Grant County
PUBLIC UTILITY DISTRICT
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VIA ELECTRONIC FILING

January 15, 2013

Kimberly D. Bose, Secretary
Federal Energy Regulatory Commission
Mail Code: DHAC, PJ-12
888 First Street, N.E.
Washington, D.C. 20426

RE: **Priest Rapids Hydroelectric Project No. 2114 Compliance Filing**
Article 401(a)(5) 2012 Hanford Reach Follow-Up Monitoring Program Report

Dear Secretary Bose,

Public Utility District No. 2 of Grant County, Washington (Grant PUD) respectfully submits to the Federal Energy Regulatory Commission (FERC) its 2012 Hanford Reach Follow-Up Monitoring Program Report for the Priest Rapids Project (Project) to meet the requirements of Article 401(a)(5).

The FERC License Order for the Project (issued April 17, 2008) incorporated the Hanford Reach Fall Chinook Protection Program Agreement (HRFCPPA) and required Grant PUD to submit a study plan by June 1, 2011. The developed Plan met the monitoring obligations under the HRFCPPA and FERC License Order and was submitted to FERC on [1]June 3, 2011. On January 12, 2012, FERC approved the Hanford Reach Follow-Up Monitoring Program Plan submitted by Grant PUD. Within the FERC order modifying and approving the Hanford Reach Follow-Up Monitoring Program Plan, FERC ordered the following:

> *(B) The licensee shall file annually with the Federal Energy Regulatory Commission (Commission) its Annual Hanford Reach Follow-Up Monitoring Program Report. The reports shall include monitoring results from the previous year and any proposed monitoring program changes for the coming year. The licensee shall allow the Fall Chinook Work Group 30 days to review and comment on the report prior to filing with the Commission. The report shall include any resource agency or Tribe*

[1] The filing for the Plan was due to FERC on June 1, 2011. Due to temporary power outage at FERC, the agency was closed and the eFiling system was not available. FERC stated on their website that any filing due May 31 or June 1 and 2, 2011 would be considered timely on the next business day that FERC was open. FERC resumed business on June 3, 2011 with the eFiling system restored.

> *comments or recommendations and the licensee's response to any such comments or recommendations. The licensee's first report shall be due to the Commission by March 1, 2012, and by January 15 in 2013 and 2014. The Commission reserves the right to make changes to the plan based upon the review of the reports.*

Consistent with the FERC ordering paragraph provided above, the enclosed document details the sampling methods and results from 2012 with a brief summary of the results from previous studies. Throughout all phases of the study, including development of the draft results, the Fall Chinook Working Group (FCWG) and Washington Department of Ecology (WDOE) were provided monthly updates. Given this extensive involvement, the FCWG and WDOE agreed to a condensed comment period rather than a thirty day comment period to allow ample time to prepare and finalize the complex analyses and report. There were only minor differences between the draft results that were presented in updates and the results that were in the final report. The comment period was from December 22, 2012 through January 7, 2013 and there were no requests for additional time to review the report and comment. Please refer to Appendix B for Grant PUD's response to the comments received.

FERC staff with any questions should contact Fish, Wildlife and Water Quality Manager Tom Dresser at 509-754-5088, ext. 2312, or at tdresse@gcpud.org.

Respectfully,

Julie E. Pyper, Manager
License Compliance and Implementation Services
jpyper@gcpud.org

Cc (via email): Fall Chinook Working Group

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The Business of Innovation

PNNL-22156

Assessment of Losses of Juvenile Fall Chinook Salmon in the Hanford Reach of the Columbia River in Relation to Flow Fluctuations in 2012

Final Report

P. Hoffarth
C. J. Murray
R. B. Langshaw
S. L. Haeseker
G. A. McMichael
J. Johnson
Y. Xie
M. C. Richmond
W. A. Perkins
J. Skalicky
S. E. Niehus
A. C. O'Toole

Battelle
Pacific Northwest Division
Richland, Washington 99352

Prepared for
Public Utility District No. 2 of Grant County
Ephrata, Washington 98823
under Contract Number 430-2464
for Project Number 60894

January 2013

LEGAL NOTICE

Assessment of Losses of Juvenile Fall Chinook Salmon in the Hanford Reach of the Columbia River in Relation to Flow Fluctuation in 2012

Final Report

Prepared for
Public Utility District No. 2 of Grant County
P.O. Box 878
Ephrata, WA 98823

Prepared by

P. Hofforth[1]
C.J. Murray[2]
R.B. Langshaw[3]
S.L. Haeseker[4]
G.A. McMichael[2]
J. Johnson[1]
Y.Xie[2]
M.C. Richmond[2]
W.A. Perkins[2]
J. Skalicky[4]
S.E. Niehus[2]
A.C. O'Toole[2]

[1]Washington Department of Fish and Wildlife
Pasco, Washington 99301

[2]Battelle – Pacific Northwest Division
Richland, Washington 99352

[3]Public Utility District No. 2 of Grant County, Washington
Ephrata, Washington 98823

[4]U.S. Fish and Wildlife Service
Columbia River Fisheries Program
Vancouver, Washington 98683

January 2013

Suggested citation for this report:

Hoffarth, P., C. J. Murray, R. B. Langshaw, S. L. Haeseker, G. A. McMichael, J. Johnson, Y. Xie, M. C. Richmond, W. A. Perkins, J. Skalicky, S. E. Niehus, and A. C. O'Toole. 2013. *Assessment of Losses of Juvenile Fall Chinook Salmon in the Hanford Reach of the Columbia River in Relation to Flow Fluctuations in 2012*. PNNL-22156, report prepared for Public Utility District No. 2 of Grant County, Washington, by Battelle–Pacific Northwest Division, Richland, Washington.

Executive Summary

Operations to increase survival of emergent and rearing fry under the 2012 Hanford Reach Fall Chinook Protection Program began March 8 and ran through June 17, 2012. Sampling to assess the effectiveness of these operations began on March 9 and continued through June 22, 2012. Washington Department of Fish and Wildlife staff dedicated to this project included three, three-person crews working seven days a week. Daily sampling effort consisted of two crews sampling for entrapments and the third crew sampling to assess the impact from stranding events. The Hanford Reach experienced higher flows than normal throughout the evaluation season and an estimated 257,689 entrapments were formed. Field crews visited 644 quadrants to conduct entrapment sampling. Flow fluctuations were not sufficient to create entrapments and/or no entrapments were found in 305 quadrants (47%). In the remaining 339 quadrants, 1,378 entrapments were sampled (0.5% of the estimated 257,689 entrapments that were formed) and 120 contained Chinook salmon (9%). Based on the randomizing Stranding/Entrapment Site Selection Model output field crews visited 307 of the 360 delineated quadrants (85%) during the 2012 season. A total of 4,611 juvenile fall Chinook salmon were recovered in entrapments with 95% of these alive at the time of initial sampling. Twelve percent of entrapments in the Middle section contained fall Chinook salmon, 5% in the Lower, and 9% in the Upper section. The Lower section had the fewest number of entrapments and the highest mean number of Chinook salmon per entrapment at nearly 6.5 fish per entrapment sampled. Field crews collected data on each entrapment sampled to estimate direct and potential mortality of fall Chinook salmon resulting from entrapment. Using a combination of field and post-season fate assignment, 70% of the 1,378 sampled entrapments were determined to have drained, 12% exceeded lethal water temperature for Chinook salmon (defined as >27°C), and 18% re-flooded prior to draining as the river elevations rose, resulting in an overall entrapment lethality rate of 82%. We estimate that 1,574,664 Chinook salmon were entrapped in 2012 with percentile-based, bias-corrected, 95% confidence interval bounds of -98,103 and 6,877,871. The number of fall Chinook salmon mortalities caused by entrapment was estimated to be 1,281,417, with percentile-based, bias-corrected, 95% confidence interval bounds of -83,112 and 5,514,367.

Stranding crews visited 189 quadrants to assess stranding impacts during the field season. Of these, 25 quadrants (13%) exhibited insufficient flow fluctuation (<1 m wetted shoreline) to sample, and 7 could not be sampled because of dense vegetation or could not be safely approached by boat. From the remaining 157 quadrants, 873 complete or partial plots were sampled. Concerns about whether the wetted shoreline could be determined in the field hours after a reduction in elevation prompted a change in the field sampling protocol for 2012 to include sampling a portion of the area above the estimated water mark. The total area surveyed was 61,465 m^2, of which, 49,092 m^2 (81%) was wet area and 12,374 m^2 (20%) were located above the wetted line. A total 67 fall Chinook salmon were recovered within the sampled plots. The highest numbers of fall Chinook salmon (33) were collected in the Middle section of the Hanford Reach. This section also exhibited the highest concentration, with one Chinook salmon being found every 450 m^2; almost twice as often as the Upper section, and about four times more frequently than the Lower section. The estimated loss due to stranding of Chinook salmon in the Hanford Reach in 2012 was 354,645, with percentile-based, bias-corrected, 95% confidence interval bounds of 180,206 and 601,625.

Results indicate that conditions in the Hanford Reach in terms of flows, flow fluctuations, and temperatures were less favorable for avoiding stranding and entrapment of juvenile fall Chinook

salmon in the Hanford Reach in 2012 than in 2011. Although there is considerable uncertainty about the combined stranding and entrapment loss estimate of 1.64 million juvenile fall Chinook salmon in 2012, an attempt was made to place this loss in the context of the population. Abundance estimates generated for a recently completed study of stock productivity were used to provide a range of potential production in the Hanford Reach. Methods to estimate the population of juvenile fall Chinook salmon in the Hanford Reach also encompassed a large amount of uncertainty; however, it appears that the estimated number of fall Chinook salmon fry lost was relatively low in comparison to the estimated number of juveniles produced by the adults that spawned in the Hanford Reach in the fall of 2011.

Acknowledgments

Many people have worked hard over the years to increase the understanding of the effects of flow fluctuations on juvenile fall Chinook salmon in the Hanford Reach of the Columbia River. To address a current need to document stranding and entrapment losses of fall Chinook salmon in the Hanford Reach, a new experimental design was developed in 2010 and 2011, and modified prior to the 2012 sampling season. The experimental design was developed collaboratively within a subgroup of the Fall Chinook Working Group and benefitted from input from the group chair Tracy Hillman as well as Steve Hays, Tom Kahler, and Ken Tiffan. The Washington Department of Fish and Wildlife field crews who spent many long hours in the field collecting the data necessary to estimate stranding and entrapment consisted of Josh Hede, Shawnaly Meehan, Patrick Kaelber, Nicole Boettner, Mike Roetner, David Patterson, Robert Warrington, Kristi Geris, LeeAnn McDonald, Charleen Taylor, Bryson Newell, Justin Burrus, Dale Johnson, Evan White, Hector Morfin, Melissa Morgan, Lars Richins, and Richard Geis. Tim Seiple and Nino Zuljevic, Battelle, developed the sampling site selector program. Susan Ennor, Battelle, edited the report and Kathy Neiderhiser formatted it. The funding to support this research was provided by the Public Utility District Number 2 of Grant County, Washington.

Terms and Abbreviations

°C	degrees Centigrade or Celsius
Battelle	Battelle−Pacific Northwest Division
BPA	Bonneville Power Administration
Chelan	Public Utility District No. 1 of Chelan County
cm	centimeter(s)
CV	coefficient of variation
Douglas	Public Utility District No. 1 of Douglas County
FERC	Federal Energy Regulatory Commission
ft	foot/feet
GIS	geographic information system
GPS	global positioning system
Grant	Public Utility District No. 2 of Grant County
ha	hectare(s)
HCA	Mid-Columbia Hourly Coordination Agreement
HRFCPPA	Hanford Reach Fall Chinook Protection Program Agreement
kcfs	thousand cubic feet per minute
km	kilometer(s)
m	meter(s)
m^2	square meter(s)
MASS1	Modular Aquatic Simulation System in one dimension
MASS2	Modular Aquatic Simulation System in two dimensions
NOAA	National Oceanic and Atmospheric Administration
rkm	river kilometer(s)
SESSM	Stranding/Entrapment Site Selection Model
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WDFW	Washington Department of Fish and Wildlife

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1.0 Introduction

Studies to evaluate the effects of fluctuations in river elevation on juvenile fall Chinook salmon in the Hanford Reach were first funded in 1997. These previous studies have been useful in the current effort to improve the study design to provide an assessment of losses throughout the entire Hanford Reach. The 2012 assessment of stranding and entrapment of juvenile fall Chinook salmon in the Hanford Reach reported here used an updated study design based on the findings and lesson learned from 10 years of research on this subject. Wagner et al. (1999) provided the following definition of the terms stranding and entrapment, which will be used throughout this report:

- “Stranding” is defined as trapping of fish on or beneath the dewatered substrate as a result of receding river level.
- “Entrapment” is defined as separation from the main channel of the river in enclosed backwater zones as a result of receding river level.

The two terms describe two phases of the same phenomenon. For example, fish caught in depressions that drain completely are first “entrapped” and then “stranded.”

1.1 Background

The Hanford Reach Fall Chinook Protection Program Agreement (HRFCPPA) was signed by Public Utility District No. 2 of Grant County (Grant), Public Utility District No. 1 of Chelan County (Chelan), Public Utility District No. 1 of Douglas County (Douglas), the U.S. Department of Energy acting by and through the Bonneville Power Administration (BPA), NOAA Fisheries (NOAA), the Washington Department of Fish and Wildlife (WDFW), the U.S. Fish and Wildlife Service (USFWS), Confederated Tribes and Bands of the Yakama Nation, and the Confederated Tribes of the Colville Indian Reservation (all entities collectively referred to as the “Parties”). This Agreement establishes the obligations of the Parties with respect to the protection of fall Chinook salmon in the Hanford Reach of the Columbia River. The Parties agree that during the term of the Agreement, these flow regimes address all issues in the Hanford Reach with respect to fall Chinook salmon protection and the impact of operation of the seven dams operating under Mid-Columbia Hourly Coordination, including the obligations of Grant, Chelan, and Douglas under any new licenses issued by the Federal Energy Regulatory Commission (FERC). As stipulated in Section C.6.c. of the Agreement, “During the Rearing Periods of 2011, 2012, and 2013, the Parties will also meet to develop a follow-up monitoring program to estimate fry losses. This monitoring program will be designed according to protocols developed from 1999 to 2003 or alternatively with different methods developed by the Parties.”

In cooperation with multiple agencies, the WDFW has conducted extensive assessments in the Hanford Reach to quantify the relationships among in-stream flows, flow fluctuations, and stranding and entrapment mortality of fall Chinook salmon (Anglin et al. 2006). In 2010, staff from WDFW, Grant, USFWS, U.S. Geological Survey (USGS), and Battelle−Pacific Northwest Division (Battelle) attended several meetings to develop a study design that would meet the requirements of Section C.6.c of the Agreement. This study panel reviewed the data collection, methods, analysis, and results of stranding and entrapment studies conducted from 1999 to 2007 in the Hanford Reach. A study plan was finalized in September 2010 and modified again prior to the 2012 field season (Appendix A).

1.2 Hanford Reach Fall Chinook Protection Plan Agreement

The HRFCPPA establishes criteria for the magnitude of daily fluctuations in discharge from Priest Rapids Dam during the period of that fry are susceptible to stranding and entrapment (Table 1). Due to the variability in power demand, water withdrawal (irrigation and urban), and weather events, precise prediction of daily average discharge at Priest Rapids Dam cannot be determined. Flow constraints are based on prior daily inflow to Wanapum Dam or BPA-forecasted weekend flows for Chief Joseph Dam including side flows. Under the criteria adopted in 2004, protection of emergent fry would begin at the estimated start of emergence and continue to be in effect until 400 temperature units (°C) had accumulated at the end of the emergence period (i.e., emergence and rearing periods).

Furthermore, according to the criteria established in the HRFCPPA, on four consecutive weekends that occur after 800 temperature units have accumulated at the end of the emergence period, Priest Rapids Dam outflow will be maintained to at least a minimum flow calculated as the average of the daily hourly minimum flow from Monday through Thursday of the current week.

Table 1 Daily operational constraints established for the Hanford Reach Fall Chinook Protection Program.

Wanapum Weekday Inflow or Chief Joseph Weekend Forecast	Operational Flow Constraint[a]
36–80 kcfs	Limit daily flow fluctuation to ≤ 20 kcfs
80–110 kcfs	Limit daily flow fluctuation to ≤ 30 kcfs
110–140 kcfs	Limit daily flow fluctuation to ≤ 40 kcfs
140–170 kcfs	Limit daily flow fluctuation to ≤ 60 kcfs
> 170 kcfs	150 kcfs minimum hourly discharge at Priest Rapids Dam

(a) Daily flow fluctuation (max-min) was calculated during the period from the hour ending and 1:00 am to midnight of each day.

1.3 Study Objective

The objective of this study was to generate mortality estimates for fall Chinook salmon fry due to stranding and entrapment events that occurred in the Hanford Reach in the 2012 emergence and rearing period.

1.4 Report Contents and Organization

The ensuing sections of this report describe the study area and methodology, and then study results, followed by related discussion. Appendix A contains detailed field sampling methods for the 2011–2013 Hanford Reach stranding and entrapment assessments.

2.0 Study Area

The Hanford Reach (or Reach) is located on the Columbia River in southeastern Washington State. The Reach extends from Priest Rapids Dam at river kilometer (rkm) 639 downstream for 82 km to the head of McNary Pool (rkm 557) near Richland, Washington (Figure 1). The study area included the entire length of the Hanford Reach.

Priest Rapids Dam is located at the head of the Hanford Reach and is part of the seven-dam hydroelectric complex on the mid-Columbia River that also includes Wanapum, Rock Island, Rocky Reach, Wells, Chief Joseph, and Grand Coulee dams (Figure 2). This seven-dam complex is operated under a power-peaking or load-following mode to meet electrical demand in the Pacific Northwest, thus hydropower generation through these projects largely governs stream flow in the Hanford Reach. The mid-Columbia projects are part of the larger Columbia River hydropower system and are operated under an international treaty and other agreements that affect river flows and fish resources. These include the Columbia River Treaty between the United States and Canada, the Pacific Northwest Coordination Agreement, Mid-Columbia Hourly Coordination Agreement (HCA), and the HRFCPPA. The HCA and HRFCPPA (formerly Vernita Bar Agreement), established as a FERC license condition for the Priest Rapids Project, have the most direct effect on daily river flows and fluctuations in the Hanford Reach.

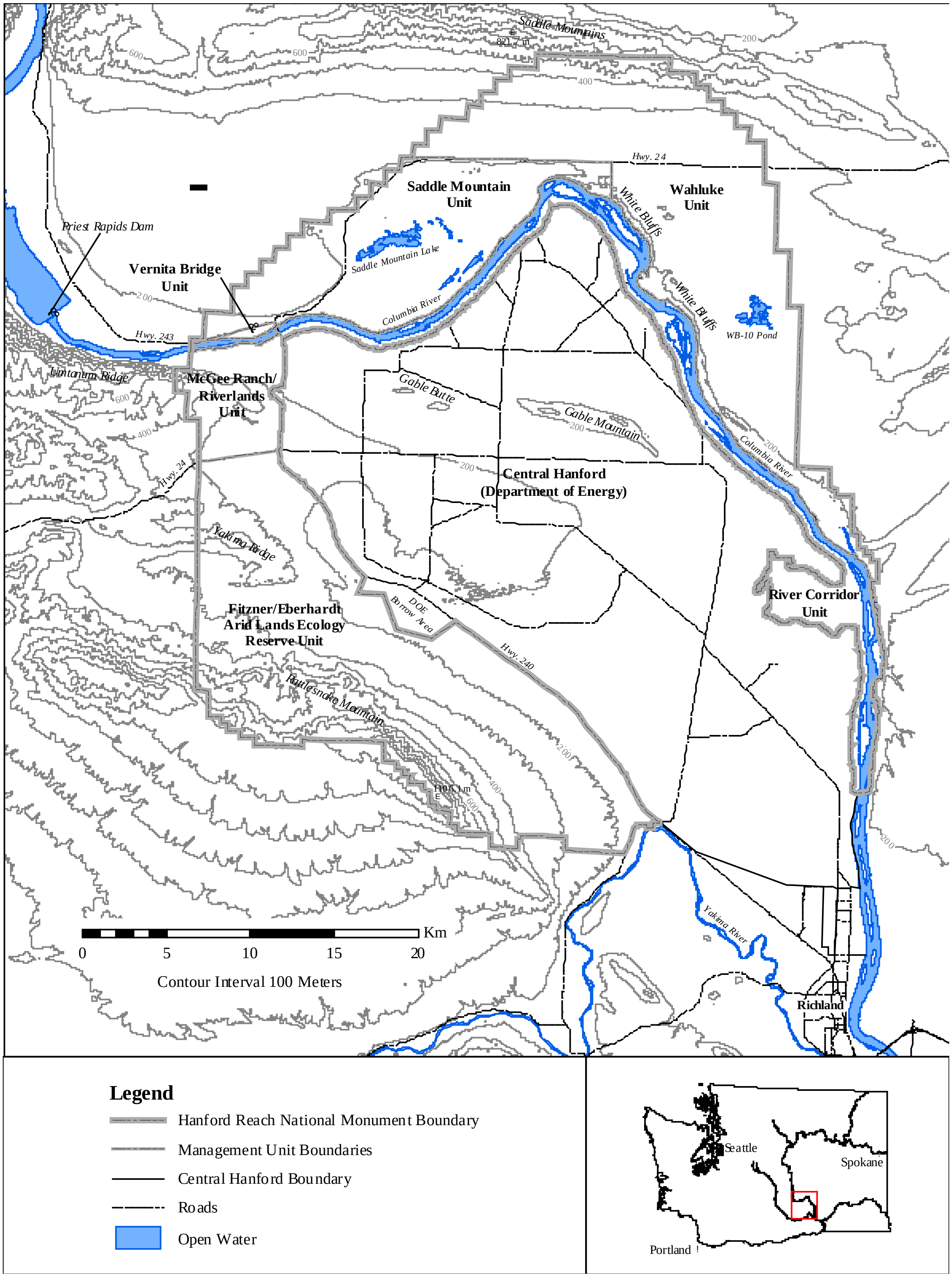


Figure 1 **Location of the Hanford Reach on the Columbia River in Southeastern Washington.**

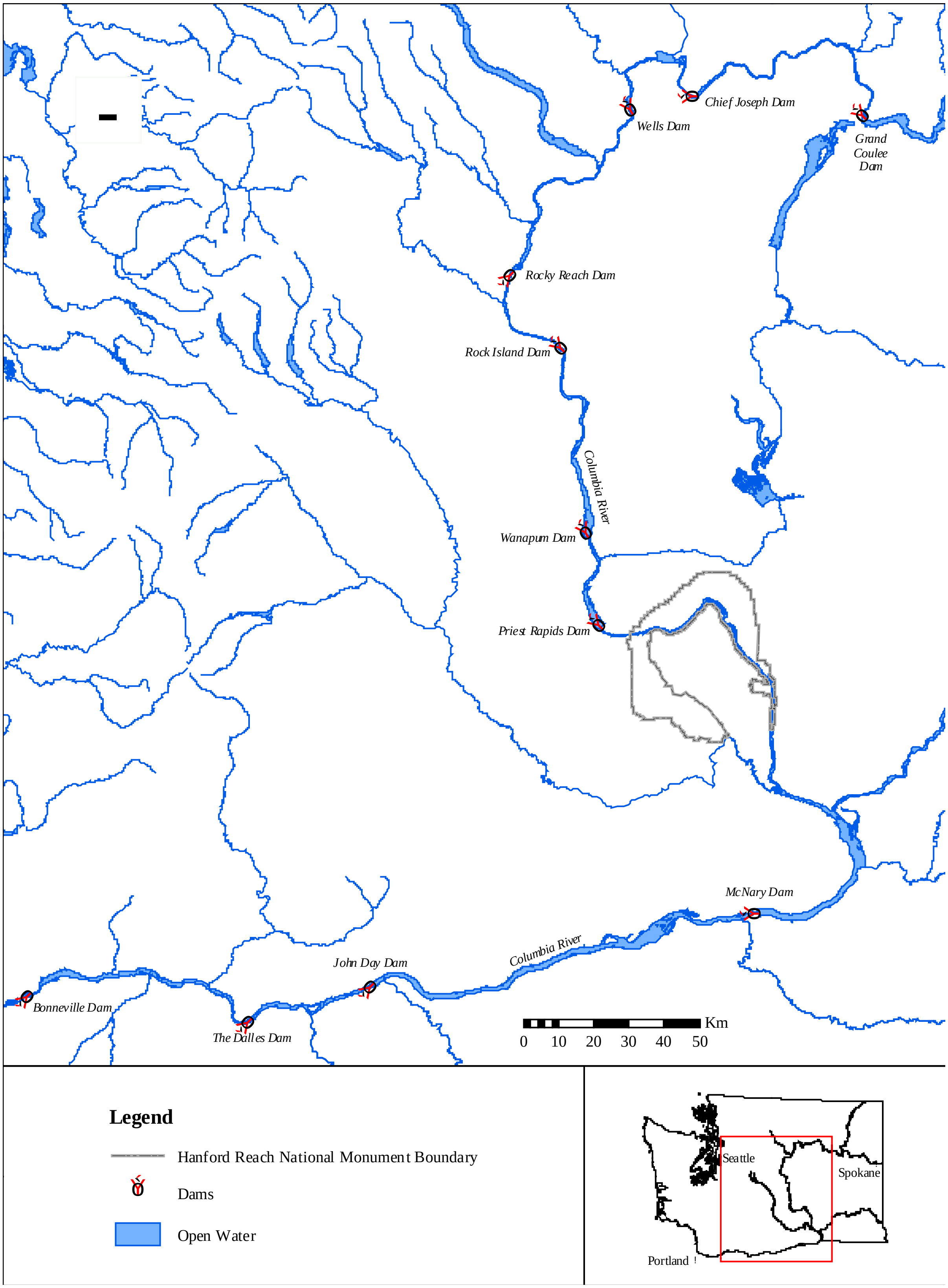


Figure 2 Major hydroelectric facilities located on the Columbia River.

3.0 Methods

Methodology and data collected during previous stranding and entrapment studies of fall Chinook salmon in the Hanford Reach (McMichael et al. 2003; Anglin et al. 2006) were reviewed to develop a field sampling protocol that will allow for a robust measure of total juvenile fall Chinook salmon losses in the Hanford Reach as a result of stranding and entrapment. These updated methods are presented in detail in the Hanford Reach Stranding and Entrapment Protocol, 2011–13 Field Sampling Methods, provided in Appendix A of this report. These protocols will be reviewed annually or as necessary throughout the duration of the study and modified as needed. The following sections provide a general summary of the methods presented in detail in Appendix A.

