Grant County
PUBLIC UTILITY DISTRICT

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January 15, 2014

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) 2013 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 2013 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 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.*

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[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.

Consistent with the FERC ordering paragraph provided above, the enclosed document details the sampling methods and results from 2013 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 18, 2013 through January 8, 2014 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,

Ross Hendrick
License Compliance and Implementation Services Manager

Cc (via email): Fall Chinook Working Group

Assessment of Losses of Juvenile Fall Chinook Salmon in the Hanford Reach of the Columbia River in Relation to Flow Fluctuations in 2013

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

Prepared By
P. Hoffarth[1]
C.J. Murray[2]
R.B. Langshaw[3]
S. Remples[1]
G.A. McMichael[2]
J. Johnson[1]
Y.Xie[2]
M.C. Richmond[2]
W.A. Perkins[2]
S.E. Niehus[2]
A.C. Hanson[2]
S.L. Haeseker[4]
J.Skalicky[4]

[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 2014

Suggested citation for this report:

Hoffarth, P., C. J. Murray, R. B. Langshaw, S. Remples, G. A. McMichael, J. Johnson, Y. Xie, M. C. Richmond, W. A. Perkins, S. E. Niehus, A. C. Hanson, S. L. Haeseker, J. Skalicky. 2014. *Assessment of losses of juvenile fall Chinook salmon in the Hanford Reach of the Columbia River in relation to flow fluctuations in 2013*. Report prepared for Public Utility District No. 2 of Grant County, Washington.

Executive Summary

Operations to increase survival of emergent and rearing fry under the 2013 Hanford Reach Fall Chinook Protection Program began March 2 and ran through June 9, 2013. 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 effect of stranding events. The Hanford Reach was delineated into 90 sites, one kilometer in length, and each site was further delineated into four quadrants. In total, field crews visited 188 of the 360 available quadrants during the 2013 season. Based on the randomizing Stranding/Entrapment Site Selection Model output, field crews visited quadrants on 351 occasions to conduct entrapment sampling. Flow fluctuations were insufficient to create entrapments and/or no entrapments were found on 183 occasions (52%). In the remaining 168 quadrants, 614 entrapments were sampled and 128 contained Chinook salmon (21%). A total of 1,923 juvenile fall Chinook salmon were recovered in entrapments with 88% of these alive at the time of initial sampling. Twenty-three percent of entrapments in the Middle section contained fall Chinook salmon, 22% in the Lower, and 20% in the Upper section. More entrapments were created in the Upper section, but the highest juvenile fall Chinook salmon density (5.3/entrapment) was observed in the Middle section. Computer simulations estimated that 116,504 entrapments were formed in the Hanford Reach throughout the season. After accounting for sampling frequency and the two-stage sampling design, we estimate that 354,467 Chinook salmon were entrapped in 2013 with percentile-based, bias-corrected, 95% confidence interval bounds of 181,635 and 646,029. 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, 77% of the 614 sampled entrapments were determined to reach lethal conditions, however only 52% of entrapments containing fish reached lethal conditions. These lethality rates were applied to the estimates of entrapped fall Chinook salmon to generate estimates of mortalities caused by entrapment. This resulted in an estimate of 267,453 mortalities caused by entrapment, with percentile-based, bias-corrected, 95% confidence interval bounds of 134,851 and 485,225.

Stranding crews visited 176 quadrants to assess stranding impacts during the field season. Of these, 39 quadrants (22%) exhibited insufficient flow fluctuation (<1 m wetted shoreline) to qualify for sampling or could not be sampled. From the remaining 137 quadrants, a total wetted area of 33,432 m^2 was surveyed in 733 complete or partial plots. A total 50 fall Chinook salmon were recovered within the sampled plots. The highest numbers of stranded fall Chinook salmon (27) were collected in the Middle section of the Hanford Reach. This section also exhibited the highest number of fish stranded per unit area sampled, with one Chinook salmon found every 336 m^2; almost twice as dense as in the Lower section, and nearly five times more dense than in the Upper section. The estimated loss due to stranding of Chinook salmon in the Hanford Reach in 2013 was 184,123, with percentile-based, bias-corrected, 95% confidence interval bounds of 79,149 and 488,088.

Results from recent stranding and entrapment studies indicate that conditions in the Hanford Reach in terms of flows, flow fluctuations, and temperatures were more favorable for avoiding stranding and entrapment during 2013. Estimates of juvenile fall Chinook salmon that died as a result of stranding and entrapment in the Hanford Reach were significantly lower than the previous two years. Columbia River flows in the Hanford Reach were slightly above the long-term mean during the 2013 spring season, but were well below that in 2011 and 2012. Given the relationships between discharge, river fluctuations, dewatered area, entrapment creation, and

estimates of stranding and entrapment, we attribute much of the reduction in the loss estimates of fall Chinook salmon to flow conditions during 2013.

Although there is considerable uncertainty about the combined stranding and entrapment loss estimate of 451,576 juvenile fall Chinook salmon, an attempt was made to place this loss in the context of the Hanford Reach fall Chinook salmon population. Pre-smolt 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 during 2013 was relatively low in comparison to the estimated number of juveniles produced by the 51,774 adults estimated to have spawned in the Hanford Reach in the fall of 2012.

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 slightly modified prior to each of the 2012 and 2013 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 Jarred Johnson, Casey Green, Kelly Martin, Andrew Majeske, Dan Kinkel, Jeff Brosnan, Kirsten Killand, Erik DeSilva, Wade Baker, Josh Fross, Ned Hastings, Sara Gerlitz, 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. Debbie Firestone edited and formatted the report. 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 provided valuable insight and helped to improve the study design to assess losses throughout the entire Hanford Reach. The 2013 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.

Mortality occurs almost immediately after fish are stranded, but mortality may not occur for fish in an entrapment if it is reflooded before conditions become lethal.

1.1 Background

The Hanford Reach Fall Chinook Protection Program Agreement (HRFCPPA) was signed by Public Utility District No. 2 of Grant County, Washington (Grant PUD), Public Utility District No. 1 of Chelan County, Washington (Chelan PUD), Public Utility District No. 1 of Douglas County, Washington (Douglas PUD), 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 PUD, Chelan PUD, and Douglas PUD 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 PUD, 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 slightly modified again prior to each of the 2012 and 2013 field seasons (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 that fall Chinook salmon 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 operation 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 2013 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 2013 Hanford Reach stranding and entrapment assessment.

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 typically 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.

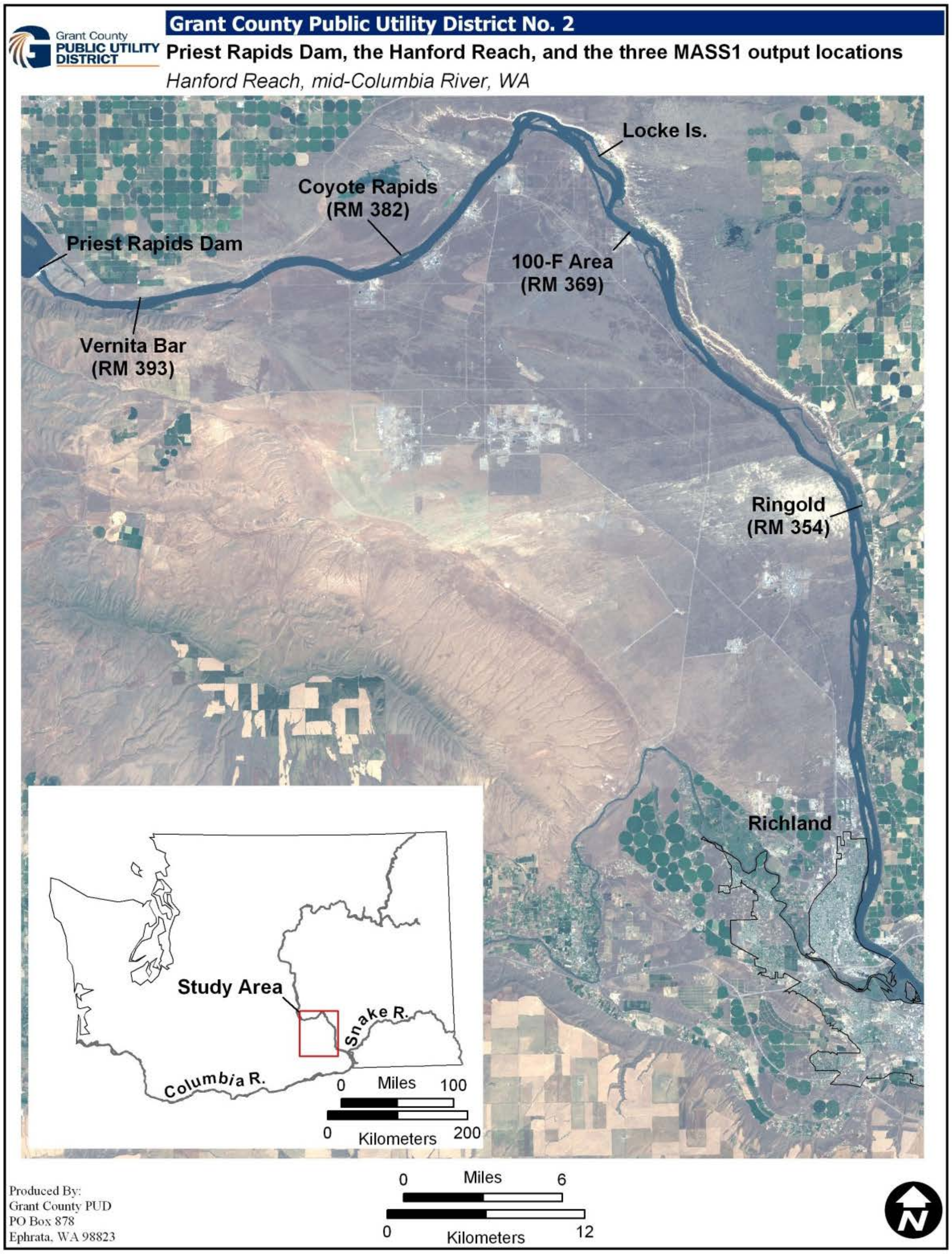

Figure 1 **Location of the Hanford Reach on the Columbia River in southeastern Washington State.**

