2002 Evaluation of Juvenile Fall Chinook Salmon Stranding on the Hanford Reach of the Columbia River

Prepared for
The Public Utility District Number 2 of Grant County

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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 2002 Evaluation of Juvenile Fall Chinook Salmon (*Oncorhynchus tshawytscha*) Stranding on the Hanford Reach of the Columbia River. The 2002 evaluation was the sixth 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 benthic macroinvertebrates of the Hanford Reach. The field effort was performed from February 20 through June 15.

The objectives of the 2002 evaluation were to determine the start and end dates of the juvenile fall chinook salmon protection program, estimate the number of juvenile fall chinook salmon killed and placed at risk within the designated sampling area during the protection program, and evaluate the impacts of flow conditions and protection measures. The 2002 Hanford Reach Juvenile Fall Chinook Salmon Interim Protection Program is provided in this report. The program set stricter flow fluctuation limits at lower flows and more operational flexibility at higher flows.

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 Pacific Norwest National Laboratory (PNNL) and WDFW prior to the 1999 field season and was implemented in 1999 through 2001. 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 to 400 kcfs. In 2002, the sample area was reduced to approximately half that of the previous years. The reduced area was selected to include the section of the river where the majority of the stranding and entrapment was observed in previous years. This area stretches from Rkm 584.5 to Rkm 600.2.

River and meteorological conditions on the Hanford Reach varied prior to and during the 2002 juvenile fall chinook salmon emergence and rearing period (March-June). Air temperatures were much warmer than normal during the winter prior to the emergence and rearing period, which contributed to warmer than usual river temperatures. Cooler than normal air temperatures during the emergence and rearing period slowed increasing river temperatures to near average. Precipitation was lower than normal during most of the emergence and rearing period, attaining only 66% of normal. Solar radiation levels, a good indication of cloud cover, were also slightly below average for most of the emergence and rearing period. Mean monthly river flows ranged from 74.8 kcfs in March to 219.9 kcfs in June.

Emergence of wild juvenile fall chinook salmon in 2002, as calculated under the terms of the Vernita Bar Settlement Agreement, was estimated to start on March 17. Population index surveys were initiated on February 20 to account for possible early emergence. Implementation criteria were met on March 19 and the 2002 Interim Protection Program began March 21. The program ended on June 4 when 400ºC ATU's following the estimated end of emergence were attained. Random sampling plan to assess the effectiveness of the 2002 Interim Protection Program began on March 22 and ended June 15.

Priest Rapids Dam discharges averaged 131.2 kcfs from March 21 through June 4. Hourly discharge from the Dam ranged from 50.8 to 293.8 kcfs. Mean daily flow fluctuation during this period was 47.1 kcfs.

A total of 194 random plots encompassing 47,234 m^2 (508,439 ft^2) were sampled within the reduced sample area in 2002. Random plots contained 188 juvenile fall chinook salmon including 89 stranded and 99 entrapped individuals. Field crews recorded 91 direct mortalities consisting of the 89 stranded and 2 thermal induced fatalities. Projected mortalities were estimated at 93 based on revisitation the next day to determine if the entrapments drained or reached lethal temperatures (>24^{o}C). Fish were first encountered in random plots on March 23 and last found on June 9. The majority (92%) of juvenile fall chinook salmon were sampled during the month of April. Only two other species of fish, sculpin (*Cottus* spp.) and threespine stickleback (*Gasterosteus aculeatus*), were found stranded or entrapped in random plots.

The estimated total number of juvenile fall chinook salmon stranding and entrapment mortalities within the reduced sample area in 2002 was calculated to be 67,409 with a 95% confidence interval between 28,623 and 106,195. The number of mortalities estimated by revisitation of entrapments was 70,903 with a 95% confidence interval between 31,517 and 110,288. Juvenile fall chinook salmon placed at risk of mortality due to stranding and entrapment was calculated to be 144,249 with a 95% confidence interval between 28,813 and 259,685.

Juvenile fall chinook salmon collected in random plots had a mean fork length of 40.7 mm and ranged from 32 to 45 mm. The majority of juvenile fall chinook salmon found in random plots in 2002 were located upstream of Rkm 595 in the Locke Island/White Bluffs Slough area (80.3%) and at flow levels between 50 and 120 kcfs (87%).

An estimated 21.4 million fall chinook salmon fry were produced on the Hanford Reach in 2002. Sampling to assess juvenile fall chinook salmon abundance and fish size began on February 20 and ended on June 19. A total of 5,550 juvenile fall chinook salmon were seined during this period. Juvenile fall chinook salmon were collected in every weekly sample from March 1 to June 19 but peak abundance occurred from March 27 to May 29. The largest catch of the season was obtained on May 15 when 1,739 individuals were sampled.

Table of Contents

Executive Summary i
Table of Contents iii
List of Figures iv
List of Tables iv
Introduction 1
Objectives 1
Methods 1
The 2002 Hanford Reach Juvenile Fall Chinook Salmon Interim Protection Program 1
Estimates of Juvenile Fall Chinook Salmon Stranding and Entrapment 1
Fall Chinook Salmon Fry Production Estimate 3
Accumulated Temperature Units and Juvenile Fall Chinook Salmon Stranding and Entrapment Susceptibility 3
Assessment of Juvenile Fall Chinook Salmon Relative Abundance and Fish Size 3
Modeling of Juvenile Fall Chinook Salmon Susceptibility to Stranding and Entrapment 4
Results 5
2002 Hanford Reach Flows and Meteorological Conditions 5
Implementation Timing and Operation of the 2002 Hanford Reach Juvenile Fall Chinook Salmon Interim Protection Program 6
Estimates of Juvenile Fall Chinook Salmon Stranding and Entrapment 8
Numbers of Juvenile Fall Chinook Salmon 8
Size Susceptibility of Juvenile Fall Chinook Salmon 9
Distribution of Juvenile Fall Chinook Salmon 10
Fall Chinook Salmon Fry Production Estimate 11
Assessment of Juvenile Fall Chinook Salmon Relative Abundance and Fish Size 11
Other Fish Species 12
Conclusions 13
References 17
Appendix A: 2002 Hanford Reach Juvenile Fall Chinook Protection Program 19
Appendix B: Substrate Size, Substrate Embeddedness, and Vegetation Codes 23
Appendix C: Estimation of Total Number of Entrapped and Dead Juvenile Fall Chinook Salmon Due to River Flow Fluctuations - 2002 Field Season 25
Appendix D: Data used in Hanford Reach Fall Chinook Salmon Fry Production Estimate 32

List of Figures

Figure 1. Modified study area on the Hanford Reach of the Columbia River, 2002. 2
Figure 2. Index site locations on the Hanford Reach of the Columbia River, 2002. 4
Figure 3. Mean daily river temperatures on the Hanford Reach of the Columbia River in 2002 and estimated timing of fall chinook salmon development, hatching, emergence, and end of stranding and entrapment susceptibility based on accumulated temperature units (ATU's). 6
Figure 4. Hourly discharge and average daily flows from Priest Rapids Dam, March 1 – June 30, 2002. 7
Figure 5. Average daily flows, daily fluctuation in discharge, and Protection Plan constraints for Priest Rapids Dam, March 1 – June 30, 2002. 8
Figure 6. Fork length measurements of juvenile fall chinook salmon collected from random plots on the Hanford Reach of the Columbia River in 2002. 9
Figure 7. Random sampling plots and number of strand and entrapped juvenile fall chinook salmon found in each plot on the Hanford Reach of the Columbia River in 2002. 10
Figure 8. Relative abundance and fork length measurements of juvenile fall chinook salmon collected from nearshore sites on the Hanford Reach of the Columbia River in 2002. 12
Figure 9. Fork length measurements of juvenile fall chinook salmon collected from random plots on the Hanford Reach of the Columbia River from 1999 to 2002. 14
Figure 10. 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. 15

List of Tables

Table 1. Operational constraints for Priest Rapids Dam during the 2002 juvenile fall chinook salmon emergence and rearing period. 1
Table 2. Comparison of 2002 monthly mean river flow, river temperature, air temperature, precipitation, and solar radiation levels to past years on the Hanford Reach of the Columbia River. 5
Table 3. Daily fluctuations in discharge from Priest Rapids Dam, March 21 – June 4, 2002. 7
Table 4. Weekly numbers of juvenile fall chinook salmon found in random plots on the Hanford Reach of the Columbia River in 2002. 9
Table 5. Flow bands and number of stranded and entrapped juvenile fall chinook salmon found on the Hanford Reach of the Columbia River in 2002. 11
Table 6. Calculation of the 2002 fall chinook salmon fry production estimate for the Hanford Reach of the Columbia River. 11
Table 7. Total number of fish other than fall chinook salmon sampled on the Hanford Reach of the Columbia River in 2002 (February 20-June 19). 13
Table 8. Timing of emergence and stranding/entrapment of juvenile fall chinook salmon on the Hanford Reach of the Columbia River from 1999 to 2002. 13
Table 9. Mean fork length and range of stranding and entrapment of juvenile fall chinook salmon found in random plots on the Hanford Reach of the Columbia River from 1999 to 2002. 14
Table 10. 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. 16

Introduction

The Washington Department of Fish and Wildlife (WDFW) has been contracted through Grant County Public Utility District (GCPUD) to perform an evaluation of juvenile fall chinook salmon (*Oncorhynchus tshawytscha*) stranding on the Hanford Reach of the Columbia River. The evaluation, in the sixth year of a multi-year study, has been developed to assess the impacts of water fluctuations from Priest Rapids Dam on rearing juvenile fall chinook salmon, other fishes, and benthic macroinvertebrates of the Hanford Reach. Previous work was funded by Bonneville Power Administration (BPA) and GCPUD. This document provides the results of the 2002 field season and a summary of findings from previous years.

Objectives

The objectives of the 2002 evaluation were as follows:

1) Determine the starting and ending dates of the juvenile fall chinook salmon protection operations.

2) Estimate the number of wild juvenile fall chinook salmon A) killed and B) placed at risk within the designated sampling area during the special operations period.

3) Evaluate the impact of flow conditions and protection measures recommended by the Hanford Stranding Policy Group on wild juvenile fall chinook salmon.

Methods

The 2002 Hanford Reach Juvenile Fall Chinook Salmon Interim Protection Program

The 2002 Hanford Reach Juvenile Fall Chinook Salmon Interim Protection Program was developed from earlier programs and modified to provide more protection to juvenile fall chinook salmon at lower flows and more operational flexibility at higher flows (**Table 1**). The 2002 protection program was implemented when a daily total of 50 or more subyearling fall chinook salmon were seined from the six established nearshore sampling sites used to assess relative abundance and fish size. The sampling of these sites was begun one week prior to the calculated start of emergence under the Vernita Bar Settlement Agreement. Seining was performed every other day to define the beginning of susceptibility then once a week thereafter. Operational constraints were lifted when 400 or more accumulated temperature units (ATU's) Celsius had accrued following the end of emergence under the Vernita Bar Settlement Agreement. The 2002 Hanford Reach Juvenile Fall Chinook Salmon Interim Protection Program is further detailed in **Appendix A**.

