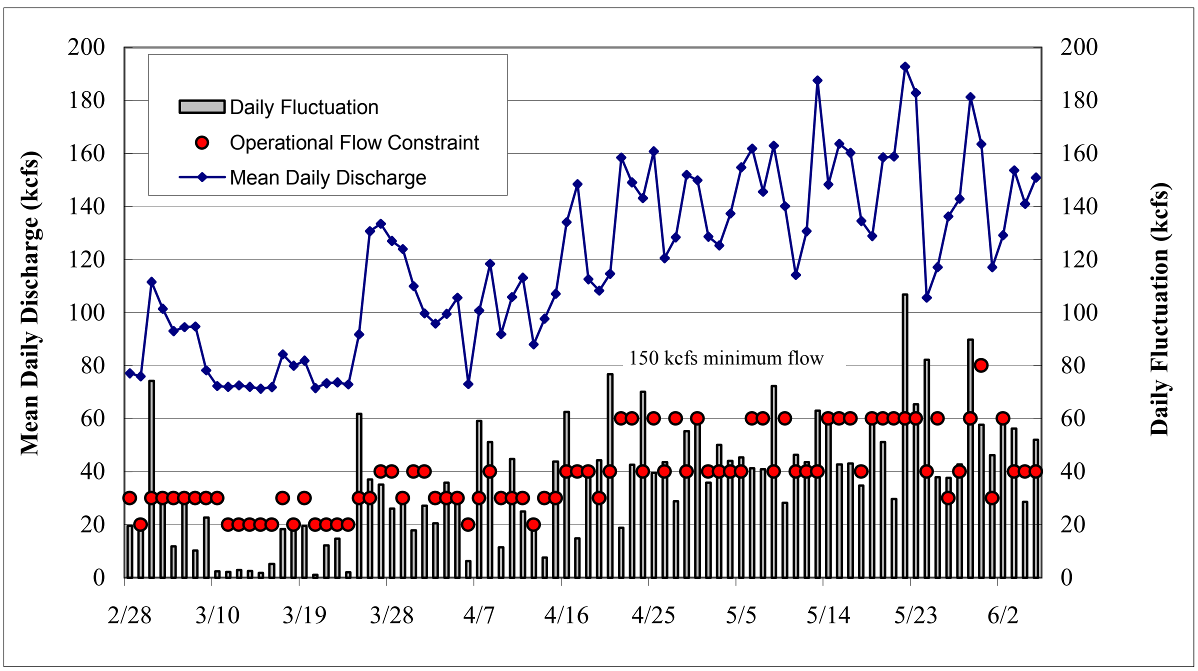

Figure 12. Average daily flows, daily fluctuation, and Protection Plan constraints for Priest Rapids Dam, February 28 – June 5, 2003.

The previous weekday discharge from Rock Island Dam was used to predict Priest Rapids discharge and to set constraints for weekdays. Weekend forecasts for Chief Joseph Dam plus side flows were used to predict weekend flows for Priest Rapids Dam and set weekend constraints. Use of previous day flows from Rock Island and weekend forecasts from Chief Joseph were used with the goal of accurrately predicting daily mean discharge for Priest Rapids Dam and thus maintaining flow fluctuations in the Hanford Reach that would reduce stranding and entrapment. Overall, constraints set using these predictive methods accurately met or were more restrictive on 75 of the 84 targets (89%) during the protection plan in 2003 (Figures 13 & 14 and Table 9). Constraints were identical on 55 predictions, more restrictive on 20 occassions, and were not restrictive enough on 9 occassions. Weekday constraints were accurately predicted on 45 days (64%), 17 daily constraints were more restrictive (24%), and 8 daily constraints were not restrictive enough based on Priest Rapids actual mean daily discharge (11%). Chief Joseph weekend forecasts accurately predicted weekend flows for Priest Rapids on 10 of the weekends (71%), 3 constraints were more restrictive (21%), and 1 constraint was not restrictive enough based on Priest Rapids actual discharge (7%).

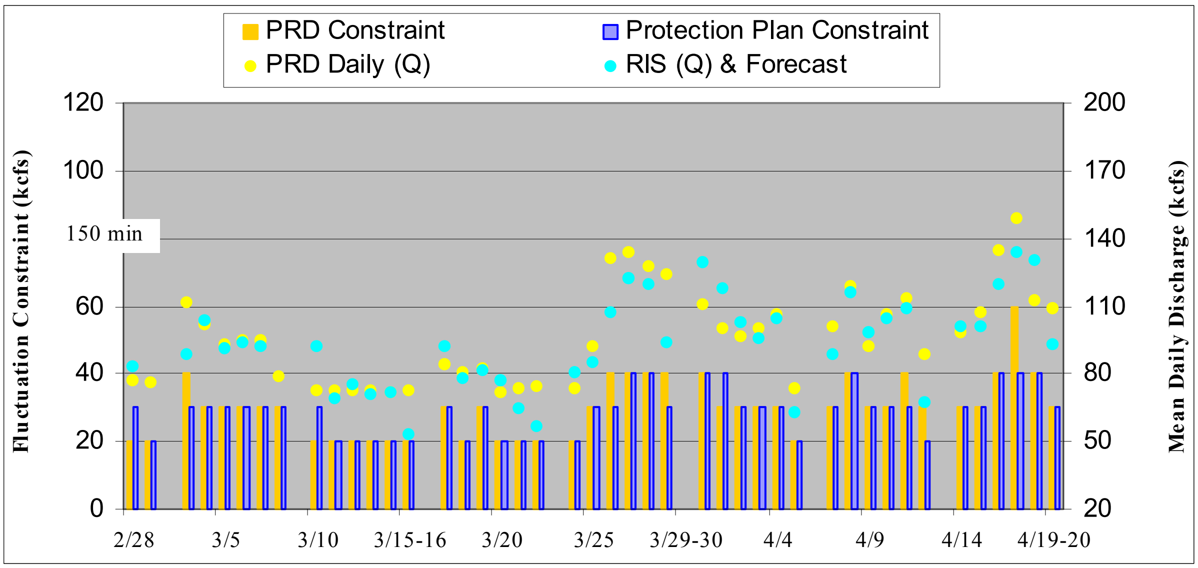

Figure 13. Mean daily discharge from Priest Rapids, previous day Rock Island flows, estimated weekend Chief Joseph flow including side flows, and Protection Plan flow fluctuation constraints, February 28 – April 20, 2003.