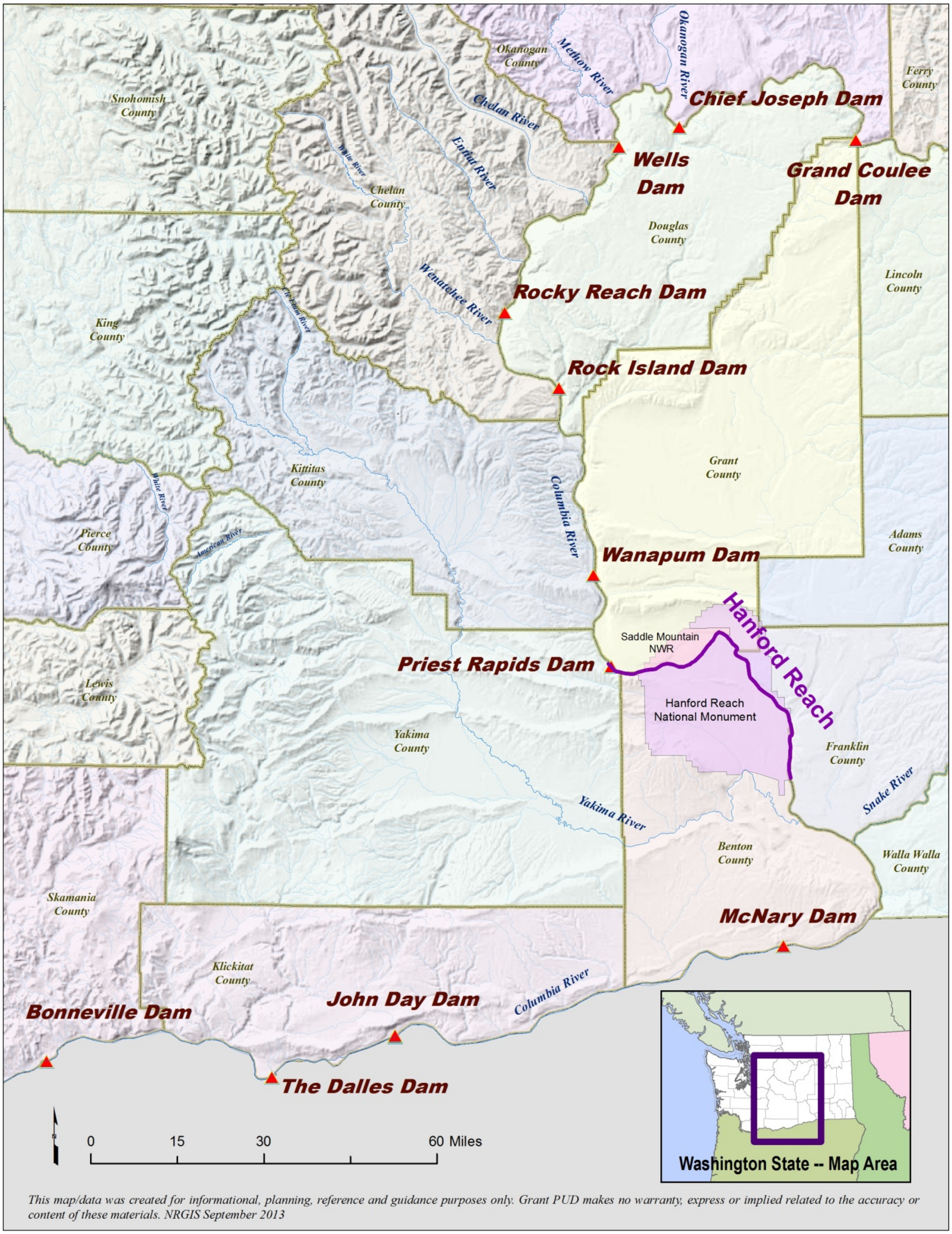

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Figure 2 **Major hydroelectric facilities located on the Columbia River.**

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; Hoffarth et al. 2012, 2013) 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, 2013 Field Sampling Methods, provided in Appendix A of this report. 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, Haeseker unpublished data and analyses). 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; Haeseker unpublished analyses; Hoffarth et al. 2013). 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) delineated by transect lines. 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 and 2013 field seasons, 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 the size and timing of discharge fluctuations from Priest Rapids Dam resulted in insufficient dewatered shoreline in downstream areas during sampling hours. Sample sites consisted of both main-channel river banks and any island shorelines. Entrapment sampling was conducted from the randomly selected transect downstream through the second adjacent quadrant (500 m total), while sampling plots surveyed for stranding were distributed directly along or adjacent to the randomly selected transect line. 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. The change of plot alignment dramatically increased the area sampled during 2012 and was continued in 2013. 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. However, no stranded juvenile fall Chinook salmon were found in sampling the dry shoreline immediately adjacent to the wetted area (Hoffarth et al., 2013), so only the wetted shoreline was sampled in 2013.

Table 2 **Delineations for the eight spatial temporal strata for the 2011 – 2013 evaluations for stranding and entrapment of juvenile fall Chinook salmon in the Hanford Reach including the number of 1 rkm 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	

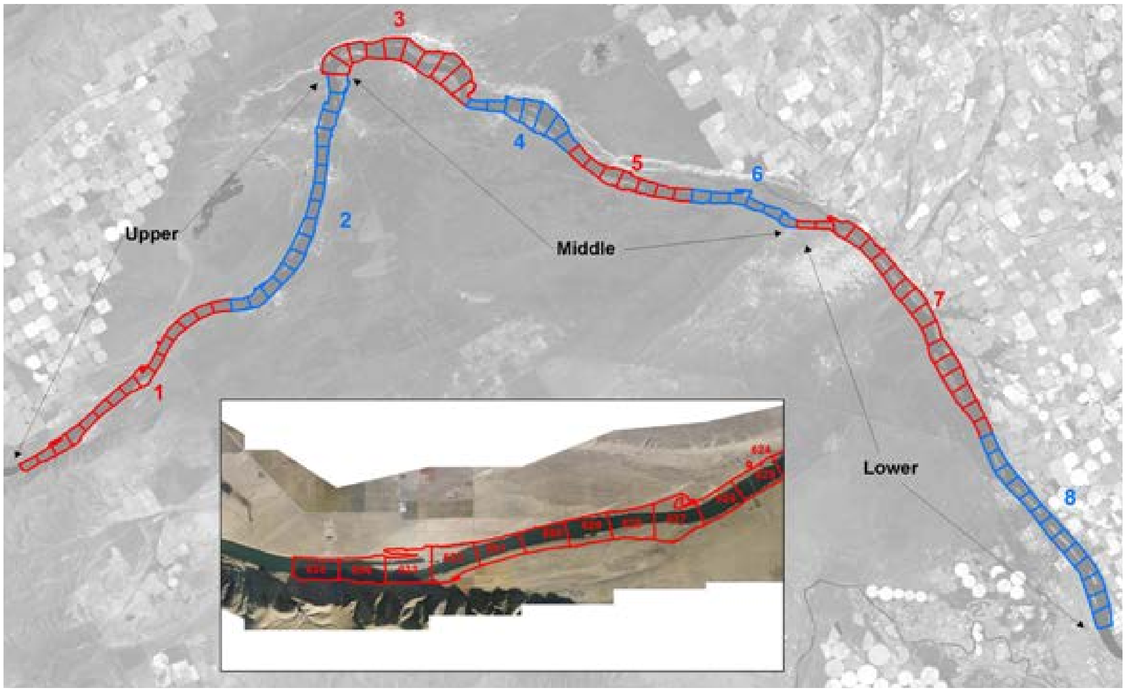

Figure 3 **Spatial strata including segments, reaches, and sites for the 2011 – 2013 evaluation of stranding and entrapment of juvenile fall Chinook salmon in the Hanford Reach.**

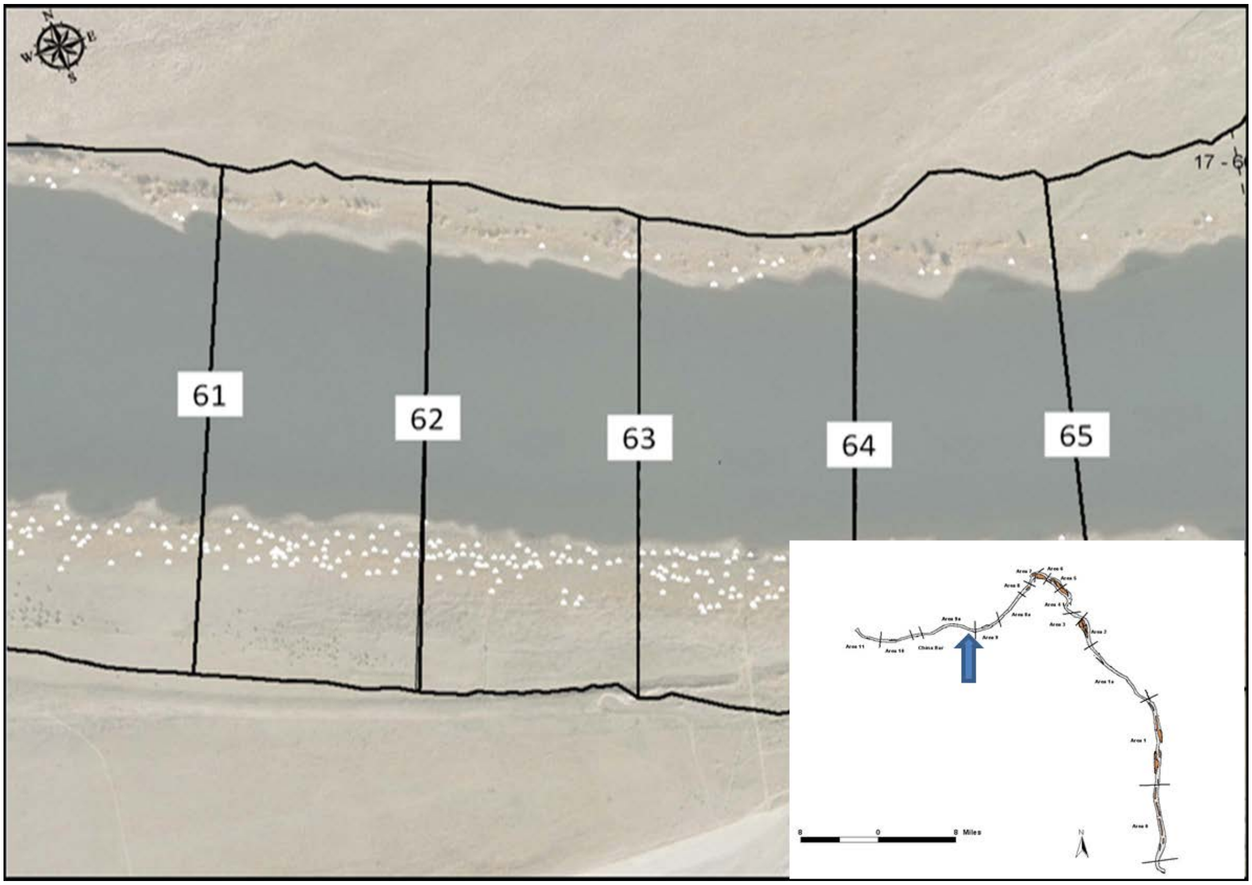

Figure 4 **Examples of an individual 1 rkm sample site, delineated into quadrants with transects (i.e., boundaries) located at 250 m intervals. White dots represent entrapment locations identified during the 2003 – 2007 assessments. The blue arrow in the inset on the lower right shows the location of this particular sample site within the Hanford Reach study area.**

A total of 360 quadrants were defined during an entrapment evaluation in 2007 (Haeseker unpublished analyses) which were used for the 2011 – 2013 evaluations. Several factors were used to determine the randomly selected quadrants sampled on any given day including the following:

- For a quadrant to be eligible for selection, the width of dewatered shoreline (measured by river top-width) within the most recent 24 hours must be greater than 9.88 m (32.4 ft.). This criterion was changed from a decrease in water-surface elevation after the 2011 season to increase sampling efficiency (Figure 5). It was determined that dewatered area is strongly correlated with the number of entrapments created. Thus, the top-width criterion increased the probability that the SESSM selected quadrants with entrapments present.
- 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/transect 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 quadrants/transects based on the criteria described above. The list of candidate locations 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 locations.