Table 1. Operational constraints for Priest Rapids Dam during the 2002 juvenile fall chinook salmon emergence and rearing period.

Mean Discharge (kcfs)[1]	Operational Flow Constraint
36[2]-80	Limit flow fluctuations to ≤ 20 kcfs
80-110	Limit flow fluctuations to ≤ 30 kcfs
110-140	Limit flow fluctuations to ≤ 40 kcfs
140-170	Limit flow fluctuations to ≤ 60 kcfs
> 170	Maintain 150 kcfs minimum hourly discharge

[1]Weekday constraints based on rolling average of the 5 previous weekdays and weekend constraints based on BPA weekend forecast for Priest Rapids Dam

[2]Vernita Bar Settlement Agreement minimum flow restriction

Estimates of Juvenile Fall Chinook Salmon Stranding and Entrapment

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 Pacific Norwest National Laboratory (PNNL) and WDFW prior to the 1999 field season and was implemented in 1999 through 2001. 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 to 400 kcfs. In 2002, the sample area was reduced to approximately half that of the previous years (**Figure 1**). The reduced area was selected to include the section of the river where the majority of the stranding and entrapment was observed in previous years. This area stretches from Rkm 584.5 to Rkm 600.2. Details of the selection process are described in **Appendix C**.

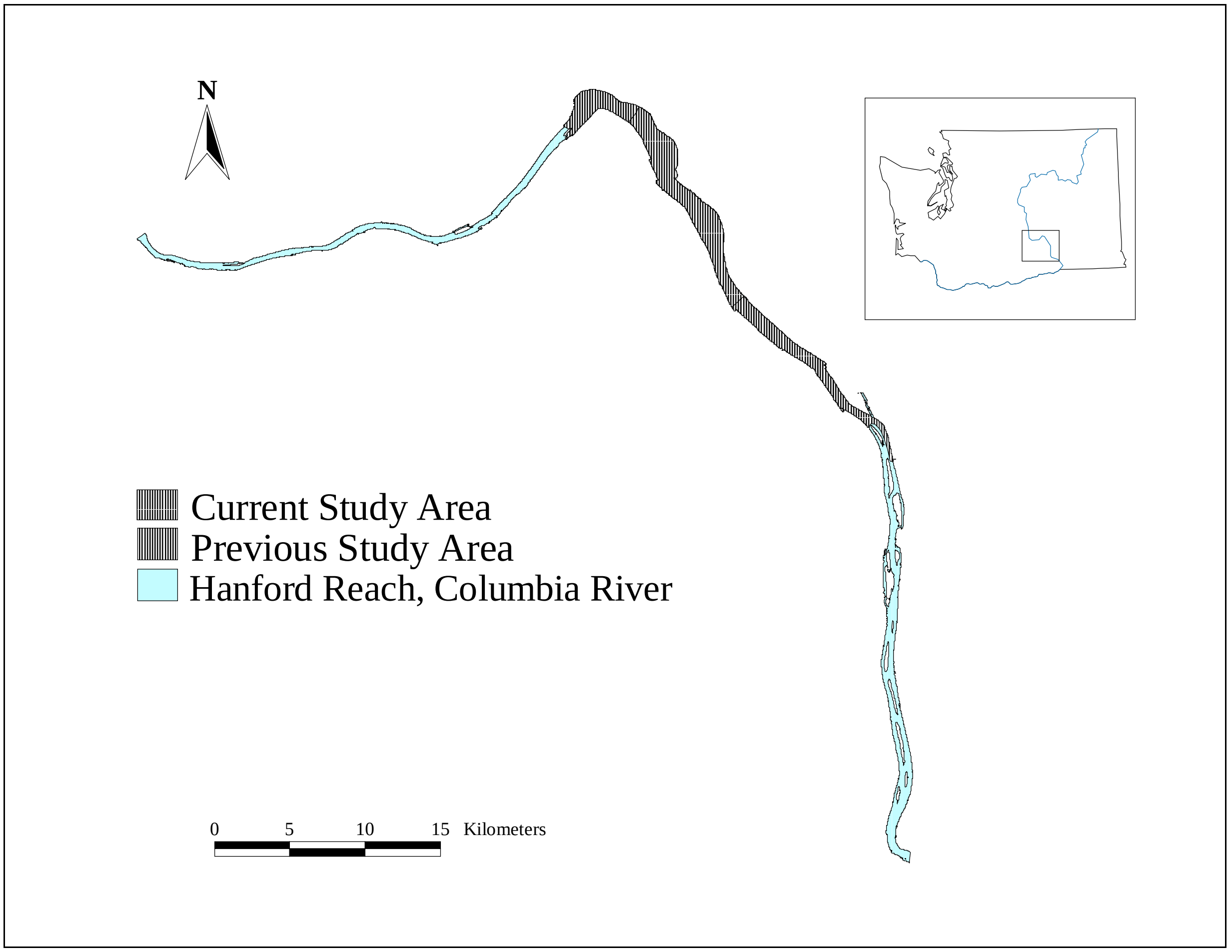

Figure 1. Modified study area on the Hanford Reach of the Columbia River, 2002.

The study area was classified into 40 kcfs flow bands and divided into 344.4 m^2 (3600 ft^2) plots or sampling cells. The sample plot size was based on the mean size of entrapments found in 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.

In previous years, 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, only one crew was used to sample the reduced area. The crew chose sample locations in the appropriate flow bands from the list of randomly generated sample plots prior to sampling. A high-performance global positioning system (GPS) with submeter accuracy was used to navigate to the sample locations.

An anchor attached to an incrementally marked cable was placed at the center of each sample plot to delineate the circular boundary of the plot. The number of juvenile fall chinook salmon and other species of fish found within the sample plot were counted and classified as alive or dead. If entrapments were encountered, an assessment was made to determine the percentage of the entrapment contained within the sample plot. Entrapments with area of 50% or greater within the circle were sampled in their entirety. Entrapments with area of greater than 50% outside of the circle were not surveyed. In cases where portions of the plot were dry or under water at the river's edge, the marked cable was used to measure the amount of wetted shoreline. A scaled drawing was produced to calculate the proportion of the plot contained within the fluctuation zone. Other data recorded at the sites included bird activity (i.e., tracks), entrapment water temperatures, dominant and subdominant substrate size, substrate embeddedness, and vegetation density. Dominant and subdominant substrate size were classified according to a modified Wentworth code (Platts et al. 1983); substrate embeddedness was classified according to Platts et al. (1983); and vegetation density was recorded as absent, sparse, medium, or dense (**Appendix B**). 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 C**.

Fall Chinook Salmon Fry Production Estimate

A coarse estimate of the 2002 fall chinook salmon fry production in the Hanford Reach was calculated to gauge the proportion of the population affected by flow fluctuations. The estimate was based on 2001 adult fall chinook salmon escapement to the Hanford Reach, female composition of the escapement, fecundity, egg retention, and egg to emergence survival. Information on escapement, female composition of the escapement, and egg retention was obtained from the 2001 WDFW Hanford Reach carcass and creel surveys (Watson 2002). The sex composition of Hanford Reach spawners was derived from the sport fishery harvest data collected during these surveys (**Appendix D**). It was assumed that anglers had an equal chance of harvesting a male or female and there were no behavioral characteristics associated with gender that would bias catch. Fecundity rates have not been established for naturally spawning fall chinook salmon on the Hanford Reach but, for this estimate, it was assumed that these rates were similar to rates of females sampled at Priest Rapids Hatchery. No studies have been conducted on egg to emergence/fry/smolt mortality rates of fall chinook salmon on the Hanford Reach. Healey (1998) reports that, 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.

Accumulated Temperature Units and Juvenile Fall Chinook Salmon Stranding and Entrapment Susceptibility

The embryonic development and growth of fall chinook salmon is highly dependent on river temperature. Accumulated temperature units (ATU's) can be used to predict the rate of development, hatching, and emergence timing of fall chinook salmon. ATU's are the cumulative total of daily river temperatures. Generally, fall chinook salmon eye at approximately 250^{o}C ATU's after spawning, hatch at around 500^{o}C ATU's and emerge at roughly 1000^{o}C ATU's. Based on data from 1999, 2000, and 2001, juvenile fall chinook salmon stranding susceptiblity on the Hanford Reach appears to end at approximately 1400^{o}C ATU's after spawning.

Assessment of Juvenile Fall Chinook Salmon Relative Abundance and Fish Size

Juvenile fall chinook salmon were seined from six nearshore sampling sites on the Hanford Reach once a week during the emergence and rearing period to assess relative abundance and fish size. The six sites included three at Locke Island (Rkm 597.0, 599.5, and 600.7), one upstream of 100 F Islands (Rkm 593.1), one at 100 F Islands (Rkm 591.4), and one at the downstream end of Savage Island (Rkm 573.2) (**Figure 2**). Seining techniques were similar to methods described by Key et al. (1994).

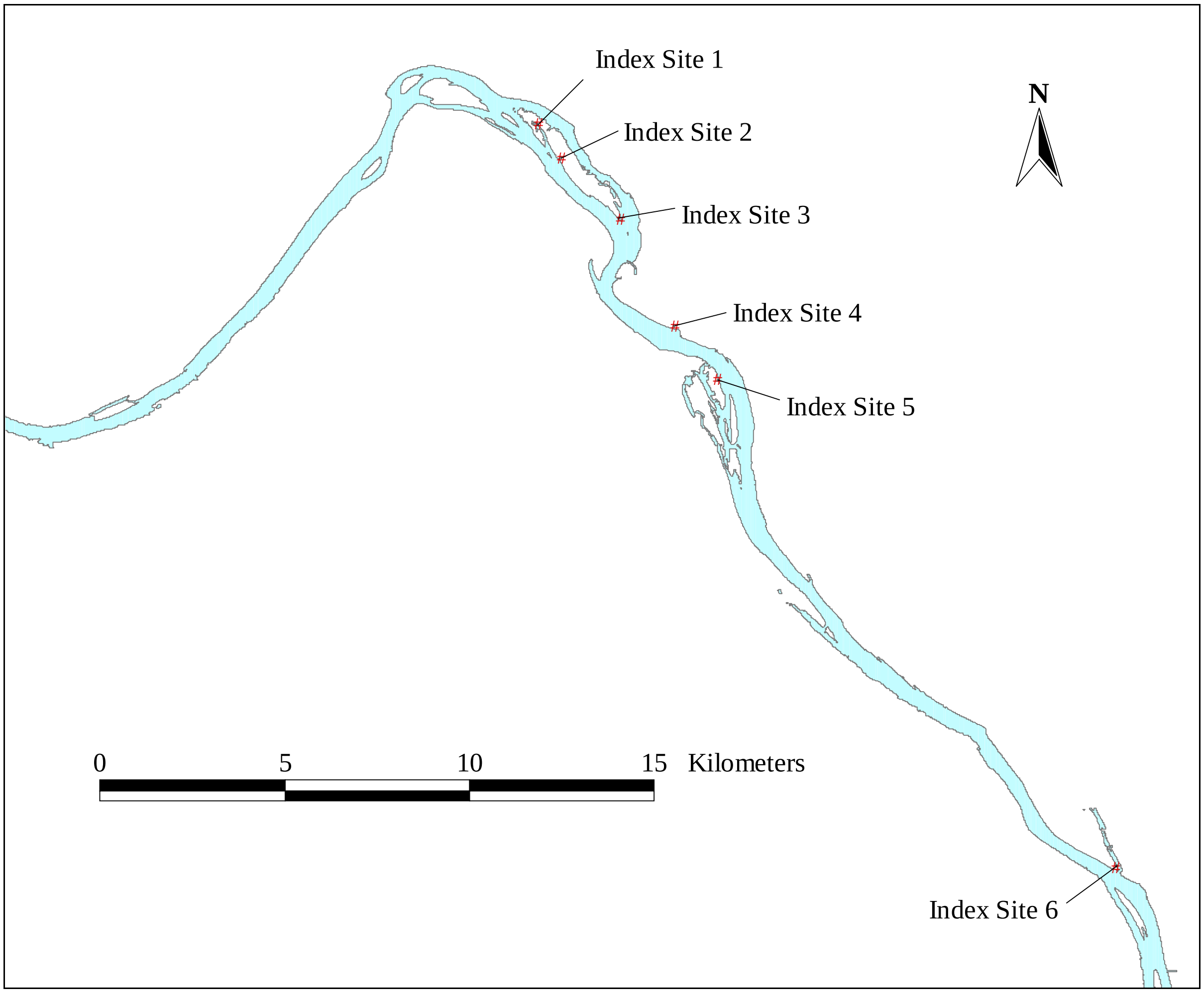

Figure 2. Index site locations on the Hanford Reach of the Columbia River, 2002.