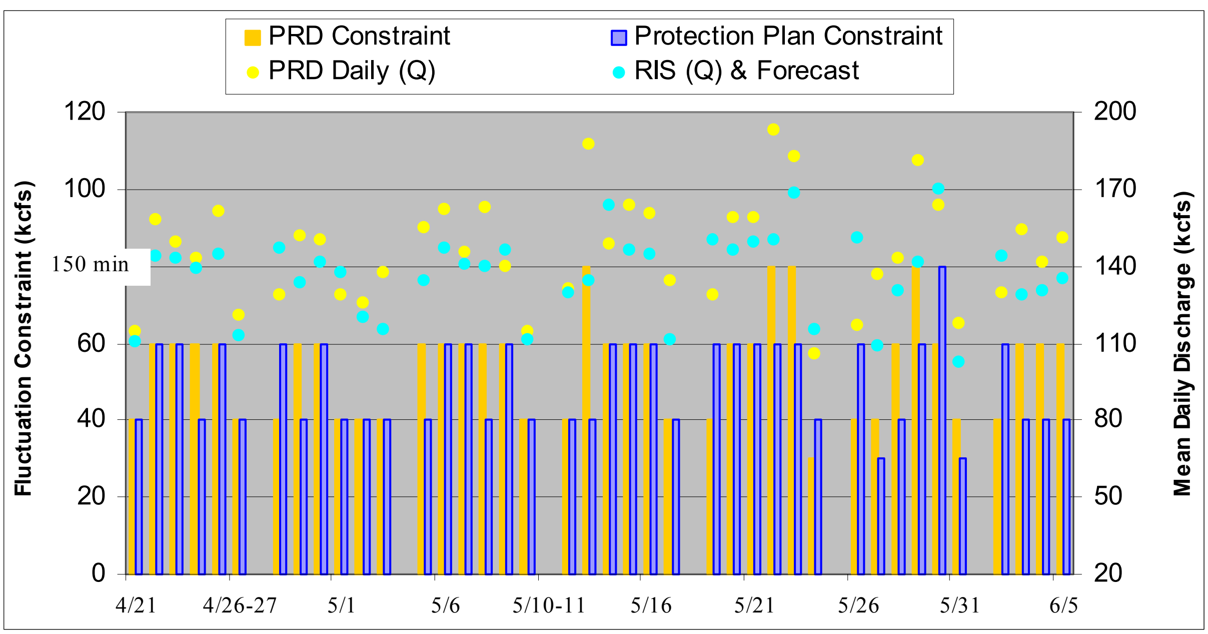

Figure 14. Mean daily discharge from Priest Rapids, previous day Rock Island flows, estimated weekend Chief Joseph flow including side flows, and Protection Plan flow fluctuation constraints, April 21 – June 5, 2003.

Table 9. Comparison of weekday and weekend constraints set using Rock Island inflows and Chief Joseph weekend forecasts to constraints based on daily Priest Rapids mean discharge, February 28 – June 5, 2003.

	Constraints	Met	More Restrictive	Less Restrictive
Weekday (#)	70	45	17	8
(%)		64.3%	24.3%	11.4%
Weekday (#)	14	10	3	1
(%)		71.4%	21.4%	7.1%
Weekday (#)	84	55	20	9
(%)		65.5%	23.8%	10.7%

As stated previously, the protection plan set 84 operational constraints for the 98 days the protection plan was in effect. Constraints were set with the goal of maintaining **daily** fluctuations within the Hanford Reach at levels where mortality of juvenile fall chinook is reduced. A review of the daily mean discharge from Priest Rapids Dam and the corresponding target maximum fluctuation in discharge showed there were 27 days when fluctuations occurred above the ideal maximums (27.6%) during the 98-day period (Table 10). In comparison, the protection plan constraints were above the ideal maximums on 35 of the 84 constraints (41.7%). For example, the mean daily discharge at Priest Rapids on May 4 was 160.7 kcfs with a daily fluctuation of 44.1 kcfs. Under the protection plan, the constraint set based on the Chief Joseph forecast allowed a maximum fluctuation of 40 kcfs for the weekend. GCPUD failed to meet the protection plan constraint though the daily fluctuation was below 60 kcfs, the maximum that would be allowed for mean daily discharges between 140 kcfs and 170 kcfs. The number of days outside of target is less than the number of constraints outside of target for the protection plan due to the fact that constraints set by the protection plan used Rock Island prior weekday flows and Chief Joseph forecasts that were often more restrictive than the constraints would have been if based on actual Priest Rapids discharge for the day. Additionally, weekend constraints as set by the protection plan were set for a 48-hour period rather than individual weekend dates used for this analysis. Fluctuations above ideal maximums most often occurred when mean daily flows were between 80 kcfs and 110 kcfs (34.8%), 110 kcfs and 140 kcfs (34.5%), and above 170 kcfs (100%).

Table 10. Summary of hourly discharge by flow band and compliance with target objective for daily fluctuations below Priest Rapids Dam, February 28 – June 5, 2003.

Flow Band	# of Days	Mean Discharge	Target Fluctuation	Daily Fluctuation (kcfs)				Fluctuations Outside of Target	
				Mean	Median	Min	Max	#	%
36-80	19	73.5	<20 kcfs	6.5	2.9	0.9	20.1	1	5.3%
80-110	23	96.0	<30 kcfs	29.7	27.2	7.6	61.9	8	34.8%
110-140	29	124.3	<40 kcfs	37.9	35.8	11.0	76.8	10	34.5%
140-170	23	152.7	<60 kcfs	45.2	43.1	14.9	72.3	4	17.4%
>170	4	186.1	150 kcfs min	81.3	77.6	63.0	106.8	4	100.0%
	98	**117.0**		**33.3**				**27**	**27.6%**

Conclusions

The 2003 evaluation of stranding and entrapment of juvenile fall chinook on the Hanford Reach of the Columbia River produced similar results to the 1997-2002 evaluations. Studies to date show that flow fluctuations strand and entrap juvenile fall chinook salmon and other fish species along shorelines and affect the nearshore community structure, density, and biomass of macroinvertebrates (Wagner et al. 1999, Nugent et al. 2001, 2002a, 2002b, and 2002c).