3.1 Sampling Site Selection

A stratification scheme for the 2011 to 2013 monitoring study years was developed from existing data, simulation modeling, and results obtained from past studies (McMichael et al. 2003; Anglin et al. 2006). This stratification scheme was designed to include spatial, temporal, and physical components to reduce variation in observations within each stratum and in the overall stranding and entrapment estimates.

The Hanford Reach was divided into three primary sections (Upper, Middle, and Lower) similar to previous study years (McMichael et al. 2003). The three sections were divided into eight river segments (Table 2 and Figure 3). River stage variation associated with the unsteady flow hydrograph is relatively consistent within each of the eight segments. Each river segment was further sub-divided into 1 rkm-long sample sites consisting of four 250-m quadrants (Figure 4). Within these sites, affected elevations on both main channel river banks, as well as on any island river banks were included in the assessment. Sites for sampling were randomly selected without replacement within spatial-temporal strata to account for seasonal changes in fish abundance, size, and distribution. Spatial-temporal strata were identified with eight 2-week periods within each of the three sections of the river, leading to a total of 24 strata. The number of temporal strata was based on the prior evaluations of fish susceptibility and details of temperature unit accumulation by incubating eggs and developing alevins and fry.

The Stranding/Entrapment Site Selection Model (SESSM), an automated, Internet-based model developed by Battelle in 2011 and updated prior to the 2012 field season, was used to generate sampling sites. The model is based on the stratification scheme described above and was used to determine river segments and sites available for each sampling day. SESSM uses the Modular Aquatic Simulation System in one dimension (MASS1; Richmond and Perkins 2009) to identify quadrants available for sampling based on real-time discharge data from Priest Rapids Dam during the previous 24 hours. Sampling was concentrated in upstream segments when discharge fluctuations from Priest Rapids Dam were too small to affect downstream areas, and distributed throughout the Reach during events with greater fluctuations. Sample sites consisted of both main-channel river banks and any island shorelines. Entrapment sampling was conducted from the randomly selected quadrant downstream through the second adjacent quadrant (500 m total), while sampling plots surveyed for stranding were distributed directly along the selected transect line generated from the SESSM. In 2012, a minor change was implemented for stranding sampling. In areas where the area recently dewatered was too narrow to allow for sampling of multiple stranding plots perpendicular to the channel, the plots were arranged parallel to the channel. In addition, concern about the shoreline drying prior to staff arriving to sample for stranding prompted a change in the protocol for 2012 to include sampling a portion of the dry shoreline (see Section 3.2.1 for details).

Table 2 **Delineations for the eight spatial temporal strata for the 2011-2013 evaluations of stranding and entrapment of juvenile fall Chinook salmon in the Hanford Reach including the number of 1 km sites within each segment.**

Section	Segment	Lower Boundary (rkm)	Upper Boundary (rkm)	Quadrants	Quadrants (# by Section)
Upper	1	620	635	1–60	120
	2	605	620	61–120	
Middle	3	595	605	121–160	120
	4	588	595	161–188	
	5	581	588	189–216	
	6	575	581	217–240	
Lower	7	558	575	241–308	120
	8	545	558	309–360	

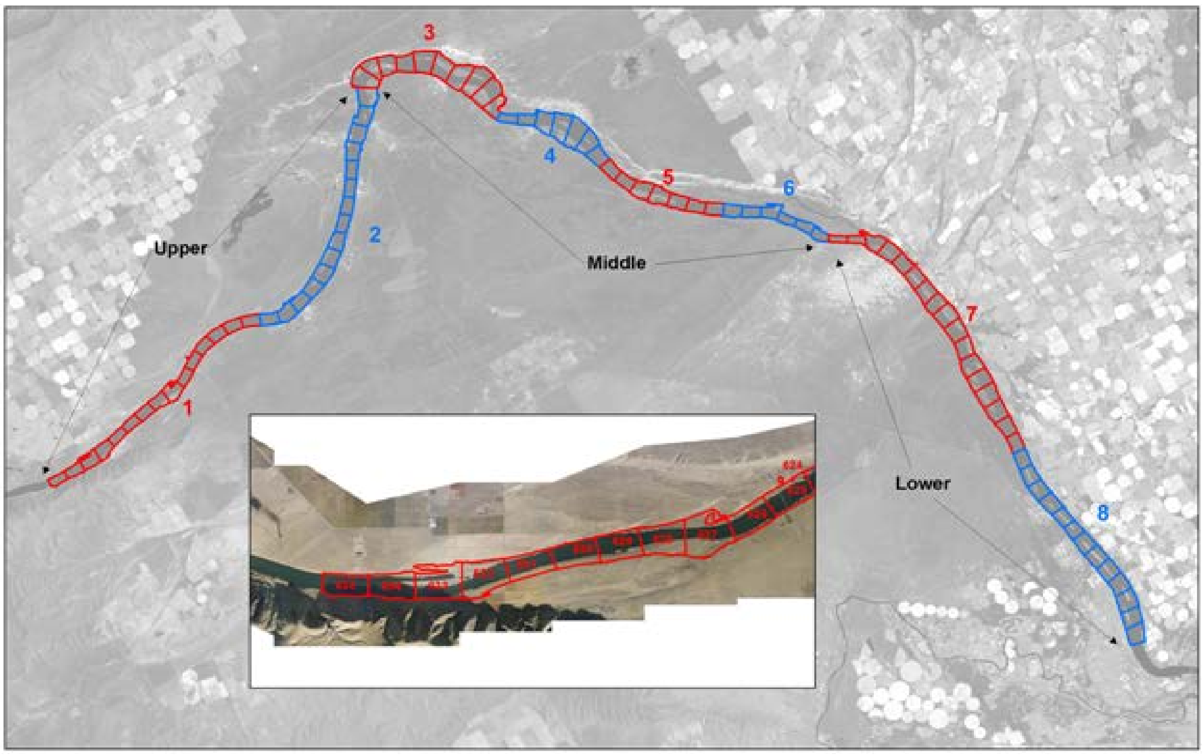


Figure 3 **Spatial strata including segments, reaches, and sties for the 2011-2013 evaluation of stranding and entrapment of juvenile fall Chinook salmon in the Hanford Reach.**

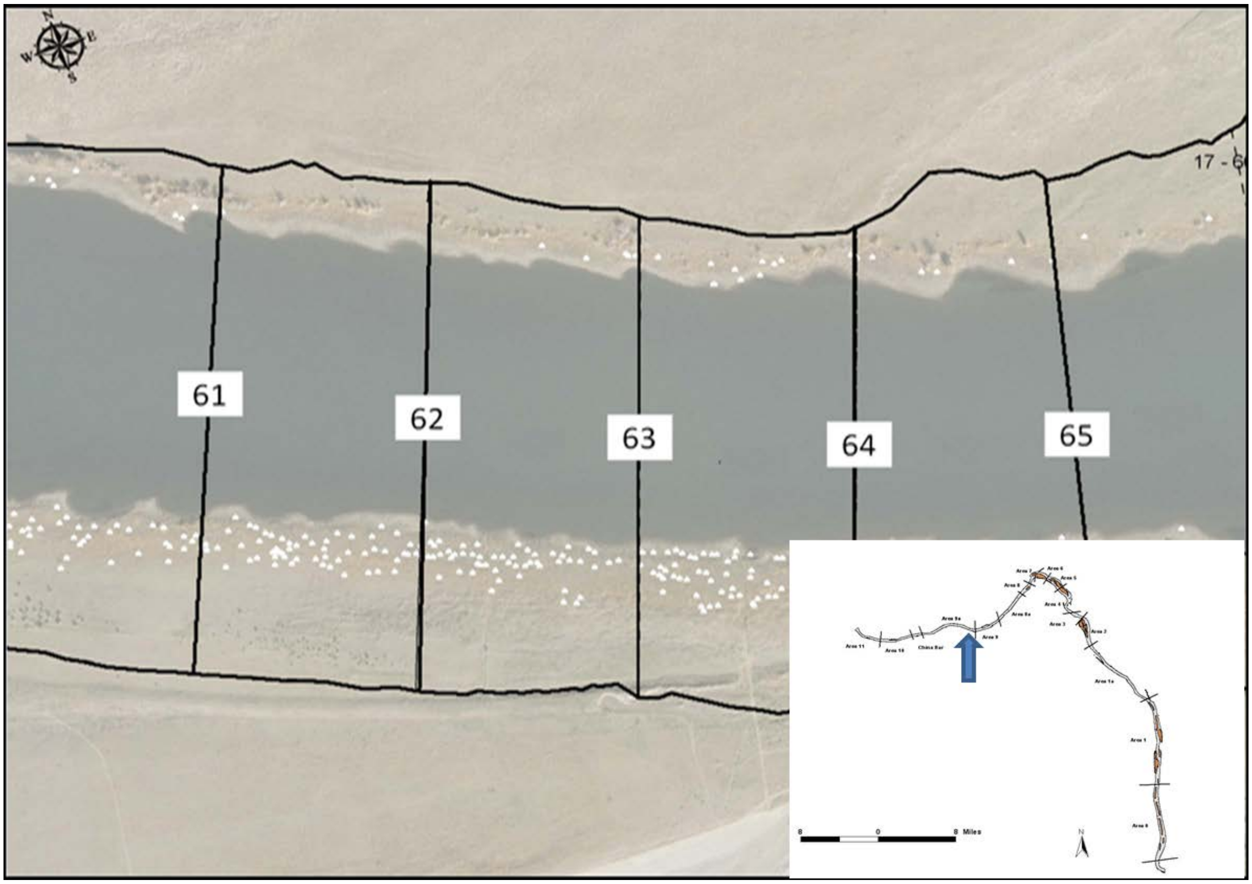


Figure 4 Example of an individual 1-km sample site, delineated into quadrants with transects located at 250-m intervals. White dots represent entrapment locations from 2003-2007 assessments. The blue arrow in the inset on the lower right shows the location of this particular sample site within the Hanford Reach study area.

A total of 360 quadrants were defined during the 2007 USFWS entrapment evaluation. Several factors were used to determine the randomly selected quadrants sampled on any given day including the following:

- The primary criterion for selecting a quadrant for sampling was changed from a decrease in water-surface elevation (used in 2011) to one based on a decrease in the top width of the river (Figure 5). The quadrant must have had a minimum decrease in river top width of 9.88 m (32.4 ft.) within the most recent 24 hours.
- Projections of the estimated water elevations using discharge data from Priest Rapids Dam were also used to ensure that the decrease in top width would be maintained during at least 2 hours within the next 8 hours (work window).
- The quadrant must not have been sampled within the current temporal strata (two weeks).

SESSM provided the sampling crews with a list of candidate stranding or entrapment sampling sites based on the criteria described above. The list of candidate sites was ordered based on a random number list that was updated daily. The sampling crew used pre-programmed hand-held global positioning system (GPS) units to navigate to the sampling sites.

After being sampled, quadrants were removed from the list of eligible sample locations for the remainder of that two-week temporal stratum. To facilitate sampling throughout each sampling day, start times for each crew were staggered.

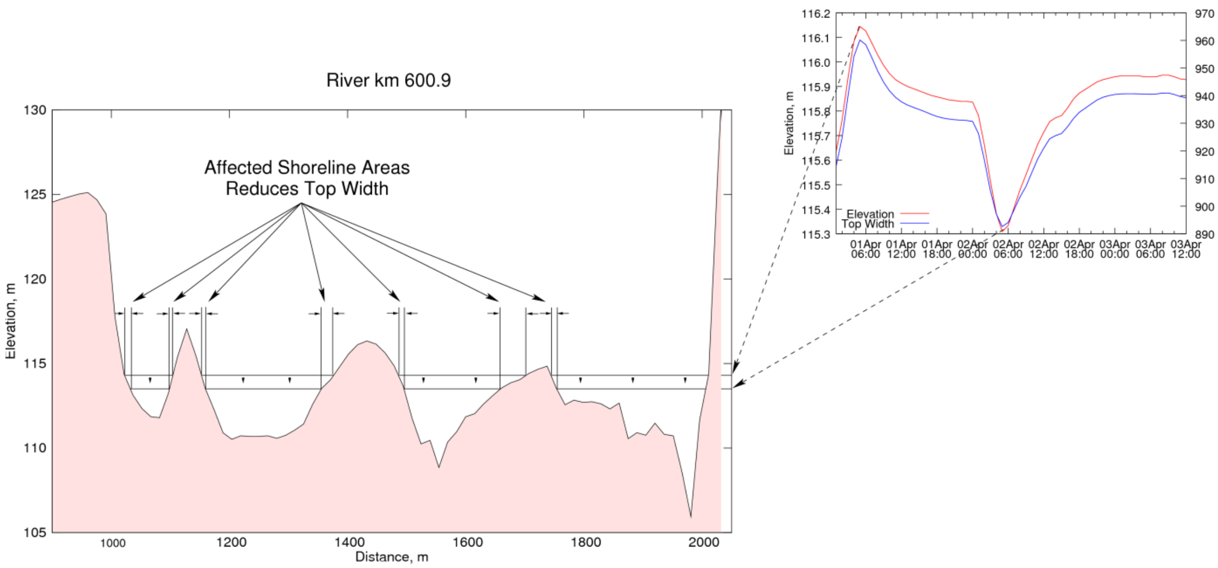


Figure 5 **Example of how top-width is related to changes in river water surface elevation in the Hanford Reach of the Columbia River.**

3.2 Stranding

Field data collection, sampling efficiencies, and data analyses related to stranding are described in the following sections.

3.2.1 Field Data Collection

Field sampling to estimate stranding impacts from flow fluctuations in the Hanford Reach on emergent and rearing juvenile fall Chinook salmon began on March 9 and continued through June 22, 2012. A three-person crew (consisting of WDFW staff dedicated to this evaluation) worked seven days a week to perform the necessary sampling.

For sampling locations with wide dewatered bands (i.e., ≥50 m), five plots were sampled (Figure 6). The center point of the first plot was 5 m inland from the water's edge along the transect and the total circular sampled area was 78.5 m^2. A scaled plot was drawn indicating information such as the river in relation to the plot location, the dewatered area, entrapments, and location where fish were recovered. Under wide flow fluctuation conditions, the second plot was located at the most inland wetted location along the transect. The center point for the third plot was an equal distance between the river and the edge of the wetted perimeter. The center point for the fourth plot was an equal distance between the center point for plots 1 and 3. Similarly, the center point for the fifth plot was an equal distance between the center points for plots 2 and 3 (Figure 6).

When the area dewatered was narrow (<50 m), plots were established adjacent to one another (Figure 7), or (new in 2012) arranged parallel to the wetted edge (Table 3, Figure 7). The center point of the first sample plot was located 5 m inland from the water's edge along the transect. The center point for plot 2 was measured 10 m from the center point of plot 1 inland along the transect line. Additional plots were established inland until the outer diameter of the plot extended beyond the wetted boundary. Also new in 2012 was the sampling of partial plots that fell above the obviously wetted area (data for wetted and unwetted areas were recorded separately).

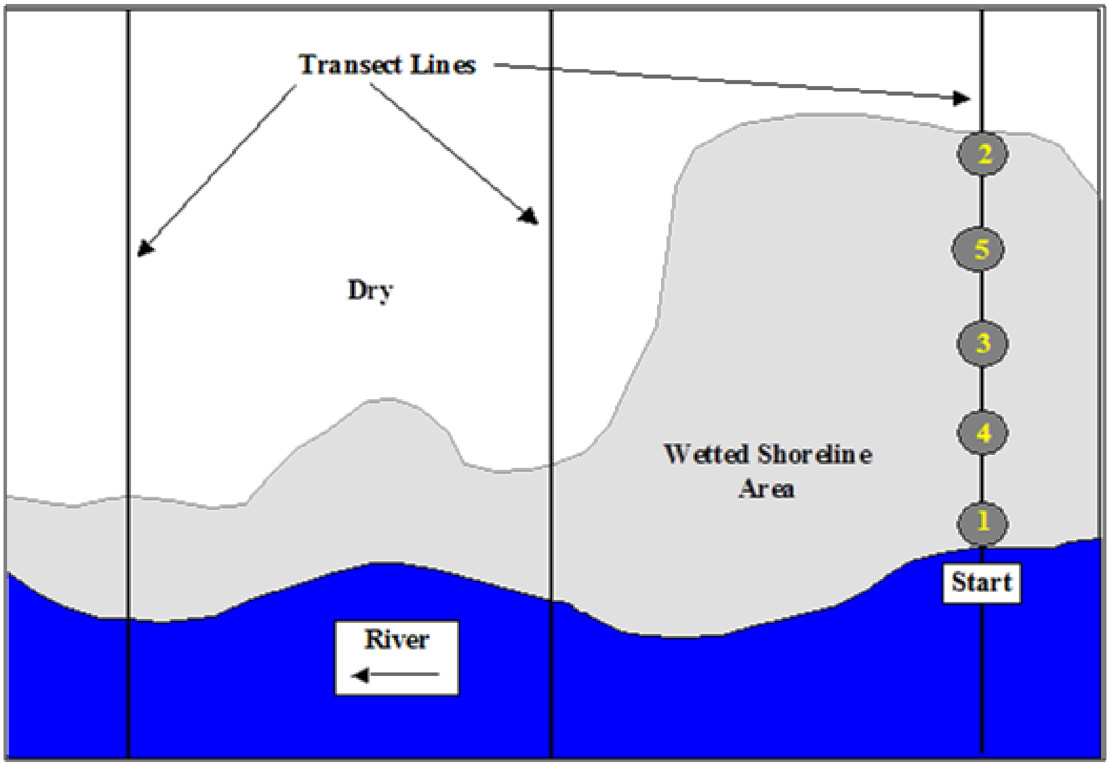


Figure 6 Sampling scheme for stranding sites within wide dewatered areas.

Table 3 Parameters for plot configurations during field stranding assessments in the Hanford Reach. A visual representation of these configurations is presented in Figure 8.

Example	Wetted Line Scenario	Anchor Placement (center of plot)	Plots (#)	Orientation
	Wetted area <1 m wide	NA	0	None
1	Wetted area 1–5 m wide	On wetted line	3	Lateral
2	Wetted area 5–10 m wide	5 m above water line	3–5	Lateral
3	Wetted area 10–15 m wide	5 m above water line and on wetted line	3	Stacked vertical and lateral
4	Wetted area >15 m wide	5 m above water line and on wetted line	≥2	Vertical

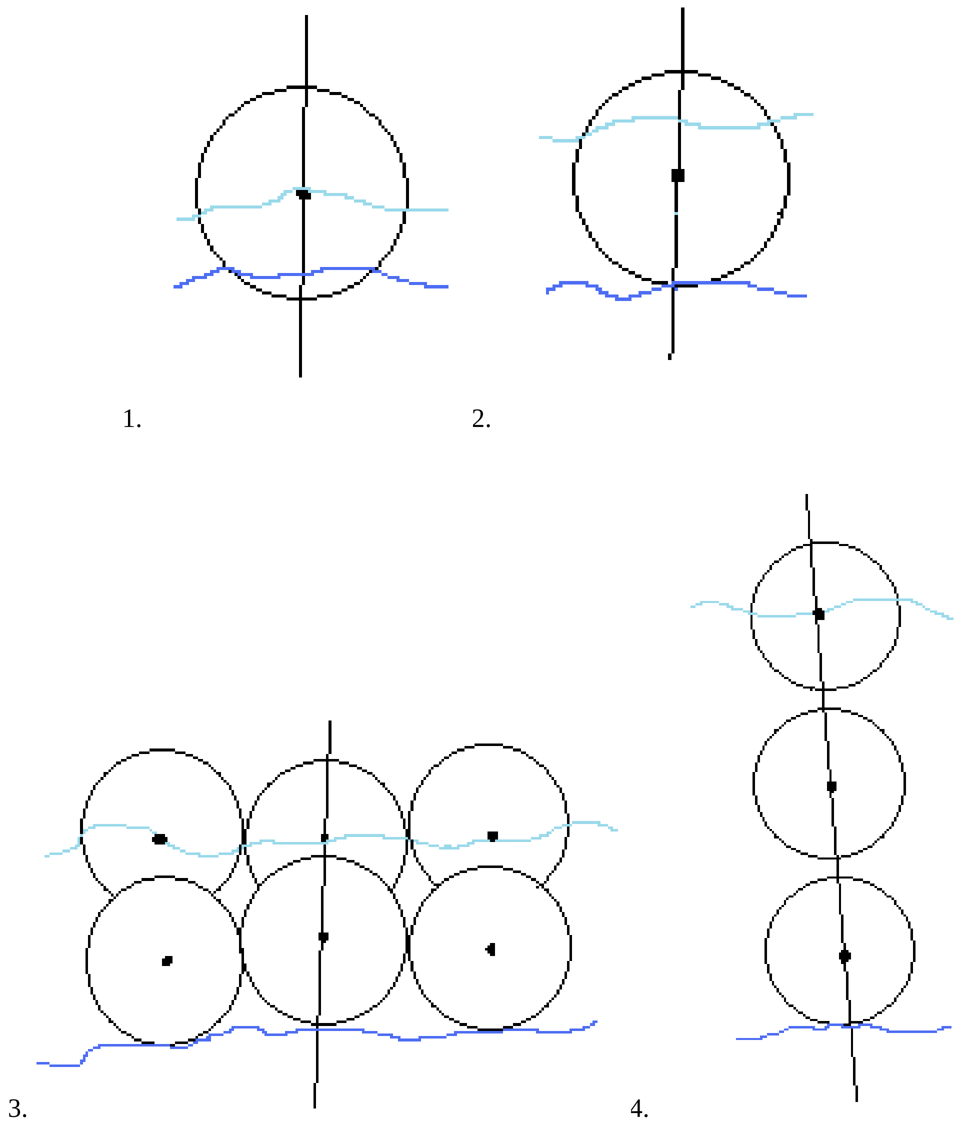


Figure 7 Plot configurations for stranding sampling based on flow band width. The parameters for these illustrations are outlined in Table 3. The dark blue line represents the waterline and the light blue represents the wetted line. In examples 1 and 2, additional plots would be located laterally adjacent to the initial sample plot.

At each plot selected for sampling, physical data including substrate size, percent embeddedness, percent fines, vegetation characteristics, and density were visually estimated and recorded. Biological data recorded at each plot included the number of Chinook salmon fry observed, the number of other species observed, and any evidence of predation (e.g., bird or animal tracks). If any entrapments were observed within the plots during the stranding sampling, the size of the entrapments and fish presence were recorded, but the entrapments were not sampled.

3.2.2 Sampling Efficiency

Sampling efficiency was assessed at areas selected from the maps that contained variable habitats similar to those encountered during sampling. Fall Chinook salmon fry were collected with a beach seine, sampled, and adipose-clipped. Twelve plots were selected within the sampling area that had variable vegetation densities. One crew member dispersed one to three fry within each sampling plot at locations where fry would typically be found (e.g., adjacent to cobble, at the base of vegetation, at the bottom of depressions). Other crew members completed sampling at each plot within 1 hour, recording the number of recovered fish at each plot.

3.2.3 Estimation of Dewatered Area

To estimate the dewatered area, the Modular Aquatic Simulation System in two dimensions (MASS2; Perkins and Richmond 2007a, 2007b) was applied to the Hanford Reach to provide spatially distributed depth and velocity estimates. MASS2 is an unsteady, two-dimensional depth-averaged hydrodynamic and water-quality model. This application was similar to the previous application (McMichael et al. 2003; Perkins et al. 2004), but was extended to the entire Hanford Reach. The computational grid for MASS2 was developed with a nominal lateral and longitudinal spatial resolution goal of approximately 10 m. The final grid encompassed approximately 7,674 ha using more than 727,800 computational cells. The grid resolution averaged 9.9 m and ranged from 4.3 to 30 m laterally. Longitudinally, the grid resolution averaged 10.7 m and ranged from 3.8 to 31.9 m. The MASS2 model was run using hourly Priest Rapids Dam discharge and temperature from January 1 to June 30, 2012, for the stranding and entrapment 2012 season.

The results of each MASS2 simulation were stored at hourly intervals. The state (velocities, water elevation, temperature, wet/dry state, etc.) of all of the model cells for every hour was saved. The state of each cell was compared to the previous state to identify whether the area was dewatered. A cell was considered "dewatered" if it was wet and in the river at the previous time, but was dry at the later time.

Each hourly time slice was classified based on the instantaneous state of the model cell. The area of each cell was computed using information from the computational grid. Total areas of each classification were computed by summing individual cells.

3.2.4 Data Analysis – Estimated of Stranding Loss

A two-stage sampling plan was used in the field survey. The primary unit of the two-stage sampling design was the *quadrant*. During each two-week period of the survey, a quadrant was randomly selected from the list of the available quadrants without replacement within the two-week period (there were minor violations of this aspect of the design; with four quadrants sampled more than once within a two-week period). Once a primary sampling unit was selected, one or more samples of a secondary unit, a *plot* which is a circle with a diameter of 10 m, were surveyed. The monitoring plan used for the study can be found in Appendix A.

For the k-th temporal-spatial stratum ($k=1,\dots,K$), we define N_k as the number of available primary units (quadrants) within the kth stratum (i.e., a two-week period for a given river section), M_{ik} as the number of available secondary units (all plots with dewatered area) within the ith primary unit of the kth stratum, and y_{ijk} as the number of stranded Chinook salmon found in the jth secondary unit (plot) of the ith primary unit (quadrant) of the kth stratum. The total number of stranded Chinook salmon in the *i*th primary unit (quadrant) of the *k*th stratum is,

$y_{ik} = \sum_{j=1}^{M_{ik}} y_{ijk}$ and the total number of stranded Chinook in the *k*th stratum is,

$$\tau_k = \sum_{i=1}^{N_k} \sum_{j=1}^{M_{ik}} y_{ijk}$$

However, there are no complete y_{ijk} for making the summation because we did not survey all M_{ik} plots in all of the N_k quadrants of the *k*th stratum. In terms of sampling from N_k and M_{ik} within the *k-th* stratum, we define n_k as the number of primary units (quadrants) sampled within the *k-th* stratum and m_{ik} as the number of secondary units (plots) actually sampled in the *i*th primary unit within the *k*th stratum. The estimate of the total number of stranded Chinook salmon within the *i*th primary unit is $\hat{y}_{ik} = A_{ik} \times \hat{r}_{ik} = A_{ik} \frac{\sum_{j=1}^{m_{ik}} y_{ijk}}{\sum_{j=1}^{m_{ik}} a_{ijk}}$, obtained by expanding the stranding rate of the *i*-th quadrant of the *k*th stratum estimated from the stranded Chinook salmon, y_{ijk}, and the surveyed area, a_{ijk}, of the m_{ik} surveyed samples (plots) to the overall dewatered area of the *i*-th quadrant of the *k*-th stratum (from the MASS2 model). An unbiased estimate of the total number of Chinook salmon entrapped within the *k*th stratum is $\hat{\tau}_k = A_k \times \hat{r}_k = A_k \frac{\sum_{i=1}^{n_k} \hat{y}_{ik}}{\sum_{i=1}^{n_k} A_{ik}}$, which is expanding the stranding rate of the *k*-th stratum estimated based on the n_k quadrants surveyed in the *k*th stratum with the overall dewatered area of the *k*-th stratum (with the dewatered area for that quadrant derived from the MASS2 model). The estimate of the total number of Chinook salmon entrapped across all three river sections and all eight 2-week sampling periods is thus $\hat{\tau} = \sum_{k=1}^{K} \hat{\tau}_k$.