A beach seine, 21.3 m x 1.8 m with a 1.8 m^2 bag, 4.8 mm diamond mesh, and 15.2 m leads, was used to collect juvenile fall chinook salmon and other fish species from the six designated nearshore sampling sites. One lead of the seine was cleated to the bow of a 5.5 m boat, the seine was folded and laid on the bow, and the other lead was held by a person on shore. The boat was then backed perpendicular to shore to a distance of 15.2 m and then backed upstream allowing the seine to be fed out parallel to shore. Once the seine was deployed, the boat was maneuvered back into shore. Both ends of the seine were then simultaneously hauled to shore. The area sampled in this manner was approximately 320 m^2. When samples contained less than 40 juvenile fall chinook salmon, all fish were anesthetized with tricaine methanesulfonate (MS 222), measured, and fork lengths were recorded. Samples containing over 40 juvenile fall chinook salmon were sub-sampled to obtain approximately 30 fish. Fish sub-sampled were anesthetized and fork lengths were recorded; the remaining fish were counted. All fish were released back into the river. Temperature, dominant and subdominant substrate size (modified Wentworth code; Platts et al. 1983), substrate embeddedness (Platts et al. 1983), and vegetation density (absent, sparse, medium, or dense) were recorded for each site (**Appendix B**).

Modeling of Juvenile Fall Chinook Salmon Susceptibility to Stranding and Entrapment

PNNL has developed a juvenile fall chinook salmon stranding susceptibility model for the portion of the Hanford Reach defined by the SHOALS bathymetry data (Rkm 571.3 to Rkm 606.9). Stranding susceptibility for a given area is modeled as a function of time dewatered and the characteristics of the dewatered substrate and as a function of the number and size of fish present. The model incorporates Modular Aquatic Simulation System 1D (MASS1), a one-dimensional unsteady flow model, to determine the influence of upstream hydrologic inputs on the amount of substrate dewatered (Richmond and Perkins 1998). The model provides time-varying water elevation information at a number of locations throughout the potential stranding area. Other inputs include fry production variables, growth variables, and habitat variables. The model takes the simulated water elevation changes, tabulates the dewatered areas, and weights them by how long they remain dewatered. The weighted area is a predictor of stranding susceptibility. The physical and biological characteristics of the weighted area are also summarized. The outputs can be used for investigating the relationships among these characteristics and stranding susceptibility.

Results

2002 Hanford Reach Flows and Meteorological Conditions

River and meteorological conditions on the Hanford Reach varied prior to and during the 2002 juvenile fall chinook salmon emergence and rearing period (March-June) (**Table 2**). Air temperatures were much warmer than normal during the winter prior to the emergence and rearing period. Average January air temperatures, for example, were 3.2ºC above normal. These elevated winter air temperatures contributed to the much warmer than usual river temperatures. Mean river temperatures in January and February were 2.2ºC and 1.0ºC warmer than the ten-year monthly means, respectively. Warm air and river temperatures did not, however, persist into the spring of 2002. Air temperatures were 2.0ºC cooler than normal in March and 1.0ºC below normal in May. Cooler springtime air temperatures slowed increasing river temperatures. River temperatures during the emergence and rearing period were near the ten-year monthly averages. Higher air temperatures returned to the Hanford Reach in June when mean monthly temperatures were 1.3ºC above normal.

Table 2. Comparison of 2002 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.	Nov.	Dec.
2002	101.0	100.9	74.8	122.5	143.9	219.9	181.3	108.3	75.5	-	-	-
Mean (1992-2001)	122.8	125.2	112.0	115.4	157.9	171.4	131.8	109.1	83.5	82.4	94.7	116.6
Departure	-21.8	-24.3	-37.2	+7.1	-14.0	+48.5	+49.5	-0.8	-8.0	-	-	-
River Temperatures[2] (°C)												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2002	5.9	4.0	4.4	7.3	10.6	13.8	17.3	19.4	19.1	-	-	-
Mean (1992- 2001)	3.7	3.0	4.5	7.3	10.6	13.9	-	-	-	15.4	11.2	7.0
Departure	+2.2	+1.0	+0.1	-0.1	-0.3	-0.3	-	-	-	-	-	-
Air Temperature[3] (°C)												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2002	3.1	3.6	5.8	11.8	15.6	22.0	26.4	24.2	19.1	-	-	-
Normal (1971-2000)	-0.1	3.3	7.8	11.9	16.6	20.7	24.6	24.1	18.8	11.7	4.5	-0.2
Departure	+3.2	+0.3	-2.0	-0.1	-1.0	+1.3	+1.8	+0.1	+0.3	-	-	-
Precipitation[3] (cm)												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2002	1.1	1.7	0.5	0.7	0.4	1.7	0.4	<0.1	<0.1	-	-	-
Normal (1971-2000)	2.2	1.7	1.5	1.1	1.4	1.0	0.7	0.7	0.8	1.2	2.5	2.8
Departure	-1.1	0.0	-1.0	-0.4	-1.0	+0.7	-0.3	-0.7	-0.8	-	-	-
Solar Radiation[3] (Langleys)												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2002	84.4	185.1	262.2	427.6	481.6	555.3	608.4	523.2	378.1	-	-	-
Mean (1980-2001)	94.6	170.2	298.8	421.3	518.4	574.1	600.1	521.8	387.4	239.9	114.1	74.7
Departure	-10.2	+14.9	-36.6	+6.3	-36.8	-18.8	+8.3	+1.4	+9.3	-	-	-

[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

Precipitation was lower than normal during most of the emergence and rearing period, attaining only 66% of normal for this time period. Although precipation was low, solar radiation levels were also low. Solar radiation levels, a good indication of cloud cover, were below the 22-year monthly means for all months during the emergence and rearing period with the exception April when levels were slightly above average.

Mean monthly river flows varied during the emergence and rearing period from an average of 74.8 kcfs in March to 219.9 kcfs in June. River flows were much less than the ten-year monthly mean in March, near in April and May, and much higher in June.

Implementation Timing and Operation of the 2002 Hanford Reach Juvenile Fall Chinook Salmon Interim Protection Program

Emergence of wild juvenile fall chinook salmon in 2002, as calculated under the terms of the Vernita Bar Settlement Agreement, was estimated to start on March 17 (**Figure 3**). Population index surveys were initiated on February 20 to account for possible early emergence. Implementation criteria (50 or more subyearling chinook salmon seined from the six established nearshore sampling sites) were met on March 19 and the 2002 Interim Protection Program began March 21. The program ended on June 4 when 400ºC ATU's following the estimated end of emergence were attained. The random sampling plan to assess the effectiveness of the 2002 Interim Protection Program began on March 22 (first sample collected March 23) and ended June 15.

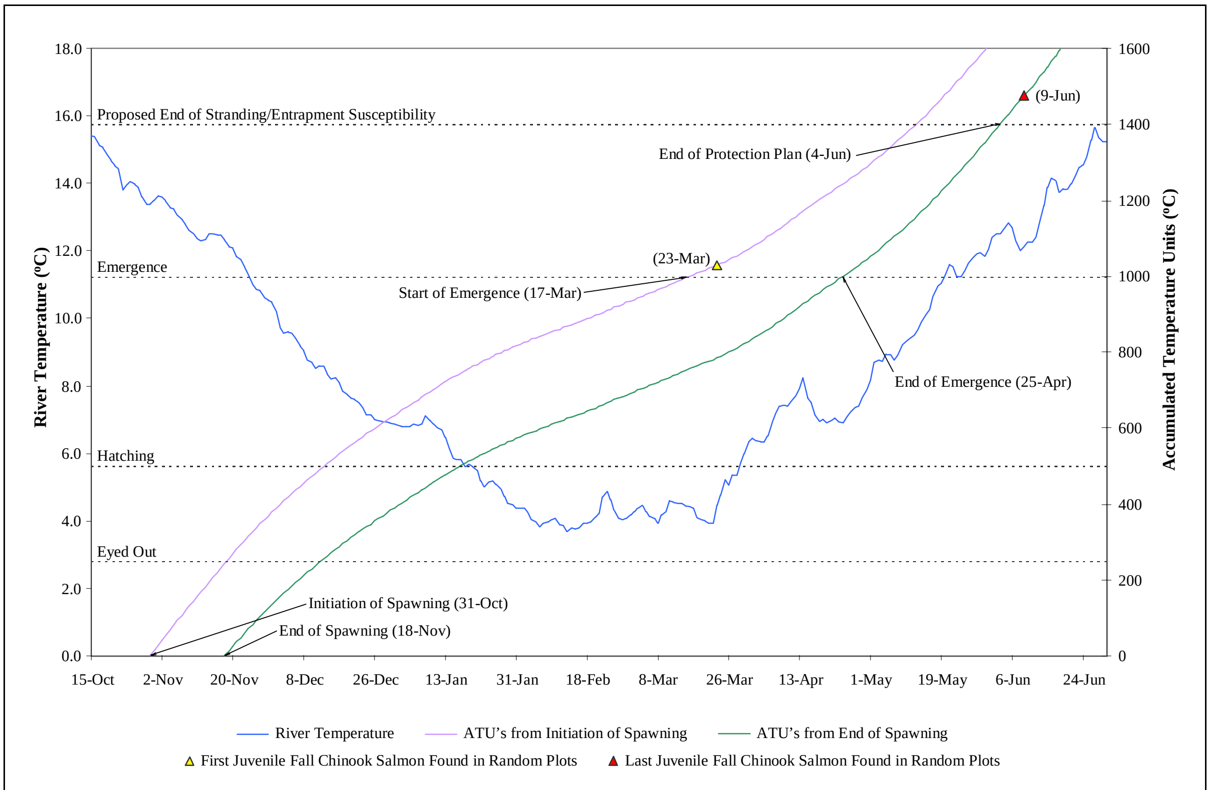

Figure 3. Mean daily river temperatures on the Hanford Reach of the Columbia River in 2002 and estimated timing of fall chinook salmon development, hatching, emergence, and end of stranding and entrapment susceptibility based on accumulated temperature units (ATU's).