Juvenile Fall Chinook Protection Plan

The embryonic development and growth of fall chinook salmon is highly dependent on river temperature. Accumulated temperature units can be used to predict the rate of development, hatching, and emergence timing of fall chinook salmon. Fall chinook salmon eye at approximately 250°C ATU after spawning, hatch at 500°C ATU, and emerge at 1,000°C ATU.

The use of nearshore sampling to determine implementation timing of the annual protection plan for emerging fall chinook can be inaccurate at predicting chinook emergence and abundance. Rearing fall chinook were most commonly found in the Hanford Reach in off-channel habitat with lower velocity and slightly warmer water temperatures than the main river channel. Changes in discharge from Priest Rapids Dam during nearshore sampling can bias the catch at designated sampling locations due to increased velocity, decreased or increased river temperature, and changes in substrate. River velocity at preselected sites can vary greatly depending on discharge and channel morphology of the location. Time of day, ambient air temperature, and changes in river elevation can have dramatic effects on river temperature and movement of chinook into and out of off-channel areas. Seining efficiency can similarly vary depending on velocity and substrate. Establishing a uniform start date for implementation of the annual protection plan for emergence and rearing based on observed spawning and incubation timing will provide better forecasting for coordination of project operations and provides an implementation date corresponding to the early stages of emergence and increasing abundance of fall chinook.

The estimated start of emergence as set by the Vernita Bar Agreement appears to correspond well to emergence and increased abundance in the Hanford Reach. In 1999 through 2002, newly emergent fall chinook salmon were first sampled in the nearshore sampling sites 1 to 16 days prior to the estimated start of emergence but typically in low numbers. In 2000 and 2002, presence of juvenile chinook in nearshore areas reached over 50 fish[5] within two days of the estimated start of emergence. In 2001, chinook abundance had begun to increase (>50 chinook) ten days prior to the estimated start of emergence and in 1999 and 2003 abundance of emergent fry did not increase until two weeks after the emergence date. Nearshore sampling was conducted weekly in 1999 and 2003 and probably led to delays in reaching start criteria in these years.

In addition to emergence timing, ATU can be used to predict susceptibility of fall chinook to stranding and entrapment. Based on data from the five years of evaluation and monitoring, juvenile fall chinook salmon susceptiblity to stranding and entrapment appears to decrease substantially by 1400 ATU after spawning. The final chinook found during randomized sampling each year has varied from 344 ATU (2003) to 602 ATU (2001). In years where chinook continue to be abundant and newly emergent fry were present in nearshore areas after 1400 ATU, susceptibility to stranding and entrapment has been low (2000, 2001, and 2003).

The establishment of protection plan constraints based on upstream discharge and flow forecasts was effective in setting constraints that would reduce the impacts to fall chinook from stranding and entrapment in the study area of the Hanford Reach in 2003. The use of prior weekday discharge from Rock Island Dam to set weekday constraints was effective in setting constraints that matched or were more restrictive than necessary to reduce stranding/entrapment in the study area on 88.6% of the weekdays (62 of 70). Weekend constraints set using Chief Joseph forecasts were accurate for setting constraints that met or were more restrictive on 13 of the 14 weekends (92.9%).

Assessment of Susceptibility of Juvenile Fall Chinook to Stranding and Entrapment

The size of stranded/entrapped juvenile fall chinook salmon and the distribution of stranded/entrapped fish on the Hanford Reach demonstrated similar patterns for the years 1999 through 2003. Juvenile fall chinook salmon collected in random plots were relatively small with a mean fork length of 42.2 mm and range of 31 mm to 86 mm (Table 11). Individuals greater than 60 mm comprised only 0.7% of the fish measured during these years (Figure 15). Most juvenile fall chinook salmon collected from random plots had fork lengths between 36mm and 45mm. Differences in preferred rearing habitat between size classes of juvenile fall chinook may explain the reduced susceptibility to stranding of fish greater than 60 mm.

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[5] Criteria for implementation of protection plan in 2000-02 was the presence of 50 or more chinook in six index locations.

Table 11. Mean and range of fork length of stranded and entrapment of juvenile fall chinook salmon found in random plots on the Hanford Reach of the Columbia River from 1999 to 2002.

Year	Mean Fork Length (mm)	Range Fork Length (mm)	Number of Chinook Measured	Number of Chinook >60 mm
2003	40.7	35-52	115	0
2002	40.7	32-45	101	0
2001	42.3	31-54	354	0
2000	41.7	33-86	512	4
1999	45.6	36-66	257	6
1999-2003	42.2	31-86	1,339	10