A bootstrap process was used to estimate the stranding loss and the variability of the estimate. When estimating the stranding loss rate in the *i*th primary unit within the *k*th stratum, $\hat{r}_{ik} = \frac{\sum_{j=1}^{m_{ik}} y_{ijk}}{\sum_{j=1}^{m_{ik}} a_{ijk}}$ and the stranding rate in the *k*-th stratum, $\hat{r}_k = \frac{\sum_{i=1}^{n_k} \hat{y}_{ik}}{\sum_{i=1}^{n_k} A_{ik}}$, m_{ik} and n_k random samples were drawn from the m_{ik} and n_k samples with replacement, and the $\hat{r}_{ik}$ and $\hat{r}_k$ are estimated from the bootstrap sample.

The changes in the stranding sampling design for 2012 discussed in Section 4.2.1 led to a significant increase in the number of plots sampled per quadrant. Table 4 shows that 99% of the quadrants had at least three plots surveyed, and that over 70% had five or more plots surveyed. This was a significant improvement over 2011 when about half of the quadrants surveyed included only one sample plot and about 80% of the quadrants surveyed had two or fewer plots (Hoffarth et al. 2012). Thus, the alternative method used to draw bootstrap samples for quadrants with less than three plots described by Hoffarth et al. (2012) was only used for a single quadrant, and bootstrap samples for the rest of the quadrants were drawn as described above.

Table 4 Distribution of the number of plots within quadrants sampled for stranded fall Chinook salmon in the Hanford Reach in 2012.

Plots in Quadrant	No. of Quadrants	%
14	1	1%
13	1	1%
12	2	1%
11	6	4%
10	1	1%
9	10	7%
8	8	5%
7	3	2%
6	42	27%
5	35	23%
4	14	9%
3	29	19%
2	0	0%
1	1	1%

The random sampling of quadrants and sample plots was repeated 10,000 times for each stratum. An array of 10,000 bootstrap estimates of the number of stranded juvenile fall Chinook salmon was obtained for each individual temporal-spatial stratum. The bootstrap estimates of the individual strata were then aggregated to provide estimates of each of the eight 2-week periods and the three river sections, as well as estimates of stranding loss for the entire Hanford Reach.

The mean of the bootstrap estimate array was taken as the bootstrap estimate and the central 95% interval of the array was taken as the 95% confidence interval. The bias of the bootstrap estimate was estimated and a bias-corrected estimate and bias-corrected confidence interval were calculated (see Efron and Tibshirani 1993, page 138). The bias of a bootstrap estimate is calculated as follows: bias = $est_{Boot} - est_{Data}$. The usual reason for estimating the bias is to provide a bias-corrected estimate: $est_{Bias\text{-}Corrected} = est_{Data} - bias = 2\ est_{Data} - est_{Boot}$, as shown by Efron and Tibshirani (1993).

The bias correction can also apply to the estimate of the confidence interval (Efron and Tibshirani 1986). For a central 1–2α confidence interval, the confidence interval consists of the values at the αB and (1–α)B position of the sorted bootstrap array with B elements that correspond to the standard normal unit of $G^{-1}(\alpha)$ and $G^{-1}(1-\alpha)$ where $G(\alpha)$ is the bootstrap cumulative distribution function. The bias-corrected confidence interval adjusts the confidence interval endpoint for accounting for the bootstrap bias through a parameter z_0. The z_0 parameter is calculated as $z_0 = \Phi^{-1}\left(\frac{\#\{\hat{\theta}^*(b) < \hat{\theta}\}}{B}\right)$ (Equation 14.14 in Efron and Tibshirani [1993]), where Φ^{-1} indicates the inverse function of a standard normal cumulative distribution function, e.g., $\Phi^{-1}(0.025) = -1.96$ and $\Phi^{-1}(0.975) = 1.96$; $\hat{\theta}^*(b)$ denotes each of the B bootstrap estimate; $\hat{\theta}$ represents the data estimate; and # stands for the number of times where the bootstrap estimate is smaller than the data estimate. When half of the bootstrap estimate is smaller than the mean of the data estimate, z_0 equals 0 ($\Phi^{-1}(0.5) = 0$). Roughly speaking, z_0 measures the median bias of $\hat{\theta}^*(b)$, that is, the discrepancy between the median of $\hat{\theta}^*(b)$ and data estimate $\hat{\theta}$, in normal units. The bias-corrected 1–2α confidence interval has the adjusted α level endpoints: $\alpha_1 = \Phi\{2z_0 + z^{\alpha}\}$ and $\alpha_2 = \Phi\{2z_0 + z^{1-\alpha}\}$, while the bias-corrected confidence interval consists of the α_1B and α_2B positions of the sorted bootstrap array with B elements.

3.3 Entrapment

Field data collection, sampling efficiencies, estimation of entrapment event history, and determination of fate of entrapped Chinook salmon, and data analyses related to entrapment are described in the following sections.

3.3.1 Field Data Collection

Entrapment field sampling in the Hanford Reach also was conducted from March 9 to June 22, 2012. Two three-person crews sampled entrapment sites seven days per week. Entrapment crew start times were staggered to allow crews to sample during all hours of daylight with the first crew starting one hour before daylight and the second crew continuing to work in the field until dusk. Entrapment sampling was conducted concurrently with stranding sampling.

The entrapment sampling crews began sampling along the shoreline at a randomly selected quadrant as determined by the SESSM (see Section 3.1), moving inshore along the transect boundary searching for entrapments. An entrapment is defined as an enclosed depression with a wetted surface area ≥1 m in diameter. Crews searched for entrapments along a quadrant until they reached the inland edge of the wetted shoreline, then they searched parallel to the inland wetted edge in the downstream direction up to a sufficient distance to allow observation of entrapment presence between survey lines (Figure 8). The crews then searched back towards the river, sampling all entrapments encountered. The pattern was completed along the full 500 m of shoreline, within two quadrants (Figure 8), and repeated along the opposite shore.

Physical data, including fish presence, substrate size, embeddedness, vegetation characteristics and density, evidence of predators, time of sampling, air and water temperature, and depth of the entrapment, were recorded at each entrapment encountered. An estimate of the original size of the entrapment when it became separated from the main river channel was recorded, as well as the current diameter of the entrapment, categorized into one of four categories:

- Type 1: 1–5 m in diameter
- Type 2: 5–15 m in diameter
- Type 3: >15 m in diameter
- Type 4: cannot be sampled due to large size or too great a depth.

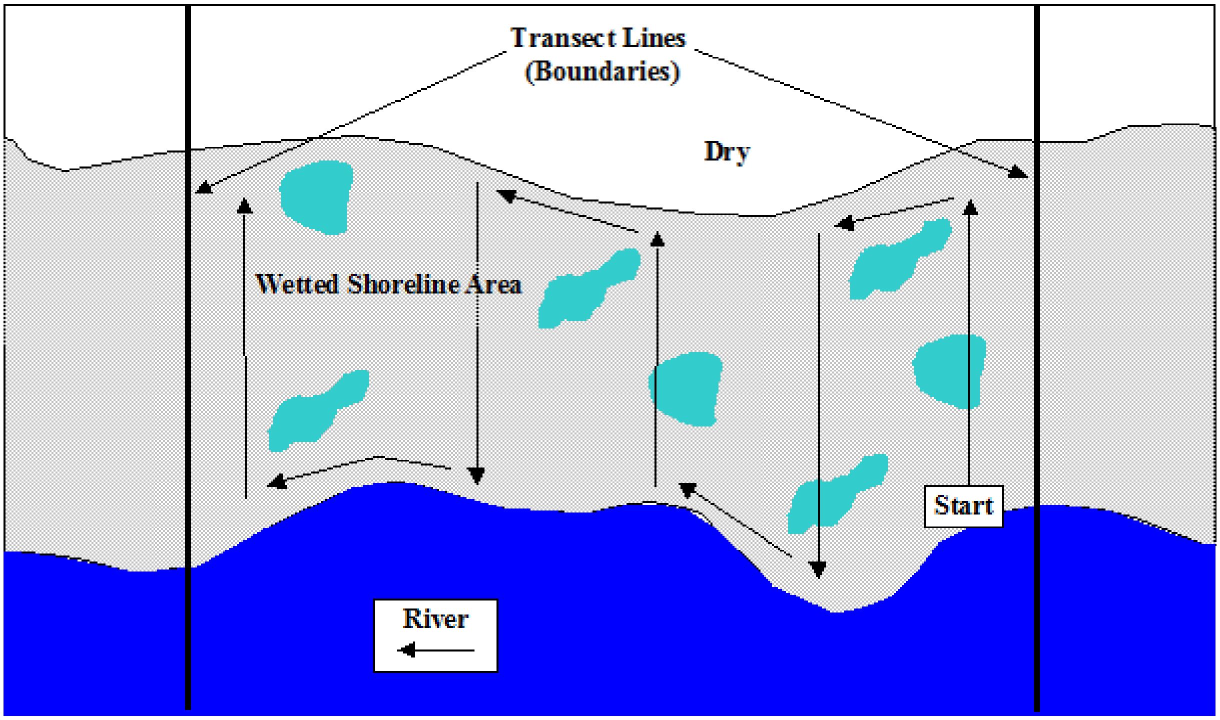


Figure 8 **Search pattern for entrapment sampling. In 2012, the sample area was double what is shown in this figure (i.e., 500 m between sample transect lines.)**

One measurement for both the length and width of the current wetted surface area of each entrapment was recorded in addition to the size classification. The fate of each entrapment was determined either in-season or post-season for the purpose of estimating fall Chinook salmon fry mortality. The fate of juvenile fall Chinook salmon in entrapments is influenced by various factors (e.g., discharge, air and water temperature), which also change over the course of the rearing period. Thus, entrapment fate was categorized and recorded as follows:

- lethal – drained
- lethal – temperature
- non-lethal – re-flooded
- unknown.

In addition, a temperature data logger was placed at the deepest point of the entrapment and the entrapment was revisited, if necessary, to determine the fate of the entrapment. When sites had low numbers of entrapments, sampling was conducted on both river banks and/or islands within the same quadrants for the extent of the allotted sampling time. If additional sampling time remained, the closest adjacent quadrant on the list was also sampled.

Biological data collected at each entrapment location included the estimated number of fall Chinook salmon fry and other species observed prior to sampling, the sampling methodology (i.e., electrofishing, beach seining, visual observation, or hand collection), the number of both live and dead fall Chinook salmon fry observed, and the number of live and dead fish of other species observed.

3.3.2 Sampling Efficiency

Entrapment sampling efficiency was evaluated for a selection of entrapments with Chinook salmon present to assess the efficiency of each of the capture methods used in the study. Captured Chinook salmon fry were adipose-clipped and released back into the entrapment. Sufficient time (10 to 15 minutes) was allowed for the fry to redistribute before being recaptured. The entrapment was again sampled using the same method, electrofishing or beach seining, with the same duration (seconds shocked) or number of seine passes as the original sample. Sampling efficiency tests were attempted on 42 entrapments. A total of 1,421 marked fall Chinook salmon were released in these entrapments and a total of 924 marked fall Chinook salmon and 1,317 unmarked Chinook salmon were sampled in the recapture efforts. Sampling efficiency can be calculated in two ways. Mark recapture efficiency was calculated by dividing the number of recaptured fish with marks (adipose-clipped) by the total number of marked fish released. Sampling efficiency could also be estimated by dividing the number of Chinook salmon initially collected by the total number of Chinook salmon recovered from the entrapment (i.e., number of fish initially collected during the first pass plus the number of fish collected without marks during the recapture pass).

3.3.3 Estimation of Entrapment Event Histories

To estimate the entrapment events, the same MASS2 simulation used to estimate dewatered area (Section 3.2.3) was used to estimate entrapment histories. Individual entrapment locations that were identified during previous studies (*n*=13,118) to create a population of entrapments were used to estimate the number of entrapments that were created during the 2012 protection period. The locations for the population of entrapments were used to identify the MASS2 computational cells used to simulate entrapment histories for each entrapment location. A computational cell was considered entrapped if it was wet and in the river at the previous time and remained wet but was no longer in the river at the later time. For each hour of the simulated time frame, depth, velocity, and temperature were interpolated in space at each entrapment location. This included whether MASS2 simulated the location as wet or dry.

Areas of the Hanford Reach lower than an elevation corresponding to an approximate discharge of 225 kcfs have been well surveyed during prior entrapment studies (e.g., 2003, 2007) so the number and locations of entrapments in that area are well known (Anglin et al. 2006). Areas above that elevation have not been well surveyed, so the number and location of entrapments is relatively unknown for elevations higher than approximately 225 kcfs. During the 2012 evaluation, Columbia River discharge was in the range of elevations that are well surveyed until April 19 (Figure 10). Discharge was above 225 kcfs for the remainder of the 2012 study period, so most of the population of known entrapment locations was not dewatered during the last five temporal strata. Thus, enumerating entrapments based on the history of known entrapment locations underestimates the actual number of entrapments that were created during the season. To address this limitation, an area-based entrapment estimate was created using the density of entrapments in the well-surveyed areas. The estimate of the total number of entrapments within the *i-th* site in the *k-th* stratum is $\hat{y}_{ik} = A_{ik} \frac{\sum_{k=1}^{5} N_{ik}}{\sum_{k=1}^{5} A_{ik}}$ where N_{ik} is the number of entrapments and A_{ik} is the dewatered area formed at the *i-th* site in the *k-th* stratum, where k=1,…,3 represents the first three strata.

3.3.4 Determination of Fate of Entrapped Chinook Salmon

Of the 1,378 entrapments sampled, the fates of entrapped Chinook salmon could be determined in the field for 733 entrapments. Fates were assigned to unknown entrapments after field sampling based on individual entrapment histories, river elevation histories generated by MASS1 at the nearest transects, and drainage rate information collected during sampling in 2012. The MASS1 model generates hourly water-surface elevation data for each of the 360 transects in the Hanford Reach. The date and time individual entrapments were sampled were compared to the water-surface elevations generated by MASS1 to estimate when the entrapment was formed and when the entrapment would reflood. As illustrated in Figure 9, the elevation at which an entrapment is formed can be estimated from the river elevation profile for the nearest transect. The number of hours before the entrapment is reconnected to the river can also be estimated from this profile. These data can also be compared to the entrapment history generated for this entrapment to further refine the date and time the entrapment was isolated and reconnected to the river.

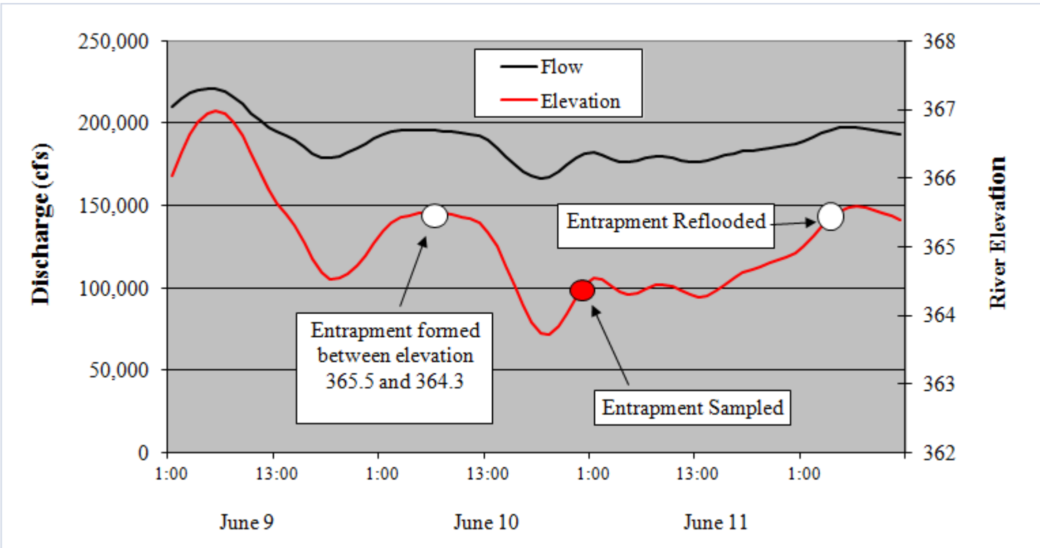


Figure 9 **Example of river discharge (black line) and the water surface elevation data from MASS1 (red line) and the time an entrapment was isolated from the river and then re-flooded and reconnected to the river (white circles) in reference to when it was sampled in the field (red circle).**

Drainage rates were applied to the last known depth of the entrapment to determine the number of hours until an entrapment would drain. Drainage rates were collected from the majority of the entrapments sampled in 2012. Where the duration between depth measurements was too brief (less than 30 minutes), the median drainage rate for entrapments from 2011 was used to estimate the number of hours before an entrapment would fully drain. The mean and median drainage rates were calculated from all entrapments in the database where there was a minimum of 30 minutes between the observed depth measurements and the variance was positive (indicating the entrapment was draining as opposed to refilling). The median rate was used because it was slower (1.6 vs. 2.5 cm per hour) and considered to be more conservative. An entrapment was considered drained, if the depth divided by the drainage rate was less than the number of hours before the entrapment reconnected with the river. Of the 645 entrapments in which the fate was originally listed as unknown, 474 were predicted to drain before river levels increased enough to re-flood, while the remaining 169 were determined to have been reconnected to the river prior to draining. After post-season fate determinations were completed, 70.4% of the entrapments drained, 17.6% reconnected to the river, and 12.0% reached water temperatures lethal to fall Chinook salmon (Table 5).

Table 5 Summary of potential mortality of fall Chinook salmon during entrapment.

		Lethal		
	Reflooded	**Temp (>27°C)**	**Drain**	**Total**
Total	242	166	970	**1,378**
Percent of total	17.6	12.0	70.4	
Known	73	164	496	**733**
Percent of known	10.0	22.4	67.7	
Unknown/Assigned	169	2	474	**645**
Percent of unknown	23.1	0.3	64.7	

For comparison, of the 59 entrapments where Chinook salmon were collected in 2011, 25 (42.4%) reconnected with the river, 32 (54.2%) drained, and 2 (3.4%) reached water temperatures above 27°C.

3.3.5 Data Analyses – Estimation of Entrapment and Entrapment Loss

Similar to the stranding methodology, a two-stage sampling design was applied within each of the K segment-sampling period combinations (K = 64, eight segments times eight sampling periods) to estimate the total number of Chinook salmon entrapped within each combination. Using notation similar to that of Thompson (1992), we define N_k as the number of primary units (sites) within the kth combination, M_{ik} as the number of secondary units (entrapments) within the ith primary unit within the kth combination, and y_{ijk} as the number of Chinook salmon for the jth secondary unit within the ith primary unit within the kth combination. The total number of entrapped Chinook salmon in the ith primary unit is $y_{ik} = \sum_{j=1}^{M_{ik}} y_{ijk}$ and the total number of entrapped Chinook salmon in the kth combination is $\tau_k = \sum_{i=1}^{N_k} \sum_{j=1}^{M_{ik}} y_{ijk}$.

In terms of sampling from N_k and M_{ik} within the K combinations, we define n_k as the number of primary units selected, and m_{ik} as the number of secondary units sampled from the ith primary unit within the kth segment-sampling period combination. The estimate of the total number of Chinook salmon entrapped within the ith primary unit is $\hat{y}_{ik} = \frac{M_{ik}}{m_{ik}} \sum_{j=1}^{m_{ik}} y_{ijk}$. An unbiased estimate of the total number of Chinook salmon entrapped within the kth segment-sampling period combination is $\hat{\tau}_k = \frac{N_k}{n_k}\sum_{i=1}^{n_k}\hat{y}_{ik}$. The estimate of the total number of Chinook salmon entrapped across sections and sampling periods is $\hat{\tau}. = \sum_{k=1}^{64}\hat{\tau}_k$.

Under this sampling design, M_{ik} is the total number of entrapments created in the *i*th site within the *k*th segment-sampling period combination. Section 3.3.3 (above) describes the methods used to calculate the M_{ik}.

The goal of the entrapment sampling was to develop estimates of the total number of Chinook salmon entrapped in each of the 64 spatial-temporal strata. However, logistical constraints occasionally resulted in no entrapments sampled in some strata. When this occurred, the data from sampled segments were combined with adjacent unsampled segments, within sampling periods. Each aggregate consisted of at least two sampled sites.

3.3.5.1 Estimating Mortality due to Entrapment

Not all entrapments of Chinook salmon result in mortalities. Entrapments can become lethal if they drain or the water temperature rises above thermal limits. However, entrapments are not lethal if they reflood prior to reaching lethal conditions. Anglin et al. (2006) identified two candidate approaches for estimating the number of Chinook salmon killed as a result of entrapment: an entrapment lethality approach and a fish lethality approach. The entrapment lethality approach divides the number of entrapments that became lethal by the total number of entrapments sampled. The fish lethality approach divides the number of fish in lethal entrapments by the total number of fish sampled in entrapments.

Simulations implementing both approaches with the historical data were unbiased over repeated sampling. However, the entrapment lethality approach was much more precise. Using the coefficient of variation (CV) as a measure of precision, the CV for the fish lethality approach was typically 5–10 times the CV of the entrapment lethality approach (e.g., CV = 81% for the fish lethality approach versus CV = 13% for the entrapment lethality approach, sampling 50 entrapments). Because the entrapment lethality approach is unbiased and more precise than the fish lethality approach, the entrapment lethality approach was implemented for calculating mortality rates of entrapped fish in 2012.

Entrapment lethality was defined as an entrapment draining prior to re-flooding or water temperatures above 27°C. Entrapment lethality was estimated for each section (Upper, Middle, and Lower) and sampling period (eight 14-day sampling periods) combination. To estimate mortality due to entrapment, the entrapment lethality rates were applied to the corresponding estimates of entrapped fish to arrive at an estimate of the number of fish killed due to entrapment in 2012.

3.3.5.2 Quantifying Uncertainty in Entrapment and Entrapment Loss

Bootstrapping (Efron and Tibshirani 1993) was used to estimate the uncertainty in $\hat{\tau}.$ in a manner consistent with the two-stage sampling design and its estimators. For each of the K combinations, n_k^* primary units (sites) were randomly selected without replacement from the N_k primary units that were available within each segment. Then within each primary unit, m_{ik}^* secondary units (entrapments) were randomly selected with replacement from the m_{ik}

entrapments that were sampled. The resulting bootstrap data sets were then analyzed according to the equations above to calculate bootstrap estimates of $\hat{\tau}_k^*$ and $\hat{\tau}.^*$.

Research on entrapment in 2007 found that bootstrapping bias (Efron and Tibshirani 1993) was often present among the bootstrap samples. To quantify and correct for bootstrapping bias, we ran 30,000 bootstrap samples for each of the eight sampling periods and subtracted the mean of the bootstrap samples from the eight, period-specific estimates. These estimates of bootstrapping bias were then incorporated into the bootstrap algorithm to produce bias-corrected bootstrap entrapment estimates. Levels of bootstrap bias were similarly estimated for the entrapment loss estimates to produce bias-corrected bootstrap entrapment loss estimates.

The bias-corrected bootstrap process was repeated 10,000 times to generate a distribution of bootstrap estimates of $\hat{\tau}.^*$, with the 2.5th and 97.5th percentiles of the ordered values representing the bounds on the 95% bootstrap percentile confidence interval.

4.0 Results

The 2012 river flow conditions, field summaries for stranding and entrapment, and detailed results for the stranding and entrapment assessments are presented in this section of the report.

4.1 2012 Flow Conditions

Due to an above average snow pack and wet spring, outflows from Priest Rapids Dam were above average throughout the spring operational period of the HRFCPPA in 2012. Mean hourly discharge from Priest Rapids Dam between March 9 and June 22, 2012, was 200.5 kcfs and mean daily flow fluctuation was 76.3 kcfs (Table 6). Flows during 2007, 2011, and 2012 were all considered high flow years but experienced very different flow patterns, peaking and waning at different times. Maximum daily discharge was highest in 2011 (378 kcfs); however, the mean daily discharge and fluctuation were greater in 2012 (Table 6; Figure 10).

The impact of these flow regime changes on emergent and rearing fry is unknown. In general, fluctuations occurring at higher elevations tend to dewater less shoreline than fluctuations at lower elevations due to channel bathymetry. Thus the impacts are expected to decrease as elevation increases. Based on this relationship, the HRFCPPA allows larger daily deltas (fluctuations) at higher mean flows.

Table 6 Mean, minimum, and maximum hourly discharge (kcfs) including daily fluctuation from Priest Rapids Dam, March 9 – June 22, 2012.

	Mean Daily Discharge (kcfs)	Mean Maximum Daily Discharge	Mean Minimum Daily Discharge	Mean Daily Discharge Delta
March	125.6	150.5	104.7	45.8
April	184.5	216.7	158.3	58.3
May	233.8	285.9	188.4	97.5
June	258.0	307.8	204.1	103.7
Mean	**200.5**	**240.2**	**163.9**	**76.3**

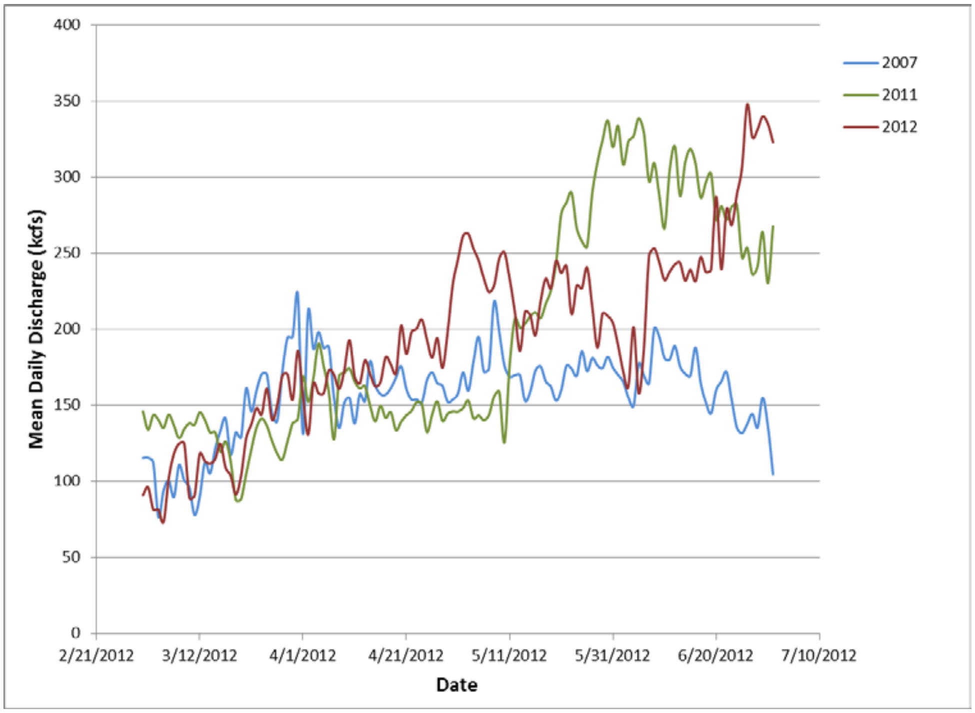


Figure 10 Average daily outflow (kcfs) downstream of Priest Rapids Dam, 2007, 2011, and 2012.