Priest Rapids Dam (Rkm 639.1) discharges averaged 131.2 kcfs from March 21 through June 4 in 2002. Hourly discharge during this time period ranged from 50.8 to 293.8 kcfs (**Figure 4**). Mean daily fluctuation during this period was 47.1 kcfs. A 17 kcfs fluctuation in discharge equates to a vertical change in river elevation of approximately 0.3 m (1.0 ft) at Vernita Bar (Rkm 632.4). The primary period of susceptibility of juvenile fall chinook salmon to stranding and entrapment in 2002 appeared to be from the start of emergence to May 17. This time period is based on the number of stranded and entrapped juvenile fall chinook salmon found in random samples (99.8%) and coincides with 200ºC ATU's following the estimated end of emergence. Mean daily flow fluctuation from Priest Rapids Dam during the primary period of susceptibility was 41.8 kcfs with 19 days of relatively stable flows (fluctuations < 20 kcfs) and 32 days of flow fluctuations greater than 40 kcfs (6 days of flow fluctuations greater than 80 kcfs) (**Table 3** & **Figure 5**).

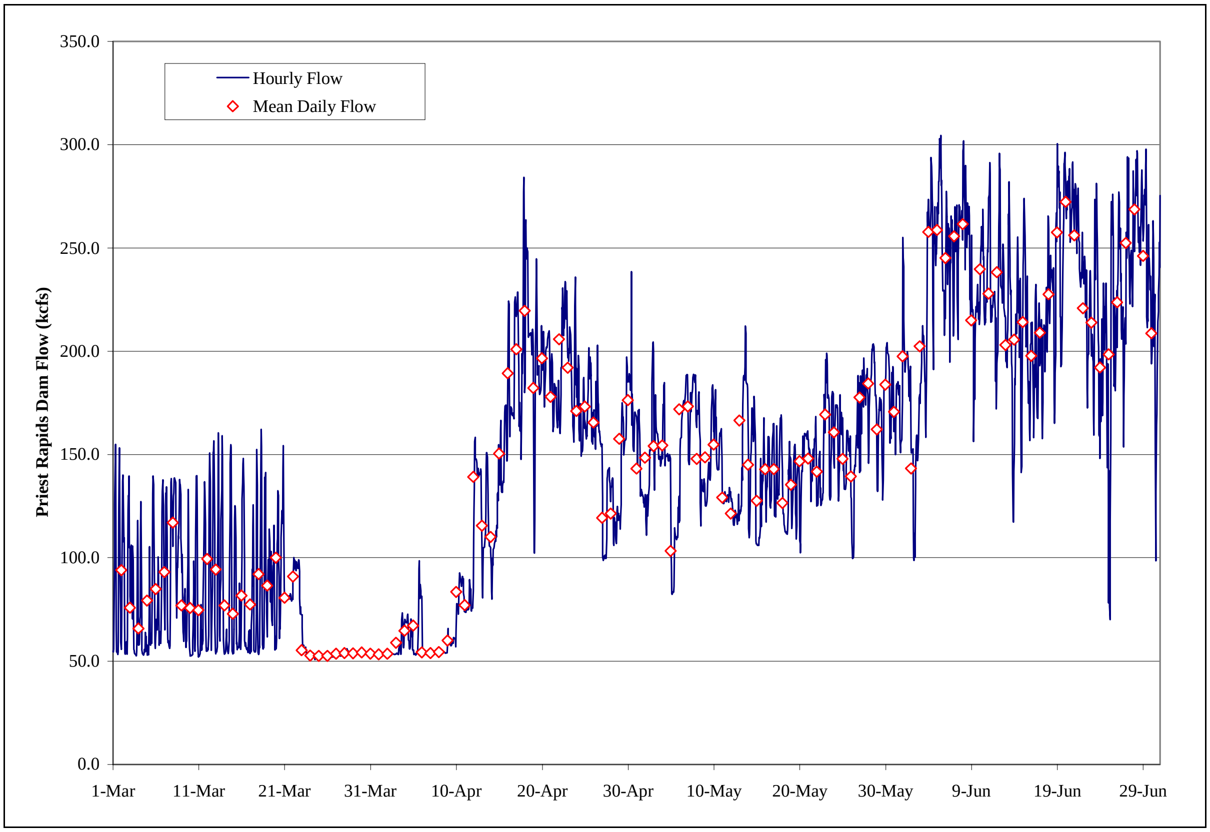

Figure 4. Hourly discharge and average daily flows from Priest Rapids Dam, March 1 – June 30, 2002.

Table 3. Daily fluctuations in discharge from Priest Rapids Dam, March 21 – June 4, 2002.

Date	Mean Flow Fluctuation (kcfs)	Number of Days				
		<20 kcfs (stable)	20-40 kcfs	40-60 kcfs	60-80 kcfs	>80 kcfs
March 21-May 17	41.8	19	7	16	10	6
May 18-June 4	63.9	0	2	10	1	5
Total	47.1	19	9	26	11	11

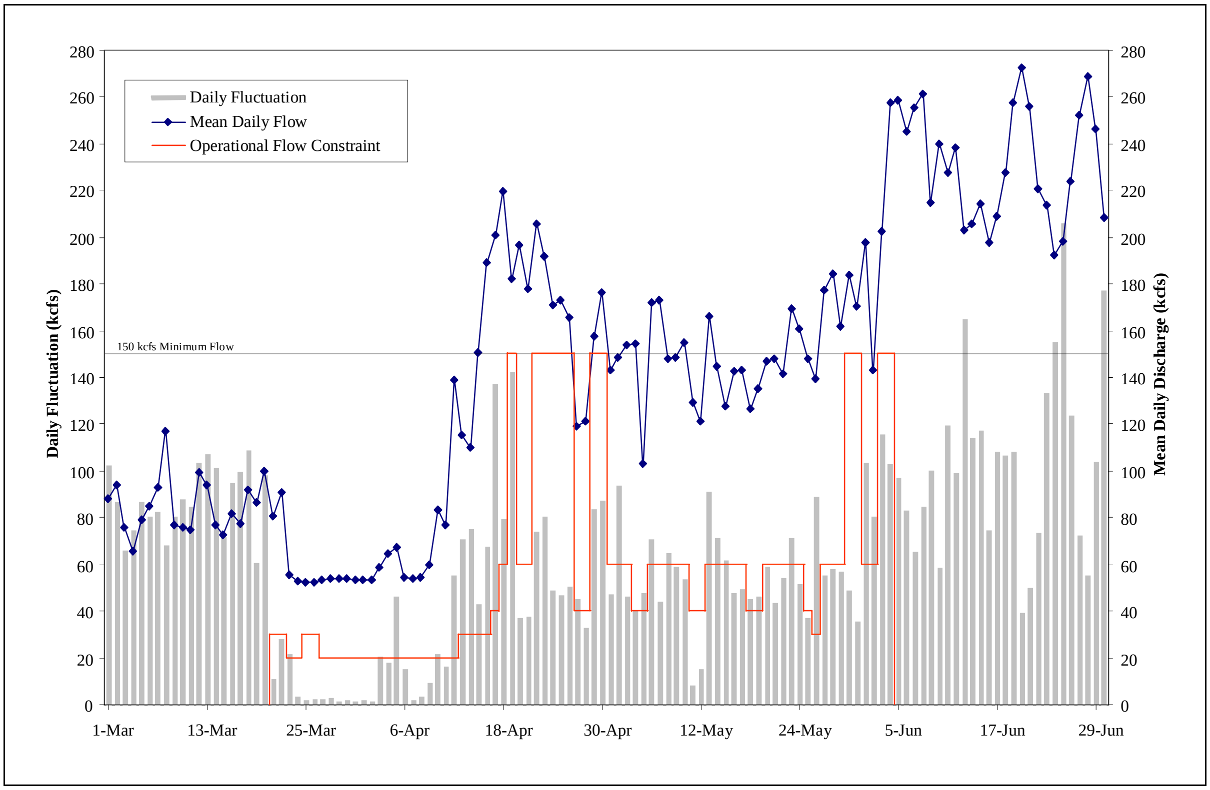

Figure 5. Average daily flows, daily fluctuation in discharge, and Protection Plan constraints for Priest Rapids Dam, March 1 – June 30, 2002.

Estimates of Juvenile Fall Chinook Salmon Stranding and Entrapment

Numbers of Juvenile Fall Chinook Salmon

A total of 194 random plots encompassing 47,234 m^2 (508,439 ft^2) was sampled within the reduced sample area in 2002. Random sampling was conducted between March 22 (first sample collected on March 23) and June 15 within six 40 kcfs flow bands (50-80, 80-120, 120-160, 160-200, 200-240, and 240-280 kcfs). The lower most 40 kcfs flow band was truncated because no fluctuations between 40-50 kcfs occurred within the study area. The area of the lowermost flow band was reduced to reflect the range over which fluctuations took place. The last stranded/entrapped juvenile fall chinook salmon was found on June 9, less than a week before the end of the random sampling effort; therefore, all samples taken during the field season were included in the estimate. The samples used in the estimates for previous years had been truncated so that samples were only included if they were taken within a week after the last stranded/entrapped fish was observed.

Random plots contained 188 juvenile fall chinook salmon in 2002 including 89 stranded and 99 entrapped individuals. Field crews recorded 91 direct mortalities consisting of the 89 stranded and 2 thermal induced fatalities (**Table 4**). Random plots with entrapments containing live juvenile fall chinook salmon were revisited during the following 24 hours to determine their fate had they been left in the entrapment. Entrapped fish were recorded as mortalities if the entrapment drained or reached lethal temperatures (>24ºC). Based on revisitation of entrapments, an additional two juvenile fall chinook salmon would have succumbed to stranding bringing the total projected mortality to 93 individuals. Juvenile fall chinook salmon were first encountered in random plots on March 23 and last found on June 9. The majority (92%) of stranded/entrapped juvenile fall chinook salmon were sampled during the month of April.

Table 4. Weekly numbers of juvenile fall chinook salmon found in random plots on the Hanford Reach of the Columbia River in 2002.

Week	Stranded[1]	Entrapped[2]	Total Mortalities (Stranded + Thermal)	Projected Chinook Mortalitites[3]	Total Chinook at Risk
March 17-23	3	0	3	3	3
March 24-30	0	0	0	0	0
March 31-April 6	29	58	29	29	87
April 7-13	37	31	37	37	68
April 14-20	10	0	10	10	10
April 21-27	3	5	3	3	8
April 28-May 4	0	0	0	0	0
May 5-11	2	0	2	2	2
May 12-18	5	3 (2)	7	7	8
May 19-25	0	0	0	0	0
May 26-June 1	0	0	0	0	0
June 2-8	0	0	0	0	0
June 9-15	0	2	0	2	2
Total	89	99 (2)	91	93	188

[1] All stranded fish were counted as mortalities.