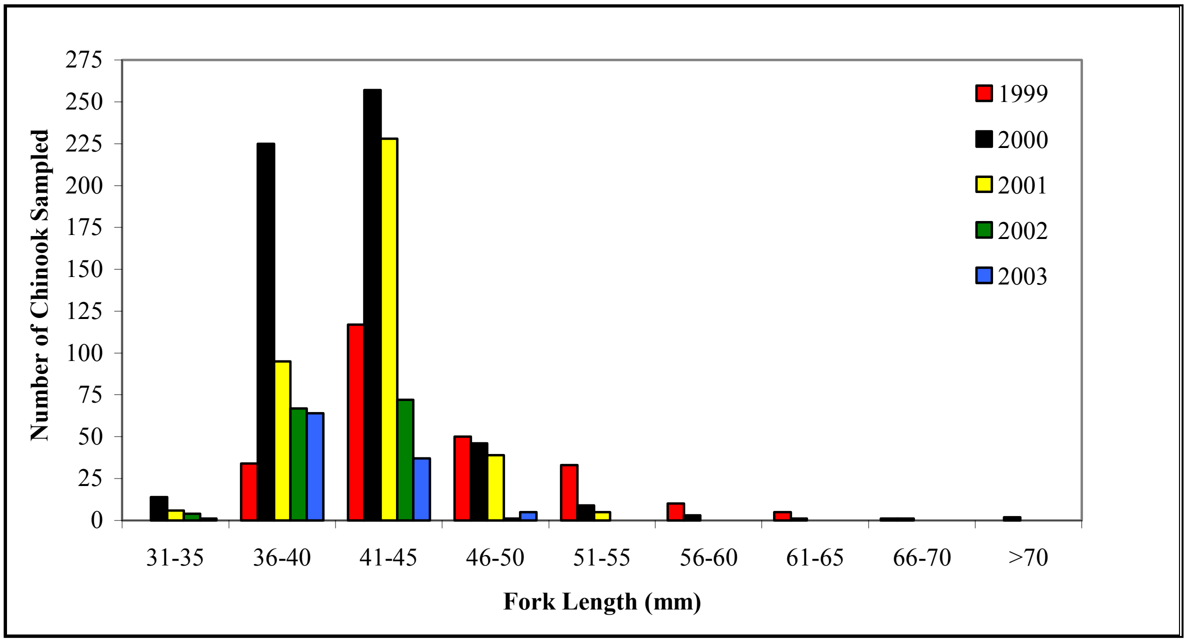

Figure 15. Fork length measurements of juvenile fall chinook salmon collected from random plots on the Hanford Reach of the Columbia River from 1999 to 2003.

Direct mortality of stranded/entrapped juvenile fall chinook most often occurs when entrapments drain or entrapment waters warm to lethal temperatures (≥24ºC). The likelihood of juvenile fall chinook salmon dying within 24 hours of being stranded or entrapped can be high as was seen in 2001 when 97.9% of fish sampled were categorized as direct mortalities at the time of sampling. Thermal stress of juvenile fall chinook salmon subsequently released from entrapments does not, however, appear to have fatal consequences. United States Geological Survey Biological Resources Division (USGS/BRD) performed thermal tolerance tests that showed juvenile fall chinook salmon exposed to entrapment conditions similar to those found on the Hanford Reach had little direct mortality and no increased vulnerability to predation. These fish did, however, show transient increases in plasma concentrations of cortisol, glucose, and lactate, and a dramatic (25-fold higher than controls) and persistent (lasting 2 weeks) increase in levels of liver hsp70. Tests were not conducted to determine the consequences of exposure to multiple, cumulative stressors.

The majority of chinook found entrapped/stranded were recovered during weekend sampling. The average number of chinook per random plot was 1.7 on the weekends compared to 0.5 chinook per plot on the weekdays. The percentage of samples with chinook was also much higher on the weekends with 35.6% of the samples containing chinook compared to 16.8% on the weekdays. Discharge from Priest Rapids Dam typically declines on weekends with the decline in the need for power. These minimal flows continue through the weekend to Monday morning which leads to the dewatering of the majority of the entrapments formed when the water level initially declined. In

addition, the water levels often decline to river elevations where, due to river morphology, large areas of shoreline are unwatered (Figure 16).
Highest concentrations of stranding and entrapment of juvenile fall chinook salmon observed within the study area occurred at island complex areas such as Locke Island/White Bluffs Slough Area (596-602 Rkm) and 100 F Islands (588-593 Rkm). These areas with their large and varied shorelines and diverse shallow water areas appear to provide excellent rearing habitat as well as high stranding potential. The amount of shoreline exposed by flow fluctuations varies by flow level. Large flats or flood terraces exposed at lower flows (40-120 kcfs) pose the greatest threat of stranding and entrapment to juvenile fall chinook salmon on the Hanford Reach.

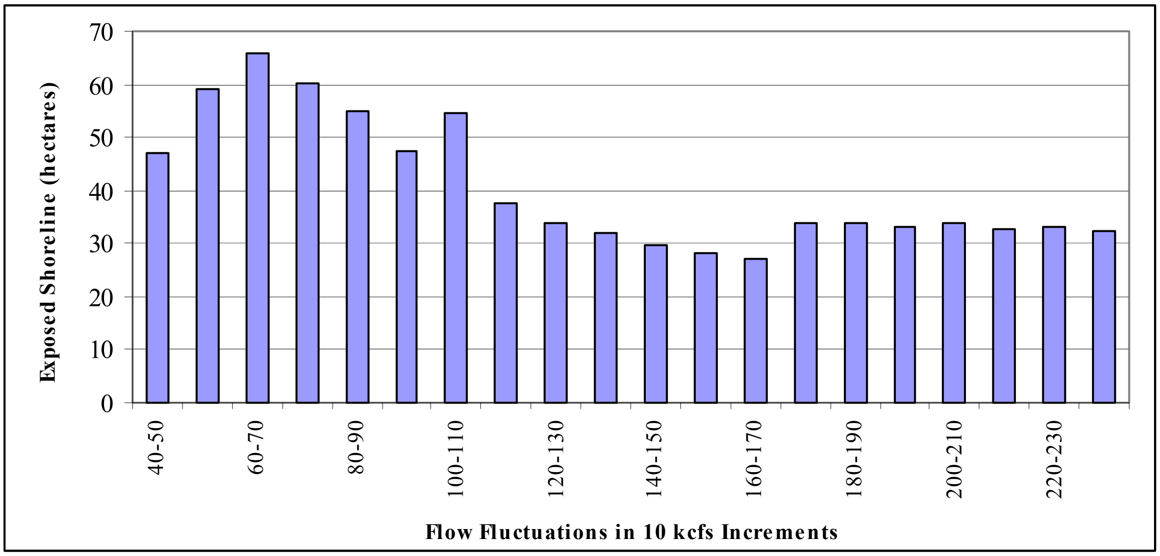

Figure 16. The area of shoreline exposed within 10 kcfs flow bands for a portion of the Hanford Reach of the Columbia River from Rkm 571.3 to 606.9.

Loss estimates of juvenile fall chinook salmon to stranding and entrapment for the 15.7 km (584.5-600.2 Rkm) section of the Hanford Reach for the years 1999 to 2002 indicate that flow fluctuations during low flow years, e.g., 2001, present the highest stranding and entrapment risk (Table 12). These findings have led to the development of a protection plan for emerging and rearing juvenile fall chinook salmon that imposes tighter restrictions on daily flow fluctuations for Priest Rapids Dam at lower flows and allows increased operational flexibility at higher flows.

Table 12. Mean river flows and loss estimates of juvenile fall chinook salmon to stranding and entrapment for a 15.7 km (584.5-600.2 Rkm) section of the Hanford Reach of the Columbia River from 1999 to 2002.