After being sampled, quadrants/transects 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.

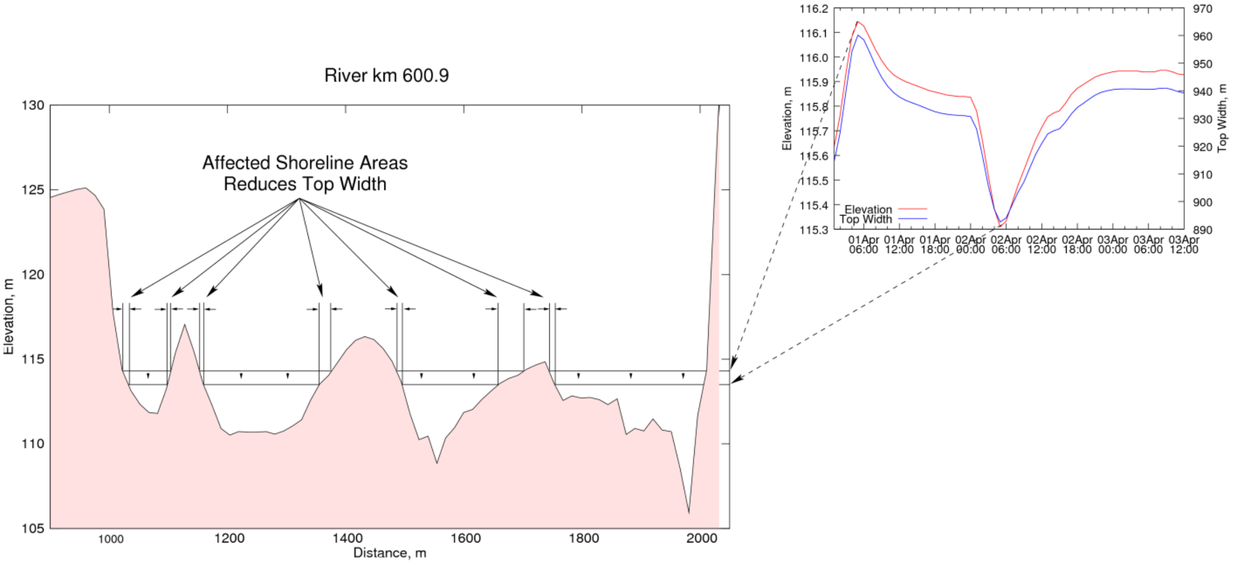

Figure 5 **Example of how top width is related to changes in river water surface elevation in the Hanford Reach of the Columbia River.**

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 2 and continued through June 9, 2013. 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 wetted shorelines, five plots were sampled. The center point of the first plot was 5 m inland from the water's edge along the transect line (Figure 6). A scaled drawing was completed for each plot that included information such as the river in relation to the plot location, the dewatered area, entrapments, and location where fish were recovered. When the wetted shoreline area was greater than approximately 50 meters, 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 (added in 2012 and 2013) 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 line. 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.

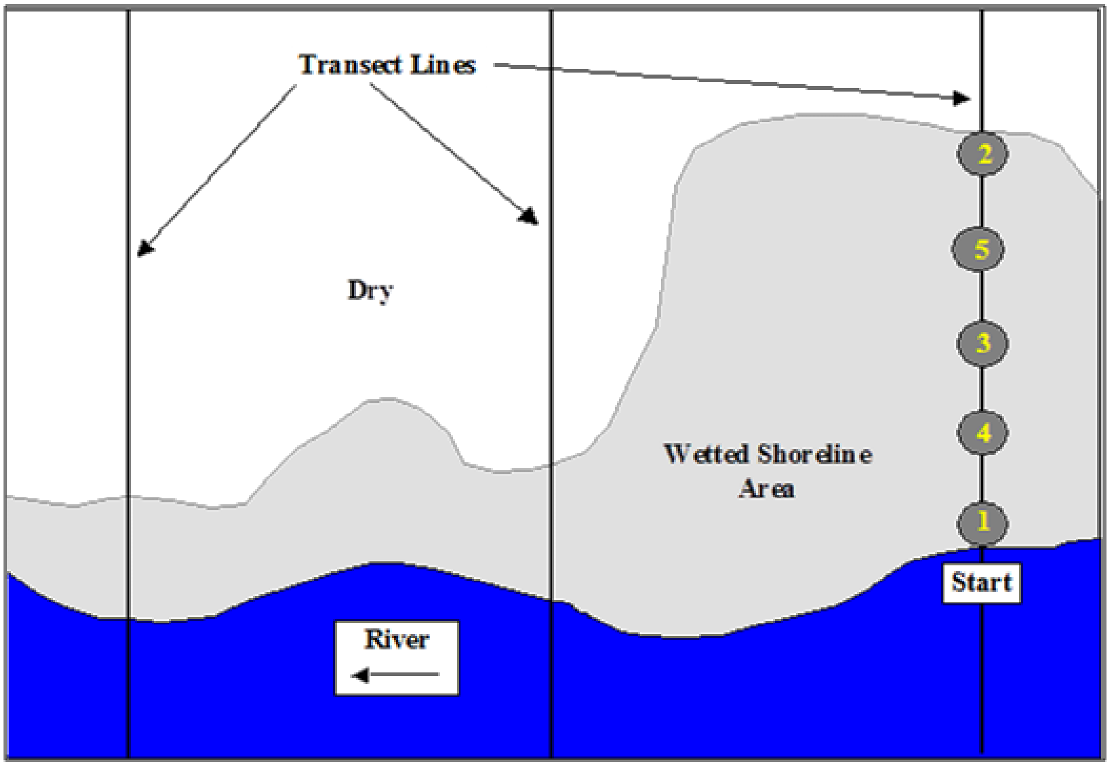

Figure 6 **Sampling scheme for stranding sites within wide dewatered areas.**

Table 3 **Parameters for plot configurations during field stranding assessments in the Hanford Reach. A visual representation of these configurations is presented in Figure 7.**

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

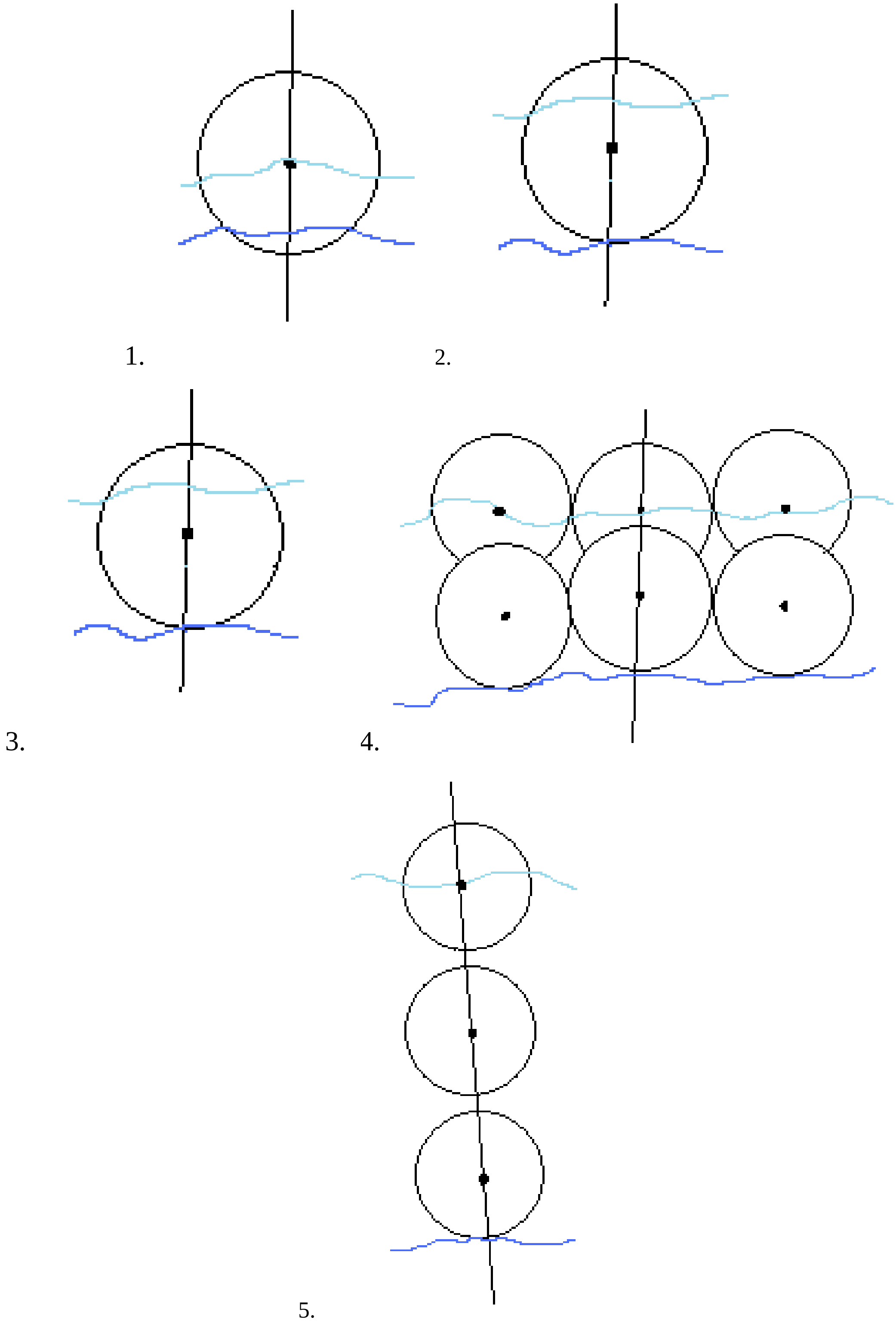

Figure 7 Plot configurations for stranding sampling based on wetted shoreline width. The parameters for these illustrations are outlined in Table 3. The dark blue line represents the waterline at the edge of the river and the light blue represents the wetted line. In examples 1 and 2, additional plots 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, measured, weighed and adipose-clipped. Twenty-nine plots were selected within the sampling area that had variable vegetation densities. One crew member dispersed two to ten 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. Efficiency trials were not “blind’, but crews attempted to maintain consistent sampling effort at all times.

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 February 1 to June 30, 2013.

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 design 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. 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 (78.5 m^2), were surveyed. The sampling plan used for the study can be found in Appendix A.