[2] Numbers in ( ) represent thermal mortalities.

[3]Entrapments were revisited the next day to determine if fish would have died from drainage of entrapments or lethal temperatures (>24^{o}C).

The estimated total number of juvenile fall chinook salmon stranding and entrapment mortalities within the reduced sample area in 2002 was calculated to be 67,409 with a 95% confidence interval between 28,623 and 106,195. The number of mortalities estimated by revisitation of entrapments was 70,903 with a 95% confidence interval between 31,517 and 110,288. Juvenile fall chinook salmon placed at risk of mortality due to stranding and entrapment was calculated to be 144,249 with a 95% confidence interval between 28,813 and 259,685. Loss estimates for the years 1999 through 2001 have been calculated for the reduced sample area and are provided in **Appendix C**.

These assessments should be considered minimum estimates because only a portion of the Hanford Reach was sampled and sampling efficiency was assumed to be 100%. Potential sources of reduced sampling efficiency included losses of fish from sample locations to scavengers/predators prior to sampling and/or less than 100% efficiency in recovery of fish by surveyors during sampling activities.

Size Susceptibility of Juvenile Fall Chinook Salmon

Juvenile fall chinook salmon collected in random plots had a mean fork length of 40.7 mm and ranged from 32 to 45 mm (**Figure 6**). These results are similar to data from previous years suggesting that juvenile fall chinook salmon greater than 60 mm are less susceptible to stranding and entrapment.

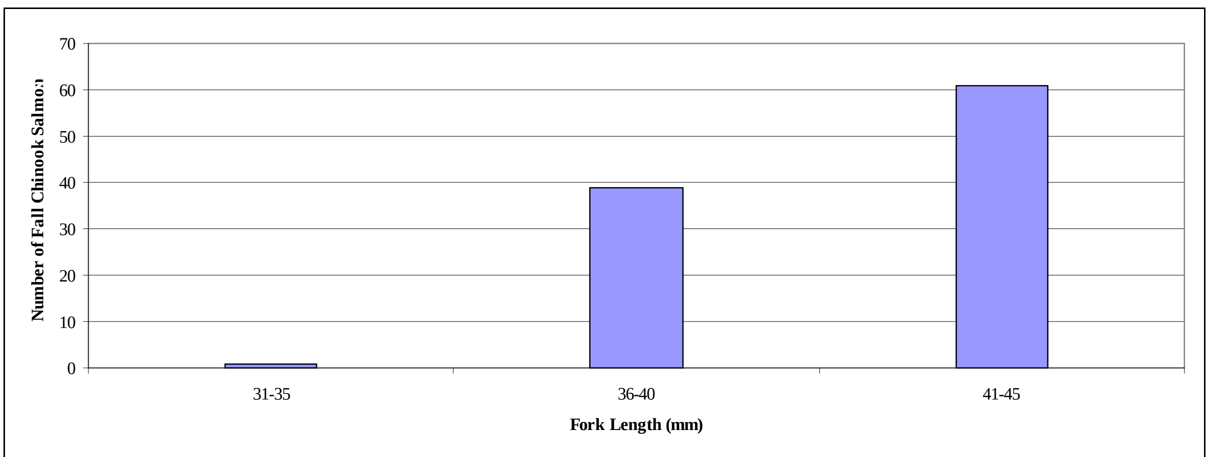

Figure 6. Fork length measurements of juvenile fall chinook salmon collected from random plots on the Hanford Reach of the Columbia River in 2002.

Distribution of Juvenile Fall Chinook Salmon

The majority of juvenile fall chinook salmon found in random plots in 2002 were located upstream of Rkm 595 in the Locke Island/White Bluffs Slough area (**Figure 7**). Although only 53.1 % of the random plots sampled in 2002 were situated in this vicinity, 80.3% of the stranding and entrapment occurred in this area. Juvenile fall chinook salmon were most often stranded and entrapped in lower flow bands (**Table 5**). Eighty-seven percent of stranded and entrapped juvenile fall chinook salmon were observed at flow levels between 50 and 120 kcfs even though only 12.1% of the flow fluctuations occurred at these levels.

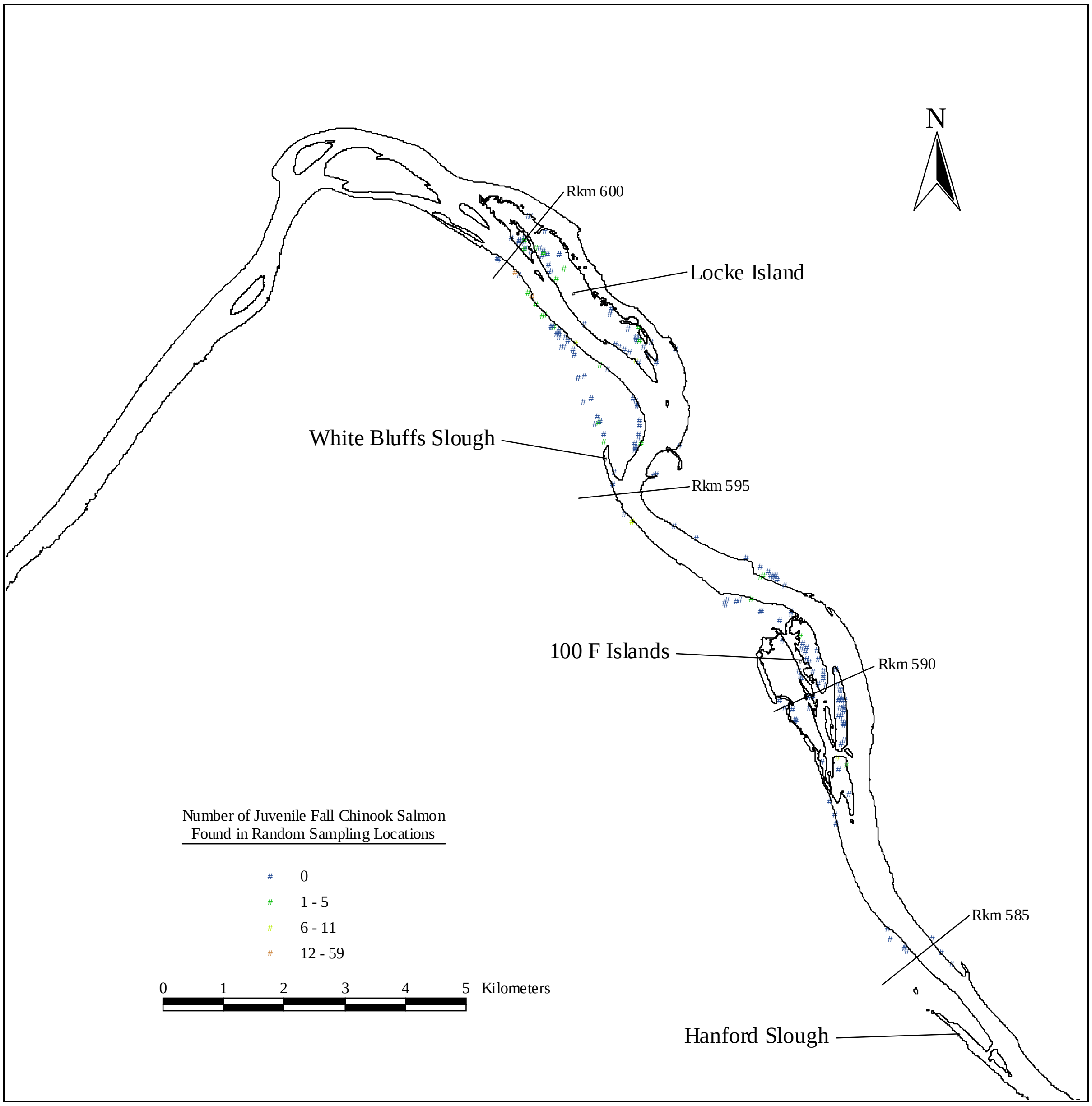

Figure 7. Random sampling plots and number of strand and entrapped juvenile fall chinook salmon found in each plot on the Hanford Reach of the Columbia River in 2002.

Table 5. Flow bands and number of stranded and entrapped juvenile fall chinook salmon found on the Hanford Reach of the Columbia River in 2002.

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
50-80	1,234.64	2.98	3,683.97	28	7.03	12	98	13.93
80-120	1,203.43	4.90	5,895.14	36	8.84	6	65	7.36
120-160	701.12	18.54	12,997.51	51	15.42	7	15	0.97
160-200	767.48	20.00	15,347.91	44	10.16	3	8	0.79
200-240	691.96	9.82	6,797.96	27	7.21	0	0	0.00
240-280	569.80	8.83	5,031.03	8	2.18	1	2	0.92
Total	5,168.43	65.07	336,320.91	194	50.84	29	188	3.70

Fall Chinook Salmon Fry Production Estimate

An estimated 21,376,153 fall chinook salmon fry were produced on the Hanford Reach in 2002 (**Table 6**). The Hanford Reach fall chinook salmon escapement estimate for 2001 was 44,140 adults and 15,708 jacks **(**Watson. 2002)**.** Jacks were removed from the calculation because they are generally all males and do not contribute to egg production. Based on sport harvest data, 684 of 1,872 (36.5%) fall chinook salmon caught on the Hanford Reach in 2001 were female (**Appendix D**). The average fecundity rate for fall chinook salmon at Priest Rapids Hatchery in 2001 was 4,418 eggs per female (S. Rogers, WDFW, Personal Communication). Egg retention of natural spawners on the Hanford Reach is typically near zero as was the case in 2001 (Watson 2002). An egg to fry survival rate of 30% was used in this estimate (Healy 1998).

Table 6. Calculation of the 2002 fall chinook salmon fry production estimate for the Hanford Reach of the Columbia River.

Component		Source
2001 Adult Fall Chinook Salmon Escapement	44,140	Hanford Reach Carcass and Creel Surveys, Watson 2002
Percent Females	36.5	Hanford Reach Sport Fishery, Watson 2002
Fecundity (Eggs per Female)	4,418	Priest Rapids Hatchery, Rogers, WDFW, Pers. Comm.
Number of Spawning Females	16,128	
Potential Eggs	71,253,844	
Egg Retention	0	Hanford Reach Carcass and Creel Surveys, Watson 2002
Total Eggs Deposited	71,253,844	
Percent Egg to Fry Survival	30.0	Literature, Healey 1998
Estimated Fry at Emergence	21,376,153	

Assessment of Juvenile Fall Chinook Salmon Relative Abundance and Fish Size

Sampling to assess juvenile fall chinook salmon abundance and fish size began on February 20, four weeks prior to the estimated start of emergence (March 17) and ended on June 19 (**Figure 8**). Sampling commenced early due to fall chinook salmon spawning activity observed prior to the initiation spawning as established by the Vernita Bar Settlement Agreement. A total of 5,550 juvenile fall chinook salmon were seined during this period. Juvenile fall chinook salmon were collected in every weekly sample from March 1 to June 19 but peak abundance occurred from March 27 to May 29. The largest catch of the season was obtained on May 15 when 1,739 individuals were sampled.