Year	Mean Flows (kcfs) March 1 to June 30 (Range)	Mean Chinook Mortalities (±1.96 S.E.)	Mean Revised Chinook Mortalities[1] (±1.96 S.E.)	Mean Chinook at Risk (±1.96 S.E.)
2003	124.7	154,853	154,853	164,643
	(39.9 to 260.9)	(83,903 to 225,802)	(83,903 to 225,802)	(91,093 to 238,192)
2002	145.0	67,409	70,903	144,249
	(50.8 to 304.4)	(28,623 to 106,195)	(31,517 to 110,288)	(28,813 to 259,685)
2001	77.5	2,013,638	2,013,638	2,013,638
	(37.5 to 206.4)	(-746,334 to 4,773,611)	(-746,334 to 4,773,611)	(-746,334 to 4,773,611)
2000	142.6	45,487	192,824	199,534
	(62.1 to 293.2)	(12,866 to 78,108)	(-70,865 to 456,514)	(-64,234 to 463,302)
1999	160.5	93,943	NA[2]	320,650
	(61.9 to 261.3)	(21,393 to 166,493)		(-54,006 to 695,307)

[1] Entrapments were revisited the next day to determine if fish would have died from drainage of entrapments or lethal temperatures (>24oC).
[2] Entrapments were not revisited in 1999.

Discussion

Evaluation of juvenile fall chinook stranding and entrapment from 1997 to 2003 has primarily been limited to the 21-mile area of the Hanford Reach from Island 1 (Rkm 571.3) to Savage Island (Rkm 606.9). Impacts to fall chinook determined from these studies cannot be directly applied to other areas within the Hanford Reach.

The effects of flow fluctuations on the overall health of the Hanford Reach and to other species of fish is outside the scope of this evaluation. Long-term tests by the University of Idaho and Streamside Programs Consultation on the effects of flow fluctuations show that benthic macroinvertebrates within the river fluctuation zone were severely limited in density and biomass compared to the communities on continually inundated areas. Total invertebrate density was approximately four times higher on substrates never dewatered than on substrates exposed only 1 to 24 hours. Mean total invertebrate density and biomass from substrates exposed up to 24 hours were reduced by 59% and 65%, respectively, to substrates never dewatered. Effects of short-term exposure scenarios revealed that a dramatic decrease in survival was found with even short duration exposures to air. Artificial exposure tests revealed that survival of macroinvertebrates on substrates exposed to air decreased dramatically with increasing duration of exposure, with only 50% survival after 1 hour of exposure. Changes in discharge and water levels also catastrophically entrained macroinvertebrates into the drift outside of behavioral diel periodicity.

Other fish species found stranded or entrapped on the Hanford Reach from 1997 through 2003 included bluegill (*Lepomis macrochirus*), dace (*Rhinichthys* spp.), bullhead (*Ameiurus* spp.), common carp (*Cyprinus carpio*), lamprey (*Lampetra* spp.), largemouth bass (*Micrpterus salmoides*), mountain whitefish (*Prosopium williamsoni*), northern pikeminnow (*Ptychocheilus oregonensis*), peamouth (*Mylocheilus caurinus*), redside shiner (*Ricardsonius balteatus*), sculpin (*Cottus* spp.), smallmouth bass (*Micropterus dolomieui*), spring chinook salmon, steelhead (*Oncorhynchus mykiss*), sucker (*Catostomus* spp.), threespine stickleback (*Gasterosteus aculeatus*), walleye (*Stizostedion vitreum*), yellow perch (*Perca flavescens*), and unidentifiable juvenile and larval fish. Species of special interest in this list include spring chinook salmon, steelhead, and lamprey.

Upper Columbia River spring chinook salmon were classified as a federal endangered species by the USFWS in March 1999. Although these juvenile spring chinook salmon tend to be large (>100 mm) and less susceptible to stranding and entrapment, three fish were seined from an entrapment at 100 F Islands (Rkm 590.7) on April 29, 1998. The National Marine Fisheries Service (NMFS) listed Upper Columbia River steelhead as a federal endangered species in 1997. The listing encompasses the Wells Hatchery stock and all naturally spawned populations of steelhead (and their progeny) in streams in the Columbia River Basin upstream from the Yakima River to the United States/Canada Border. This listing includes the Hanford Reach where steelhead redds have been reported in the past (Eldred 1970; Watson 1973; Becker 1985). Steelhead on the Hanford Reach would most likely spawn between February and early June, with peak spawning in mid-May (Mueller and Geist 1999). Depending on water temperatures, fry would emerge in mid-June to mid-August. Three juvenile steelhead were collected on June 11, 2001 from three separate entrapments, two on Wooded Island (Rkm 560.7 and 561.6) and one on Homestead Island (Rkm 564.4).

Pacific and river lamprey are listed as federal species of concern and river lamprey are also designated as a Washington State candidate species. Both species have been observed on the Hanford Reach (Gray and Dauble 1977). Ten juvenile lamprey were sampled as mortalities in stranding and entrapment sites during our study, three sites (Rkm 548.9, 595.8, and 614.7) containing 5 fish in 1998,one site (Rkm 582.6) containing 3 fish in 1999, and one site (Rkm 597.4) containing 2 fish in 2001. Since lamprey ammocoetes spend 4-6 years in mud as filter feeders before migrating to the ocean, it is difficult to assess the impacts of flow fluctuations on the Hanford Reach to these species.

References

Becker, C. D. 1985. Anadromous salmonids of the Hanford Reach, Columbia River: 1984 Status. PNL-5371. Pacific Northwest Laboratory, Richland, Washington.

Eldred, D. 1970. Steelhead spawning in the Columbia River, Ringold to Priest Rapids Dam, September 1970 Progress Report. Washington Department of Game, Ephrata, Washington. 4 pp.

Gray, R. H. and D. D. Dauble. 1977. Checklist and relative abundance of fish species from the Hanford Reach of the Columbia River. Northwest Science 51(3):208-215.

Hanford Meteorological Station. 2002. http://etd.pnl.gov:2080/HMS. Access date October 31, 2002.

Healey, M. C. 1998. Life history of chinook. In Pacific salmon life histories. C. Groot and L. Margolis, eds. pp. 311-394. UBC Press, Vancouver, British Columbia.