4.2 Stranding

The following sections summarize results related to stranding field data, sampling efficiency, and data analysis regarding the estimation of losses due to stranding.

4.2.1 Field Data Summary

The stranding field crew visited 189 quadrants between March 9 and June 22, 2012. Of these, 25 quadrants did not have sufficient fluctuation (wetted shoreline area) to adequately assess stranding impacts. Seven quadrants could not be sampled due to dense vegetation at the site, or could not be safely approached by boat. At the remaining 157 quadrants, 873 plots were sampled. The standard plot area was 78.54 m^2 (10-m-diameter circular plot) and the mean plot area was 70.4 m^2. As noted in Section 3.2.1, an effort was made to survey area that was within a sample plot, but above the wetted line; dry and wet areas were recorded separately. The total area surveyed was 61,465 m^2, of which 12,374 m^2 was dry. No Chinook salmon were found in the dry area, and based on that finding, which confirmed that the sampling method used in 2011 was appropriate, only the wet sampling area was considered in the stranding loss data analysis and estimate. A total wet area of 49,092 m^2 (Table 7) was sampled. A total of 67 juvenile fall Chinook salmon were recovered from the 873 sampled plots (Table 8). The highest numbers of fall Chinook salmon were recovered in the Middle section of the Hanford Reach (segments 3–6; Table 8). Sampling effort, numbers of plots sampled, and area sampled were relatively evenly distributed among the three sections, although a somewhat higher percentage of samples was collected in the Upper reach, which is most heavily affected by flow fluctuations at the dam. Many flow fluctuations that affect the Upper section are attenuated before reaching the Middle and Lower sections.

Table 7 Summary of sampling data collected by segment during the fall Chinook salmon stranding evaluation in the Hanford Reach, March 9 – June 22, 2012.

Section	Segment	Transects Visited	Plots Sampled		Plots (#)	Wet Area Sampled (m^2)	Chinook (#)
			No	Yes			
Upper	1	56	8	48	256	15,333	15
Upper	2	35	3	32	143	8,964	13
Middle	3	25	4	21	130	7,637	14
Middle	4	17	5	12	74	4,209	2
Middle	5	8	1	7	39	2,017	3
Middle	6	5	1	4	21	993	14
Lower	7	27	6	21	138	6,370	5
Lower	8	16	4	12	72	3,569	1
	Total	**189**	**32**	**157**	**873**	**49,092**	**67**

Table 8 Summary of sampling data collected by reach during the fall Chinook salmon stranding evaluation, March 9 – June 22, 2012.

Segment	Quadrants Visited	Plots Sampled		Plots (#)	Wet Area Sampled (m^2)	Chinook (#)
		No	Yes			
Upper	91	11	80	399	24,297	28
Middle	55	11	44	264	14,856	33
Lower	43	10	33	210	9,939	6
Total	**189**	**32**	**157**	**873**	**49,092**	**67**

4.2.2 Sampling Efficiency

Twelve sampling efficiency evaluations were conducted during the 2012 season. Four efficiency evaluations were completed in 2011 and the results very similar for both years. During 2012, a total of 24 fish were marked and placed within sample plots for possible recapture. Sampling efficiency plots were selected based on the four categories of vegetation: none, sparse, moderate, or dense. As vegetation density increased (e.g., Figure 11), the sampling efficiency decreased (Table 9). In total, 67% of the marked fish were recaptured in 2012 and sampling efficiency ranged from 38% to 100% (Table 9).

Figure 11 Example of fall Chinook salmon fry observed lying in dense vegetation in the Hanford Reach.

Table 9 2012 results of stranding efficiency tests by vegetation density category.

Vegetation	Mark-Release (#)	Mark-Recapture (#)	Efficiency (%)
1 - None	7	5	71.4
2 - Light	1	1	100
3 - Moderate	8	7	87.5
4 - Dense	8	3	37.5
Total	**24**	**16**	**66.7**

4.2.3 Data Analysis – Stranding Loss Estimate

4.2.3.1 Dewatered Area

MASS2 was used to estimate the amount of dewatered area in each spatial-temporal stratum (Figure 12). A total of 277 million square meters was dewatered over the course of the sampling season and most of this dewatered area occurred in the upper portion of the Hanford Reach during the second half of the season. This was greater than the dewatered area of 195 million square meters observed in 2011 (Hoffarth et al. 2012).

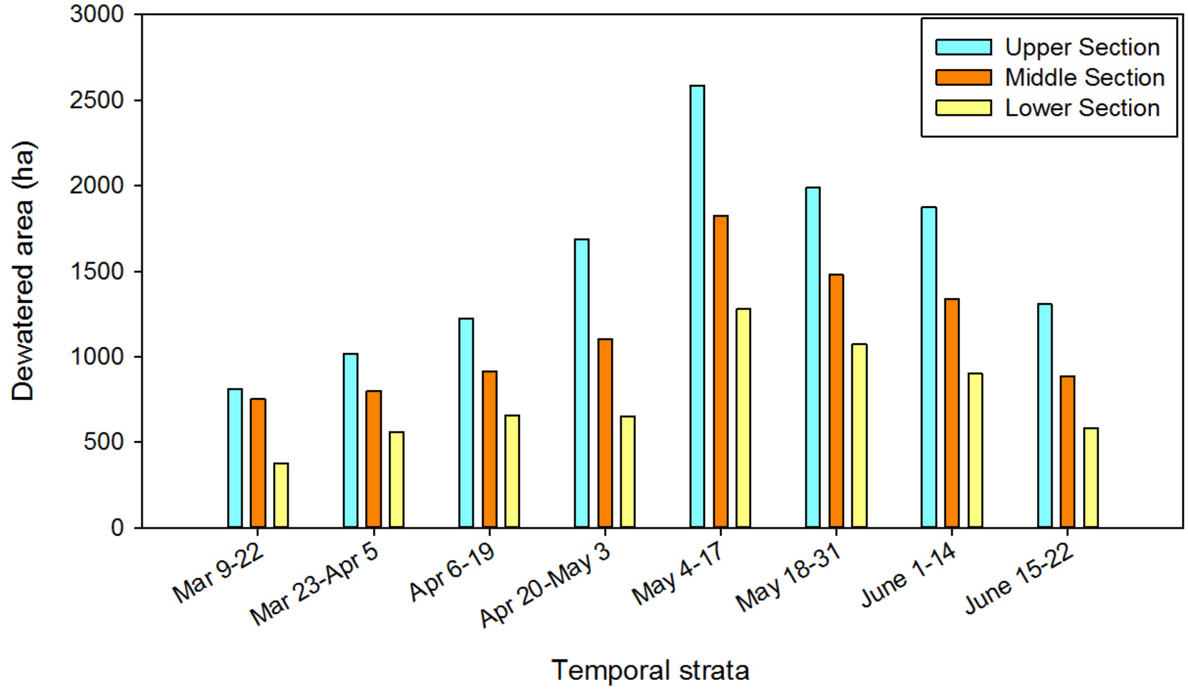


Figure 12 **Dewatered area estimates for the Hanford Reach from the MASS2 model by section and sampling period. It is estimated that a total of 276,673,945 m^2 was dewatered during 2012.**

4.2.3.2 Estimation of Stranding Loss

Section 4.2.1 of this report summarizes the results of the field sampling of stranded juvenile fall Chinook salmon. The summary of the number of stranded Chinook salmon found in each strata are shown in Table 10. This shows that most of the stranded Chinook salmon were found in the Upper and Middle sections of the Hanford Reach. In the Upper section, stranding was more evenly distributed over time, while in the Middle section almost all stranding occurred in periods 4 and 5, which corresponds to April 20–May 17. Using the field stranding data and the dewatered area modeling results, we generated 10,000 bootstrap estimates of the stranding loss for each spatial-temporal stratum. By aggregating the strata for each bootstrap replicate, we generated 10,000 estimates of the total loss due to stranding in the Hanford Reach (Figure 13).

Table 10 **Field sampling data showing stranded Chinook salmon found for each strata (time period and section) for the Hanford Reach. Sampling periods for the strata are given in Figure 13.**

	Sampling period								
Section	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
Upper	1	2	4	2	8	3	5	3	**28**
Middle	0	0	2	17	13	0	1	0	**33**
Lower	0	0	0	0	5	0	1	0	**6**
Total	**1**	**2**	**6**	**19**	**26**	**3**	**7**	**3**	**67**

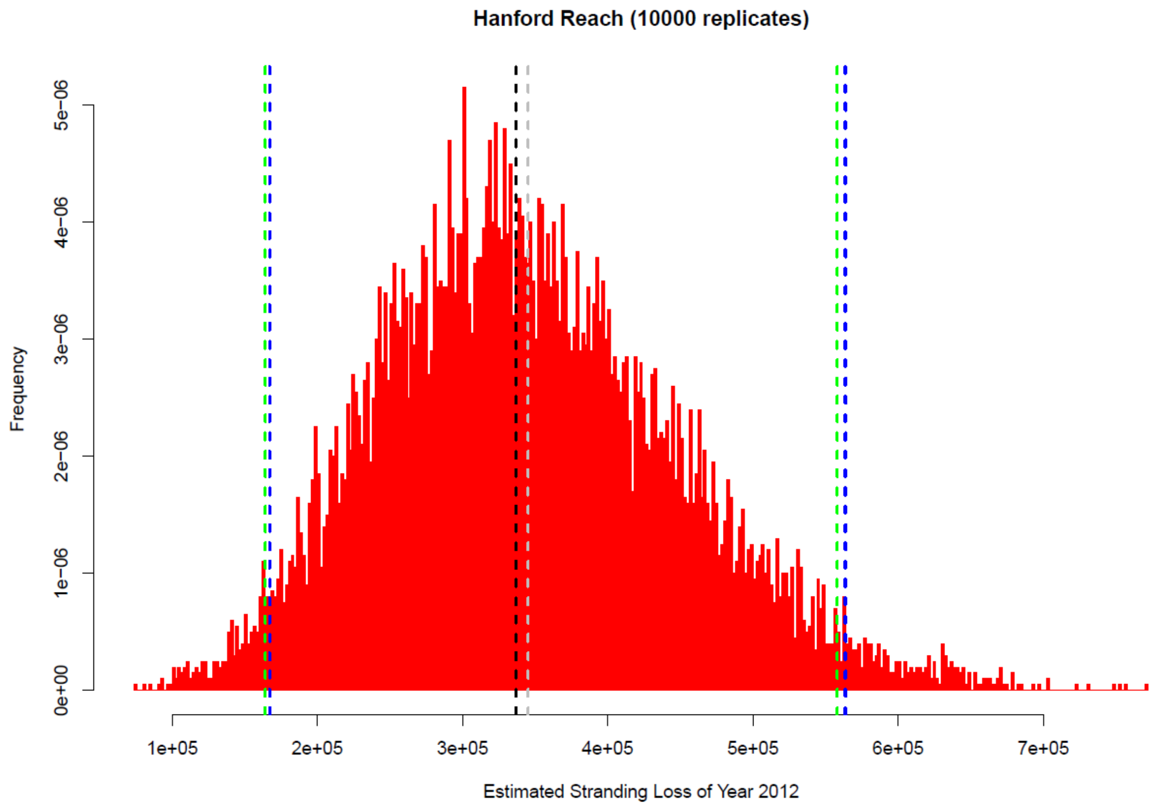


Figure 13 Histogram of bootstrap replicates of total juvenile fall Chinook salmon stranding loss in the Hanford Reach. Blue dashed lines represent a 95% probability interval; green lines indicate a bias corrected 95% probability interval. The gray dashed line represents the mean loss estimate (345,208), the black dashed line represents the median (336,883).

The mean loss estimate for the Hanford Reach as a whole is 345,208 juvenile fall Chinook salmon, with a bias-corrected 95% probability interval extending from 164,156 to 558,073 (Table 11). The largest loss for any one stratum occurred during the period from May 4 through May 17, and was focused in the Middle section of the Hanford Reach, similar to that found by previous investigators (McMichael et al. 2003; Anglin et al. 2006). However, unlike previous years, the largest overall loss occurred in the Upper section of the Reach (Table 11).

No stranded fish were found within sampling plots in 10 of 24 of the spatial-temporal strata, leading to zero estimates for those strata during the bootstrap estimation process. However, Chinook salmon were known to be present in the Hanford Reach during those time periods. Therefore, an alternative estimate of stranding loss was prepared by aggregating strata so that at least one non-zero Chinook salmon sample was included in each of the combined strata. The combination process resulted in the delineation of 14 aggregate strata, including 4 that spanned the entire Hanford Reach (Table 12).

Table 11 Summary of bootstrap stranding loss estimates of juvenile fall Chinook salmon for the entire Hanford Reach, broken out for each two week time period, and for the Upper, Middle, and Lower sections of the Hanford Reach.

	Mean	Mean (BC)	Percentile LL	Percentile UL	LL (BC)	UL (BC)
Hanford Reach (total)	**345,208**	**323,496**	**167,292**	**563,711**	**164,156**	**558,073**
Mar 9–Mar 22	3,700	3,849	0	16,052	0	20,973
Mar 23–Apr 5	7,704	7,409	0	25,553	0	29,436
Apr 6–Apr 19	45,563	43,691	1,890	113,824	5,012	125,104
Apr 20–May 3	62,903	46,247	6,126	162,633	5,972	160,869
May 4–May 17	176,427	177,350	40,159	356,628	48,798	377,368
May 18–May 31	5,117	4,400	0	14,975	0	16,110
Jun 1–Jun 14	21,490	19,759	0	64,912	0	74,496
Jun 15–Jun 22	22,303	20,791	0	82,880	0	108,205
Upper Section	171,551	158,906	63,626	315,847	63,007	314,533
Middle Section	128,681	116,394	20,751	292,624	22,363	300,431
Lower Section	44,976	48,196	0	113,950	0	123,503

BC indicates bias corrected; LL is lower 95% probability limit; UL is upper 95% probability limit.

Table 12 Combined strata formed from aggregation of individual strata.

Strata	Sampling Periods	Hanford Reach Sections Included
1	Mar 9 – Mar 22	All sections of Hanford Reach
2	Mar 23 – Apr 5	All sections of Hanford Reach
3	Apr 6 – Apr 19	Upper section
4	Apr 6 – Apr 19	Middle and Lower sections
5	Apr 20 – May 3	Upper section
6	Apr 20 – May 3	Middle and Lower sections
7	May 4 – May 17	Upper section
8	May 4 – May 17	Middle section
9	May 4 – May 17	Lower section
10	May 18 – May 31	All sections of Hanford Reach
11	Jun 1 – Jun 14	Upper section
12	Jun 1 – Jun 14	Middle section
13	Jun 1 – Jun 14	Lower section
14	Jun 15 – Jun 22	All sections of Hanford Reach

An alternative estimate of the stranding loss in the Hanford Reach was generated using 10,000 bootstrap samples of the combined strata identified in Table 12 (Figure 14 and Table 13). By ensuring non-zero mean estimates for all strata, the mean estimate for the Hanford Reach was higher for the combined strata, at 370,103, versus 345,208 for the mean estimate for the individual strata. All other statistics from the bootstrap samples were also higher for the combined strata (Table 13).

Table 13 Summary of bootstrap stranding loss estimates of juvenile fall Chinook salmon for the entire Hanford Reach, and broken out for each of the combined strata, based on 10,000 bootstrap samples.

Bootstrap Estimate	Mean	Median	Mean (BC)	Percentile LL	Percentile UL	LL (BC)	UL (BC)
Hanford Reach (total)	**370,103**	**362,386**	**354,645**	**180,258**	**601,685**	**180,206**	**601,625**
Mar 9–Mar 22_sec123	3,148	0	3,111	0	14,373	0	19,716
Mar 23–Apr 5_sec123	10,879	8,567	11,270	0	36,404	0	43,947
Apr 6–Apr 19_sec1	38,265	33,316	37,385	0	104,259	0	117,850
Apr 6–Apr 19_sec23	10,605	7,970	10,604	0	37,602	0	47,565
Apr 20–May 3_sec1	35,423	25,622	25,271	0	125,829	0	142,301
Apr 20–May 3_sec23	34,109	29,321	29,247	0	96,245	0	105,280
May 4–May 17_sec1	45,282	40,949	50,098	0	119,579	2,632	136,688
May 4–May 17_sec2	86,120	76,326	82,109	0	246,350	0	264,704
May 4–May 17_sec3	42,576	39,327	47,594	0	111,693	0	122,983
May 18–May 31_sec123	7,842	6,748	7,329	0	23,327	0	26,285
Jun 1–Jun 14_sec1	12,212	8,198	11,250	0	50,727	0	65,703
Jun 1–Jun 14_sec2	7,741	6,707	7,044	0	33,895	0	43,131
Jun 1–Jun 14_sec3	1,468	954	1,534	0	7,116	0	10,512
Jun 15–Jun 22_sec123	34,434	24,648	30,799	0	134,224	0	180,112

BC indicates bias corrected; LL is lower 95% probability limit; UL is upper 95% probability limit.

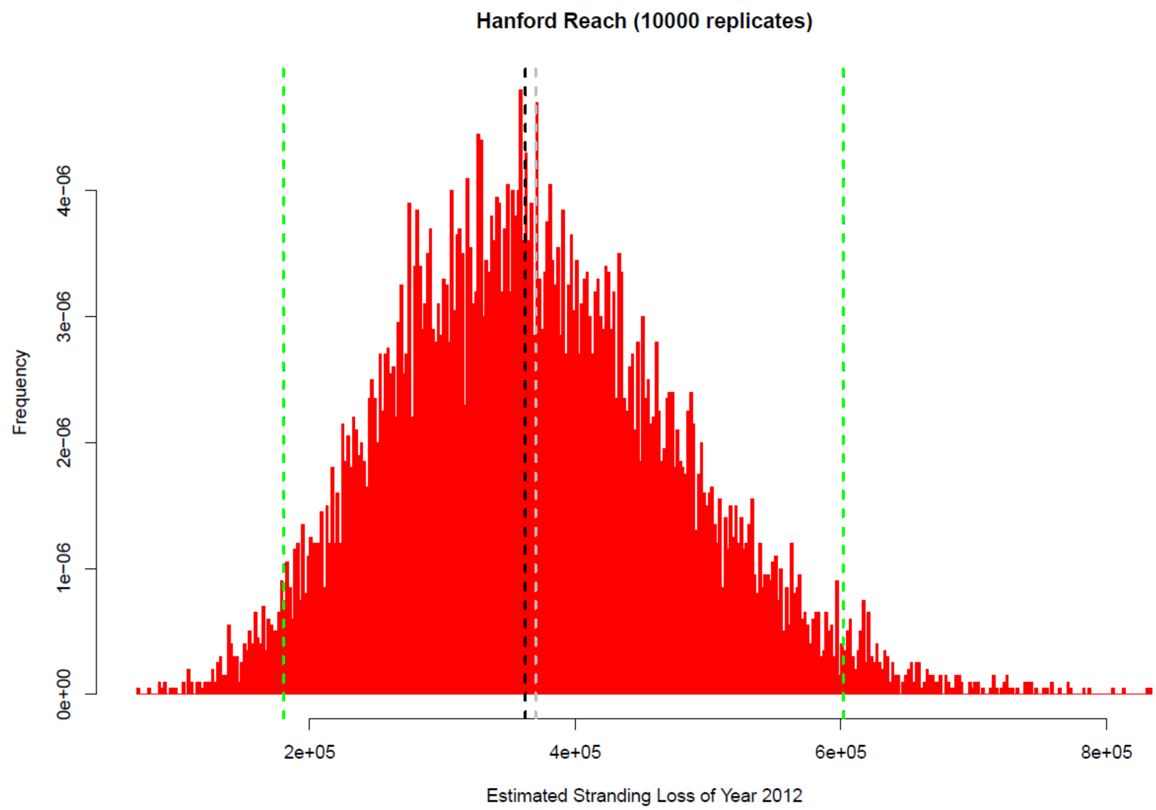


Figure 14 Histogram of bootstrap replicates of total stranding loss of juvenile fall Chinook salmon in the Hanford Reach for the combined strata identified in Table 12. Blue dashed lines represent a 95% probability interval; the green lines indicate a bias corrected 95% probability interval. The gray dashed line represents the mean loss estimate (370,103); the black dashed line represents the median (362,386).

For comparison with the bootstrap estimates, a simpler estimate of the stranding loss can be made using the stranding data and the dewatered area and assuming simple random sampling over the entire Hanford Reach. The 67 stranded Chinook salmon were sampled from an area of 49,092 m^2 (Table 7), giving an estimate of 0.0014 stranded Chinook salmon per square meter. Applying that estimate to the total dewatered area of 276,673,945 m^2 (Figure 12), gives an estimated loss of 377,603 stranded Chinook salmon over the sampling period, which is slightly higher than the uncorrected mean estimate for the combined strata of 370,103 (Table 13).

4.3 Entrapment

The following sections summarize results related to entrapment field data, sampling efficiency, and the estimation of losses via entrapment.

4.3.1 Field Data Summary

Between March 9 and June 22, 2012, field crews conducted entrapment sampling at 644 sites (i.e., 1,288 quadrants) in the Hanford Reach (Table 14). The sampling season lasted a total of 106 days and field crews located entrapments and collect entrapment data on 94 days within the sampling season. Within 318 of the 665 sites (48%) selected by the model, either water-level fluctuations were not sufficient to create entrapments or no entrapments were present. Field crews visited 307 of the 360 quadrants (85%) during the 2012 season, with an average of 13.7 quadrants visited per day. The 53 quadrants not sampled at all during the season were distributed throughout the seven lower river segments (Table 15).

Table 14 Summary of entrapment sampling by segment in the Hanford Reach, 2012.

Segment	Sites Visited	Entrapments Present		% of Sites Sampled	Entrapments Sampled	Mean # Entrapments per site	Entrapments with Chinook	% Entrapments with Chinook
		Yes	No					
1	158	102	56	65%	348	2.2	36	10%
2	119	72	47	61%	295	2.5	20	7%
3	65	39	26	60%	154	2.4	20	13%
4	44	22	22	50%	86	2.0	12	14%
5	40	17	23	42%	87	2.2	10	11%
6	39	17	22	44%	73	1.9	4	5%
7	114	58	56	51%	274	2.4	15	5%
8	65	12	53	18%	61	0.9	3	5%
Total	**644**	**339**	**305**	**53%**	**1,378**	**2.1**	**120**	**9%**

Table 15 Distribution of quadrants visited and not visited during the 2012 stranding and entrapment program, Hanford Reach, 2012.

Segment	# Quadrants not Visited	# Quadrants Available	% Quadrants Visited
1	0	60	100.0
2	6	60	90.0
3	5	40	87.5
4	3	28	89.3
5	9	28	67.9
6	4	24	83.3
7	16	68	76.5
8	10	52	80.8
Total	**53**	**360**	**85.3**

A total of 1378 entrapments were sampled from the 339 selected sites (Table 14). Entrapments ranged in size from 1 m to >100 m in diameter and a depth of zero (drained) centimeters to 94 cm deep. The mean area of entrapments sampled was 38.3 m^2 with a mean maximum depth of 10.4 cm. Entrapments were categorized into four size groups based on their maximum diameter: 1–5 m, 5–15 m, >15 m, and not sampled ([NS], i.e., too large or deep to effectively sample). Measurements were taken at the time of arrival, for size classification and initial size at the time of separation from the main channel was estimated. The majority of those sampled were in the 1- to 5-m-diameter category (865, 63%) (Table 16). Only 19 entrapments (1%) encountered were determined to be too large or deep to effectively sample. Chinook salmon were found in 120 (9%) of the sampled entrapments (Table 14).

Table 16 **Summary of entrapment size and distribution based on size at arrival, Hanford Reach, 2012.**

Segment	1−5 m	5−15 m	>15 m	>15 m (NS)	NA
1	272	63	11	2	NA
2	176	102	15	2	NA
3	100	43	10	1	NA
4	49	22	14	1	NA
5	37	33	11	6	NA
6	43	21	9	NA	NA
7	151	90	26	6	1
8	37	19	4	1	NA
Total	**865**	**393**	**100**	**19**	**1**
% of Total	**63%**	**29%**	**7%**	**1%**	**0%**

NA = not applicable; NS = not sampled.

Vegetation density was recorded for each entrapment sampled in the Hanford Reach. Vegetation was recorded as

- Type 1) None
- Type 2) Sparse
- Type 3) Moderate (e.g., Figure 15)
- Type 4) Extremely dense grass, brush, trees or a combination of all three.
- Type 5) Vegetation too dense to accurately sample.

Figure 15 **Entrapments formed above the usual high water mark in the Hanford Reach in 2011.**

Table 17 Summary of vegetation density and entrapments containing Chinook salmon in the Hanford Reach, 2012.

Vegetation Density	Total Chinook	% Total	# Live	# Dead	% Live	Total Entrapments	Entrapments with Chinook #	Entrapments with Chinook %
1	2,224	48%	2,178	46	98%	436	39	9%
2	1,012	22%	969	43	96%	345	27	8%
3	1,178	26%	1,134	44	96%	232	28	12%
4	197	4%	99	98	50%	318	26	8%
5 (NS)	0	0%	0	0	NA	42	NA	NA
NA	0	0%	0	0	NA	5	NA	NA
Total	**4,611**	**100%**	**4,380**	**231**	**95%**	**1,378**	**120**	**9%**

NA = not applicable; NS = not sampled.

Field crews attempted to recover all fish present in entrapments during sampling. Recovery of fish was inherently difficult because detection rates were low even when fish were present. Obstacles to live fish capture include substrate embeddedness, vegetation, and entrapment size. Mortality caused by entrapment is difficult to assess within the Hanford Reach. With receding water, fish tend to migrate downward through large, loosely aggregated cobble, requiring excavation of the site to locate fish. On fine particulate substrates, fish are exposed to predators and are often quickly preyed upon. In 2011 and 2012, flows through the Hanford Reach were the highest encountered compared to any year these evaluations have been conducted. At these higher river elevations fall Chinook salmon rearing habitat was displaced to areas of heavy vegetation located above the normal high-water line. Because of the problems with detection of stranded and entrapped fish in these habitats, the estimates of stranding and entrapment impacts are likely biased low.