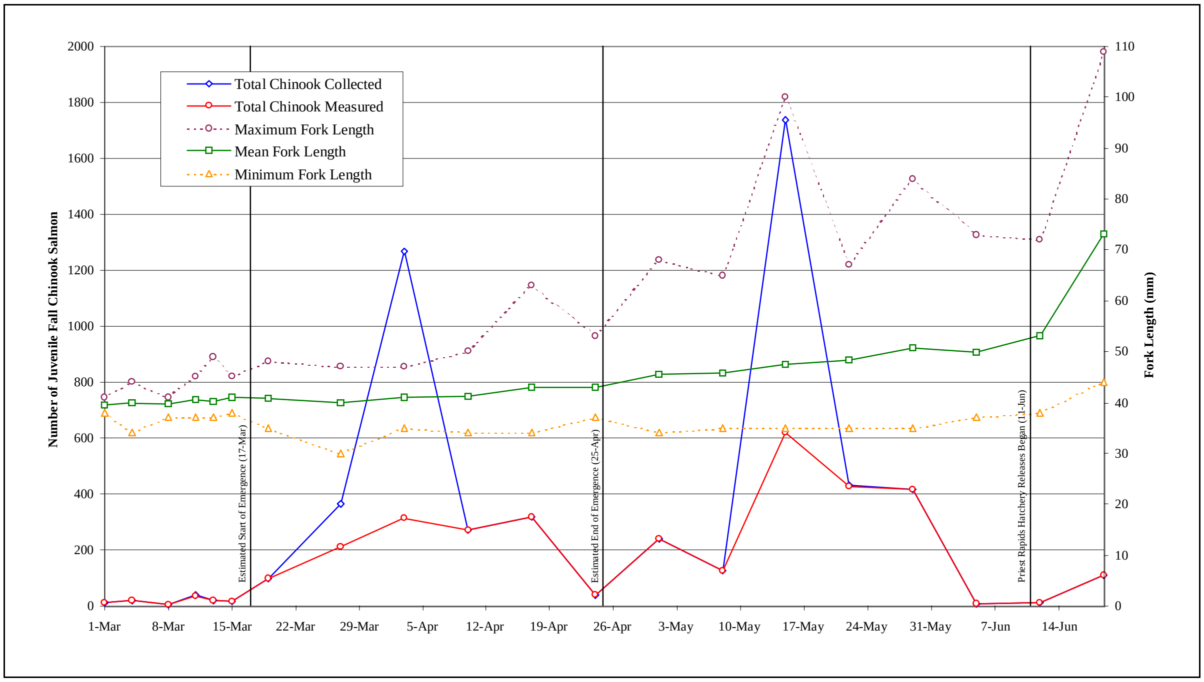

Figure 8. Relative abundance and fork length measurements of juvenile fall chinook salmon collected from nearshore sites on the Hanford Reach of the Columbia River in 2002.

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 at or below 42 mm. Juvenile fall chinook salmon with fork lengths at or below 42 mm made up a minimum of 30% of the fish seined in the Hanford Reach until May 15 and fish of this size remained in the samples through June 12. Juvenile fall chinook salmon with fork lengths greater than 59 mm, the size threshold that individuals are thought to become less susceptible to entrapment (Nugent et al. 2001), began to appear in the samples on April 17 but were not collected in considerable numbers (>5%) until May 29. Priest Rapids Hatchery released 6.8 million subyearling fall chinook salmon from June 11 to June 21 which resulted in an increase in the number and size of the fish collected on the Hanford Reach at that time.

Other Fish Species

Minimum numbers of fish other than fall chinook salmon were sampled on the Hanford Reach in 2002 (February 20 – June 19). Spring chinook salmon (*Oncorhynchus tshawytscha*) and at least 15 other species of fish were collected in nearshore sites and random plots (**Table 7**). Anadromous species sampled included spring chinook, coho (*Oncorhynchus kisutch*), and sockeye salmon (*Oncorhynchus nerka*). Yearling chinook salmon were distinguished from subyearling chinook salmon based upon size and morphological characteristics. Spring chinook salmon naturally outmigrate during the second year of life as yearlings in the mid and upper Columbia River and, therefore, most of the yearlings sampled were believe to be spring chinook salmon. Resident species found consisted of bluegill (*Lepomis macrochirus*), chiselmouth (*Acrocheilus alutaceus*), common carp (*Cyprinus carpio*), mountain whitefish (*Prosopium williamsoni*), northern pikeminnow (*Ptychocheilus oregonensis*), peamouth (*Mylocheilus caurinus*), redside shiner (*Richardsonius balteatus*), sculpin (*Cottus* spp.), smallmouth bass (*Micropterus dolomieui*), sucker (*Catostomus* spp.), threespine stickleback (*Gasterosteus aculeatus*), walleye (*Stizostedion vitreum*), and yellow perch (*Perca flavescens*). Sculpin and threespine stickleback were the only species other than fall chinook salmon represented in random plots.

Table 7. Total number of fish other than fall chinook salmon sampled on the Hanford Reach of the Columbia River in 2002 (February 20-June 19).

Common Name	Scientific Name	Nearshore	Stranded[1]	Entrapped[2]	Total Fish
Spring Chinook Salmon	*Oncorhynchus tshawytscha*	6	0	0	6
Coho Salmon	*Oncorhynchus kisutch*	1	0	0	1
Sockeye Salmon	*Oncorhynchus nerka*	1	0	0	1
Bluegill	*Lepomis macrochirus*	2	0	0	2
Chiselmouth	*Acrocheilus alutaceus*	1	0	0	1
Common Carp	*Cyprinus carpio*	1	0	0	1
Mountain Whitefish	*Prosopium williamsoni*	18	0	0	18
Northern Pikeminnow	*Ptychocheilus oregonensis*	266	0	0	266
Peamouth	*Mylocheilus caurinus*	4	0	0	4
Redside Shiner	*Richardsonius balteatus*	755	0	0	755
Sculpin	*Cottus* spp.	18	2	0	20
Smallmouth Bass	*Micropterus dolomieui*	1	0	0	1
Sucker	*Catostomus* spp.	2	0	0	2
Threespine Stickleback	*Gasterosteus aculeatus*	138	7	1	146
Walleye	*Stizostedion vitreum*	1	0	0	1
Yellow Perch	*Perca flavescens*	4	0	0	4
Unkown	-	0	1	0	1
Total		1,219	10	1	1,230

[1] All stranded fish were counted as mortalities.

[2] No entrapped fish were found dead.

Conclusions

The results of the 2002 evaluation support our findings on stranding and entrapment of juvenile fall chinook salmon and other fish species on the Hanford Reach of the Columbia River from previous years. Our studies to date (1997 to 2002) 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).

Timing of emergence and stranding/entrapment of juvenile fall chinook salmon on the Hanford Reach exhibited similar patterns for the years 1999 through 2002 (**Table 8**). The start of emergence of juvenile fall chinook salmon as calculated under the Vernita Bar Settlement Agreement was estimated to occur between early March and early April. Newly emergent fall chinook salmon were first sampled in the six established nearshore sampling sites 3 to 16 days prior to the estimated start of emergence but generally in low numbers. The first stranded or entrapped juvenile fall chinook salmon were found in late March to mid April (4 to 12 days after the estimated start of emergence) while the last stranded/ entrapped juvenile fall chinook salmon were located in early to late June (31 to 45 days past the estimated end of emergence). The majority (95%) of stranding and entrapment in these four years occurred from late March to late May.

Table 8. Timing of emergence and stranding/entrapment of juvenile fall chinook salmon on the Hanford Reach of the Columbia River from 1999 to 2002.

	Estimated Emergence		Nearshore SamplingSites	Stranded/Entrapped		
Year	Start	End	First Chinook	First Chinook	Peak	Last Chinook
1999	March 8	May 11	March 5	March 20	March 25-May 25	June 12
2000	March 20	May 2	March 13	March 24	March 27-May 17	June 2
2001	April 1	May 10	March 15	April 13	April 25-May 10	June 22
2002	March 17	April 25	March 1	March 23	April 5-May 15	June 9

The size of stranded/entrapped juvenile fall chinook salmon and the distribution of stranded/entrapped fish on the Hanford Reach also demonstrated similar patterns for the years 1999 through 2002. Juvenile fall chinook salmon collected in random plots from 1999 through 2002 were relatively small with a mean fork length of 42.6 mm and range of 31 to 86 mm (**Table 9**). Individuals greater than 60 mm comprised only 0.8% of the fish measured during these years (**Figure 9**).

Table 9. 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
1999	45.6	36-66	257	6
2000	41.7	33-86	512	4
2001	42.3	31-54	364	0
2002	40.7	32-45	101	0
1999-2002	42.6	31-86	1,234	10

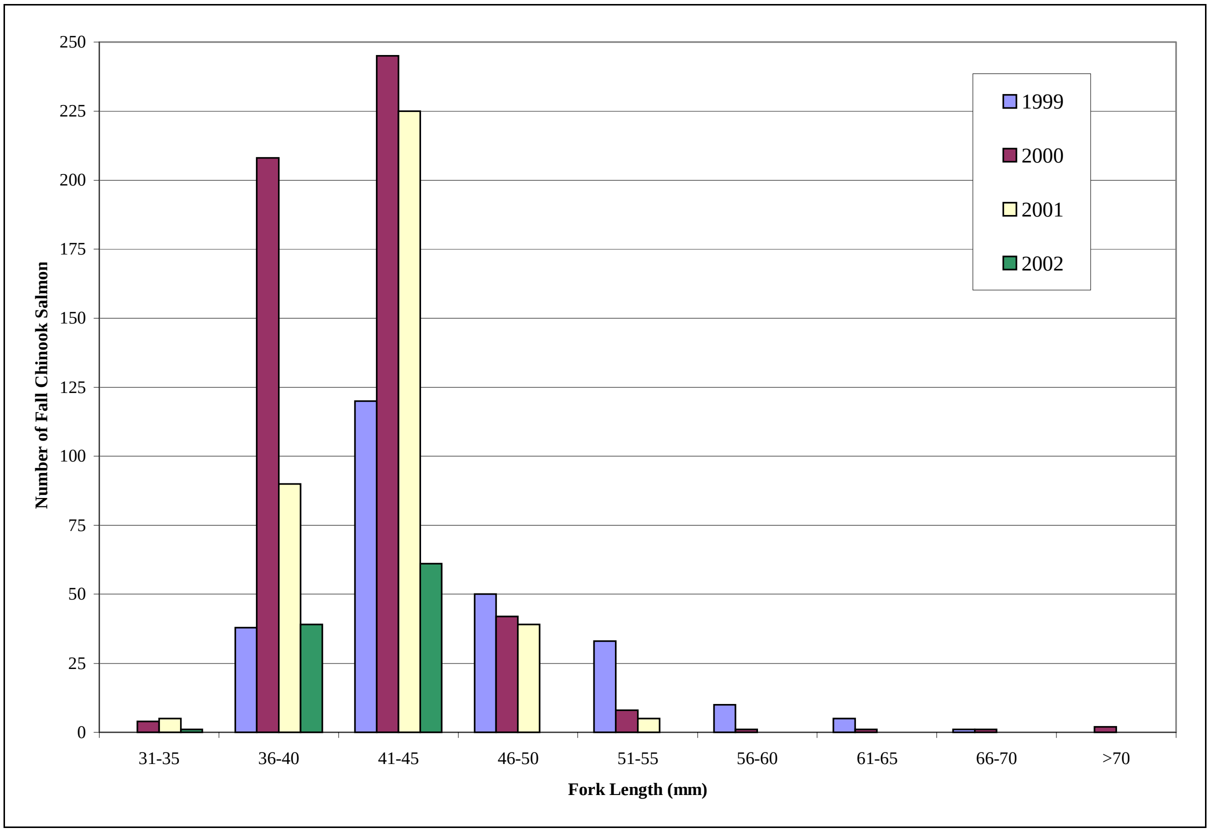

Figure 9. Fork length measurements of juvenile fall chinook salmon collected from random plots on the Hanford Reach of the Columbia River from 1999 to 2002.