For the k-th temporal-spatial stratum (k=1,…,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 ith primary unit (quadrant) of the kth stratum is,

$y_{ik} = \sum_{j=1}^{M_{ik}} y_{ijk}$ and the total number of stranded Chinook in the kth 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 kth 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 ith primary unit within the kth stratum. The estimate of the total number of stranded Chinook salmon within the ith primary unit is $\hat{y}_{ik} = A_{ik} \times \hat{r}_{ik} = A_{ik} \dfrac{\sum_{j=1}^{m_{ik}} y_{ijk}}{\sum_{j=1}^{m_{ik}} a_{ijk}}$, obtained by expanding the stranding rate of the i-th quadrant of the kth 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 kth stratum is $\hat{\tau}_k = A_k \times \hat{r}_k = A_k \dfrac{\sum_{i=1}^{n_k} \hat{y}_{ik}}{\sum_{i=1}^{n_k} A_{ik}}$, which is expanding the stranding rate of the k-th stratum estimated based on the n_k quadrants surveyed in the kth 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 ith primary unit within the kth stratum,

$\hat{r}_{ik} = \dfrac{\sum_{j=1}^{m_{ik}} y_{ijk}}{\sum_{j=1}^{m_{ik}} a_{ijk}}$ and the stranding rate in the k-th stratum, $\hat{r}_k = \dfrac{\sum_{i=1}^{n_k} \hat{y}_{ik}}{\sum_{i=1}^{n_k} A_{ik}}$, 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.

As during 2012, nearly all the quadrants that were sampled during 2013 contained at least three plots (Table 4). 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 three quadrants, 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 2013.

Plots in Quadrant	No. of Quadrants	%
17	2	1%
12	2	1%
10	1	1%
9	7	5%
8	3	2%
7	3	2%
6	37	27%
5	47	34%
4	1	1%
3	31	23%
2	1	1%
1	2	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 = $\text{est}_{\text{Boot}} - \text{est}_{\text{Data}}$. The usual reason for estimating the bias is to provide a bias-corrected estimate: $\text{est}_{\text{Bias-Corrected}} = \text{est}_{\text{Data}} - \text{bias} = 2\ \text{est}_{\text{Data}} - \text{est}_{\text{Boot}}$, 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

As with stranding, entrapment sampling in the Hanford Reach was conducted from March 2 to June 9, 2013. 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, but the crews were independent.

The entrapment sampling crews used a systematic search pattern and sampled all entrapments, defined as an enclosed depression with a wetted surface area ≥1 m in diameter, encountered within each sampled quadrant. Crews began sampling along the shoreline and moved inshore along the quadrant boundary (i.e., transect) until they reached the inland edge of the wetted shoreline. The crews moved parallel to the inland wetted edge in the downstream direction. The crews would then turn back towards the river ensuring all entrapments could be observed between survey lines (Figure 8). The objective was to complete this pattern along all wetted shorelines and islands until all entrapments were sampled within the two quadrants. If all shorelines within both quadrants were completely sampled, crews moved to the closest adjacent quadrant on the randomized list and continued sampling until their work shift was complete.

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 effectively sampled because it’s too large or deep.

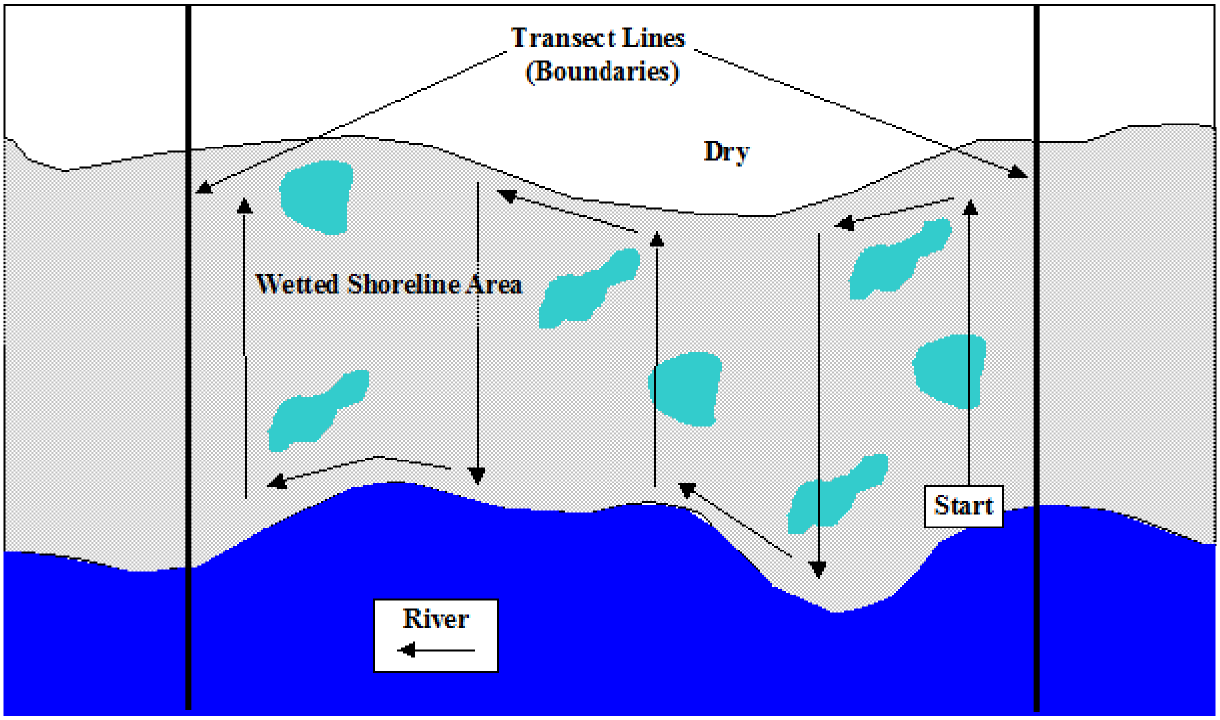

Figure 8 **Search pattern for entrapment sampling. In 2012, the sample area was double what is shown in this figure (i.e., 500 m between sample transect lines).**

If necessary, entrapments were revisited and remeasured to help to determine the fate of each entrapment. 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 9)
- Type 4) Extremely dense grass, brush, trees or a combination of all three.
- Type 5) Vegetation too dense to accurately sample.

Figure 9 **An example of entrapments formed above the usual high water mark in the Hanford Reach with moderate vegetation densities, 2011.**

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 or captured, and the number of live and dead fish of other species observed or captured.

3.3.2 Sampling Efficiency

Entrapment sampling efficiency was evaluated for 26 entrapments with Chinook salmon present to assess the efficiency of each of the capture methods used in the study. Captured Chinook salmon fry were caudal-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 can be calculated in two ways. Mark recapture efficiency was calculated by dividing the number of recaptured fish with marks (caudal-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

The same MASS2 simulation used to estimate dewatered area (Section 3.2.3) was used to estimate the number of entrapments that were created throughout the Hanford Reach. Individual entrapment locations that were identified during previous studies were used to create a population of entrapments (*n*=13,118) in the Hanford Reach. The locations for the population of entrapments were used to identify the MASS2 computational cells used to simulate entrapment histories for each entrapment location. An entrapment event was determined to have occurred when a computational cell 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) if the population of entrapments is stable through time. 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 2013 evaluation, Columbia River discharge was in the range of elevations that are well surveyed except for the period from May 8 to June 4 (Figure 11). Discharge was above 225 kcfs for most of the two temporal strata from May 8 through June 4th, so most of the population of known entrapment locations was not dewatered during that four-week time period. Thus, enumerating entrapments based on the history of known entrapment locations underestimates the actual number of entrapments that were created during the season. As during previous years, we addressed this limitation by creating an area-based entrapment estimate 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 $\hat{y}_{ik} = A_{ik}\frac{\sum_{k=1}^{6} N_{ik}}{\sum_{k=1}^{6} A_{ik}}$ 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,…,6 represents the six temporal strata for which the vast majority of flows were less than 225 kcfs.

3.3.4 Determination of Fate of Entrapped Chinook Salmon

The fate of each sampled entrapment was determined either in-season or post-season for the purpose of estimating fall Chinook salmon fry mortality. Of the 614 entrapments sampled, the fates could be determined in the field for 285 entrapments. 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 – reflooded
- unknown.

Fates were assigned to entrapments with unknown fates 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 2013. 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 10, 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 then reconnected to the river.

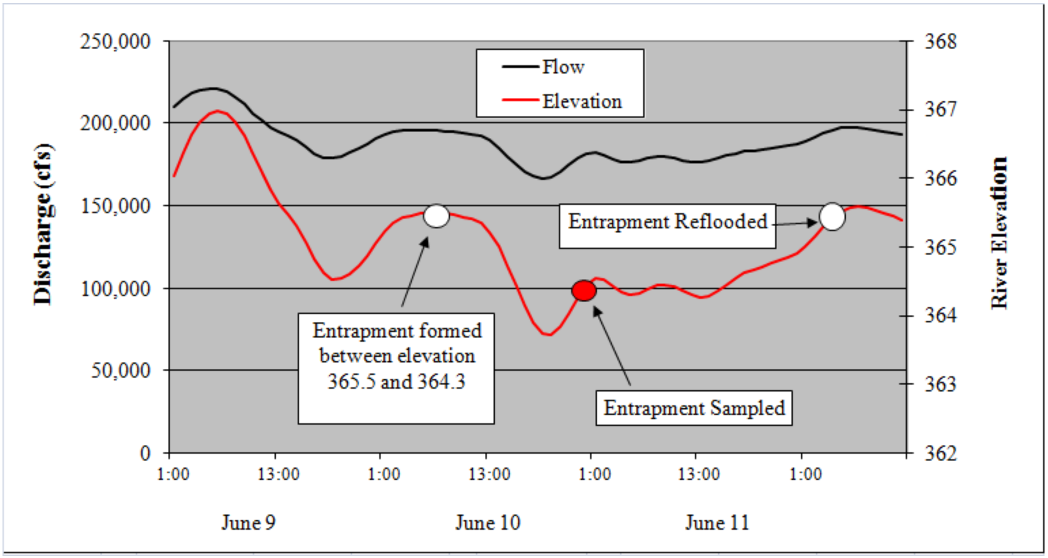

Figure 10 **Example of river discharge (black line) and the water surface elevation data from MASS1 (red line) and the time an entrapment was isolated from the river and then reflooded and reconnected to the river (white circles) in reference to when it was sampled in the field (red circle).**

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 2013. When the duration between depth measurements was too brief (i.e., less than 30 minutes), the median drainage rate for entrapments from 2013 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 drainage rate is slower than the mean (1.6 vs. 2.0 cm per hour), but was used to determine entrapment fates because it is less influenced by the wide range of variation in drainage rates. 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.

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 *i*th 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 *k*th 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 prevented sampling in some strata. To ensure all strata could contribute to entrapment and variance estimates, some strata were aggregated within sampling periods. Aggregate strata that contained at least two sampled sites were created by combining unsampled segments with adjacent segments that were sampled.

3.3.5.1 Estimating Mortality due to Entrapment

Not all entrapments of Chinook salmon result in mortalities. An entrapment can become lethal if it drains or the water temperature rises above the thermal tolerance limit of Chinook salmon. However, entrapments are not considered 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 completed in 2007 using both approaches with the historical data were unbiased over repeated sampling (Haeseker unpublished data and analyses). However, the entrapment lethality approach was much more precise as measured by the coefficient of variation (CV). 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 simulations using the entrapment lethality approach were unbiased and more precise than the fish lethality approach, the entrapment lethality has been used for all analyses since 2007.