Beach seines, backpack electrofishing equipment, and dip nets were used to sample entrapments for fish (Figure 16). Sampling method was greatly influenced by habitat characteristics. Table 18 illustrates the number of times each sample method was used based on entrapment size and vegetation density. Three major observations were noted during field sampling: 1) small entrapments <5 m^2 tended also to be shallow and easy to visually inspect for live and dead fish; 2) dense vegetation limited the effectiveness of seining by lifting the lead line off the bottom, allowing fish to escape; and 3) extremely shallow entrapments with loosely aggregated rock restricted the effectiveness of electrofishers. Training for crew members and crew supervisors was conducted on March 8 to provide guidance on sample method selection based on the habitat characteristics present.

Figure 16 Seining a large entrapment for fall Chinook salmon fry in the Hanford Reach.

Table 18 Summary of habitat classification and sampling method frequency, Hanford Reach, 2012.

Habitat	Habitat Classification	# Occurrences				
		Not Sampled	Seine	Shock	Visual	Total
Entrapment Size	1–5	20	0	59	786	**865**
	5–15	15	4	65	309	**393**
	>15	4	9	21	66	**100**
	>15 (NS)	19	0	0	0	**19**
	NA	0	0	0	1	**1**
Vegetation Density	1	4	8	51	373	**436**
	2	3	2	39	301	**345**
	3	2	3	31	196	**232**
	4	7	0	24	287	**318**
	5 (NS)	42	0	0	0	**42**
	NA	0	0	0	5	**5**

NA = not applicable; NS = not sampled.

The Hanford Reach was divided into three primary sections: Upper, Middle, and Lower, as in previous years. The three sections were further divided into eight river segments because the river stage variation associated with the unsteady flow hydrograph is relatively consistent within each of the eight segments. Of the 1,378 entrapments sampled, 120 contained Chinook salmon (9%). The mean number of entrapments per site was 2.1, indicating a relatively low number of entrapments present in quadrants sampled during 2012. A total of 4,611 juvenile fall Chinook salmon were recovered in entrapments with 95% collected alive. Fall Chinook salmon were found in 5% of entrapments in the Lower section, 12% in the Middle section, and 9% in the Upper section. (Table 19). Entrapments in the Lower section produced the highest number of Chinook salmon with nearly 6.5 fish per entrapment (Table 19). This number was inflated by the small number of entrapments being sampled and a single event which entrapped a total of 2,008 fall Chinook salmon. Entrapments containing Chinook salmon occurred more frequently in the Upper and Lower sections of the Reach early in the field season.

Table 19 Summary or entrapment sampling and Chinook salmon presence by river section, Hanford Reach, 2012.

River Section	Sites Visited	Entrapments Present			Entrapments Sampled	Mean # Entrapments per site	Entrapments with Chinook		# Chinook	Chinook per Entrapment
		Yes	No	%			#	%		
Upper	277	174	103	63%	643	2.3	56	9%	837	1.30
Middle	188	95	93	51%	400	2.1	46	12%	1,605	4.01
Lower	179	70	109	39%	335	1.9	18	5%	2,169	6.47
Total	**644**	**339**	**305**	**53%**	**1,378**	**2.1**	**120**	**9%**	**4,611**	**3.35**

Fork length was measured for fall Chinook salmon found in entrapments on 28 days throughout the 2012 field season. Mean fork length was near 40 mm throughout the first seven temporal strata (Figure 17). During the last week of sampling, mean fork length increased to 53 mm but susceptibility decreased dramatically and only three Chinook salmon were sampled during this period. This is consistent with previous monitoring and it is expected that the length and presumably mobility of juvenile fall Chinook salmon greatly affects their susceptibility to becoming entrapped.

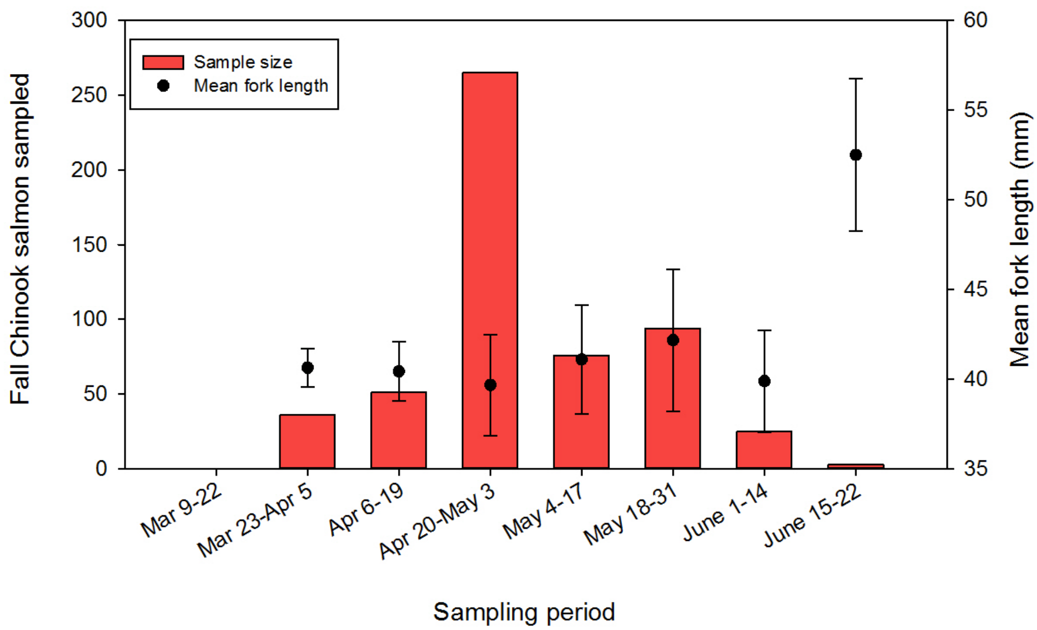


Figure 17 Mean fork length and standard deviation of entrapped fall Chinook March 9 – June 22, 2012, Hanford Reach.

Chinook salmon presence and fate in entrapments is highly dependent on entrapment size; larger entrapments hold more live and fewer dead fish. Eighteen percent of the entrapments >15 m in diameter contained fall Chinook salmon, while only 8% of entrapments that were 1–5 m in diameter contained Chinook salmon. In addition to a higher occurrence rate of fall Chinook salmon, larger populations also were present; 90% of the live fall Chinook salmon sampled in 2012 came from entrapments that were >15 m in diameter. Large entrapments had less mortality caused by dewatering (as time needed to drain increased, so did the likelihood of re-flooding) and thermal lethality was decreased (thermal buffering properties of water). The ratio of live to dead Chinook salmon increased substantially with increased entrapment size (Table 20).

Table 20 Summary of entrapment sampling and fish frequency based on entrapment size estimate upon separation from the main channel, Hanford Reach, 2012.

Entrapment Size	# Entrapments	Entrapments with Chinook	% Entrapments with Chinook	# Chinook Collected		Live:Dead Ratio	# Chinook Total
				Live	Dead		
1–5	865	58	7%	186	150	1.2:1	336
5–15	393	44	11%	268	56	4.8:1	324
>15	100	18	18%	3,926	25	157:1	3,951
>15 NS	19	NA	N/	NA	NA	NA	NA
NA	1	NA	NA	NA	NA	NA	NA

NA = not applicable; NS = not sampled.

Although the majority of juvenile fish encountered in entrapments were fall Chinook salmon, 361 individuals of other species were also recovered. Three-spined sticklebacks (*Gasterosteus aculeatus*), northern pikeminnow (*Ptychocheilus oregonensis*), and Sculpin (*Cottus spp.*) were the most common (Table 21). A large number of unidentified larval juvenile fish were observed and noted on datasheets, but not tallied and no attempt was made to identify them to species. Biological data were not collected and sampling efficiency estimates were not conducted for non-target species.

Table 21 Summary of non-salmon incidental catch in the Hanford Reach, 2012.

Segment	STB	COT	NPM	SUK	RSS	DACE	SMB	PM	SOC	WF
1	5	18	0	0	1	0	0	0	1	0
2	8	18	8	22	7	2	0	0	0	0
3	4	29	1	3	3	1	0	0	0	0
4	55	10	71	23	5	5	0	0	0	0
5	1	0	0	0	1	0	3	1	0	0
6	1	2	0	0	0	0	0	0	0	0
7	38	4	3	1	7	0	1	0	0	0
8	2	0	0	0	0	0	0	0	0	1
Total	**114**	**81**	**83**	**49**	**24**	**8**	**4**	**1**	**1**	**1**

Species codes are STB (three-spined stickleback), COT (sculpin species), NPM (northern pikeminnow), SUK (sucker species), RSS (Red side shiner), DACE (dace species), SMB (smallmouth bass), PM (peamouth), SOC (sockeye), WF (mountain whitefish).

Field crews collected data at each entrapment to estimate direct and potential mortality to fall Chinook salmon resulting from entrapment. Of the overall total of 1,378 entrapments sampled, 36% of the entrapments drained, 12% reached lethal water temperature (>27°C) for Chinook salmon fry, 5% re-flooded prior to draining as the river elevations rose, and for 47% of the entrapments fates could not be determined in the field (Table 22). Post-season fate determination indicated that 18% of the sampled entrapments were reflooded and 82% were lethal. Fall Chinook salmon were confirmed present in 120 entrapments and 38% of them drained, 5% reached lethal water temperatures, 14% re-flooded prior to draining as the river elevations rose, and for 42% of the entrapments, fates could not be determined from field sampling. Post-season fate determination indicated that 34% of the entrapments with fall Chinook salmon present were reflooded and 66% were lethal. On average, Chinook salmon were recovered in entrapments that had nearly double the surface area (70.0 vs. 38.3 m^2) and depth (24.0 vs. 12.8 cm) of other entrapments sampled during this field season.

Table 22 Summary of final and initial fate determinations for entrapments that were sampled in the Hanford Reach, 2012. In season fate determinations were based on in situ observations and post-season determinations were modeled for all others.

	In-Season Fate Determination					Post-Season Fate Determination (%)	
Segment	**Dewatered**	**Temp (>27°C)**	**Reflooded**	**Unknown**	**Total**	**Lethal**	**Reflooded**
1	135	23	24	166	348	87.1	12.9
2	59	28	9	199	295	80.0	20.0
3	72	27	7	48	154	89.0	11.0
4	32	8	4	42	86	82.6	17.4
5	40	14	8	25	87	81.6	18.4
6	30	9	2	32	73	80.8	19.2
7	101	56	17	100	274	78.8	21.2
8	27	1	2	31	61	70.5	29.5
Total	**496**	**166**	**73**	**643**	**1,378**		
Percent of total	36	12	5	47		82	18
Entrapments w/fish	**47**	**6**	**17**	**50**	**120**		
Percent of total	9	4	23	8	9	66	34

4.3.2 Entrapment Sampling Efficiency

Although crews attempted to recover all fish present in entrapments, fish entrapped in depressions within the Hanford Reach are often inherently difficult to find (i.e., detection is low even when fish are present). Entrapped fish are exposed to predators and are often quickly preyed upon (Figure 18). In 2011 and 2012, flows through the Hanford Reach were higher compared to previous study years. At these higher river elevations, fall Chinook salmon rearing habitat is displaced to areas of heavy vegetation located above the normal high-water line. Thus, detection of stranded and entrapped fish may have been reduced and the estimates of stranding and entrapment impacts may have been biased low.

Figure 18 Egrets preying on fish in entrapments in the Hanford Reach.

Assessments were completed at 42 entrapments containing fall Chinook salmon during the 2012 field season to determine sampling efficiency for each of the capture methods (seining and backpack electrofishing) used during this study. Fish were collected 10 times using a beach seine and 9 mark-recapture efficiencies were completed to assess the collection efficiency. Backpack electrofishing was more effective on small, shallow entrapments, and was used more frequently. Electrofishing entrapments successfully captured fall Chinook salmon 51 times, and 33 mark-recaptures were conducted. Mark-recapture efficiency was greater than 64% for both methods based on the total number of marked Chinook salmon recovered. Beach seining in entrapments 5- to 15-m in diameter exhibited a 98% mark-recapture efficiency, but it was 64% when the diameter was greater 15 m (Table 23). Backpack electrofishing collection efficiency also decreased as entrapment size increased. In entrapments 1- to 5-m in diameter the mark-recapture efficiency was 80% for backpack electrofishing, but fell to 62% when the diameter was greater than 15 m (Table 23). Fall Chinook salmon are able to evade capture easier in large entrapments regardless of the sampling method. Vegetation, substrate embeddedness, and substrate size are not as positively correlated with changes in sampling efficiency as entrapment size. However, in general, sampling efficiency declines with increases in vegetation density (Table 23).

Table 23 Evaluation of field collection efficiencies of Juvenile fall Chinook salmon for visual observation, backpack electrofishing (Shock), and beach seining (Seine) in the Hanford Reach, 2012.

		Seine				Shock			
Habitat	**Habitat Classification**	**# Mark Released**	**# Mark Recapture**	**# UM Recapture**	**Mark-Recap Efficiency**	**# Mark Released**	**# Mark Recapture**	**# UM Recapture**	**Mark-Recap Efficiency**
Entrapment Size	1–5					94	75	36	80%
	5–15	45	44	0	98%	121	81	61	67%

	>15	1,070	682	1,182	64%	91	56	38	62%
	Total	**1,115**	**726**	**1,182**	**65%**	**306**	**212**	**135**	**69%**
Vegetation Density	1	271	142	940	52%	66	38	29	58%
	2	345	310	191	90%	172	115	94	67%
	3	499	260	51	52%	58	51	10	88%
	4					10	8	2	80%
	Total	**1,115**	**712**	**1,182**	**31%**	**306**	**212**	**135**	**69%**

4.3.3 Entrapment Loss Estimate

A total of 257,689 entrapments were estimated to have been created during the 2012 sampling season (Table 24). The highest numbers of entrapments were created in the Upper section of the Reach (117,073), with lower numbers created in the Middle (89,985) and Lower (50,631) sections (Figure 19). Across the sampling season, sampling period one (March 9–22) had the fewest entrapments created (17,358) and period five (May 14–17) had the highest number created (52,646). The other strata generally had 20,000 to 40,000 entrapments created per period.

Table 24 Total number of entrapments created by temporal strata and river section, 2012.

	Sampling Period								
Section	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
Upper	8,910	9,638	9,728	15,884	24,283	18,654	17,619	12,357	**117,073**
Middle	5,601	8,208	10,596	11,036	17,882	14,935	13,349	8,378	**89,985**
Lower	3,027	5,141	5,499	5,379	10,480	8,761	7,567	4,776	**50,631**
Total	**17,538**	**22,987**	**25,823**	**32,300**	**52,646**	**42,349**	**38,535**	**25,511**	**257,689**

The number of Chinook salmon per entrapment varied by river section and temporal strata (Table 25). Few Chinook salmon were found during the last sampling period in any of the river sections. The highest number of Chinook salmon per entrapment (108.0) occurred during the sixth period (May 18–31) in the Lower section. The Lower section during period four (April 20–May 3) and the Middle section during period seven (June 1–14) also had relatively high numbers of Chinook salmon per entrapment, with 15.0 and 19.1 Chinook salmon per entrapment, respectively. The Middle section had the highest mean Chinook salmon per entrapment during four of the eight sampling periods, while the Upper and Lower sections each had the highest means during two of the eight periods.

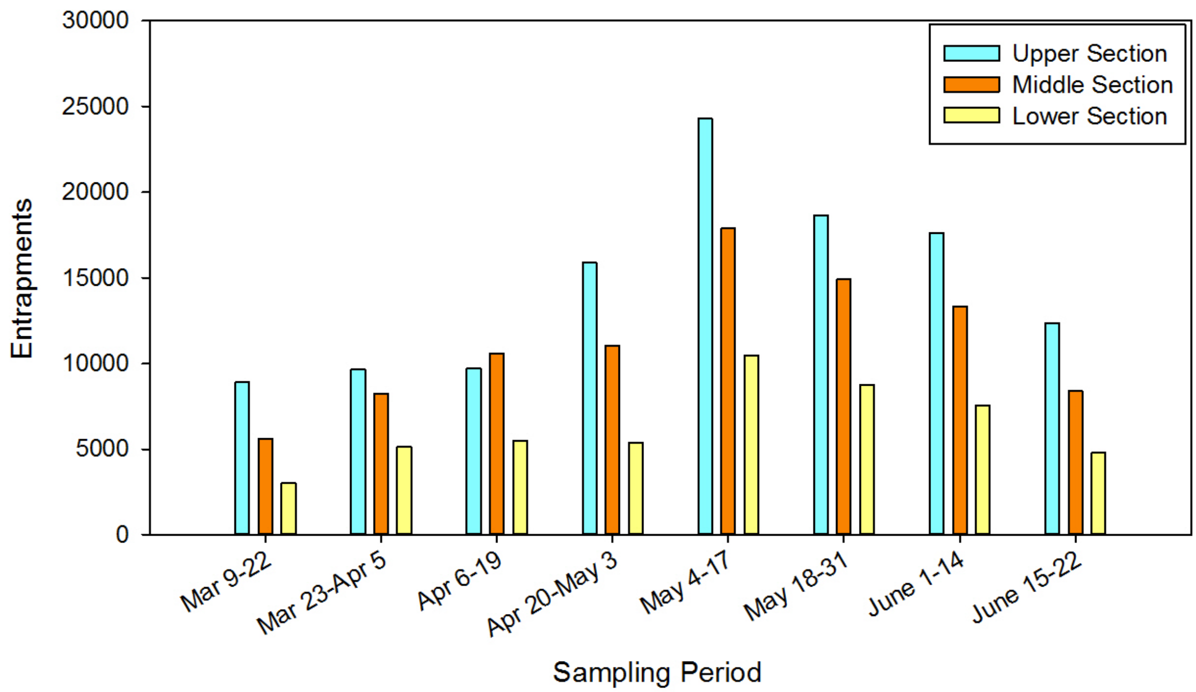


Figure 19 **Total number of entrapments created by temporal strata and river section, 2012.**

Table 25 **Mean number of juvenile fall Chinook salmon per entrapment by sampling period and river section, 2012.**

	Sampling Period							
Section	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Upper	0.1	0.0	0.8	1.2	7.9	0.3	0.1	N/A
Middle	0.4	0.5	0.1	3.2	4.8	0.4	19.1	0.1
Lower	0.1	0.2	0.4	15.0	0.0	108.0	0.7	0.0

Combining the number of Chinook salmon per entrapment with the number of entrapments that were created in the two-stage sampling design, we estimate that 1,574,664 Chinook salmon were entrapped in 2012 with percentile-based, bias-corrected, 95% confidence interval bounds of -98,103 and 6,877,871 (Table 26, Figure 20).

The highest estimate of entrapped Chinook salmon occurred in the sixth sampling period (May 18–31) within the Lower section of the Reach (826,887). The Middle section had the highest estimates of entrapped Chinook salmon in five of the eight sampling periods, although the overall total was highest in the Lower section. The majority of the entrapped Chinook salmon occurred during sampling periods five through seven (May 4–June 14); 93% of the total number of entrapped Chinook salmon occurred during this six-week period and 75% of the total number of entrapped Chinook salmon occurred during the four-week period from May 4–May 31.

Table 26 Estimates of the number of entrapped Chinook salmon by sampling period and river section, 2012.

Section	Sampling Period 1	2	3	4	5	6	7	8	Total
Upper	1,595	286	9,675	20,181	110,380	7,222	1,205	1,063	**151,607**
Middle	2,211	15,056	35	43,618	229,026	4,442	284,850	0	**579,239**
Lower	292	394	1,282	12,075	0	826,887	2,889	0	**843,818**
Total	**4,098**	**15,736**	**10,992**	**75,874**	**339,407**	**838,551**	**288,944**	**1,063**	**1,574,664**

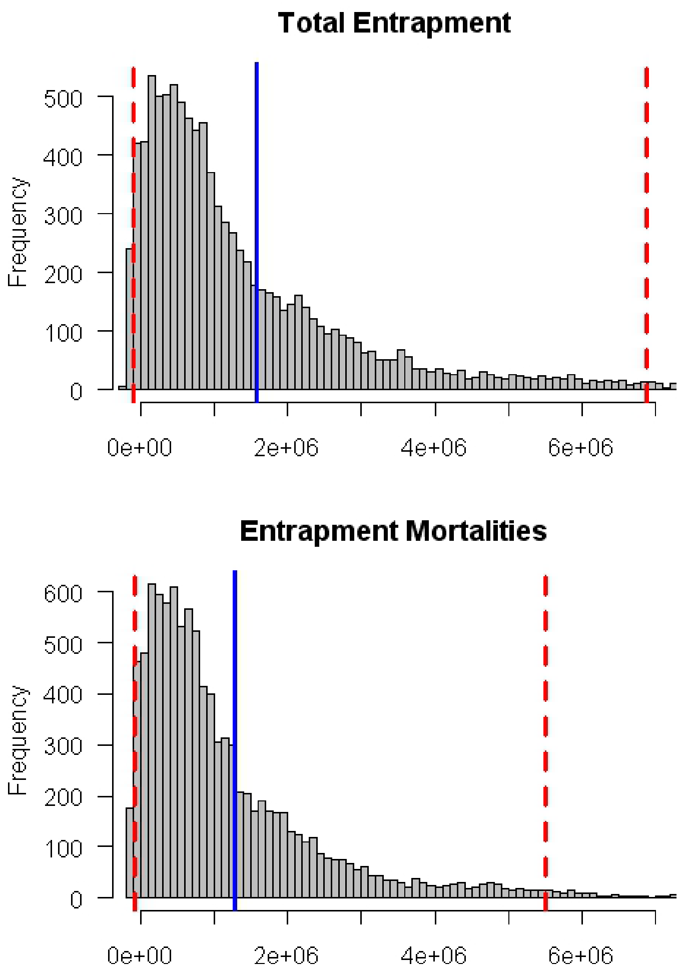


Figure 20 Histograms of 10,000 bootstrap samples of the total number of entrapped Chinook salmon (top) and the number of Chinook salmon entrapment mortalities (bottom) in the Hanford Reach, 2012. The blue vertical lines denote the bootstrap means and the vertical, dashed, red lines denote the percentile-based, 95% confidence interval bounds.

Entrapment lethality varied by sampling period and river section, ranging between 0% in the fourth sampling period in the Lower section (when only two entrapments were evaluated for lethality) and 97% (Table 27). There were no consistent spatial patterns apparent in the lethality data, but there was a general increase in lethality over the season (Figure 21). The entrapment lethality over all samples was 82%.

Table 27 Estimates of entrapment lethality rates for juvenile fall Chinook salmon by sampling period and river section, 2011.

	Sampling Period							
Section	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Upper	0.73	0.69	0.89	0.72	0.97	0.88	0.93	0.90
Middle	0.73	0.86	0.80	0.83	0.94	0.82	0.87	0.90
Lower	0.76	0.54	0.79	0.00	0.93	0.74	0.79	0.93

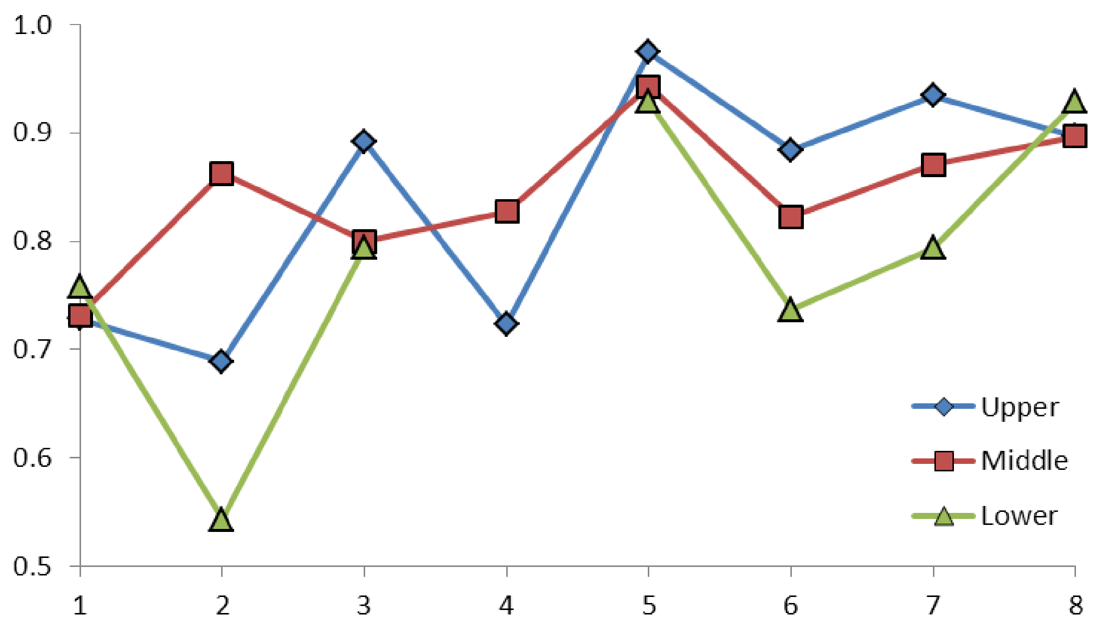


Figure 21 Estimates of entrapment lethality rates (y-axis) for juvenile fall Chinook salmon by sampling period (x-axis) in the Upper (diamonds), Middle (Squares), and Lower (triangles) river sections. The estimate in the Lower section during period four had too few samples to calculate a reliable lethality rate and was not plotted.

Combining the data on Chinook salmon per entrapment and the estimated number of entrapments in the two-stage sampling design along with the entrapment lethality data, we estimate that there were 1,281,417 entrapment mortalities, with percentile-based, bias-corrected, 95% confidence interval bounds of -83,112 and 5,514,367 (Table 28, Figure 20). The highest estimate of Chinook salmon mortalities (609,318) occurred in the Lower section during sampling period six (May 18–31). The estimates of entrapment mortalities were similar between the Middle and Lower sections, which had 518,095 and 622,779 estimated entrapment mortalities across the season, respectively. The Middle section had the highest estimates of entrapped Chinook salmon mortalities in five of the eight sampling periods, although the overall total was highest in the Lower section. The majority of the entrapped Chinook salmon occurred during sampling periods five through seven (May 4–June 14), with 93% of the total number of entrapment mortalities occurring during this six-week period and 74% of the total number of entrapment mortalities occurring during the four-week period from May 4–31.

Table 28 Estimates of the number of entrapped Chinook salmon mortalities by sampling period and river section, 2012.