Direct mortality of stranded/entrapped juvenile fall chinook salmon most often occurs when entrapments and interstitial spaces where they are found 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 projected mortalities. 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.

Highest concentrations of stranding and entrapment of juvenile fall chinook salmon observed on the Hanford Reach during our study 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 (**Figure 10**). 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.

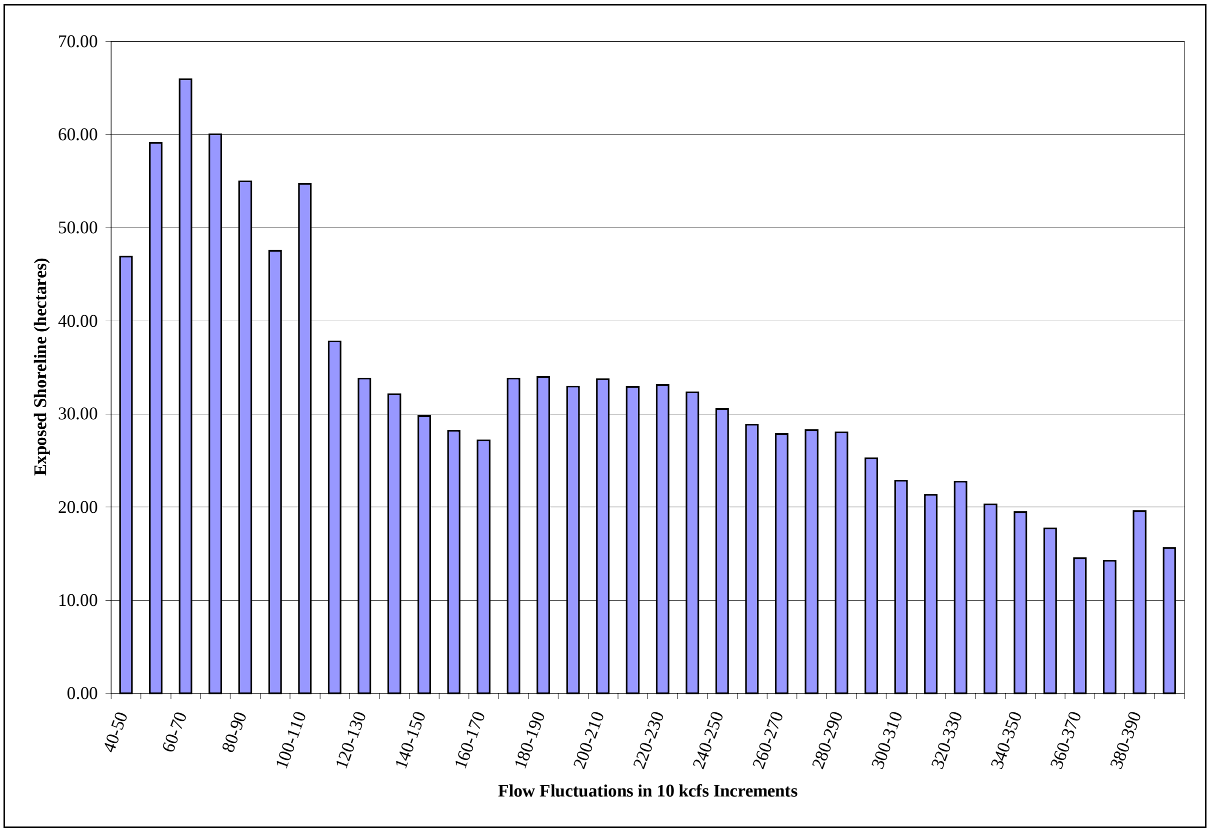

Figure 10. The area of shoreline exposed within 10 kcfs flow bands for a portion of the Hanford Reach of the Columbia River from Rkm 571.3 to 606.9.

Loss estimates of juvenile fall chinook salmon to stranding and entrapment for a 15.7 km (584.5-600.2 Rkm) section of the Hanford Reach[1] 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 10**). 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 Raipids Dam at lower flows and allows more operational flexibility at higher flows (**Table 1 and Appedix A**).

[1]The entire length of the Hanford Reach is approximately 90 km depending on the elevation of the McNary Reservoir.

Table 10. 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.)
1999	160.5 (61.9 to 261.3)	93,943 (21,393 to 166,493)	NA[2]	320,650 (-54,006 to 695,307)
2000	142.6 (62.1 to 293.2)	45,487 (12,866 to 78,108)	192,824 (-70,865 to 456,514)	199,534 (-64,234 to 463,302)
2001	77.5 (37.5 to 206.4)	2,013,638 (-746,334 to 4,773,611)	2,013,638 (-746,334 to 4,773,611)	2,013,638 (-746,334 to 4,773,611)
2002	145 (50.8 to 304.4)	67,409 (28,623 to 106,195)	70,903 (31,517 to 110,288)	144,249 (28,813 to 259,685)

[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.

The effects of flow fluctuations on the overall health of the Hanford Reach and to other species of fish is less understood. Long-term tests by the University of Idaho (U of I) and Streamside Programs Consultation (SPC) on the effects of flow fluctuations clearly 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 4 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 2002 included bluegill, dace (*Rhinichthys* spp.), bullhead (*Ameiurus* spp.), common carp, lamprey (*Lampetra* spp.), largemouth bass (*Micrpterus salmoides*), mountain whitefish, northern pikeminnow, peamouth, redside shiner, sculpin, smallmouth bass, spring chinook salmon, steelhead (*Oncorhynchus mykiss*), sucker, threespine stickleback, walleye, yellow perch, 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. These individuals were not adipose fin clipped and may have been from wild stocks. Flow fluctuations from Priest Rapids Dam during juvenile spring chinook salmon migration may impact this species.

Based on determinations by the National Marine Fisheries Service (NMFS), Upper Columbia River steelhead were listed 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.

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Appendix A

2002 Hanford Reach Juvenile Fall Chinook Protection Program

Proposed 2002 Hanford Reach Juvenile Fall Chinook Protection Program

February 25, 2002

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.

2002 Program Elements

Starting Program Operating Constraints

1. Begin index seining (6 standard beach seine hauls at pre-determined locations) one week prior to the calculated start of emergence under the Vernita Bar Agreement. Index seining will be conducted daily to define the beginning of susceptibility.

2. Start operational constraints for 2002 program when a daily total of 50 or more sub-yearling chinook is sampled from the 6 index seining stations. During each index seining sample, sub-yearling fork length will be reported. After program is initiated, decrease index seining to one time per week.

When PRD discharge[2] is between Vernita Bar Agreement minimum and 80 kcfs:

When discharge at Priest Rapids is between VBA minimum and 80 kcfs, the mid-Columbia projects will limit flow fluctuations at Priest Rapids to no more than 20 kcfs.

When PRD discharge is between 80 and 110 kcfs:

When discharge at Priest Rapids is between 80 and 110 kcfs, the mid-Columbia projects will limit flow fluctuations at Priest Rapids to no more than 30 kcfs.

When PRD discharge is between 110 and 140 kcfs:

When discharge at Priest Rapids is between 110 and 140 kcfs, the mid-Columbia projects will limit flow fluctuations at Priest Rapids to no more than 40 kcfs.

[2] Priest Rapids discharge will be calculated in 2 separate ways: for weekdays it will be a rolling 5-day average of the previous 5 weekdays; for weekends it will be the BPA Friday PRD estimates for Saturday and Sunday.

When PRD discharge is between 140 and 170 kcfs:

When discharge at Priest Rapids is between 140 and 170 kcfs, the mid-Columbia projects will limit flow fluctuations at Priest Rapids to no more than 60 kcfs.

When PRD discharge is greater than 170 kcfs:

When discharge at Priest Rapids is greater than 170 kcfs, the mid-Columbia projects will maintain a 150 kcfs minimum hourly discharge at Priest Rapids.

Ending Program Operating Constraints

When 400 or more temperature units (°C) have accumulated following the end of emergence under the Vernita Bar Agreement, the operating constraints identified above will end.

Monitoring will continue depending on presence of subyearling chinook as identified below.

Monitoring, Evaluation and Adaptive Management

1. Monitoring under this program would consist of random sampling on a 8.5 mile subsection of the Hanford Reach (RM 364.5 to RM 373). This stretch runs from approximately the upstream end of Locke Island down to an area just upstream of Hanford Slough. Crews would consist of a two person crew consisting of WDFW and Grant PUD personnel 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 and a weekly summation will be provided to Grant PUD.

2. 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 expeditiously.

3. Until stranding susceptibility ends, a weekly report for the Monday through Sunday time period will be produced by Grant County PUD and the WDFW. This report will be available on the Technical Management Team (TMT) website at the following URL:
   < www.nwd-wc.usace.army.mil/cgi-bin/proposal.cgi?type=index>
   and will be presented at the weekly TMT meetings. This report will also be distributed to the Hanford Reach Stranding Policy Group each Tuesday morning by e-mail. The TMT will serve as a forum for information exchange and will not be involved in decision making under this Program. It is anticipated that TMT decisions will facilitate and support activities under

this Program. The authority for implementing any changes under this Program rests with the mid-Columbia projects and any disputes will be handled through meetings of the Hanford Reach Stranding Policy Group.

A. The weekly report will include the following operational information for each day: minimum hourly discharge from Priest Rapids Dam (PRD), maximum hourly discharge from PRD and day average discharge at PRD. The report will also provide weekly average discharge at PRD for each day which will be calculated as a rolling seven day average.

B. The weekly reports will also include the following field monitoring information for each day: number of samples taken, number of stranded or entrapped chinook fry and number of chinook mortalities.