Key, L. O., J. A. Jackson, C. R. Sprague, and E. E. Kofoot. 1994. Nearshore habitat use by subyearling chinook salmon in the Columbia and Snake rivers. In identification of the spawning, rearing and migratory requirements of fall chinook salmon in the Columbia River Basin. D. W. Rondorf and W. H. Miller, eds. pp. 120-150. Annual Report to Bonneville Power Administration, Contract DE-AI7991BP21708, Portland, Oregon.

Mueller, R. P. and D. R. Geist. 1999. Steelhead spawning surveys near Locke Island, Hanford Reach of the Columbia River. PNNL-13055. Pacific Northwest National Laboratory, Richland, Washington.

Nugent, J., T. Newsome, M. Nugent, W. Brock, P. Wagner, and L. Key. 2001. 1998 Evaluation of juvenile fall chinook salmon stranding on the Hanford Reach of the Columbia River. Prepared for The Bonneville Power Administration and the Public Utility District Number 2 of Grant County. BPA Contract Number 97BI30417 and GCPUD Contracts Document 430-647.

Nugent, J., T. Newsome, M. Nugent, W. Brock, P. Wagner, and P. Hoffarth. 2002a. 1999 Evaluation of juvenile fall chinook salmon stranding on the Hanford Reach of the Columbia River. Prepared for The Bonneville Power Administration and the Public Utility District Number 2 of Grant County. BPA Contract Number 9701400 and GCPUD Contracts Document 97BI30417.

Nugent, J., T. Newsome, M. Nugent, W. Brock, P. Hoffarth, and P. Wagner. 2002b. 2000 Evaluation of juvenile fall chinook salmon stranding on the Hanford Reach of the Columbia River. Prepared for The Bonneville Power Administration and the Public Utility District Number 2 of Grant County. BPA Contract Number 9701400 and GCPUD Contracts Document 97BI30417.

Nugent, J., T. Newsome, P. Hoffarth, M. Nugent, W. Brock, and M. Kuklinski. 2002c. 2001 Evaluation of juvenile fall chinook salmon stranding on the Hanford Reach of the Columbia River. Prepared for The Bonneville Power Administration and the Public Utility District Number 2 of Grant County. BPA Contract Number 9701400 and GCPUD Contracts Document 97BI30417.

Platts, W. S., W. F. Megaham, and H. W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. U.S. Forest Service, General Technical Report INT-138, Intermountain Forest and Range Experiment Station, Ogden, Utah.

Richmond, M. C. and W .A. Perkins. 1998. Draft MASS1 Modular Aquatic Simulation System 1D. A one dimensional hydrodynamic and water quality model for river systems. Pacific Northwest Laboratory, Richland, Washington.

United States Geological Survey Gauging Station # 12472800 below Priest Rapids Dam. 2002. http://www.cqs.washington.edu/dart/headwater_com.html. Access Date October 31, 2002.

Wagner, P., J. Nugent, W. Price, R. Tudor, and P. Hoffarth. 1999. 1997-99 Evaluation of juvenile fall chinook stranding on the Hanford Reach. 1997 Interim Report. Prepared for The Bonneville Power Administration and the Public Utility District Number 2 of Grant County. BPA Contract Number 97BI30417 and GCPUD Contracts Document 430-647.

Watson, D. G. 1973. Estimate of steelhead trout spawning in the Hanford Reach of the Columbia River. Battelle Pacific Northwest Laboratories, Richland, Washington.

Watson, R. 2002. Hanford Reach upriver brights escapement sampling 2001. Washington Department of Fish and Wildlife.

Appendix A

Substrate Size, Substrate Embeddedness, and Vegetation Codes

Substrate Codes

Dominant substrate is most common to the sample area and subdominant is the next most common substrate class.

Code	Substrate class
1	Fines (clay to coarse sand (<1 mm))
2	Very coarse sand (1-2 mm)
3	Fine gravel (2-4 mm)
4	Medium gravel (4-8 mm)
5	Coarse gravel (8-16 mm)
6	Small pebble (16-32 mm)
7	Large pebble (32-64 mm)
8	Cobble or rubble (64-256 mm)
9	Boulder (>256 mm)

Substrate Embeddedness Codes

The substrate embeddedness is estimated visually. Substrate embeddedness refers to the degree that the interstices between the larger particles are filled by sand, silt or clay.

Code	% Fines	Description
1	0-25	Openings between dominant sized particles are 1/3 to 1/2 the size of the particles. Few fines in between. Edges are clearly discernable.
2	25-50	Openings are apparent but <1/4 the size of the particles. Edges are discernable but up to half obscured.
3	50-75	Openings are completely filled but half of edges are still discernable.
4	75-100	All openings are obscured. Only one or two edges discernable and size cannot be determined without removal.

Vegetation Codes

Vegetation is assessed visually to estimate the percent of ground coverage.

Code	Description
1	No vegetation present.
2	Sparse vegetation, substrate is completely evident.
3	Medium vegetation, substrate is only partially obscured.
4	Dense vegetation, substrate is nearly or completely obscured by the vegetation.

Appendix B

Estimation of Total Number of Entrapped and Dead Juvenile Fall Chinook Salmon Due to River Flow Fluctuations - 2003 Field Season

The total number of juvenile fall chinook salmon mortalities due to stranding/entrapment was estimated for a portion of the Hanford Reach during the period from March 19th to June 7th, 2003. Sampling in earlier years had included the entire area within the Hanford Reach for which Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) topographic and bathymetric data are available. As in 2002, sampling for stranding effects was performed with a single crew during the 2003 field season, and the sample area was reduced to approximately half that of the area originally studied during 1999-2001. In 2002 and 2003, sampling was confined to the section of the Hanford Reach from river kilometer 600.2 to river kilometer 584.5.

A total of 193 samples were taken during the sampling season, which extended from March 20th till June 14th. As with previous years, the samples used in the estimates were truncated so that samples were only included if they were taken within a week after the last stranded or entrapped fish was observed. In 2003, the last observation of juvenile fall chinook salmon at risk occurred on May 31st, so 18 samples taken during the period from June 8th till June 14th, all of which were zeroes, were dropped from the estimate. Thus, 174 of the 193 samples were used in constructing the loss estimates.