	Sampling Period								
Section	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
Upper	1,162	197	8,619	14,592	107,513	6,381	1,125	953	**140,542**
Middle	1,618	12,979	28	36,079	215,813	3,653	247,925	0	**518,095**
Lower	221	214	1,018	9,747	0	609,285	2,293	0	**622,779**
Total	**3,001**	**13,390**	**9,666**	**60,419**	**323,327**	**619,318**	**251,343**	**953**	**1,281,417**

5.0 Discussion

The 2012 assessment of stranding and entrapment of juvenile fall Chinook salmon in the Hanford Reach used an updated study design that was based on the findings and lessons learned from the previous year. Sampling crews were directed to sampling locations by a re-designed web-based application (SESSM) that used hydraulic modeling results (MASS1) to identify potential sampling sites based on reductions in the wetted width of the river at each quadrant. This year a 9.9-m (32.4-ft) decrease in the wetted width over the previous 24 hours was used to select candidate quadrants for sampling, rather than the 15-cm drop in water-surface elevation used in 2011. This worked much better than the previous criteria, so that stranding crews were able to sample 86% of the quadrants visited in 2012, relative to the 51% rate the previous year. Modifying the sampling plan to take more stranding samples along the wetted perimeter of the river (see Section 3.2.1), also led to a large improvement in sample size. Although fewer quadrants were visited in 2012, more than twice as many plots were sampled, and the total area sampled in 2012 of 49,092 m^2 was more than double the area sampled in 2011.

Estimation of the dewatered area for 2012 indicated a 42% increase from 2011 and the estimated number of entrapments in 2012 was 37% higher than in 2011. The highest amount of dewatered area occurred in the Upper section (45%), and 33% occurred in the Middle section. The temporal distribution of dewatered area showed the greatest tendency for high values during the middle of the sampling season, April 20–May 31. This differed from 2011, when the distribution of dewatered area was relatively even, with a spike only occurring in the last time period (Hoffarth et al. 2012).

The results of field sampling for stranded juvenile fall Chinook salmon during 2012 were different from those observed in 2011. Almost as many stranded fish were found in the Upper section of the Reach as in the Middle section (28 vs. 33), and very few were found in the Lower section in 2012. This is a marked change from the data recorded in 2011, when 55% of the stranded fish were found in the Middle section, 35% were found in the Lower section, and only 10% were found in the Upper section (Hoffarth et al. 2012). There was also a much broader temporal distribution in the Upper section in 2012; stranded juvenile fall Chinook salmon were found in every sampling period from March 9 through June 22. Stranded salmon were more likely to be found during the middle of the sampling season in the Middle and Lower sections of the Hanford Reach. The density of stranded fish was extremely low, and variation and frequency of detection likely contributed to the difference in patterns observed between the two years. Modification of the sampling protocol for stranding surveys dramatically increased the total area sampled during 2012 and appears to have resulted in a broader distribution of fish observations (Figure 22).

The 42% increase in the estimates of dewatered area for 2012 relative to 2011 did not translate into a large increase in the bootstrap estimates of stranding loss in the Hanford Reach, and the mean bootstrap estimate for 2012 of 345,208 stranded juvenile fall Chinook salmon is very close to the 348,899 mean bootstrap estimate for 2011. The major reason for the slight decrease appears to be a significant drop in the density of stranded fish found in 2012. There was a 37% increase in the number of stranded Chinook salmon found in 2012, but this increase was spread over a sampled area that was more than double that of 2011, so that the overall density of stranded Chinook salmon dropped from 0.0021 to 0.0014 stranded Chinook salmon per square meter. The decrease in density appears to be the major cause of small decreases in the size of the bootstrap loss estimate in 2012, as well as a decrease in a simple loss estimate based on assuming random sampling over the entire dewatered area.

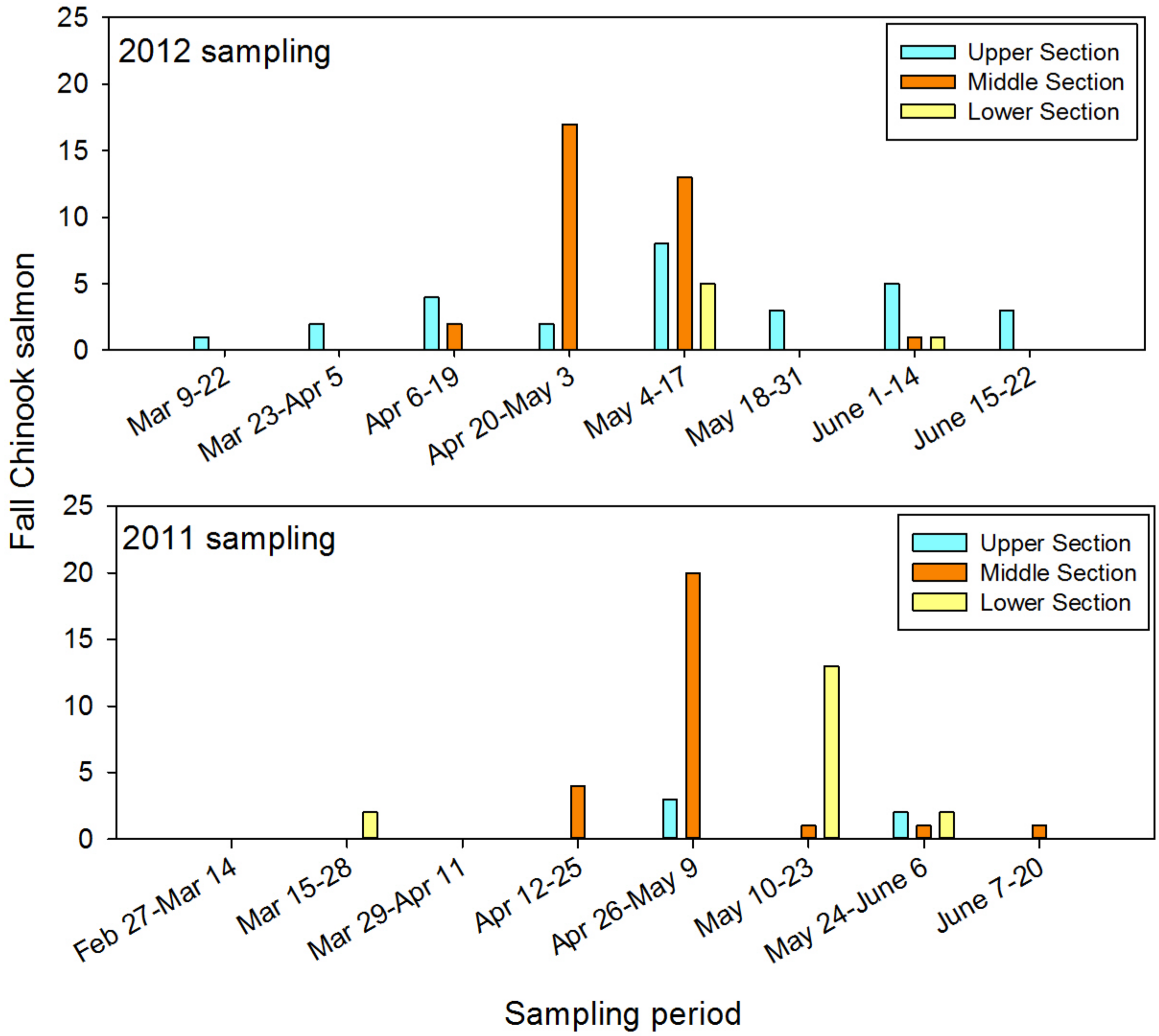


Figure 22 **Counts of fall Chinook salmon found in stranding surveys in the Hanford Reach during 2012 and 2011. Approximately 4.9 and 2.3 ha of dewatered shoreline were sampled in 2012 and 2011, respectively.**

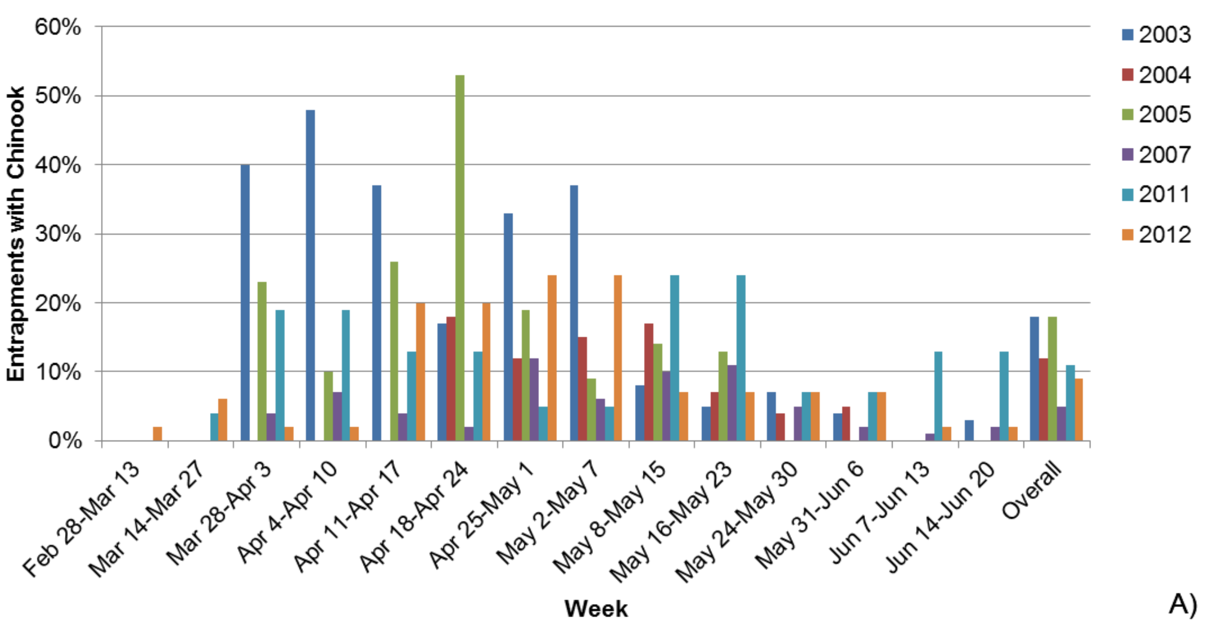
As in 2011, there were a number of two-week strata for which no fish were found, although in 2012, they were confined to the Middle and Lower sections of the river. As an alternative estimate, we constructed combined strata to ensure all spatial strata contained at least one sample with stranded juvenile fall Chinook salmon. Strata where no fish were found were combined with adjacent spatial strata where stranded fish were found. The combined strata were then used as the basis for an alternative bootstrap estimate. The bootstrap estimates for the combined strata were 7% higher than the standard bootstrap estimate. This is smaller than the 16% increase found for the combined strata bootstrap estimate in 2011.

The changes in sampling design and the increase in sampling efficiency discussed above contributed to a decrease in the variability of the bootstrap estimate of stranding loss relative to the variability of the estimate in 2011. The bias corrected 95% probability interval for 2012 was 393,917, compared to an interval of 668,703 in 2011. This represents a 41% decrease in the range of the bias-corrected 95% probability interval.

High river discharge in 2012, especially after mid-April, made finding stranded and entrapped fish difficult. The higher river levels resulted in the shallow early rearing habitat of the juvenile Chinook salmon being in areas often dominated by annual, and sometimes perennial, vegetation. Locating small stranded fish in areas of moderate to dense vegetation was difficult, as evidenced by the reduced efficiency estimates in the limited number of stranding efficiency tests. Similarly, capturing fish in entrapment pools in vegetated areas was difficult and resulted in reduced capture efficiency compared to areas with little or no vegetation. Data on the distribution of vegetation throughout the Hanford Reach are limited and the number of efficiency tests conducted in 2012 was relatively low, so we elected not to adjust the loss estimates by the efficiency estimates. Therefore, the loss estimates presented should be considered to be minimum estimates of loss for juvenile fall Chinook salmon in the Hanford Reach in 2012.

Studies to evaluate the effects of fluctuations in river elevation on juvenile fall Chinook salmon in the Hanford Reach were first funded in 1997. The data collected from the first few years of the evaluations indicated that the formation of pools that isolated fish from the river as water levels receded could potentially affect the survival of rearing juvenile fall Chinook salmon in the Hanford Reach. That is, larger numbers of Chinook salmon were found entrapped or dead in these isolated pools (entrapments) than were found along gently sloped shorelines (stranded). In 2003, the USFWS working in conjunction with WDFW began an assessment to determine the number of juvenile fall Chinook salmon placed at risk within these entrapments Reach-wide. In 2003 to 2005, entrapment sampling began well after the estimated start of fall Chinook salmon emergence. Sampling began on April 1 in 2003, whereas the estimated start of emergence was February 20. Limited funding was available for monitoring in 2004 and 2005, but staff were able to collect sufficient data to make comparisons between years feasible. In 2007, 2011, and 2012, contracts and staff were in place and sampling was able to begin at or near the estimated start of emergence.

In 2012, 9% of the entrapments sampled had Chinook salmon present (Figure 23). This was the second lowest percentage of entrapments with Chinook salmon present during the six years that entrapment studies have been conducted in the Hanford Reach. The percentage of entrapments with Chinook salmon was only lower in 2007 and was similar to 2011 and 2012 in that flows were elevated during the spring emergence and rearing period. The number of Chinook salmon per entrapment was estimated to be 3.3 in 2012. This was the third lowest estimate of Chinook salmon per entrapment of the six years of studies specifically targeting entrapment in the Hanford Reach. In contrast, in 2003, 18% of entrapments sampled had Chinook salmon present and more than 30% of the entrapments had Chinook salmon present during 5 of the 13 weeks of the study (Figure 23). The mean number of Chinook salmon per entrapment was also higher in 2003 compared to other years; the mean was 35.5 Chinook salmon per entrapment (Figure 23). This is particularly relevant considering the estimated population of Chinook salmon fry in the Reach in 2003 was almost half the size of the fry estimate in 2004 and one-third lower than the 2005 fry estimate. Monitoring did not begin until well after the estimated start of emergence in all years with the exception of 2007, 2011, and 2012 (this was especially true for the 2004 field season). These incomplete data collection periods may bias the mean annual estimates for percentage of entrapments with Chinook salmon present and Chinook salmon per entrapment. Trends within each section were similar for all six study years. A higher percentage of entrapments with Chinook salmon present and significantly higher numbers of Chinook salmon per entrapment were typically observed in the Middle of the Hanford Reach (Table 30). An exception is that the highest number of Chinook salmon per entrapment were found in the Lower section in 2012.



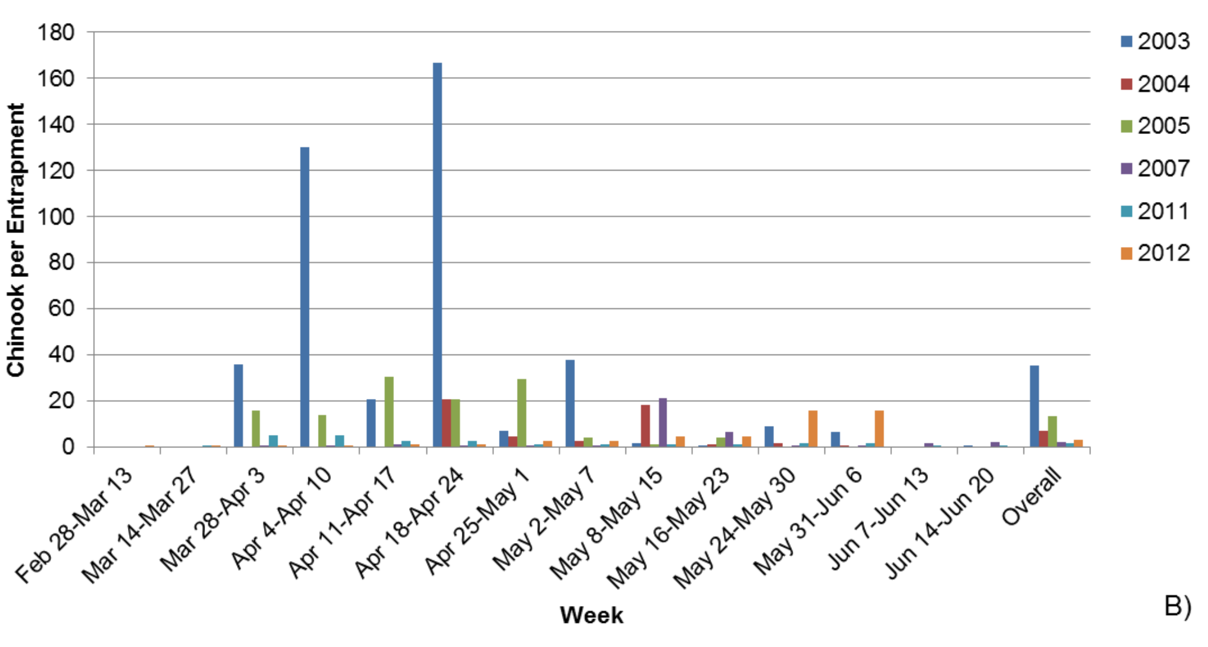


Figure 23 Comparison of A) percent entrapments with Chinook salmon and B) mean number of Chinook salmon per entrapment in the Hanford Reach, 2003–2012. Weekly time periods varied from year to year. Values are for week closest to the dates indicated.

Nearshore abundance seining and entrapment sampling suggest a second potential trend of downstream movement of fry as the rearing period progresses. A decline in the number of Chinook salmon inhabiting nearshore areas and in the number of Chinook salmon stranded entrapped in the upstream locations shortly after the estimated end of emergence has also been observed. This trend continues as the rearing period progresses with a decline in the number of Chinook salmon in the Middle Reach, followed by a decrease in downstream areas (McMichael et al. 2003). The percentage of entrapments that contained Chinook salmon fry and the number of Chinook salmon per entrapment began to decline within a week after the estimated end of emergence for all years except 2011 (Figure 23).

A larger percentage of the smaller entrapments tended to become dewatered and larger entrapments tended to reflood (Table 29). Small and medium entrapments contained 14% of the Chinook salmon found in in 2012. Larger entrapments tended to be less likely to become lethal (dewatered or >27 C; 69.0%) than medium (79.4%) or smaller (86.1%) entrapments. Although only 7.2% of the entrapments sampled were large, they accounted for 86% of the fall Chinook salmon sampled during 2012.

Based on the field summary data, the number of fall Chinook salmon fry per entrapment in the Hanford Reach were lowest in 2011 and greatest in 2003 (Table 30). Furthermore, stranding and entrapment loss estimates in 2001 (an extremely low flow year) were the highest on record (1.6 million in a portion of the Hanford Reach and up to 6.8 million for an expanded estimate intended to include the entire Hanford Reach; McMichael et al. 2003). Even though flows were relatively high in 2012, the combined stranding and entrapment loss estimates were relatively high (1.63 million).

Table 29 Summary of entrapment fate for each entrapment size at arrival of sampling.

Entrapment Size at Arrival	N	Entrapment Fate		
		Dewatered	Thermal (>27°C)	Reflooded
1–5	866	78.5%	7.6%	13.9%
5–15	393	59.5%	19.8%	20.6%
>15	100	51.0%	18.0%	31.0%
>15 NS	19	26.3%	21.1%	52.6%
Total	**1,378**	**70.4%**	**12.0%**	**17.6%**

The 2011 and 2012 results are noteworthy because the estimated spawning escapements preceding those years was similar to those preceding the 2003 and 2004 stranding and entrapment sampling seasons (Table 30; Langshaw and Hoffarth 2011). Assuming the availability of fall Chinook salmon fry to be stranded is related to the size of the spawning population from the previous fall, it appears that there is not a clear relationship between the number of Chinook salmon per entrapment and the availability of fry.

Table 30 Comparison of entrapments with Chinook salmon and mean number of Chinook salmon per entrapment in the Hanford Reach, 2003 – 2012. Estimated escapement for the prior year is also shown (e.g., the escapement estimate shown for the entrapment data from 2007 was for fish that spawned in the fall of 2006).

	Entrapments with Chinook (%)				Number of Chinook per Entrapment				
Year	**Upper**	**Middle**	**Lower**	**Total**	**Upper**	**Middle**	**Lower**	**Total**	**Escapement**
2012	9	12	5	9	1.3	4	6.5	3.4	**65,724**
2011	8	18	6	10	0.5	3.5	0.6	1.4	**80,408**
2007	4	7	3	5	0.3	4.1	2.7	2.5	**47,095**
2005	15	24	15	18	1.8	31.8	6.1	13.2	**78,347**
2004	8	18	8	12	3.7	12.6	4.1	7.0	**88,154**
2003	17	19	17	18	4.0	74.9	10.8	35.5	**67,515**
Mean	**10.2**	**16.2**	**9.2**	**12.3**	**2.0**	**21.8**	**5.2**	**10.5**	**71,207**

River flow in the Hanford Reach during the 2012 emergence and rearing period for fall Chinook salmon was considerably (45%) higher when compared to all other years since the interim Fall Chinook Protection Program began in 1999 (Table 31). The HRFCPPA allows larger daily deltas (i.e., discharge fluctuations) at higher flows and the mean daily delta from Priest Rapids Dam is highly correlated with mean daily discharge (R^2 = 0.93, Figure 24). However, the relationship between dewatered shoreline and mean daily discharge (R^2 = 0.25) or mean daily delta (R^2 = 0.46) is less strong because of differences in channel bathymetry (i.e., lower elevations tend to have lower gradient profiles). In general, fluctuations in river elevation at higher flows tend to dewater less shoreline than fluctuations at lower elevations, so entrapment and stranding risk may be reduced under higher discharge conditions (Figure 24). While stranding and entrapment was relatively low when discharge was the highest, these conditions occurred during the final two weeks of the protection program when there are fewer susceptible fry. Because this is the first time sampling has been conducted under these conditions, it is currently uncertain whether impacts would be similar when more susceptible fry are present.

During the higher flow years of 2007, 2011, and 2012, flows remained elevated and water temperatures were relatively cool throughout the emergence and rearing period such that the rearing period extended through mid-late June in the past three study years. In most prior years, the protection plan and sampling ended by early to mid-June. In 2007, 2011, and 2012, sampling crews often worked in areas with dense riparian vegetation that hindered both the detection and sampling of entrapments. Sampling under these difficult conditions contributed to lower numbers of detected entrapments, fewer entrapments that could be sampled due to dense vegetation, and likely reduced collection efficiencies. While, the area-based method is reasonable to estimate the number of entrapments that were created during high flows in 2011 and 2012, it is unknown whether the entrapment density is consistent across elevations.

Table 31 Summary of mean hourly discharge from Priest Rapids Dam during the primary period for emergence and rearing of fall Chinook salmon fry in the Hanford Reach.

Year	March	April	May	June	Mean
2012	121.0	177.9	226.9	251.6	**194.4**

2011	134	158.8	224.4	296	**203.3**
2007	134.3	169.3	175.4	164.9	**161**
2006[a]	94.8	156.1	181.3	214.6	**161.7**
2005	98.4	90	131.8	135.9	**114**
2004	77.3	95.4	128	141.3	**110.5**
2003	89	115.6	144.6	150.2	**124.8**
2002	76.1	128.3	150.6	227	**145.5**
2001	81.7	70.2	64.1	93.8	**77.4**
2000	110.2	160	166.2	134.1	**142.6**
1999	140	145.4	164.3	192.3	**160.5**
Mean 1999–2012	**105.2**	**133.4**	**159.8**	**182.0**	**145.1**

(a) No monitoring/evaluations

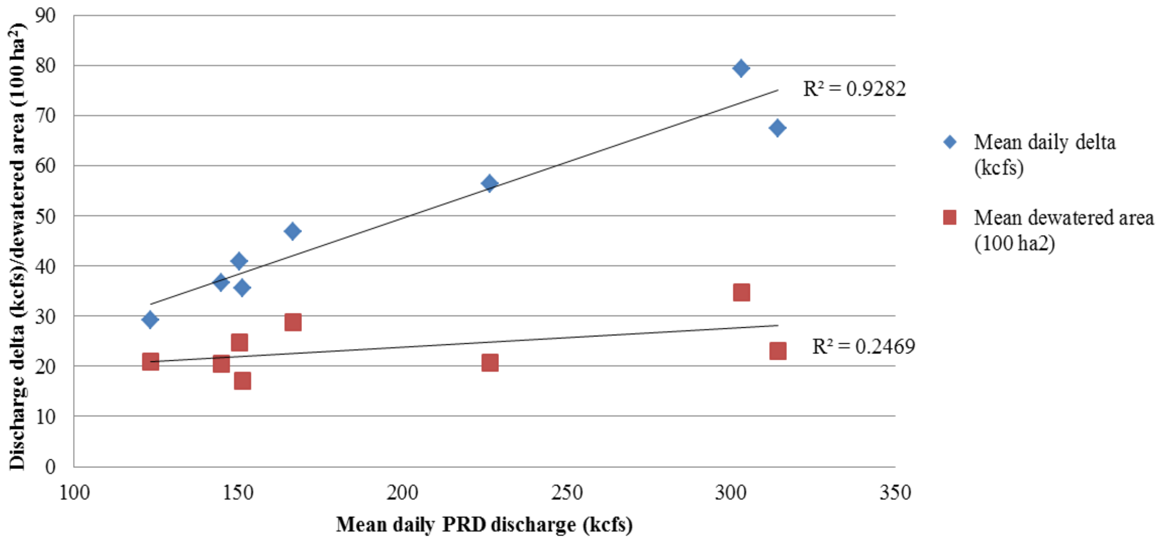


Figure 24 Mean Priest Rapids Dam discharge, daily delta, and dewatered area in the Hanford Reach during each sampling stratum during 2011.

Providing context is a critical component of any research or monitoring project. The easiest method to provide context is to generate estimates for the proportion of the population that is lost due to stranding and entrapment. Generating unbiased estimates and fully accounting for error in pre-smolt production and losses are difficult because of the scale of the Hanford Reach. A simplistic approach is to provide a range of estimates for historical production and losses during 2012.

Combining the bias-corrected mean estimates of stranding and entrapment resulted in an estimated loss of 1.63 million juvenile fall Chinook salmon during 2012. However, simply combining the loss estimates does not fully account for error, and methodologies to address this issue have not been developed yet. A simplistic approach is to combine the bias-corrected 95% confidence intervals for the loss estimates, which resulted in a range of 0.1 to 6.1 million. While this is an oversimplified method to generate error estimates, it provides a reasonable estimate for the range of losses due to stranding and entrapment.