Entrapment lethality was defined as an entrapment draining prior to reflooding 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 2013.

3.3.5.2 Quantifying Uncertainty in Entrapment Loss Estimates

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 $\hat{\tau}.^*$.

Analyses of the entrapment data collected 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 2013 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 2013 Flow Conditions

Outflows from Priest Rapids Dam were above average throughout much of the 2013 spring operational period of the HRFCPPA. Mean hourly discharge from Priest Rapids Dam between March 2 and June 9, 2013, was 149.3 kcfs and mean daily flow fluctuation was 38.7 kcfs (Table 5). Flows during 2007 and 2013 were slightly higher than the 10-year mean, while 2011 and 2012 were considerably higher. All four years had different flow patterns, peaking and waning at different times. Maximum daily discharge was highest in 2011 (378 kcfs); however and the mean daily discharge and discharge delta were greatest in 2012 (200.5 and 76.3 kcfs, respectively 75.6; Figure 11).

The impact of these flow regime differences 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 of the water surface elevation changes are expected to decrease as elevation increases. Based on this relationship, the HRFCPPA allows larger daily deltas (fluctuations) when inflows are higher.

Table 5 **Mean, minimum, and maximum hourly discharge (kcfs) including daily fluctuation from Priest Rapids Dam, March 9 – June 22, 2013.**

	Mean Daily Discharge	Mean Maximum Daily Discharge	Mean Minimum Daily Discharge	Mean Daily Discharge Delta
March	80.9	89.4	75.3	15.3
April	160.3	179.5	141.5	39.6
May	197.2	219.8	168.1	53.9
June	175.1	199.0	142.4	61.4
Mean	**149.3**	**166.7**	**130.0**	**38.7**

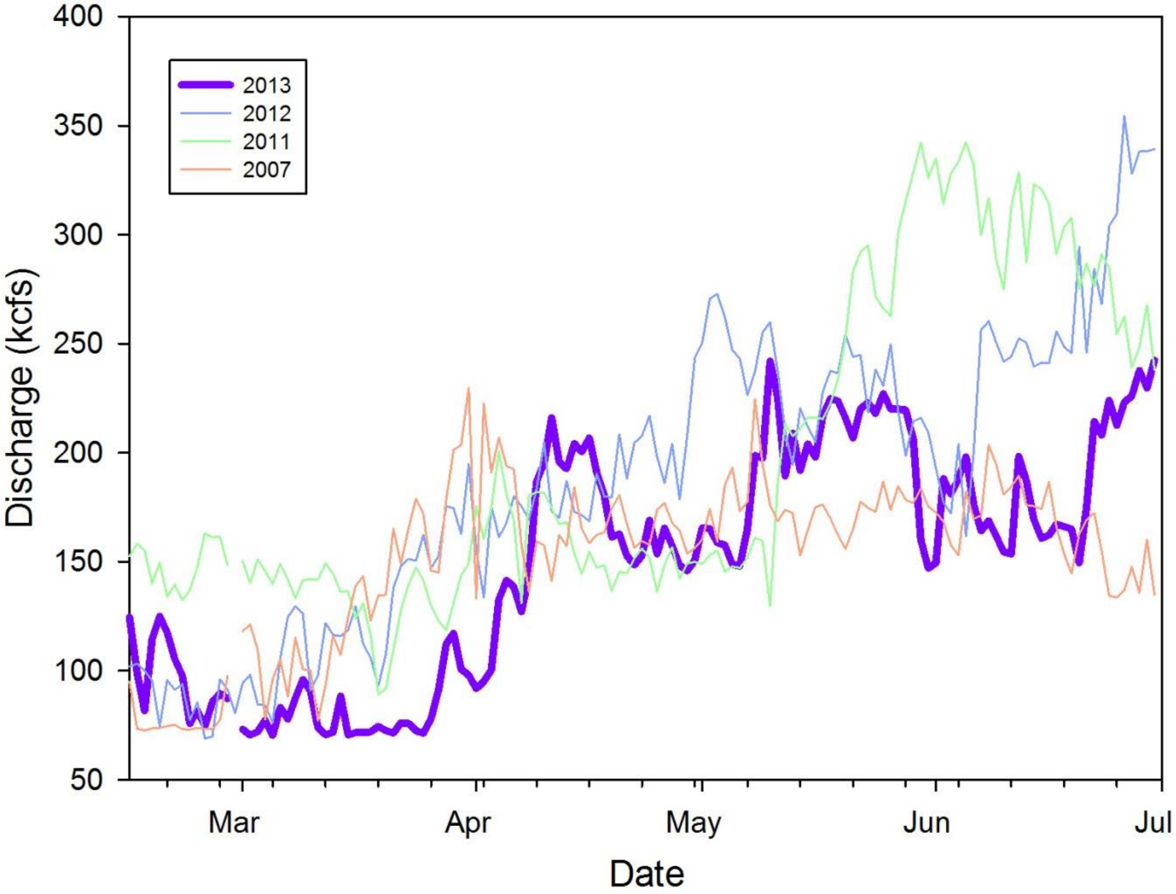

Figure 11 **Mean daily discharge (kcfs) from Priest Rapids Dam, 2007, 2011, 2012, and 2013.**

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 176 quadrants between March 2 and June 9, 2013. Of these, 39 quadrants did not have sufficient fluctuation (wetted shoreline area) to adequately assess stranding impacts. At the remaining 137 quadrants, 733 plots were sampled. The standard plot area was 78.54 m^2 (10-m-diameter circular plot) and the mean plot area was 45.6 m^2. A total wet area of 33,432 m^2 (Table 6) was sampled. A total of 50 juvenile fall Chinook salmon were recovered from the 733 sampled plots (Table 7). The highest numbers of fall Chinook salmon were recovered in the Middle section of the Hanford Reach (segments 3–6; Table 7). 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 6 **Summary of sampling data collected by segment during the fall Chinook salmon stranding evaluation in the Hanford Reach, March 2 – June 9, 2013.**

Section	Segment	Transects Visited	Plots Sampled No	Plots Sampled Yes	Plots (#)	Area Sampled (m^2)	Chinook (#)
Upper	1	45	9	36	177	7,300	7
Upper	2	43	8	35	161	9,322	3
Middle	3	16	4	12	74	3,101	2
Middle	4	18	7	11	95	4,475	24
Middle	5	5	0	5	28	1,224	1
Middle	6	3	1	2	8	264	0
Lower	7	37	8	29	159	6,248	13
Lower	8	9	2	7	31	1,497	0
	Total	176	39	137	733	33,432	50

Table 7 **Summary of sampling data collected by river section during the fall Chinook salmon stranding evaluation, March 2 – June 9, 2013.**

Section	Quadrants Visited	Plots Sampled No	Plots Sampled Yes	Plots (#)	Wet Area Sampled (m^2)	Chinook (#)
Upper	88	17	71	338	16,623	10
Middle	42	12	30	205	9,063	27
Lower	46	10	36	190	7,746	13
Total	**176**	**39**	**137**	**733**	**33,432**	**50**

4.2.2 Sampling Efficiency

Relative to previous years, sampling efficiency evaluation effort was increased during 2013 with 29 trials conducted throughout the season. However sampling efficiency results were similar to previous years, when 12 and four efficiency evaluations were completed in 2012 and 2011, respectively. During 2013, a total of 145 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. Substrate composition and emebeddedness was also included for plots with sparse or no vegetation. As vegetation density increased (e.g., Figure

12), the sampling efficiency decreased (Table 8). In total, 73% of the marked fish were recovered in 2013 and sampling efficiency ranged from 65% to 93% (Table 8).

Figure 12 **Example of fall Chinook salmon fry observed lying in dense vegetation in the Hanford Reach.**

Table 8 **Stranding efficiencies by habitat type for the Hanford Reach, 2013.**

Habitat Type	Vegetation	Substrate/ Embedded	Plots Sampled	Mark-Release (#)	Mark-Recapture (#)	Efficiency (%)
1	None	Fines/ embedded	4	27	25	93
2	Sparse	Mixed/ Moderate embedded	9	45	34	76
3	Sparse/none	Cobble	7	35	25	71
4	Moderate	Mixed	4	15	11	73
5	Dense	Mixed	5	23	15	65
Total			**29**	**145**	**110**	**76**

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 13). A total of 135 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 about half of the 277 million square meters dewatered in 2012 and 69% of the dewatered area of 195 million square meters observed in 2011 (Hoffarth et al. 2013).

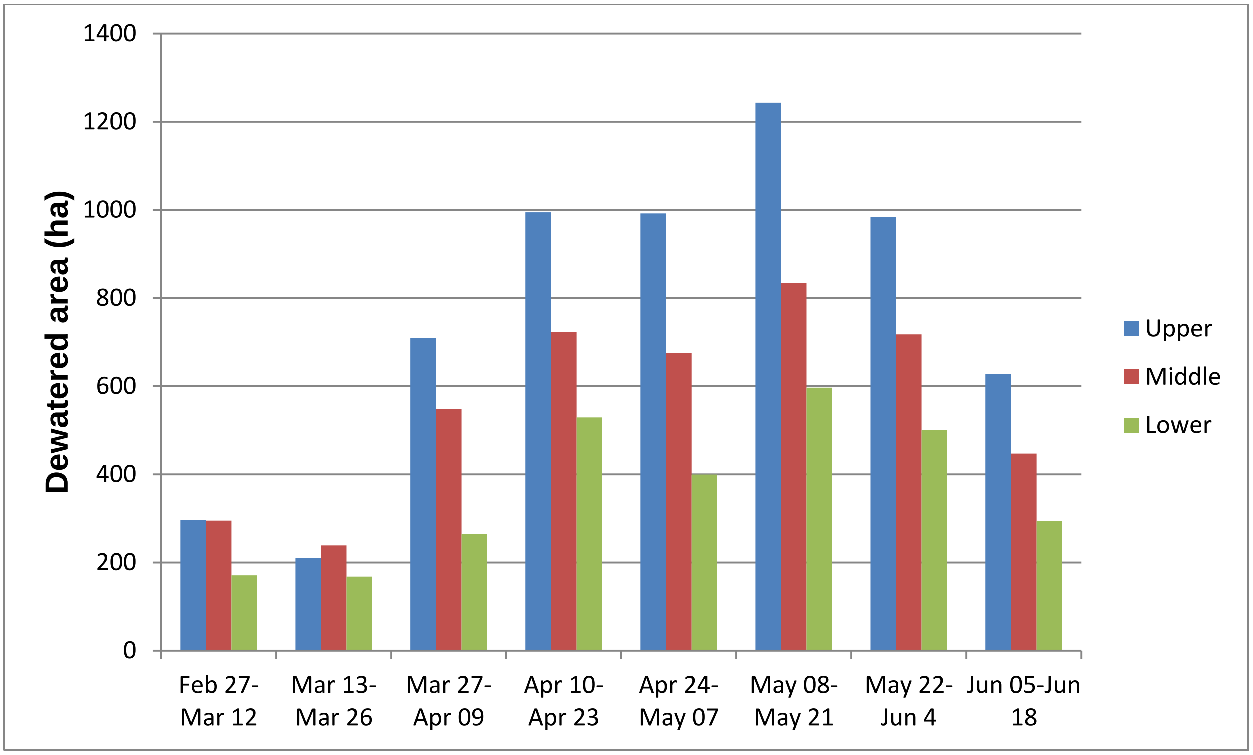

Figure 13 **Dewatered area estimates for the Hanford Reach from the MASS2 model by section and sampling period. It is estimated that a total of 134,587,700 m² was dewatered during 2013.**

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 9. This shows that most of the stranded Chinook salmon were found in the Middle section of the Hanford Reach, with sub-equal amounts found in the Upper and Lower sections. In the Upper and Middle sections, stranding mostly occurred in period 4 (April 24-May 7) and period 6 (May 8-May 21), respectively. Stranding loss in the Lower section was concentrated in periods 2 and 3 (March 13-April 9), which is earlier than that observed in the Upper and Middle sections. 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 14).