The estimate for 2003 included four 40 kcfs flow bands of the Hanford Reach: 70-80, 80-120, 120-160, and 160-200 kcfs. Note that the lowermost 40 kcfs band, which would normally extend from 40-80 kcfs was truncated because no fluctuations occurred in the range from 40-70 kcfs. The area of that flow band was reduced to equal the range over which fluctuations occurred. In addition, one sample was not included in the estimate because it fell into the 200-240 kcfs flow band, and only a single sample was available to estimate the fish at risk and mortalities for that flow band.

The estimate derived from the sampling is only representative of a portion of the entire Hanford Reach, and must be considered a minimum estimate. The flow bands that were sampled in the study area can be considered as four strata with different properties relative to stranding and entrapment, so estimation of the total number of stranded/entrapped juvenile fall chinook salmon was performed using a stratified random sampling algorithm.

A sampling plan was designed by Pacific Northwest National Laboratory (PNNL) and Washington Department of Fish and Wildlife (WDFW) prior to the 2003 field season that identified all potential sampling locations in the reduced study area and determined which flow band they fell in using the SHOALS data and the Modular Aquatic Simulation System 1D (MASS1) flow model. The sample plot size used in the study was approximately 3600 sq ft. Samples were selected randomly from the population of potential samples within each flow band, with the number of random samples selected being proportional to the size of the flow band. A list of random samples, with location coordinates and the flow band to which they belonged, was provided to the WDFW. Each morning, the target flow band(s) for sampling were identified based on the flow fluctuations in the previous 48 hr period. A list of samples would then be selected from the list of random samples for sampling that day. The sampling crew would use a high-resolution global positioning system (GPS) to navigate to the selected sample locations on the list. An anchor weight was placed at the center of each sample plot, and an incrementally marked wire cable was used to determine the boundary of the circular sampling plot. In many cases, the entire area of the plot could not be sampled, because portions of the plot were still under water at the rivers edge, or were above the wetted shoreline. In those cases, a scaled drawing was made that was later used to estimate the proportion of the plot that could actually be sampled. The number of juvenile fall chinook salmon at risk, dead, or likely to die due to stranding or thermal stress in an entrapment (i.e., due to imminent drainage of the entrapment or high temperature) were counted for each sample plot. Other data were also recorded, including the substrate type, embeddedness, and vegetation density. In 2000 through 2003, an additional step was taken, to revisit entrapments the following day and determine the fate of juvenile fall chinook salmon that had been entrapped.

The first step in the calculation of the total number of dead juvenile fall chinook salmon was to calculate the number of dead juvenile fall chinook salmon per sample plot. If the entire plot could not be sampled, then the number of juvenile fall chinook salmon that would be found in a full size sample plot was estimated by dividing the number of juvenile fall chinook salmon found by the proportion of the area of the plot that was sampled to the standard plot size. The average number of juvenile fall chinook salmon per plot in each flow band, $\bar{x}_h$, was calculated as the sample mean of the number of stranded/entrapped juvenile fall chinook salmon for all samples collected within a flow band h, where samples are denoted as x_{hi}, with $h = 1, 2, 3\ldots$ and $i = 1\ldots n_h$. Here h is the index of the flow band and n_h is the number of samples taken within a flow band h. The equation for estimating the stratified average number of dead juvenile fall chinook salmon per sample plot is:

$$\bar{x}_{st} = \sum_{h=1}^{3} W_h \bar{x}_h \qquad [1]$$

where W_h is the weight of a flow band h. The weights for each flow band are found by calculating the total number of plots in a flow band, N_h, and dividing by the total number of potentially impacted plots in all flow bands. Note that N_h also accounts for the number of fluctuations of flow over the area of a flow band h, that is, the total number of potentially impacted plots N_h is the number of plots in a flow band h multiplied by the number of fluctuations affecting that flow band (given below). In equation 1, $\bar{x}_h$ is the sample mean of the number of stranded/entrapped juvenile fall chinook salmon per sample plot within a flow band h.

The number of fluctuations occurring during the study period in each of the flow bands was counted by WDFW personnel using hourly discharge data from Priest Rapids Dam that had been processed using the MASS1 model. The processing was performed to account for attenuation of the amplitude of the fluctuations in river flows as recorded at the project as the flows translate through the Hanford Reach. This attenuation causes a reduction in the number of fluctuations that would be counted at areas downstream of the project. For the estimate, the decision was made to use the number of fluctuations calculated for the middle cross-section in the SHOALS study area (Transect #85) for the approximate time period covered by the random sampling data (March 19 – June 7, 2003). This is the same procedure followed in 1999 through 2002. The numbers of fluctuations found for each of the four flow bands included in the 2003 estimate (70-80, 80-120, 120-160, and 160-200 kcfs) are 3.4, 10.5, 20.8, and 9.6, respectively.

An unbiased estimate of the variance of the stratified average (Var ($\bar{x}_{st}$)) is derived from the weighted sample variance using Eq.[2]:

$$s^2\left(\overline{x}_{st}\right)=\sum_{h=1}^{3}W_h^2\frac{s_h^2}{n_h} \qquad [2]$$

where the variance of the number of dead juvenile fall chinook salmon per sample plot for each flow band is calculated using equation 3:

$$s_h^2=\frac{1}{n_h}\sum_{i=1}^{n_h}\left(x_{hi}-\overline{x}_h\right)^2 \qquad [3]$$

The total number of dead juvenile fall chinook salmon, $\hat{I}$, over the entire area of the flow bands is estimated by Eq.[4]:

$$\hat{I}=\sum_{h=1}^{3}N_h\overline{x}_h=N\overline{x}_{st} \qquad [4]$$

The estimate of the variance of $\hat{I}$ is also used to estimate the standard error and was obtained from Eq.[5]:

$$s^2\left(\hat{I}\right)=N^2s^2\left(\overline{x}_{st}\right) \qquad [5]$$

The 95% confidence interval of the estimated total number of juvenile fall chinook salmon mortalities is determined by Eq.[6]:

$$\hat{I}\pm1.96*s\left(\hat{I}\right) \qquad [6]$$

assuming a normal distribution.