Estimates of fall Chinook salmon pre-smolt abundance in the Hanford Reach were generated in a recently completed study of stock productivity (Harnish et al. 2012). Cohort-reconstruction and mark-recapture methodologies were used to generate abundance estimates for pre-smolt fall Chinook salmon (~48 to 80 mm fork length) in the Hanford Reach (brood years 1975–2004). Including estimates of error, the mean abundance estimate for brood years 1975−2004 was 39.0 million pre-smolts with a range from 1.4 to 184.7 million (Figure 25). Since implementation of protections provided by the Vernita Bar Settlement and Hanford Reach Fall Chinook Protection Program agreements (i.e., ~1986), the mean abundance estimate was 44.8 million pre-smolts with a range from 14.0 to 184.7 million. Because the methods for generating pre-smolt abundance estimates require tagged juveniles to be recaptured, an estimate for brood year 2011 cannot be completed for several years. While these methods for estimating pre-smolt abundance do not account for all sources of error and we have not generated an estimate for 2012 yet, the historical abundance estimates provide a range of production potential for the Hanford Reach. We are currently working to develop methodologies to better account for error in the fry loss and pre-smolt abundance estimates. More comprehensive analyses and discussion of error and context will be provided in a summary report covering monitoring completed during 2011, 2012, and 2013.

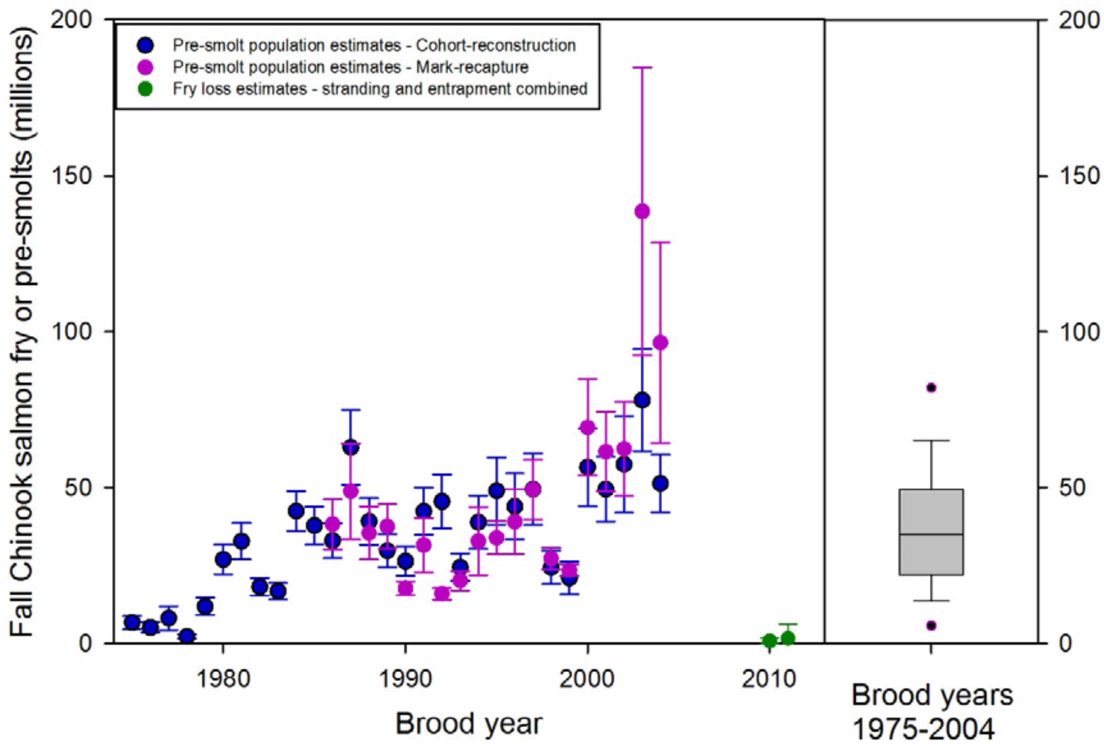


Figure 25 **Hanford Reach fall Chinook salmon pre-smolt population estimates based on cohort-reconstruction and mark-recapture methodologies (with one standard deviation). The box plot was generated with mean and error estimates from the cohort-reconstruction and mark-recapture methodologies. The estimates of fry loss were generated by combining the bias-corrected mean and error estimates for stranding and entrapment mortalities.**

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Appendix A
Hanford Reach Stranding and Entrapment Protocol, 2011-13 Field Sampling Methods

Updated for 2012 sampling by: S. Haeseker (USFWS), T. Hillman (Bioanalysts), P. Hoffarth (WDFW), R. Langshaw (GCPUD), G. McMichael (Battelle), C. Murray (Battelle), T. Pearsons (GCPUD), J. Skalicky (USFWS), K. Tiffan (USGS)

Methods used and data collected during previous studies of stranding and entrapment of fall Chinook in the Hanford Reach (McMichael et al. 2003, Anglin et al. 2006) were reviewed to develop the methods described below. The objective was to develop field sampling protocol that will allow for a robust measure of total fall Chinook losses in the Hanford Reach as a result of stranding and entrapment. These protocols will be reviewed annually or as necessary, throughout the duration of the study, and modified as needed.

1.0 Protocol - Stratification of data collection

Past sampling data, GIS analyses, and simulation modeling were used to examine and re-analyze results from 2003 and 2007 to develop a stratification scheme for 2011, 2012, and 2013. The stratification scheme is designed to reduce variation in entrapped and stranded fish observations within each stratum, and thus reduce variation in the overall entrapment estimate. Stratification will also allow for a more detailed examination of timing, habitat usage and area effects.

1.1 Spatial

This spatial stratification scheme will be used in development of the protocol for daily sample site selection throughout the stranding and entrapment sampling season.

1) The Hanford Reach will be divided into three primary sections, Upper, Middle, and Lower, similar to previous years. The three sections will be further divided into eight river segments (Table 1 & Figure 4). River stage variation associated with the unsteady flow hydrograph is relatively consistent within each of the eight segments.

Table 1. Delineations for the eight spatial strata for the 2011-13 evaluation of stranding and entrapment of juvenile fall Chinook in the Hanford Reach.

Section	Segment	Lower Boundary (rkm)	Upper Boundary (rkm)	Transects per Segment	Transects (#)
Upper	1	620	635	1-60	120
	2	605	620	61-120	
Middle	3	595	605	121-160	120
	4	588	595	161-188	
	5	581	588	189-216	
	6	575	581	217-240	
Lower	7	558	575	241-308	120
	8	545	558	309-360	

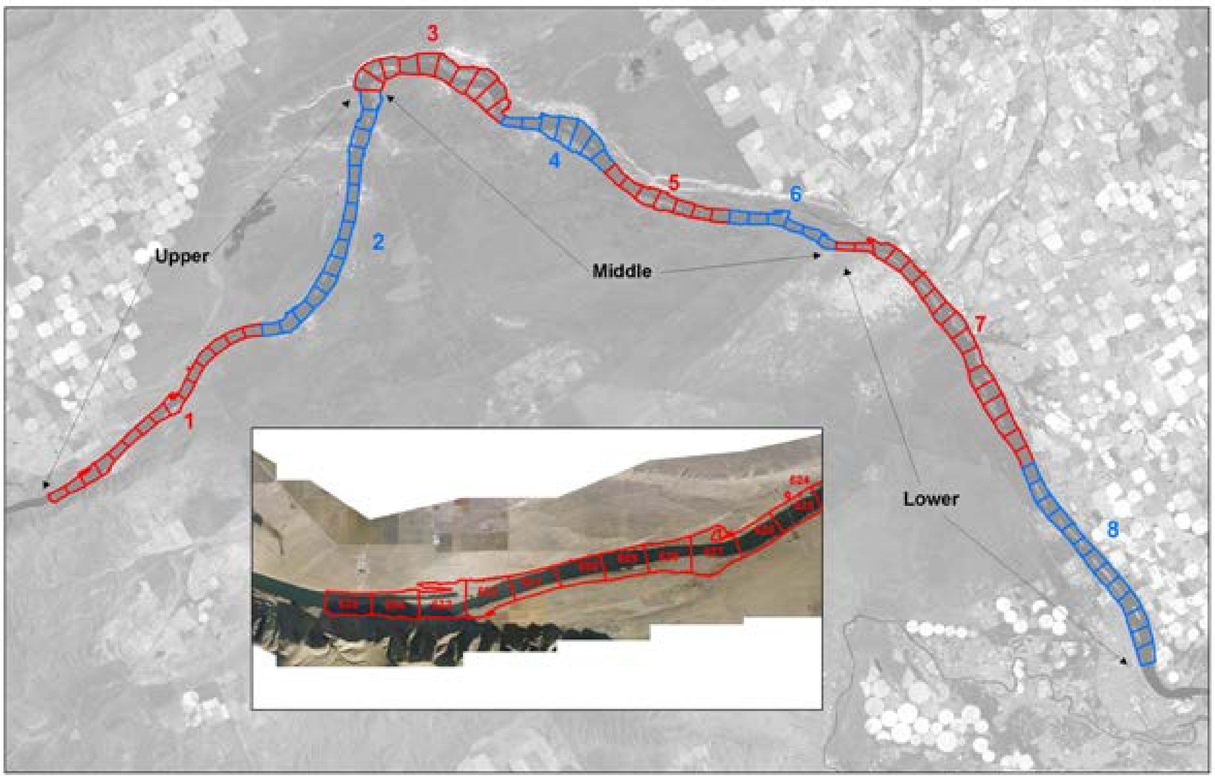

Figure 2. Spatial strata for the 2011-13 evaluation of stranding and entrapment of juvenile fall Chinook in the Hanford Reach.

2) Each river segment will then be further sub-divided into sample sites delineated by transect lines located at ~250 meter intervals (Figure 3 and Figure 4). The entrapment sample locations (quadrants) are bounded by adjacent transect lines. Within these sites, affected flow bands will occur on main channel, side channel, and island structure shorelines.

3) The population of known entrapments within the Hanford Reach is georeferenced with information about longitude, latitude, elevation and size.

4) The process for selecting sampling sites will be random selection, without replacement within the two week temporal strata. To be available for selection sample locations must exhibit a minimum 10 meter reduction in surface top width based on the SESSM using MASS1.

5) In order to avoid surveyor bias, shoreline sampling order will be determined by coin toss randomization before arrival on site.

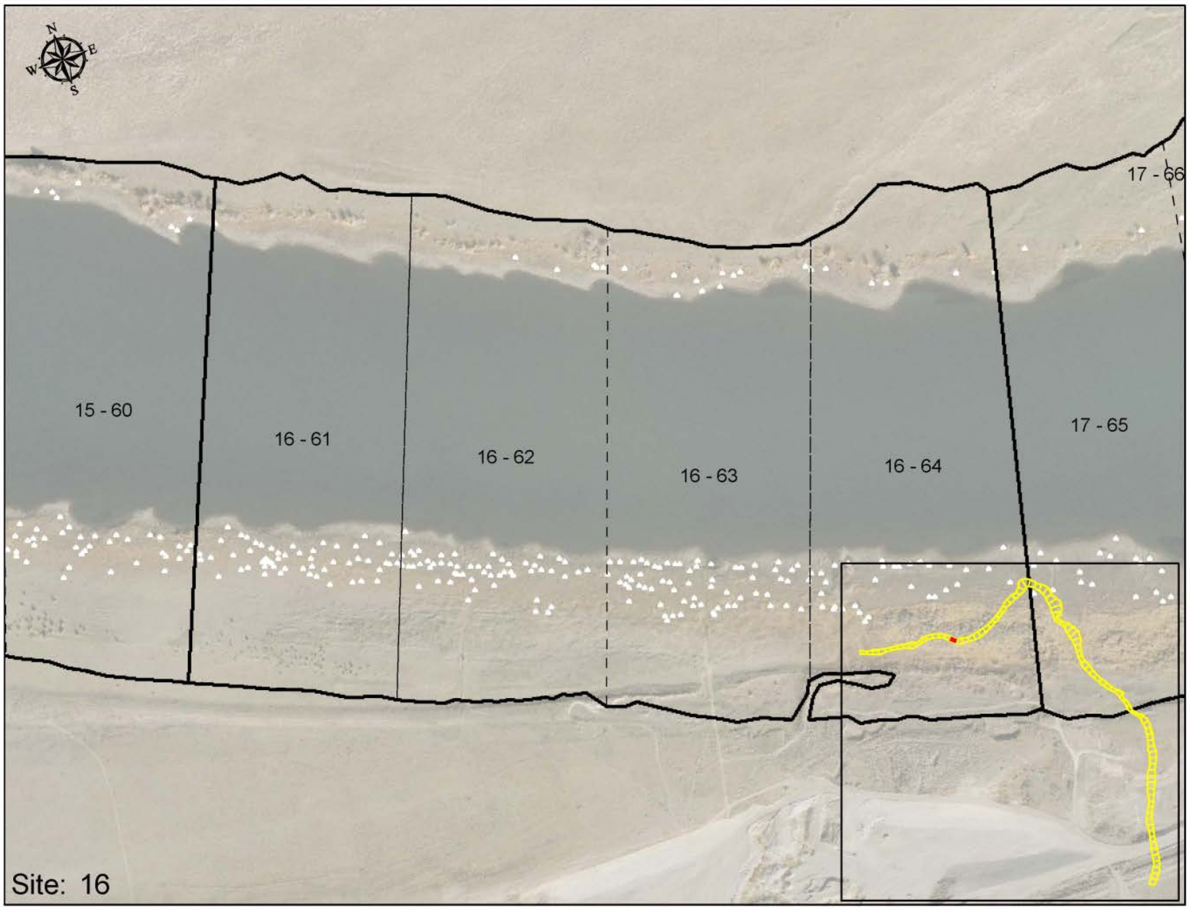

Figure 3. Example of an individual sample site (Site 16), quadrants (16.1-16.4), and entrapments (white dots).

1.2 Temporal

Since simulations from prior studies did not indicate any need for changes in temporal stratification two week strata will be used in 2011-2013 investigations to account for seasonal changes in fish abundance, size, and distribution. The number of temporal strata will be based on the prior evaluations of susceptibility during the rearing period and details of temperature unit accumulation by incubating eggs, developing alevin and fry. Prior studies have resulted in eight temporal strata and will likely be the norm through 2013.

1.3 Physical

Field sampling of entrapments will be conducted using a random process. Analytically, results from field sampling may be examined *a posteriori* by each of the habitat strata: entrapment size, substrate size, substrate embeddedness, and vegetation density.

A) The total population of entrapments have been classified into four size ranges:

- 1-5m in diameter,
- 5-15 m in diameter,
- >15 m in diameter,
- Not sampleable due to size or depth

In combination with the size classification both length and width measurements will be taken for *a posteriori* calculation of watered surface area for entrapment basins possessing a measurable depth and wetted area of drained entrapments.

B) Substrate classification will further be broken down into dominate and sub-dominate sizes (1-9) based on the Wentworth code described by Platts *et al* 1983 (Figure 4).

C) Embeddedness is a relative measure of the interstitial space amongst the substrate and percentage of fine particulate.

1) loosely aggregated
2) moderate
3) little space
4) fully compacted

D) Vegetation density on the Hanford Reach fluctuates greatly among sample sites.

1) None
2) Sparse
3) Moderated
4) Extremely dense grass, brush, trees or a combination of all three.
5) Not sampleable due to vegetation

1.4 River Segment and Site Selection

An automated, Internet-based model (Model) that is based on the stratification scheme described above, will be used to determine river segments and sites that are available for sampling each day. The Model will use the Modular Aquatic Simulation System in one dimension (MASS1) to identify quadrants available for sampling based on real time discharge data from Priest Rapids Dam during the previous 24-hours.

A total of 360 quadrants were defined during the 2007 USFWS entrapment evaluation and the Model will create a random list of quadrants for each crew to visit during each sample period. The generated list will include up to 10 quadrants, in random order, that are projected to experience a decrease in surface water top width of 10 meters by the time of sampling. This is cumulative among all shorelines included along the transect (i.e. no island structures 2 shorelines, one island 4 shorelines, etc.). In order to facilitate sampling throughout each sampling day, start times for each crew will be staggered. Quadrants are selected without replacement within temporal strata, meaning quadrants will only be sampled once per two-week period. The Model will track cumulative sampling effort within each temporal and spatial stratum to assure that an adequate number of sample sites are assessed.

Sample sites consist of both main-channel, side channel and island shorelines within 0.5 km of the river. Entrapment sampling will be conducted within randomly selected quadrants bounded by transect lines and stranding survey plots will be distributed along randomly selected transect lines. Several factors will determine the number of randomly selected quadrants that will be sampled on any given day. Because of flow attenuation, sampling will be concentrated in upstream segments when fluctuations are too small to affect downstream areas and sampling can be distributed throughout the Hanford Reach during widespread flow events.

Other factors include:

- The total number of segments affected by the previous day's operation that need to be sampled. If fewer segments are affected, sampling will be concentrated. If more segments are affected, sampling may be more dispersed.
- The cumulative number of sites within a segment that have already been sampled within the current temporal strata. Segments with fewer quadrants may be less likely to be sampled during a given event.
- The number of crews available for sampling. Each day, one crew is dedicated to stranding sampling and two crews are dedicated to entrapment sampling.
- The amount of time available for sampling during drop.
- The water surface top width decrease of at least 10 meters must be available a minimum of two hours to be included on the list of randomly generated sample quadrants.

1.4.1 Tasks for sampling crews

The following tasks will be completed daily by each crew:

Task 1) Review flow records for the current and previous day to gain a strong perspective on expected river elevations and navigation hazards. Discharge information can be found on two websites:

http://waterdata.usgs.gov/wa/nwis/uv/?station=12472800
http://www.nwd-wc.usace.army.mil/report/prdhr.htm

Task 2) Run the SESSM to identify sampling locations for the day. The list name should read as follows: crew ID followed by the four digit date (e.g. A0402).

Task 3) Post the generated list with the crew ID (A, B or C), and date on the board. This will inform the other crews and supervisor of the boat launch being used and work location of the day.

Task 4) Check the revisitation file for entrapment sites near your destination where entrapment fates need to be assessed prior to the start of sampling for a new day.

Task 5) Upon arriving at the boat ramp, turn on the Garmin GPS receiver and Trimble GPS/data logger. Using the Trimble create a new file for storing the day's features. Use the Map screen on the Garmin unit to locate and navigate to the sample location.

Task 6) Determine the shoreline sampling order by flipping a coin marked right shore and left shore. This will randomize the sampling order to eliminate bias caused by time constraints associated with shift period and changes in flow.

2.0 Entrapment Sampling

Physical and biological sampling of entrapments will be conducted by two, three person crews, and seven days per week. Ideally sampling will begin one week prior to the estimated date of emergence and terminate one week after the termination of the HRFCPPA (approx. 16 weeks). If during the last week of sampling, fish are still being entrapped, an additional week of sampling should ensue. Sampling will likely occur from approximately March 1 through June 15 annually. Both physical and biological data collection will be conducted for all entrapments that are identified within the sample quadrants. The number of entrapments that are sampled at a site will be a function of the number, size, and complexity of the entrapments and the hours available for sampling.

2.1 Entrapment Data Collection

Physical and biological data will be collected for each entrapment that is sampled.

2.1.1 Tasks for sampling crews

The following tasks will be completed by sampling crews at each site or entrapment:

Task 1) Upon arriving at the upstream transect bounding the two sample quadrants, secure the boat in a suitable spot near the streambank and proceed downstream to where the transect meets the river. From this point, staff should move inshore along the transect boundary looking for entrapments within the wetted perimeter of the shoreline. An entrapment is defined as an enclosed depression with a wetted surface area of one meter in diameter or greater. All entrapments encountered meeting this criteria will be sampled. Crews will continue to move along the transect boundary within the wetted perimeter of the shoreline. Once the crew reaches the inland edge of the wetted shoreline they will move parallel to the river along the wetted edge within a sufficient distance to allow observation of any entrapment formed between the prior survey line and their current position. Crew will then move back towards the river sampling all entrapments observed (Figure 6). This pattern will be repeated along 500 meters of shoreline (two quadrants) with the goal of observing and sampling all entrapments along one bank within the two quadrants. If all entrapments are surveyed along one bank, move across the river to sample any other shorelines within the two quadrants. Once all the shorelines have been sampled within the bounding transect lines crews should move to the next closest transect generated by the site selection model.

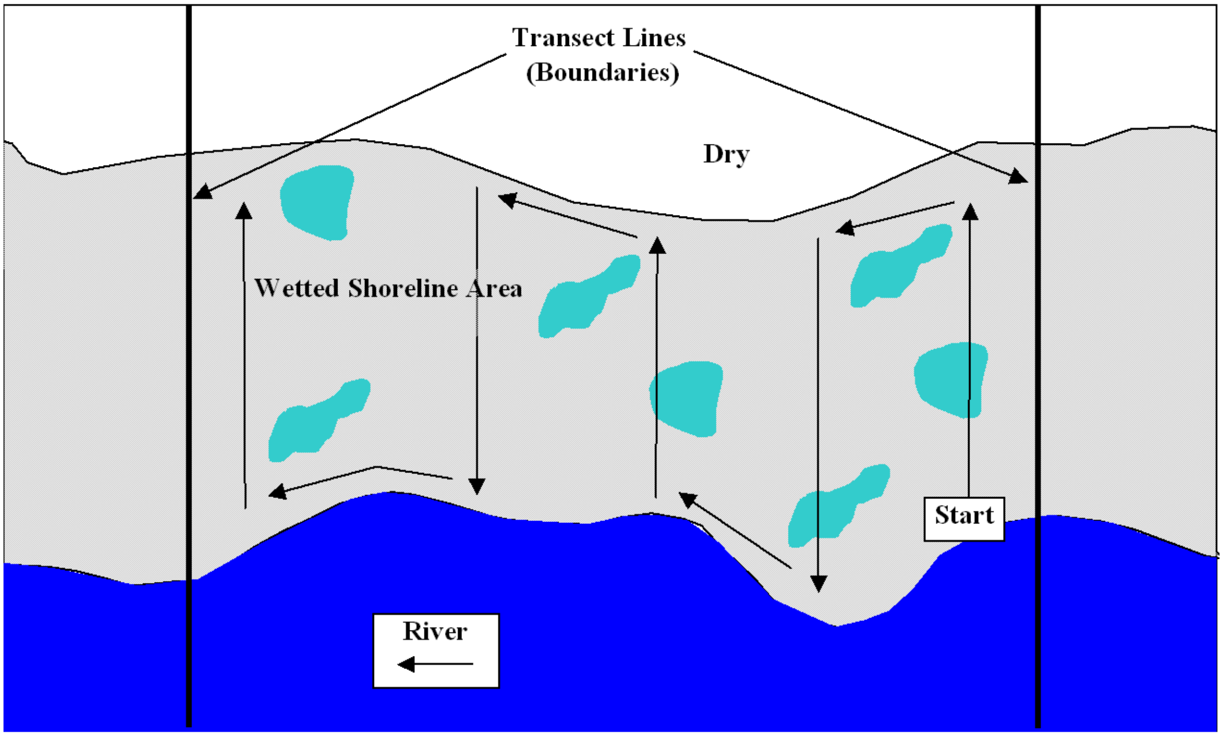

Figure 4. Search pattern for sampling entrapments.

Task 2) Upon arriving at an entrapment that will be sampled, create a waypoint with the Garmin GPS and Trimble datalogger. The waypoint name must follow the standardized format without spaces or punctuation: Crew ID (A or C), transect # (001-360), shoreline (RS, LS, etc.) and the entrapment number (ex. A059RS01). This unique identifier will be duplicated on the hard copy datasheet, Trimble sample location and Trimble sample area. It is unnecessary to include the date and/or time in the waypoint name because these attributes are automatically recoded with the waypoint. Waypoints should be collected as close to the geometric center of the entrapment as possible for comparison with historically mapped entrapments.

Task 3) Record the date and entrapment number on a survey flag and place the flag within the entrapment, preferably at the deepest point or at the center point if the entrapment is greater in depth than the height of the flag. A reference depth may be denoted with a survey flag for drain rate calculation.

Task 4) Complete data collection on the data logger and hard copy datasheet with the exception of the recheck information.

2.1.2 Physical data for each entrapment

Physical data that will be collected at each entrapment sampled includes:

A) Fish present: Yes or NO, this is a general observation of fish presence;

B) The total population of entrapments have been classified into four size ranges:

- 1-5m in diameter,
- 5-15 m in diameter,
- >15 m in diameter,
- Not sampleable due to size or depth

In combination with the size classification both length and width measurements will be taken for *a posteriori* calculation of watered surface area for entrapment basins possessing a measurable depth and wetted area of drained entrapments.

C) Substrate classification will further be broken down into dominate and sub-dominate sizes (1-9) based on the Wentworth code described by Platts *et al* 1983 (Figure 4).

D) Embeddedness is a relative measure of the interstitial space amongst the substrate and percentage of fine particulate.

1) Loosely aggregated
2) Moderate
3) Little space
4) Fully compacted

E) Vegetation density on the Hanford Reach fluctuates greatly among sample sites.

1) None
2) Sparse
3) Moderated
4) Extremely dense grass, brush, trees or a combination of all three
5) Not sampled due to vegetation

F) Evidence of Predators: Surveyors must note seeing piscivorous and scavenging birds, bird tracks, coyotes or other mammal tracks present in or around the immediate vicinity of the entrapment.

G) Time: Record start time for initiation of sampling the entrapment as well as time of recheck using military time format. Accurate times are important for determining entrapment drainage rates.

H) Air temperature: Record air temperature at the time of sampling (C°);

I) Water temperature: Collected at the deepest point of the entrapment (C°);

J) Depth: record depth using either a staff gage or standpipe placed at the deepest point of the entrapment, mark the location of measurement with the survey flag for the site or metal washer. If the deepest point is greater than the height of the staff use a reference depth marked with a survey flag.

K) Entrapment fate: Record entrapment fate as (defined in section 2.1.2.1);
1) Drained-lethal
2) Thermal-lethal
3) Reflood-non-lethal, or
4) Unknown

2.1.2.1 Fate of Entrapments

To determine the mortality to fall Chinook resulting from entrapment the fate of each entrapment will be determined either *in situ* through direct observation and measurement or post-season utilizing the data collected in conjunction with the MASS1 and MASS2 models. It is assumed that each pool that is isolated from the river with receding water elevation has the potential to entrap Chinook. The abundance/concentration of fall Chinook changes significantly by location and developmental life stage throughout the sampling period. Variables that influence the fate of entrapments (i.e. discharge, air and water temperature, etc.) also vary throughout the Rearing Period. Increased solar radiation and air temperatures lead to shorter time durations for entrapments to warm above lethal temperatures for fall Chinook. Flows in the Columbia River tend to be at their lowest in the early spring and at their highest in late spring. The substrate of the Hanford Reach tends to be less embedded in the lower elevations resulting in faster drainage rates for entrapments formed at theses elevations. The proportion of lethal entrapments will be used to estimate mortality for fall Chinook in the Hanford Reach rather than the morality of Chinook sampled in the entrapments. This greatly increases the sample size and provides changes in abundance, air and water temperatures, and river elevation.