Table 9 **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 12.**

	Sampling period								
Section	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
Upper	0	1	0	1	7	0	1	0	**10**
Middle	1	0	1	1	0	23	1	0	**27**
Lower	0	6	5	1	0	0	1	0	**13**
Total	**1**	**7**	**6**	**3**	**7**	**23**	**3**	**0**	**50**

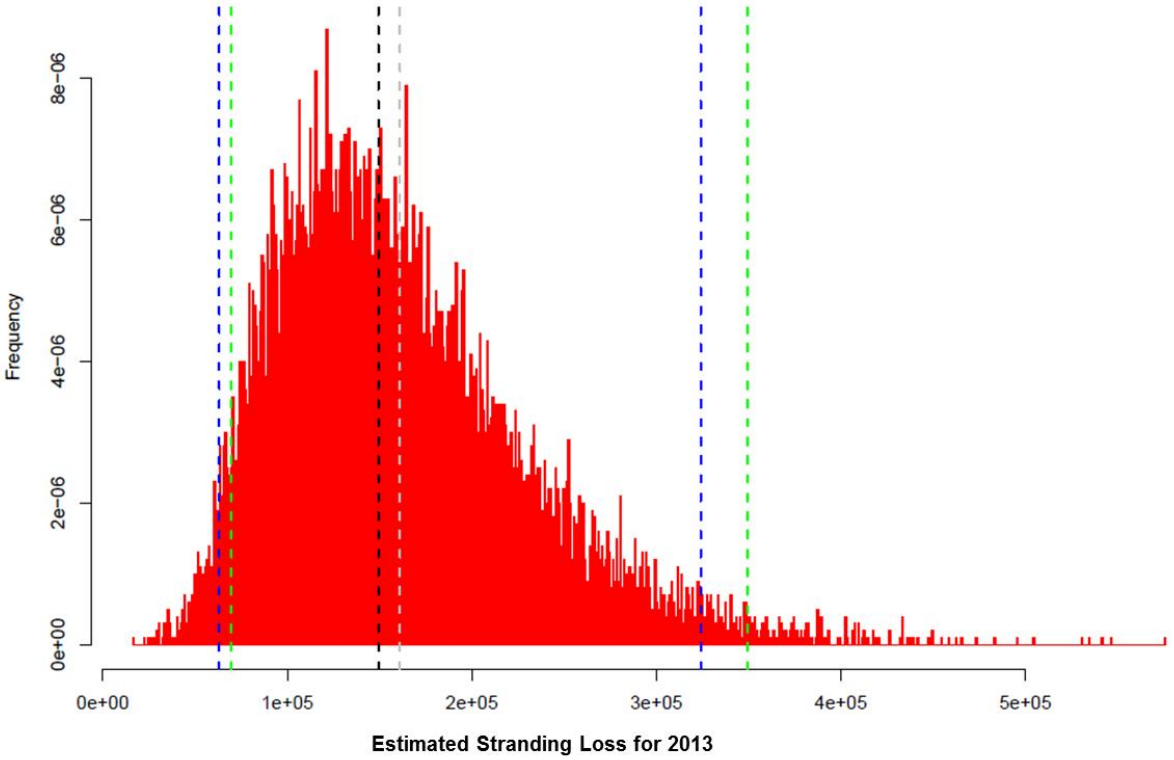

Figure 14 **Histogram of bootstrap replicates of total juvenile fall Chinook salmon stranding loss in the Hanford Reach. Blue dashed lines represent a 95% probability interval; green lines indicate a bias corrected 95% probability interval. The gray dashed line represents the mean loss estimate (160,824); the black dashed line represents the median (149,317).**

The mean loss estimate for the Hanford Reach as a whole is 160,824 juvenile fall Chinook salmon, with a bias-corrected 95% probability interval extending from 69,653 to 349,360 (Table 10). The largest loss for any one stratum occurred during the period from May 8 through May 21, 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). The largest overall loss occurred in the Middle section of the Reach (Table 10).

No stranded fish were found within sampling plots in 11 of 24 of the spatial-temporal strata (Table 10), 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 11).

Table 10 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)	160,824	152,672	63,135	324,145	69,563	349,360
Feb 27-Mar 12	4,984	4,273	0	21,982	0	28,863
Mar 13-Mar 26	9,091	5,273	0	34,702	0	37,680
Mar 27-Apr 09	31,384	25,661	4,260	79,172	4,260	78,863
Apr 10-Apr 23	11,598	13,517	0	32,403	0	38,037
Apr 24-May 07	27,155	26,736	0	65,054	4,015	70,418
May 08-May 21	50,272	47,781	0	204,394	0	257,228
May 22-Jun 04	26,340	29,431	0	72,573	0	84,684
Jun 05-Jun 18	0	0	0	0	NA	NA
Upper Section	40,685	40,626	63,626	315,847	63,007	314,533
Middle Section	78,711	73,977	20,751	292,624	22,363	300,431
Lower Section	41,429	38,069	0	113,950	0	123,503

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

Table 11 Combined strata formed from aggregation of individual strata.

Strata	Sampling Periods	Hanford Reach Sections Included
1	Feb 27-Mar 12	All sections of Hanford Reach
2	Mar 13-Mar 26	Upper and Middle sections
3	Mar 13-Mar 26	Lower section
4	Mar 27-Apr 9	Upper and Middle sections
5	Mar 27-Apr 9	Lower section
6	Apr 10-Apr 23	Upper section
7	Apr 10-Apr 23	Middle section
8	Apr 10-Apr 23	Lower section
9	Apr 24-May 7	All sections of Hanford Reach
10	May 8-May 21	All sections of Hanford Reach
11	May 22-Jun 4	Lower section
12	May 22-Jun 4	Upper section
13	May 22-Jun 4	Middle section
14	Jun 5-Jun 18	All sections of Hanford Reach

The alternative estimate of the stranding loss in the Hanford Reach was generated using 10,000 bootstrap samples of the combined strata identified in Table 11 (Figure 15and Table 12). By ensuring non-zero mean estimates for all but one strata, the mean loss estimate for the Hanford Reach was 23,299 higher than when individual strata were used (i.e., 184,123 vs. 160,824). All other statistics from the bootstrap samples were also higher for the combined strata (Table 12).

Table 12 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)	184,123	164,660	183,041	63,608	414,179	79,149	488,088
Feb27_Mar12_sec123	3,736	2,213	3,222	0	17,077	0	23,325
Mar13_Mar26_sec12	2,701	2,016	2,509	0	12,341	0	16,391
Mar13_Mar26_sec3	7,357	4,672	3,849	0	33,038	0	37,680
Mar27_Apr9_sec12	4,683	3,199	3,476	0	20,779	0	27,710
Mar27_Apr9_sec3	21,191	21,165	21,140	4,206	42,331	0	42,061
Apr10_Apr23_sec1	1,477	1,121	1,320	0	6,431	0	8,438
Apr10_Apr23_sec2	3,257	0	3,637	0	14,004	0	19,026
Apr10_Apr23_sec3	6,927	6,600	8,497	0	26,560	0	31,523
Apr24_May7_sec123	36,206	33,021	35,079	0	87,721	0	98,122
May8_May21_sec123	70,026	45,451	71,103	0	288,605	0	380,851
May22_June4_sec1	10,622	6,768	10,842	0	46,694	0	60,455
May22_June4_sec2	9,528	8,018	14,241	0	35,926	0	45,155
May22_June4_sec3	6,412	3,704	4,126	0	30,889	0	40,591
June5_June18_sec123	0	0	0	0	0	NA	NA

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

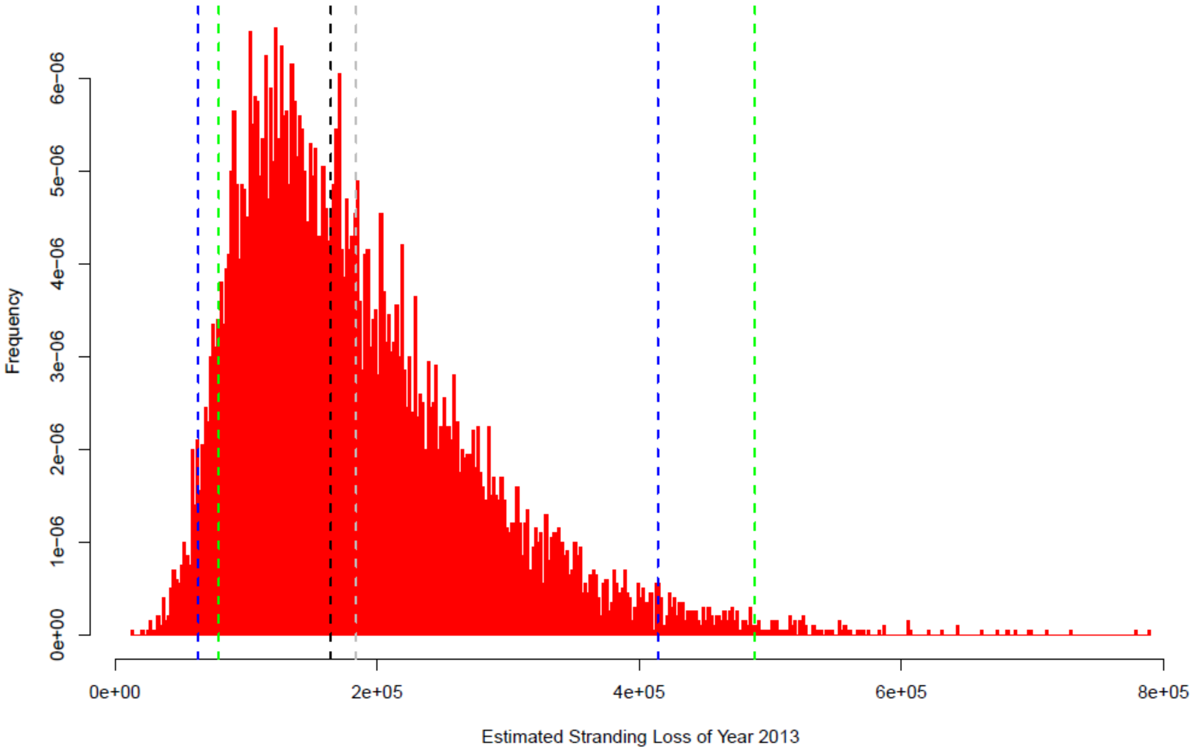

Figure 15 **Histogram of bootstrap replicates of total stranding loss of juvenile fall Chinook salmon in the Hanford Reach for the combined strata identified in Table 12. Blue dashed lines represent a 95% probability interval. The gray dashed line represents the mean loss estimate (184,123); the black dashed line represents the median (164,660).**

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 50 stranded Chinook salmon were sampled from an area of 33,432 m^2 (Table 6), giving an estimate of 0.0015 stranded Chinook salmon per square meter. Applying that estimate to the total dewatered area of 134,587,700 m^2 (Figure 13), gives an estimated loss of 201,286 stranded Chinook salmon over the sampling period, which is slightly higher than the uncorrected mean estimate for the combined strata of 184,123 (Table 12).