Appendix B

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 C

Estimation of Total Number of Entrapped and Dead Juvenile Fall Chinook Salmon Due to River Flow Fluctuations - 2002 Field Season

Estimation of Total Number of Entrapped and Dead Juvenile Fall Chinook Salmon Due to River Flow Fluctuations - 2002 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 sampling period from March 23 to June 15, 2002. Sampling for stranding effects was performed with a single crew during the 2002 field season, and the sample area was reduced to approximately half that of previous years (1999-2001). Sampling in previous 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. Because of the necessity to cut the study area, a preliminary study was done to determine the stretch of the Hanford Reach within the SHOALS area where the majority of the stranding had occurred. The preliminary study calculated the sampling area and juvenile fall chinook at risk for all possible continuous river sections covered by the SHOALS data that contained approximately half the previous study area. The continuous sections were each determined from an upstream transect of the river to a downstream transect of the river, where the transects are the Army Corps of Engineers river transects used in flow modeling of the Hanford Reach. The transects are spaced approximately 250 m apart through the Hanford Reach. Figure 1 shows that the river section from river kilometer (Rkm) 600.2 to Rkm 584.5 (transects 64 to 91) contained the highest proportion of nonzero samples and the highest number of juvenile fall chinook at risk during the previous three years of the stranding study (1999-2001). Therefore, in 2002, sampling was confined to the section of the river from Rkm 600.2 to Rkm 584.5 (transects 64 and 91).

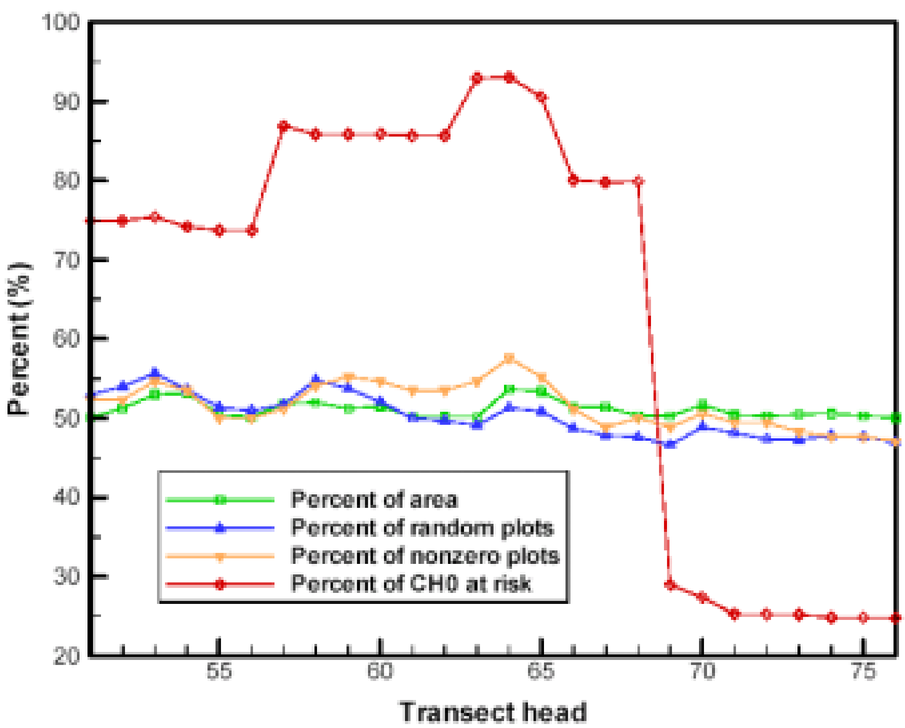

Figure 1. Plot of sampling efficiency for a series of subsections of the Hanford Reach, used to determine an upper and lower transect to bound a reduced sample area containing approximately half the area sampled in the years 1999-2001.

The estimate for 2002 was based on 194 sample measurements taken in six 40 kcfs flow bands of the Hanford Reach: 50-80, 80-120, 120-160, 160-200, 200-240, and 240-280 kcfs. Note that the lowermost 40 kcfs band was truncated because no fluctuations occurred in the range from 40-50 kcfs, so the area of that flow band was reduced to equal the range over which fluctuations occurred. Figure 2 shows a plot of the samples taken in 2002 in red versus those taken in the previous years to indicate the location of the reduced study area. The 2002 samples were collected randomly within each flow band in the reduced study area. 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 six flow bands that were sampled in the study area can be considered as three strata, so estimation of the total number of stranded/entrapped juvenile fall chinook salmon was performed using a stratified random sampling algorithm.

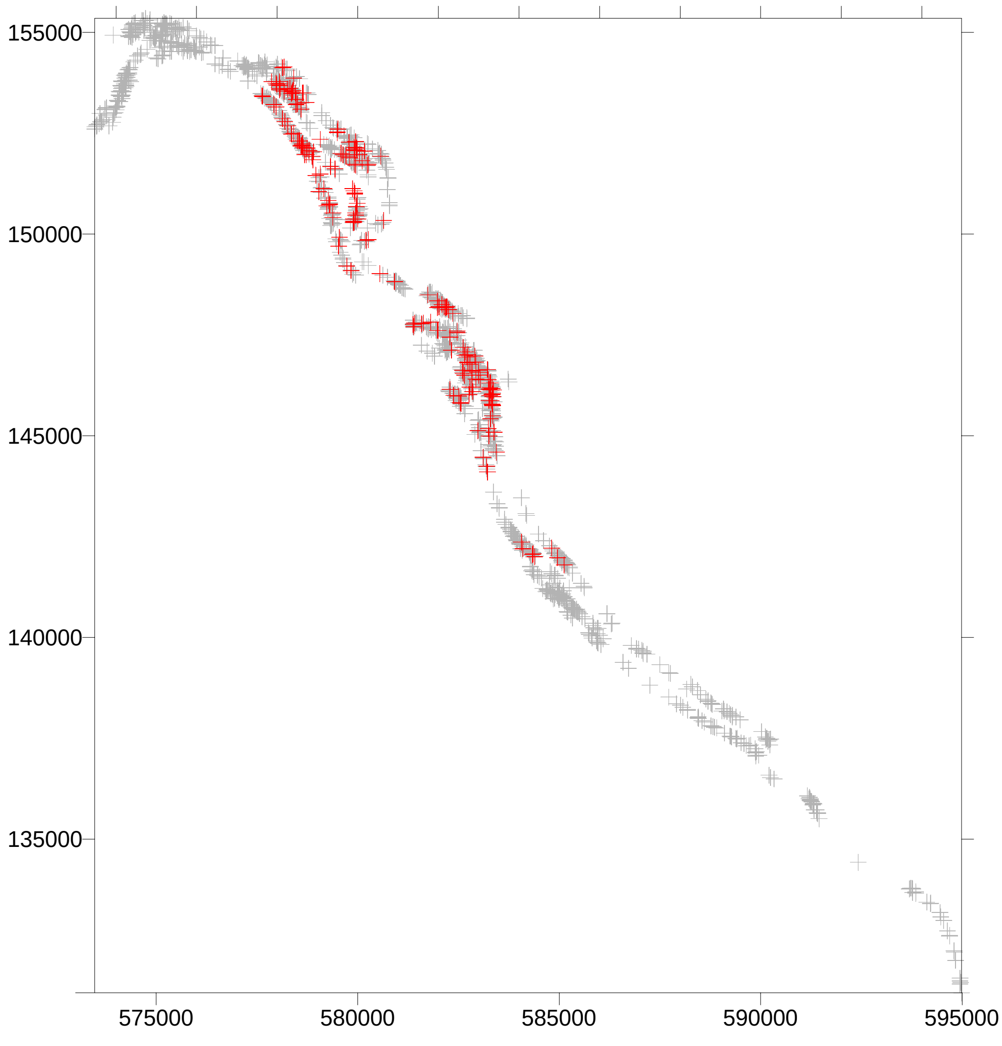

Figure 2. Plot of random sampling locations for 1999-2001 (gray), and 2002 (red), that shows the location of the reduced sampling area for 2002 relative to the SHOALS area used in previous years.

All samples taken during the field season were included in the estimate because the last stranded/entrapped fish was found on June 9th, less than a week before the end of the random sampling effort on June 15th. The samples used in the estimates for previous years had been truncated so that samples were only included if they were taken within a week after the last stranded/entrapped fish was observed.

A sampling plan was designed by Pacific Northwest National Laboratory (PNNL) and Washington Department of Fish and Wildlife (WDFW) prior to the 2002 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 then 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 for sampling was 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. Each 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 2002, 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, $\overline{x}_h$, 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 and i = 1… 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:

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

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 three 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, $\overline{x}_h$ 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 six 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 study area (Transect #85) for the approximate time period covered by the random sampling data (March 21 – June 15, 2002). This is the same procedure followed in 1999 through 2001. The numbers of fluctuations found for each of the six flow bands included in the 2002 estimate (50-80, 80-120, 120-160, 160-200, 200-240, and 240-280 kcfs) are 2.2, 4.9, 18.5, 20.0, 9.8, and 8.8, respectively.

An unbiased estimate of the variance of the stratified average (Var ($\overline{x}_{st}$)) 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 by

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

The total number of dead juvenile fall chinook salmon, $\hat{I}$, over the entire area of the three 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]:

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

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

$$\hat{I} \pm 1.96 * s\left(\hat{I}\right) \qquad [6]$$

assuming a normal distribution.

The results of the computation of the number of juvenile fall chinook salmon mortalities due to stranding and those at risk are listed in the table at the end of this memo. The results from the 1999 through 2001 field seasons are also included in the table. 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 with those from previous years, the estimates for 1999-2001 given in the table below have been recomputed from those issued in previous years so that they are based only on samples from the reduced study area used in 2002. The number of Morts given in the table for 2002 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 2002, there were five sites where there were entrapped fish that were not immediately classed as mortalities, but at only one of the sites were entrapped fish reclassified as mortalities when the site was revisited. Therefore, the difference between the Mort and Rev Mort estimates is small, and the difference between juvenile fall chinook at risk and the revised mortality estimate is larger than it was in 2000 and 2001.

The estimate of the total number of juvenile fall chinook salmon that died within the reduced study area during the period from March 23 – June 15, 2002 is 67,409 (see table below) and a 95% confidence interval for that estimate is [28,623 to 106,195]. The number of mortalities estimated by revisiting the site is slightly higher, and the estimated number of juvenile fall chinook salmon at risk is about twice as high as the number of estimated mortalities (see table below). The number of dead juvenile fall chinook salmon identified in 2001 was much higher, about 30 times the number estimated for 2002. As noted in the report issued in 2001, the estimated mortalities in 2001 far exceed those in other years. 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. 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 very small number of fluctuations in that flow band (2.2) in 2002, relative to the number that occurred in 2001 (14.6). The number of mortalities recorded in 2002 is similar to that found in the 1999 and 2000 field seasons.

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.

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

Chris Murray

Pacific Northwest National Laboratory
August 2002

Appendix D

Data used in Hanford Reach Fall Chinook Salmon Fry Production Estimate

2001 Hanford Reach Fall Chinook Salmon Sport Harvest (Watson 2002)

Week	Male	Female	Jack	Total Adults	Percent Female
August 15-19	0	0	0	0	
August 20-26	0	0	0	0	
August 27-September 2	1	6	0	7	85.7
September 3-9	17	14	7	31	45.2
September 10-16	62	45	21	107	42.1
September 17-23	129	76	43	205	37.1
September 24-30	256	148	78	404	36.6
October 1-7	240	147	79	387	38.0
October 8-14	212	111	83	323	34.4
October 15-21	196	116	92	312	37.2
October 22-28	69	20	33	89	22.5
October 29-31	6	1	2	7	14.3
Total	1,188	684	438	1,872	36.5