Entrapment fate is based on the effects of drainage, water temperature, and re-flooding as defined below.

Drained entrapments that drained prior to sampling, during sampling or through as *posteriori* determination, will be defined as lethal. In order to establish an accurate loss estimate, fates of either drained or re-flooded were assigned to all entrapments with unknown fates after direct observation. This method for determining lethality likely underestimates the loss by precluding mortality caused directly by radiative heating leading to thermally lethal water temperatures and indirect loss from avian, mammalian, and teleost predators. These post assigned fates are based on hydrodynamic flow model.

Post Assigning Fate Methodology:
1. Calculate the amount of time required for the entrapment to drain entirely using a drainage rate and a measured maximum depth at a known time.
2. Determine the time before reflood using the MASS1 model. From the modeled surface elevation at the time of sampling (known separation from main channel) till the modeled surface elevation exceeds the original height.
3. The *in situ* measured drainage rate, mean drainage rate (1.93 cm/hr) and median drainage rate (1.46 cm/hr) were used to evaluate the efficacy of any one measurement. If all drainage rates agree then the identified fate was assigned.

4. If we have a high confidence in *in situ* measurements then that drainage rate was applied to the entrapment. High confidence was defined as a measurable change in depth or a time stamp greater than 30 minutes between arrivals, sampling, and recheck.
5. If the calculated time before reflood is greater than the time required for the entrapment to drain completely then the fate: dewatered or drained is assigned and 100% fish loss in that entrapment is assumed. Conversely if the time before reflood is less than the time required to drain then we assign a reflooded fate and 0% fish mortality.
6. If no measured drainage rate exists then the median and mean drainage rates are applied.
7. Entrapments become separated from the main channel throughout a drop in surface elevation and therefore we must account for some period of time elapsing between separation from the channel and time of sampling. To this end we are applying a 50% rule. Whereby 50% of the total time elapsed between the beginning of the current flow drop and the flows return its initial elevation is added to the known time delta between measured separation elevations. This effectively calculates a secondary time change while minimizing bias to favor either possible fate.

Water temperature: Entrapments with observed water temperatures greater than 27°C will be defined as lethal. There are two methods for determining thermal lethality: 1) Min-Max temperature probes will be used on all entrapments encountered and 2) if live Chinook are present a tidbit temperature data logger will be activated and anchored in the deepest part of the entrapment. Suggestions have also been made to develop reference entrapments for *a posteriori* comparison between similar volume and surface area entrapments to infer thermal maximums. HOBO temperature and density data loggers will be used to record data at half hour intervals throughout the sampling period. If the reference entrapment water temperature exceeds 27°C then the similar entrapment sampled will be determined lethal based on temperature. This did not occur during the 2012 HRFCPPA however may be added to the protocol during proceeding studies.

Re-flood: All entrapments that are observed or modeled to reconnect or reflood during sampling are considered non-lethal. Large-deep entrapments and short duration drops in surface water elevation will likely experience a high frequency of re-flooding.

Unknown: If the fate of the entrapment cannot be determined in the field the entrapment fate is classified as “Unknown”. Revisit all entrapments with unknown fates prior to the end of the shift. If fate is still not established and there are fall Chinook present, leave site flag, notify other crews, complete a Revisitation Form for the entrapment, and file the form in the office upon return. These entrapments will be assessed during proceeding operational periods until a fate is determined.

2.1.3 Biological data for each entrapment

Biological data that will be collected at each entrapment selected for sampling includes:

A) Fish collection method selected (i.e. visual, electroshocker, or seineing) (detailed in section 2.1.3.1).

B) Number or passes and/or shock time as well as information necessary to conduct an accurate mark-recapture experiment to estimate the total number of fish in the population.

C) An accurate count on all live, dead, marked, and unmarked fish species observed within the entrapment.

D) Forklength measurements will also be collected on a representative sample of fall Chinook (mm).

2.1.3.1 Sampling methods to enumerate fish in entrapments

Beach seines, backpack electrofishing equipment and dip nets were used to sample entrapments for fish. Sample type and sample efficiency is greatly influenced by habitat characteristics. The most effective method must be determined to accurately capture fish for enumeration. Mark-Recapture sampling efficiency estimates should be conducted on all entrapments. Efficiency estimates will be evaluated and pooled based on sample method and habitat characteristics to estimate total populations. Methods to enumerate fish species are as follows:

Dip Net: locate, collect and identify fish by species, enumerate and record the data. This technique is primarily used when all the fish observed are deceased or in small, shallow entrapments that have little vegetation and are heavily embedded.

Beach Seine: Seine the entrapment collecting as many fish as possible. Enumerate the fish captured and collect fork length measurements on an adequate sub-sample. This technique is most effective in deep entrapments with sparse vegetation and embedded substrate. A large number of fish should be marked with Bismark Brown or AD-clipped and released back into the entrapment. Hold the marked fish for 5 to 10 minutes after marking to assess mark caused mortality. A sufficient amount of time should be allocated for the fish to resume their natural distributing before attempting to recapture them. The recapture effort should be the same as the initial capture event (i.e. 1, 2, or 3 passes with the seine).

Electrofishing: Use the timer on the electrofisher to evaluate the effort allocated to capture events. Team members should work cooperatively to shock and net the stunned fish. An effort should be made to capture as many fish as feasible followed by a mark-recapture estimate similar to seining described above. Instead of using the number of passes to evaluate effort, the recorded shock time from the initial capture event will be used.

2.1.4 Sampling entrapments with large numbers of Chinook present

Individual entrapments with large numbers of Chinook present (e.g. several hundred or thousands) have a significant influence on the overall estimate of fish per entrapment within the strata. These entrapments are a priority for conducting accurate mark-recapture estimates as well as fate determinations. To this end, complete the tasks listed in Section 2.1 and secure a temperature datalogger at the deepest point within the entrapment. Notify any remaining crews of your location and confirm they can revisit the site prior to end of shift. If no crews are available, in addition to filing a Revisitation Form leave a note on the white board in the office for the next available crew.

2.1.5 Sampling sites with small numbers of entrapments

Complete sampling of all entrapments at the first location (two quadrants) generated by the SSEM. As time permits conduct sampling on all shorelines within the selected quadrants. Once those are completed proceed to the closest adjacent transect on the list. Repeat this process while time permits additional sampling. Leave adequate time within the operational period to revisit all entrapments with unknown fates.

2.2 Estimating Sampling Efficiencies for Entrapment

Sampling efficiencies will be evaluated on all entrapments with Chinook present. If possible, some overnight or extended re-sampling will occur. Conduct sampling per efficiency protocols above. Sampling efficiencies for each method will be combined, reviewed, and documented in the final report.

3.0 Evaluation of Stranding Events

Stranding of juvenile fall Chinook salmon occurs when the fish are trapped on or beneath the dewatered substrate as the river level recedes. Entrapment occurs when the fish are separated from the main river channel in depressions as the river level recedes. Entrapped fish may become stranded when depressions drain completely. 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 Northwest National Laboratory (PNNL) and WDFW prior to the 1999 field season and was implemented from 1999 through 2003 (McMichael et al. 2003). These years of study are collectively known as "Stranding Studies" as the sample cells were $3600ft^2$ plots around a randomly generated data point within the effected flow band. The number of juvenile fall Chinook salmon and other species of fish found within the sample lot were counted and classified as alive or dead within the sample plot. Entrapments with area of 50% outside 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 rope 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. Methods will be similar during this study, but entrapments are being sampled separately and will not be sampled as part of the stranding plots.

3.1 Stranding Sampling

Physical and biological sampling for stranding will be conducted by one, three-person crew, seven days per week. Entrapment and stranding sampling will be conducted concurrently. Sampling will likely occur from approximately March 1 through June 15th annually. Both physical and biological data will be collected from sample plots that are located on transects that define the quadrant boundaries. A separate, but identical, Model will be used to generate a random list of quadrants available for sampling each day. The number of plots that will be sampled at a site will be a function of the size and complexity of the site and the hours available for sampling.

3.2 Stranding Data Collection

Physical and biological data will be collected for each stranding plot that is sampled.

3.2.1 Tasks for sampling crews

The following tasks will be completed by sampling crews at each site or plot:

Task 1) Use the Garmin GPS to navigate to the transect selected for sampling (see GPS instructions).

Task 2) Upon arrival at the sampling location, secure the boat in a suitable spot along the streambank. Locate the point where the transect line meets the river and proceed along the transect inland to a distance of five meters. This will be the center point of the first plot at the site. Set the center pin and survey the area within the circular boundary established by the five meter cable. The area of a complete plot is $78.5m^2$.

Task 3) Turn on the Trimble GPS/ datalogger, create a new file identified by the group name (i.e. B) followed by the four digit date (mmdd), (e.g. B0401). Then record a sample location at the center of each circle plot sampled.

The plot configuration will be determined by clearly defined rules located in the field guide and summarized in Figure 5.

Example	Wetted Line Scenario	Anchor Placement (Plot Center)	Plots (#)	Orientation
	Wetted line < 1 m wide.	NA	0	None
1	Wetted line >1 m and <5 m wide	On wetted line	3	Lateral
2	Wetted line >5 m and <10 m wide	5 m ↑ water line	3-5	Lateral
3	Wetted line > 10 m and < 15 m wide	(1)5 m ↑ water line and (2) on wet line	3	Stacked Vertical and Lateral
4	Wetted line > 15 m wide	(1)5 m ↑ water line and (2)on wet line. Fit in as many complete circles as possible	≥2	Vertical

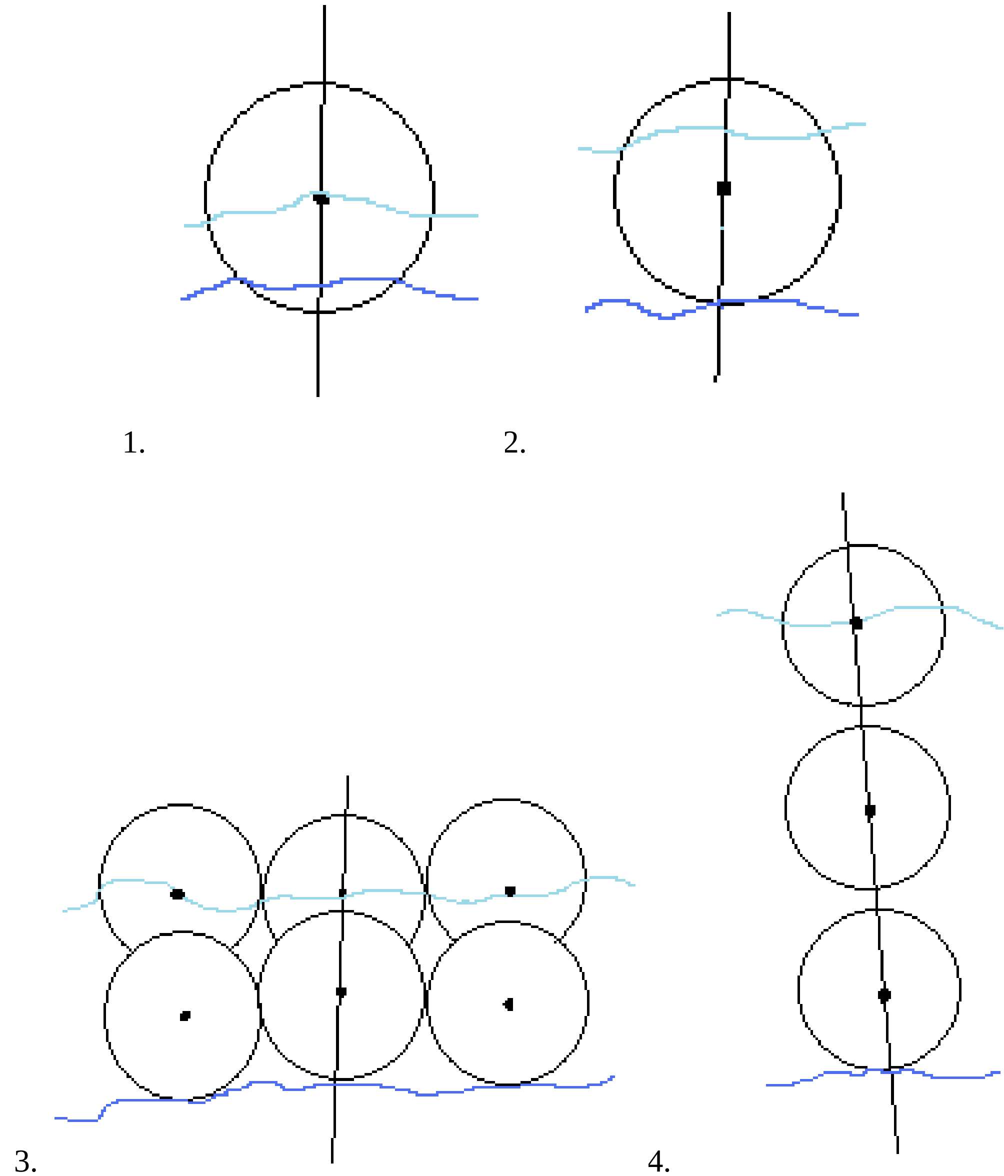

Figure 5. Plot configuration based on flow band width.

Task 4) Draw a map of the plot on the data sheet indicating pertinent information such as the river location, wetted and dry area, entrapments present, and location where fish were recovered. Clearly illustrate the dry, wetted and submerged areas with measurements to the nearest .5 m. This information will be used to calculate delineations between area sampled vs. not sampled and dry vs. wet.

Task 5) Fill out the hard copy datasheet ensuring all the fields are completed.

Using these rules, plots will vary in size depending on flowband and shoreline contour. This methodology will increase the mean number of plots that are sampled during the operational period and clearly identify expectations for stranding plot sampling.

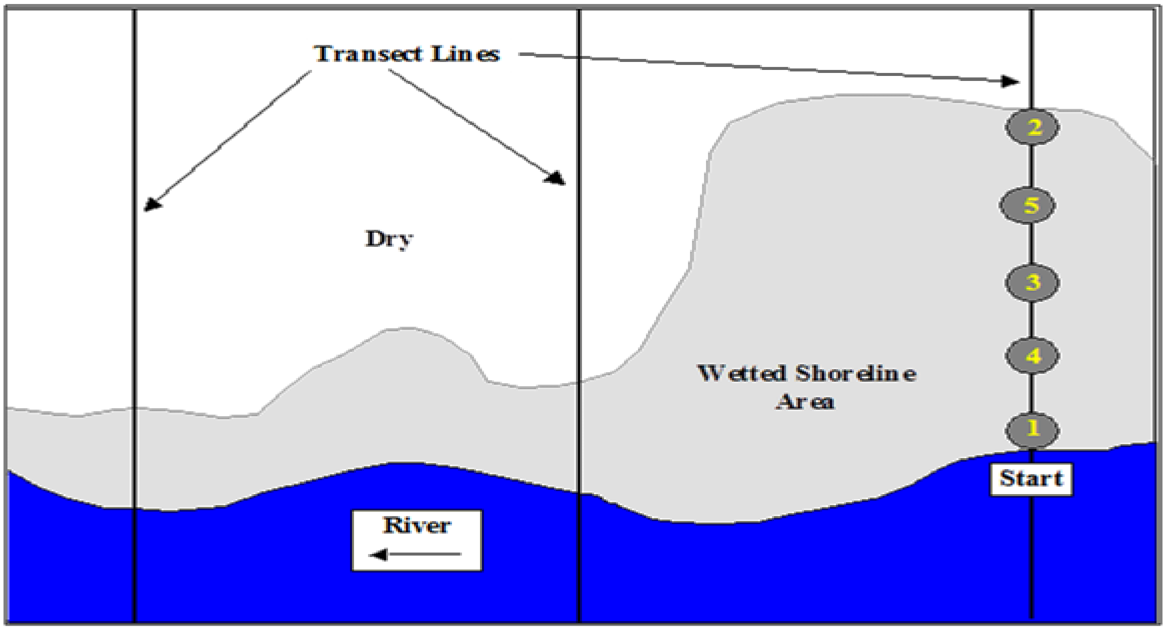

Figure 6. Sampling scheme for stranding site within wide flow bands and along transect lines.

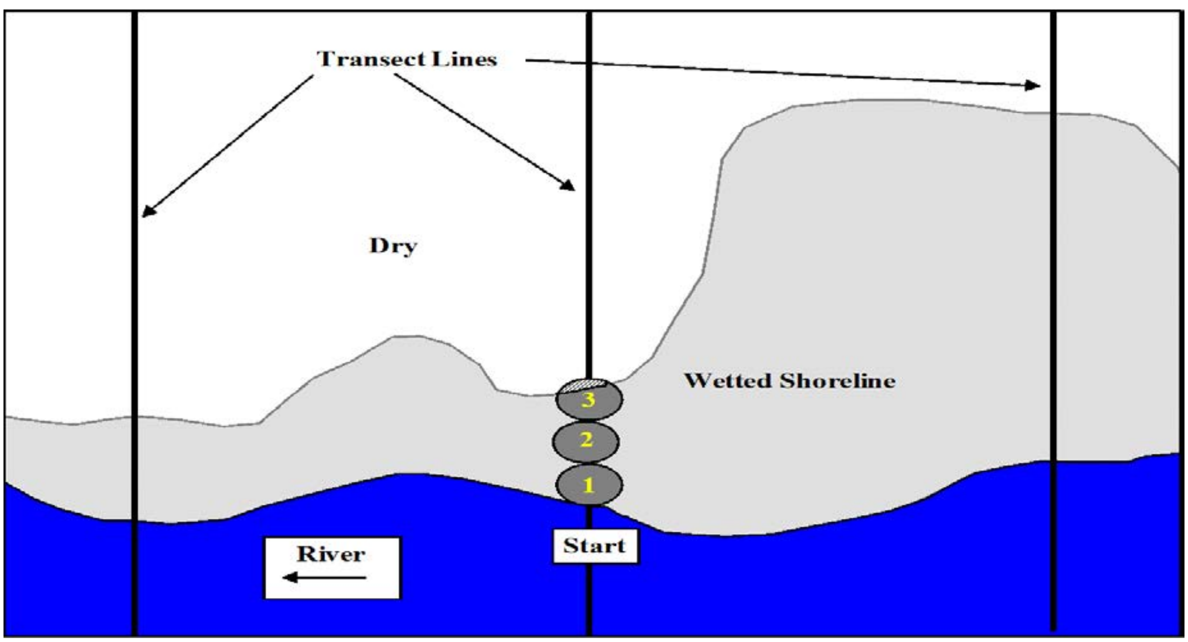

Figure 6. Sampling scheme for stranding site within narrow flow bands and along transect lines.

Task 6) If the sampling for a given quadrant is complete the crew will move to the next sampling transect provided by the Model. Follow the protocols listed above. Continue to sample until the shift is complete.

3.2.2 Physical data for each plot

The following physical data will be collected at each plot selected for sampling:

A) Site ID: Without spaces or punctuation the site ID should be group designation (i.e. B), transect number (1-360), shoreline (RS, LS, etc.) and plot number (1-6) (ex. B125RS02).

B) Date and Time: Precision is important to compare trends in timing of stranding events.

C) GPS Location: At the center of each plot record the latitude and longitude on the datasheet and collect waypoints with the Garmin GPS and Trimble.

D) Substrate size and embeddedness or % fines: Record embeddedness and the dominant and subdominant substrate size as classified according to a modified Wentworth code (Platts et al. 1983) (Figure 4);

E) Vegetation density:

1 - None
2 - Sparse
3 - Moderate
4 - Dense
5- Too dense to sample

F) Entrapments Present: Record yes or no;

G) Size class of Entrapment: Record size of entrapment at time of sampling;
Size categories as measured by diameter:

- 1-5 m
- 5-15 m
- >15 m
- Cannot be sampled due to size or depth;

H) Fish Present in Entrapment: Record the number of fish observed (Visual observation only)

3.2.3 Biological data for each plot

The following biological data will be collected at each site selected for sampling:

•The number and species of fish collected within the sample plot.

•Evidence of piscivorous avian and mammalian animals in the immediate vicinity of sample plots.

3.2.4 Calculating Sample Area

Do not sample entrapments. Record physical and biological data listed for entrapments in Section 3.2.2. Be sure to include a scale diagram with measurement of all entrapments within plot boundary. Record the GPS coordinates at the center of the entrapment. Sites that are sampled in their entirety will be labeled "All" indicating that all of the area within the site was surveyed. The sampled area within partial sites, either due to the wetted area within the site or when an entrapment is present, will be calculated with an excel plot simulation diagram. A box plot overlay will be used as a back-up method to rectify discrepancies. Either the number of boxes in the plot that were not sampled or the number of boxes that were sampled can be counted. The number of boxes divided by the total number of boxes in the Grid will yield an estimate of the area sampled.

For example, if there's an entrapment that covers 10 boxes of the plot:

40 of 50 boxes were sampled
40 (boxes sampled) ÷ 50 = 0.80;
0.80 x 78.5m2 = 62.8m2 sampled

3.3 Estimating sampling efficiencies for stranding

On those days when flow fluctuations are not sufficient in magnitude to produce a measureable effect in river elevation, field sampling efficiency will be evaluated.

Task 1). A test site in the Hanford Reach will be selected from the site maps that contains variable habitat similar to that encountered during sampling.

Task 2). The crew will use frozen juvenile fall Chinook collected either from the PRD Hatchery or from stranding and entrapment events which resulted in mortality earlier in the year. These frozen samples should be transported in a small hard sided ice chest to keep the samples from spoiling or getting disfigured. Fry will be adipose clipped to distinguish sample fry from the general population.

Task 3). Upon arrival at the site, the test proctor will delineate a survey area with flags, selecting locations with divergent substrate and vegetation types. Habitat characteristics which should be represented during these efficiency trials include:

- Type 1: High percentage of fines and/or embeddedess, and no vegetation
- Type 2: Mixture of fines and cobble with moderate embeddedness and sparse vegetation
- Type 3: Moderate to large cobble, sparse to no vegetation
- Type 4: Moderate vegetation
- Type 5: Dense vegetation

Task 4). The test proctor will be responsible for dispersing the fry within each sample site. A minimum of 1 and a maximum of 10 fry will be dispersed per site at the discretion of the proctor. Chinook should be placed in a location in each site where they would be typically found, e.g. adjacent to cobble, base of vegetation, bottom of depressions. The crew will be allotted ample time to complete the sampling at each site. Start and stop times will be recorded. Crew members should be rotated between the sample plots to account for human factors (i.e. experience, eyesight, attention, etc.) Unused Chinook should be saved for future testing.

Task 5) All data should be recorded on site and proofed for accuracy and completion. The test proctor may use this as a training experience to point out important trends and failings amongst samplers. An attempt should be made to complete these trials with at least 50 fish throughout the year.

4.0 Data Management

GPS receivers/data loggers will be used to record data in the field. Each field crew will have a backup receiver, as well as hard copies of maps and data sheets to ensure that no down time occurs. A data dictionary will be uploaded to Trimble data loggers and used to record site characteristics and fish presence. As a result, data entry will be intuitive in the field, and effort in the office will be reduced by direct downloads to the “Master Database”. The database structure will allow data queries and extracting specific datasets for analysis will be straight forward. Requirements for analytical tasks will also be integrated into the database design. This process will allow efficient transfer of data from the field to the office database. All GPS’s and data loggers must be downloaded weekly to the appropriate files on the primary data management computer. Hard copies of the data forms will be compiled and stored in three ring binders and organized by bi-weekly period and data. A routine and rigorous data entry and QA/QC schedule must be maintained throughout the survey season to ensure completion of bi-weekly reports on time.

5.0 Data analyses

The protocol described in this appendix is for collection of field data. Methods of statistical analyses and estimates of loss will be consistent with previous stranding and entrapment studies. Expanded analysis techniques may be employed as technology advances and trends develop to evaluate these impacts. Specific methods will be described in annual reports.

Literature Cited

Anglin, D. R., and 7 coauthors. 2006. Effects of Hydropower Operations on Spawning Habitat, Rearing Habitat, and Stranding/Entrapment Mortality of Fall Chinook Salmon in the Hanford Reach of the Columbia River. Prepared for the U.S. Fish and Wildlife Service//U.S. Geological Survey// Washington Department of Fish and Wildlife// Yakama Nation// Columbia River Inter-Tribal Fish Commission// Alaska Department of Fish and Game, Vancouver, WA.

McMichael, G. A., and 12 coauthors. 2003. Subyearling Chinook salmon stranding in the Hanford Reach of the Columbia River. Battelle-Pacific Northwest Division Report prepared for Public Utility District 2 of Grant County, PNWD-3308, Richland, Washington.

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

Appendix B
GCPUD Response to Comments

Source	Comment	Response
Columbia River Inter-Tribal Fish Commission – Written comments submitted 1/7/13	Figure 4, the inset is difficult to make out. Perhaps make it a bit smaller to get it below the white dots and then give it some other colored background to make it apparent it is not part of the main figure.	The figure was modified to address this comment before the report was finalized.
Columbia River Inter-Tribal Fish Commission – Written comments submitted 1/7/13	Page 38 states that "detection of stranded and entrapped fish may have been reduced and the estimates of stranding and entrapment impacts may have been biased low." Do you have any estimates as to how much biased low these estimates may be?	Previous studies recognized sampling bias, but did not attempt to quantify it. Mark-recapture trials were incorporated into the 2011-13 studies, but estimates of sampling bias are limited by data availability. Vegetation mapping and efficiency sampling would need to be increased significantly to generate precise estimates of bias. The current approach balances sampling effort and provides readers a relative measure of sampling efficiency and bias.
Columbia River Inter-Tribal Fish Commission – Written comments submitted 1/7/13	Can you make any estimates as to what the losses would be in terms of returning adults since this tends to be what most are concerned with?	The Fall Chinook Work Group, Hanford Reach Working Group, and co-authors of the report are working to develop methodologies to provide context for losses from stranding and entrapment of fall Chinook salmon in the Hanford Reach. This comment will be addressed with more comprehensive analyses and discussion that will be included in the report for monitoring completed during 2013.
Fall Chinook Work Group - Discussion during the 1/8/13 meeting	Members of the FCWG agree that context is important for the estimates of losses due to stranding and entrapment.	This comment will be addressed with more comprehensive analyses and discussion that will be included in the report for monitoring completed during 2013.
Fall Chinook Work Group - Discussion during the 1/8/13 meeting	Sample variation for entrapment estimates were relatively high for 2012 and the FCWG discussed the potential to improve precision.	During previous studies, temporal and spatial stratification were used to improve the precision of entrapment estimates. Entrapment size is likely related to sample variation, so the co-authors of the report will investigate the potential to stratify by entrapment size. The results of the investigation will be discussed during the February meeting of the FCWG to determine whether additional or alternative stratification will be implemented in 2013.