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 2 and June 9, 2013, field crews conducted entrapment sampling at 351 quadrants in the Hanford Reach (Table 13). The sampling season lasted a total of 100 days and flow fluctuations were sufficient in magnitude and duration to generate sampling quadrants on 89 days. Within 183 of the 396 sites (52%) visited, either water-level fluctuations were insufficient to create entrapments or no entrapments were present. Of the 360 quadrants (52%) the Hanford Reach, field crews visited 188 at some point during the season with an average of 3.9 quadrants visited per day. The 172 quadrants not sampled during the season were distributed throughout all the river segments (Table 14).

Table 13 **Summary of entrapment sampling by segment in the Hanford Reach, 2013.**

Segment	Quadrants Visited	Quadrants With Entrapments	% Quadrants with Entrapments	Entrapments Sampled	Mean # Entrapments per quadrant	Entrapments with Chinook	% Entrapments with Chinook
1	79	48	60.8	192	2.4	27	14.1
2	72	37	51.4	152	2.1	40	26.3
3	57	20	35.1	78	1.4	6	7.7
4	35	17	48.6	70	2.0	23	32.9
5	23	10	43.5	43	1.9	15	34.9
6	6	2	33.3	1	0.2	0	0
7	48	29	60.4	69	1.4	15	21.7
8	31	5	16.1	9	0.3	2	22.2
Total	**351**	**168**	**47.9**	**614**	**1.7**	**128**	**20.8**

Table 14 **Distribution of quadrants visited during entrapment sampling in the Hanford Reach, 2013.**

Segment	Quadrants Visited (#)	Quadrants Available (#)	Quadrants Visited (%)	Number of Periods Quadrants Revisited
1	36	60	60.0	2.2
2	34	60	56.7	2.1
3	28	40	70.0	2.0
4	17	28	60.7	2.1
5	15	28	53.6	1.5
6	6	24	25.0	1.0
7	28	68	41.2	1.7
8	24	52	46.2	1.3
Total	**188**	**360**	**52.2**	**1.9**

A total of 614 entrapments were sampled from the 351 quadrants visited (Table 13). Entrapments ranged in size from 1 m to >100 m in diameter with depths from zero (drained) to 74 cm deep (mean =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 15). Only 19 entrapments (3%) encountered were determined to be too large or deep to effectively sample. Chinook salmon were found in 128 (21%) of the sampled entrapments (Table 13).

Table 15 **Entrapment size and distribution based on size at arrival, in the Hanford Reach, 2013.**

Segment	1−5 m	5−15 m	>15 m	>15 m NS	<15 m NS
1	156	37	5	3	9
2	112	44	10	2	16
3	46	28	7	2	5
4	45	25	3	1	4
5	10	20	16	5	8
6	0	1	0	1	1
7	56	17	11	4	19
8	6	4	0	1	2
Total	**431**	**176**	**52**	**19**	**64**
% of Total	**63.6**	**26.0**	**7.7**	**2.8**	**9.4**

NS = not sampled.

Table 16 **Summary of vegetation density and entrapments containing Chinook salmon in the Hanford Reach, 2013.**

Vegetation Density	Total Chinook	% Total	# Live	# Dead	% Live	Total Entrapments	Entrapments with Chinook #	%
1	714	37.1	679	35	95.1	308	61	19.8
2	817	42.5	720	97	88.1	149	33	22.1
3	243	12.6	189	54	77.8	102	19	18.6
4	147	7.6	95	52	64.6	53	14	26.4
ND	2	0.1	2	0	100	2	1	50.0
Total	**1,923**		**1,685**	**238**	**87.6**	**614**	**128**	**20.8**

ND = no data; NS = not sampled.

Field crews attempted to recover all fish present in entrapments during sampling but sampling efficiently can be highly variable (see Section 4.2.3). 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 can be 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. Flows during 2013, were only slightly above average and generally stayed below the normal high-water line.

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 17). Training for crew members was conducted on March 3 to provide guidance on sample method selection based on the habitat characteristics present and ensure consistency throughout the sampling season. 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.

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

Table 17 Summary of habitat classification and sampling method frequency in the Hanford Reach, 2013.

		# Occurrences				
Habitat	**Habitat Classification**	**Not Sampled**	**Seine**	**Shock**	**Visual**	**Total**
Entrapment Size	1–5	15	0	110	306	**431**
	5–15	24	3	70	79	**176**
	>15	6	6	27	13	**52**
	>15 (NS)	19	0	0	0	**19**
Vegetation Density	1	1	7	80	221	**309**
	2	4	2	54	93	**153**
	3	3	0	41	61	**105**
	4	0	0	31	22	**53**
	5 (NS)	56	0	0	0	**56**
	ND	0	0	1	1	**2**

NA = no data; 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 614 entrapments sampled, 128 contained Chinook salmon (21%). The mean number of entrapments sampled per site was 4.3, which is more than double the number that were sampled during 2012. A total of 1,923 juvenile fall Chinook salmon were recovered in entrapments with 88% collected alive. The percent of entrapments containing Chinook salmon were very similar (i.e., 19-23%) across all three river sections (Table 18). Chinook salmon densities in entrapments were greatest in the Middle section and lowest in the Upper section, with 5.3 and 2.0 fish per entrapment respectively (Table 18).

Table 18 **Summary of entrapment sampling and Chinook salmon presence by section of the Hanford Reach, 2013.**

River	Sites	Entrapments Present			Entrapments Sampled		With Chinook		Chinook Salmon Collected	
Section	Visited	Yes	No	%	Total	Mean/Site	Total	%	Total	Mean/Entrapment
Upper	151	85	66	56	344	5.0	67	19.5	704	2.0
Middle	121	49	72	41	192	4.3	44	22.9	1,014	5.3
Lower	79	34	45	43	78	2.8	17	21.8	205	2.6
Total	**351**	**168**	**183**	**48**	**614**	**4.3**	**128**	**20.8**	**1,923**	**3.1**

Fork length was measured for fall Chinook salmon found in entrapments on 28 days throughout the 2012 field season, but was only measured from large entrapments on seven days towards the end of the 2013 field season. Similar to 2012, mean fork length was less than 45 mm until it abruptly increased near the end of the season (Figure 17). It is unclear why fork length abruptly increases as the number of entrapped juvenile fall Chinook salmon dramatically decreases toward the end of the season.

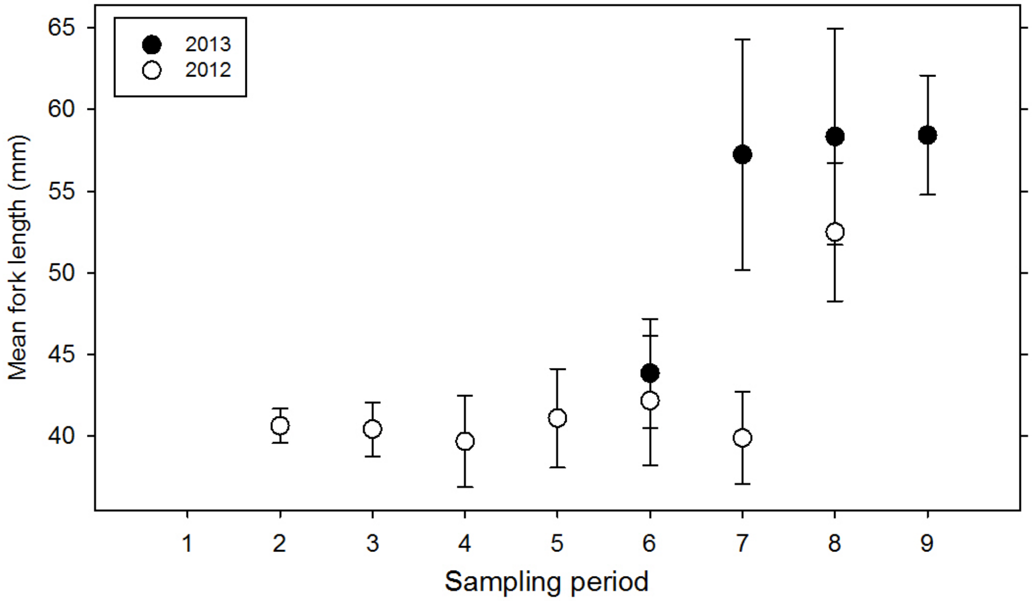

Figure 17 **Mean fork length and standard deviation of entrapped fall Chinook salmon in the Hanford Reach, 2012 and 2013.**

Chinook salmon presence and fate in entrapments is highly dependent on entrapment size. Entrapments containing Chinook salmon were nearly as twice as deep as those without (18.8 vs. 10.1 cm) and larger entrapments hold more live and fewer dead fish (Table 19). Thirty-one percent of the sampled entrapments >15 m in diameter contained fall Chinook salmon, while only 15% of entrapments that were 1–5 m in diameter contained Chinook salmon. Larger entrapments also contained more fall Chinook salmon, 27% of the live fall Chinook salmon sampled in 2013 came from entrapments that were >15 m in diameter. Large entrapments also had less mortality caused by dewatering (as time needed to drain increased, so did the likelihood of reflooding) 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 19).

Table 19 **Summary of entrapment sampling and fish frequency based on entrapment size estimated upon separation from the main channel of the Hanford Reach, 2013.**

Entrapment Size	# Entrapments	Entrapments with Chinook	% Entrapments with Chinook*	# Chinook Collected		Live:Dead Ratio	# Chinook Total
				Live	Dead		
1–5	358	52	14.9	250	98	2.6:1	348
5–15	202	49	27.2	921	114	8.1:1	1035
>15	80	23	32.4	439	27	16.3:1	466
>15 NS	38	4	26.7	74	0	1:0	74

NS = Too large to sample when initially separated from river, but could be sampled when crews arrived.
*Adjusted for 64 entrapments were not sampled for various reasons.