The results of the computation of the number of juvenile fall chinook salmon mortalities due to stranding in 2003 are listed in the Table 1 at the end of this memo. The results from 2003 along with results from the 1999 through 2002 field seasons are included in Table 2. Note that the lower bound of the 95% confidence intervals of the estimates are sometimes less than zero. While these negative numbers have no physical meaning, they are included so that the reader can see the full width of the confidence interval, which provides a measure of the variability around the estimate. A more realistic lower bound for the 95% confidence interval in those cases would be the actual number of juvenile fall chinook that were found during the surveys. In order to be able to compare the results from 2002 and 2003 with those from previous years, the estimates for 1999-2001 given in Table 2 have been recomputed from those issued in earlier years so that they are based only on samples from the reduced study area used in 2002 and 2003. The number of Morts given in Table 2 for 2003 is the number of dead juvenile fall chinook salmon estimated using the original procedure followed in 1999. The estimate denoted Rev Morts for each year indicates the number of dead juvenile fall chinook salmon based on revisiting the sites of randomly sampled entrapments to determine the number of juvenile fall chinook salmon at risk that died over the next 24 hours due to drainage of the entrapment, high temperatures, etc. In 2001, all of the juvenile fall chinook salmon entrapment events observed in random samples from the reduced study area were immediately classified as mortalities, therefore the Mort, Rev Mort, and At Risk estimates for 2001 are identical. In 2003, there was only one site where there were entrapped fish that were not immediately classed as mortalities, and there was no change in status of the entrapped fish when the site was revisited 24 hours later. Therefore, the difference between the chinook at risk and Mort estimates is small and the Rev Mort estimate for 2003 is identical to the Mort estimate.

The estimate of the total number of juvenile fall chinook salmon that died within the study area during the period from March 19 – June 7, 2003 is 154,853 (Table 1) and a 95% confidence interval for that estimate is [83,903 to 225,802]. The number of mortalities estimated by revisiting the site is identical, and the estimated number of juvenile fall chinook salmon at risk is slightly higher than the number of estimated mortalities (Table 2).

The number of dead juvenile fall chinook salmon estimated in 2003 is about 1.5 to 3.5 times the number estimated for 1999, 2000, and 2002. However, the estimated number of salmon at risk in 2003 is only greater than the results for one year (2002), suggesting that the total potential impact in 2003 is not greater than it was in other years. As noted in the report issued in 2001, the estimated mortalities in 2001 far exceed those in other years, including 2003, which it exceeds by roughly an order of magnitude. The high number of mortalities in 2001 appears to be caused by low river flows. Studies by PNNL and the WDFW indicate that there is a higher proportion of extensive flat areas within the 40-80 kcfs flow band than are found in the higher flow bands where the majority of fluctuations have occurred in other years, including 2003. The 40-80 kcfs flow band appears to have a higher susceptibility to stranding and mortality of juvenile fall chinook salmon, and there were a small number of fluctuations in that flow band (3.4) in 2003, relative to the number that occurred in 2001 (14.6).

Note that these estimates are all minimum estimates, because the random sampling program only sampled a portion of the Hanford Reach (approximately half of the portion of the Reach with SHOALS coverage), and we assume 100% efficiency during the sampling, i.e., that no dead juvenile fall chinook salmon were missed during the sampling of each random plot.

Table 1. Estimated mortalities for 2003 field season

Strata	**No. Plots (area)**	**No. Flow Fluct.**	**N_h, #plots * #fluct**	**W_h**	**n_h**	**mean_ h, no./plot**	**N_h*mean_h, no.**
70-80	1081	3.4	3686	0.04	6	4.08	15053
80-120	3343	10.5	34968	0.35	72	2.02	70540
120-160	1948	20.8	40577	0.41	74	1.68	68334
160-200	2132	9.6	20362	0.20	22	0.05	926
Sum	8504	44	99593	1	174		**total number 154853** **95% confidence interval: 83903 225802**

Table 2. Comparative stranding results for 1999-2003

2003 Field Season

	Mean	Mean - 1.96 S.E.	Mean + 1.96 S.E.
Morts	154,853	83,903	225,802
Rev Morts	154,853	83,903	225,802
At Risk	164,643	91,093	238,192

2002 Field Season

	Mean	Mean - 1.96 S.E.	Mean + 1.96 S.E.
Morts	67,409	28,623	106,195
Rev Morts	70,903	31,517	110,288
At Risk	144,249	28,813	259,685

2001 Field Season

	Mean	Mean - 1.96 S.E.	Mean + 1.96 S.E.
Morts	2,013,638	-746,334	4,773,611
Rev Morts	2,013,638	-746,334	4,773,611
At Risk	2,013,638	-746,334	4,773,611

2000 Field Season

	Mean	Mean - 1.96 S.E.	Mean + 1.96 S.E.
Morts	45,487	12,866	78,108
Rev Morts	192,824	-70,865	456,514
At Risk	199,534	-64,234	463,302

1999 Field Season

	Mean	Mean - 1.96 S.E.	Mean + 1.96 S.E.
Morts	93,943	21,393	166,493
Rev Morts	NA	NA	NA
At Risk	320,650	-54,006	695,307

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Appendix C

Female Composition of Fall Chinook Salmon Harvest in the Hanford Reach, 2002

Week	Male	Female	Jack	Total Adult	% Female
8/15 - 8/18	0	1	0	1	100%
8/19 - 8/25	0	0	0	0	
8/26 - 9/1	2	0	0	2	0%
9/2 - 9/8	8	9	0	17	53%
9/9 - 9/15	30	39	4	69	57%
9/16 - 9/22	90	78	15	168	46%
9/23 - 9/29	169	128	32	297	43%
9/30 - 10/6	167	125	42	292	43%
10/7 - 10/13	170	89	32	259	34%
10/14 - 10/20	183	94	33	277	34%
10/21 - 10/27	34	18	5	52	35%
10/28 - 11/3	7	1	0	8	13%
Totals	860	582	163	1,442	40.4%

Appendix D

Hanford Reach Adjusted Escapement 1990-2002

Year	Adult	Jack	Total
2002	69,342	15,167	84,509
2001	44,140	15,708	59,848
2000	36,027	11,993	48,020
1999	27,012	2,800	29,812
1998	29,410	5,983	35,393
1997	34,007	9,486	43,493
1996	37,548	5,701	43,249
1995	38,381	16,827	55,208
1994	48,857	14,246	63,103
1993	30,650	6,697	37,347
1992	29,449	12,503	41,952
1991	31,971	20,225	52,196
1990	40,117	17,034	57,151