Although the majority of juvenile fish encountered in entrapments were fall Chinook salmon, 1,418 individuals of other species were also recovered. Three-spined sticklebacks (*Gasterosteus aculeatus*), northern pikeminnow (*Ptychocheilus oregonensis*), peamouth (*Mylocheilus caurinus*), and sculpin (*Cottus spp.*) were the most common other species observed in entrapments (Table 20). Thousands of larval fish were observed and recorded, but no attempt was made to enumerate these fish. An attempt was made to identify fish to species, which included carp (*Cyprinus carpio*), three-spined stickleback, smallmouth bass (*Micropterus dolomieu*) and unidentified suckers (*Catostomus spp*). Biological data were not collected and sampling efficiency estimates were not conducted for non-target species.

Table 20 **Summary of non-salmon species collected in the Hanford Reach, 2013. Abbreviations are three-spined sticklebacks (STB), sculpin (COT), northern pikeminnow (NPM), suckers (SUK), red-side shiners (RSS), dace (DACE), peamouth (PM), and Pacific lamprey (PL).**

Segment	STB	COT	NPM	SUK	RSS	DACE	PM	PL
1	4	6	3	1	2	4	0	0
2	540	24	223	3	5	0	0	0
3	4	2	269	5	0	0	137	0
4	16	21	6	1	0	9	0	0
5	6	2	1	0	0	3	0	0
6	0	0	0	0	0	0	0	0
7	64	2	30	2	0	20	0	1
8	2	0	0	0	0	0	0	0
Total	**636**	**57**	**532**	**12**	**7**	**36**	**137**	**1**

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 678 entrapments observed, 27% of the entrapments drained, 5% reached lethal water temperature (>27°C) for Chinook salmon fry, 13% reflooded prior to draining as the river elevations rose, and fates could not be determined in the field for 55% of the entrapments (Table 21). Post-season fate determination indicated that 24% of the sampled entrapments were reflooded and 76% were lethal. Fall Chinook salmon were confirmed to be present in 128 entrapments and post-season fate determination indicated that 48% of them were reflooded and 52% were lethal.

Table 21 Summary of final and initial fate determinations for entrapments that were sampled in the Hanford Reach, 2013. In season fate determinations were based on *in situ* observations. If fate could not be determined during sampling, MASS1 simulation was used to make a post season determination.

	In-Season Fate Determination					**Final Fate Determination (%)**	
Segment	**Dewatered**	**Temp (>27°C)**	**Reflooded**	**Unknown**	**Total**	**Lethal**	**Reflooded**
1	67	3	29	102	201	80.6	19.4
2	41	10	25	92	168	76.0	24.0
3	11	5	3	64	83	74.7	25.3
4	22	2	9	41	74	73.0	27.0
5	6	0	14	31	51	54.9	45.1
6	1	0	0	1	2	50.0	50.0
7	29	14	6	39	88	84.1	15.9
8	2	0	2	7	11	72.7	27.3
Total	**179**	**34**	**88**	**377**	**678**		
Percent of total	27	5	13	55		76.2	23.8
Entrapments w/fish							
2013	**46**	**3**	**55**	**24**	**128**	**51.6**	**48.4**
2012	47	6	17	50	120	66	34
2011	19	2	17	21	59	57.6	42.4

4.3.2 Entrapment Sampling Efficiency

Although crews attempted to recover all fish present in entrapments, fish entrapped in depressions within the Hanford Reach can be difficult to find and are exposed to predators (Figure 18). Assessments were completed at 26 entrapments containing fall Chinook salmon during the 2013 field season to determine sampling efficiency for each of the capture methods. Mark-recapture efficiency for entrapments greater than 15 meters in diameter using beach seines was 49% and 23% when using electroshockers (Table 22). Seining was only conducted on entrapments greater than 15m with either sparse or no vegetation, due to the influence of vegetation on sampling effectiveness of beach seines on these types of entrapments. Conversely, backpack electroshockers were most effective in smaller (1-5 m) and heavily vegetated entrapments (67 % and 64%, respectively). Similar patterns were observed for collection efficiencies (Table 22). Fall Chinook salmon are able to evade capture easier in large entrapments regardless of the sampling method. It appears that entrapment size explains more of the variation in sampling efficiency than vegetation, embeddedness, and substrate size does.

Sampling efficiency decreased as entrapment size increased but vegetation did not appear to have an effect on overall efficiency.

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

Table 22 Evaluation of field collection efficiencies of Juvenile fall Chinook salmon for visual observation, backpack electrofishing (Shock), and beach seining (Seine) in the Hanford Reach, 2013.

		Seine (n=3)				Shock (n=23)			
			Recapture				Recapture		
Habitat	**Habitat Type**	**Mark Released**	**Mark**	**No Mark**	**Mark-Recap Efficiency**	**Mark Released**	**Mark**	**No Mark**	**Mark-Recap Efficiency**
Entrapment Size	1–5					129	99	43	67
	5–15					113	64	43	52
	>15	105	51	8	49	67	16	73	23
	Total	**105**	**51**	**8**	**49**	**309**	**179**	**159**	**53**
Vegetation Density	1	35	6	7	17	107	65	54	61
	2	70	45	1	64	132	69	69	52
	3					75	29	48	39
	4					25	16	12	64
	Total	**105**	**51**	**8**	**49**	**339**	**179**	**183**	**53**

4.3.3 Entrapment Loss Estimate

A total of 116,504 entrapments were estimated to have been created in the Hanford Reach during the 2013 sampling season (Table 23), which represents a 55% drop from the number of entrapments estimated to have been created in 2012. The highest numbers of entrapments were created in the Upper section (54,613), with lower numbers created in the Middle (36,560) and

Lower (25,331) sections (Figure 19). Estimates across the sampling season showed that, period two (March 13-26) had the fewest entrapments created (3,853) and period six (May 8-21) had the highest number created (23,320).

Table 23 Total number of entrapments created by temporal strata and river section, 2013.

	Sampling Period								
Section	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
Upper	2,984	1,924	7,286	6,448	10,088	11,319	9,006	5,558	54,613
Middle	1,034	674	3,986	6,283	6,603	7,098	6,104	4,778	36,560
Lower	1,499	1,255	2,249	4,042	4,305	4,903	4,317	2,761	25,331
Total	5,517	3,853	13,521	16,773	20,996	23,320	19,427	13,097	116,504

The number of Chinook salmon per entrapment varied by river section and sampling period, but the three highest densities were found in the Middle section (Table 24). No Chinook salmon were found during the last sampling period in any of the river sections. The greatest number of Chinook salmon per entrapment (16.6) occurred during the second period (March 13–26) in the Middle section. The location of peak Chinook salmon densities within entrapments varied within sampling periods, but three of the five periods with densities greater than 5.0 occurred in the Middle section (Table 24).

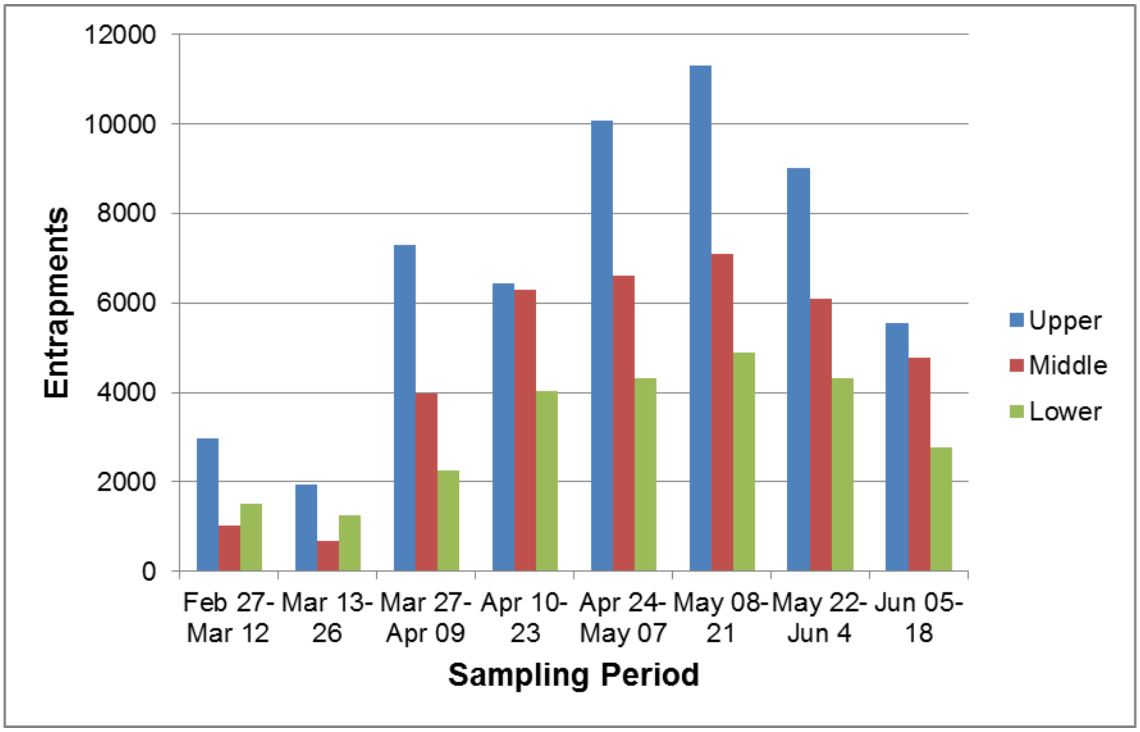

Figure 19 Total number of estimated entrapments created by temporal strata and river section of the Hanford Reach, 2013.

Table 24 **Mean number of juvenile fall Chinook salmon per entrapment aggregated by sampling period and river section of the Hanford Reach, 2013.**

	Sampling Period							
Section	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Upper	0	1.0	2.8	3.0	2.8	2.4	1.5	0
Middle	0.3	16.6	2.2	6.1	1.0	12.9	0	0
Lower	1.6	1.1	0	6.0	0	0.5	5.2	0

The highest estimate of entrapped Chinook salmon occurred in the sixth sampling period (May 8–21) within the Middle section of the Reach (91,463), which also had the highest overall total for the study period (Table 25). The majority of the entrapped Chinook salmon were sampled during periods four through six (April 10–May 21); 74% of the estimated total number of entrapped Chinook salmon occurred during this six-week period. After accounting for sampling frequency and the two-stage sampling design, we estimate that 354,467 Chinook salmon were entrapped in 2013 with percentile-based, bias-corrected, 95% confidence interval bounds of 181,635 and 646,029 (Figure 20).

Table 25 **Estimates of the number of entrapped Chinook salmon aggregated by sampling period and river section in the Hanford Reach, 2013.**

	Sampling Period								
Section	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
Upper	0	1,867	20,358	19,534	28,484	27,404	13,180	0	**110,826**
Middle	304	11,188	8,697	38,614	6,349	91,463	0	0	**156,615**
Lower	2,385	1,394	0	24,252	0	2,452	22,544	0	**53,027**
Total	**2,689**	**14,450**	**29,055**	**82,400**	**34,833**	**121,318**	**35,724**	**0**	**320,469**

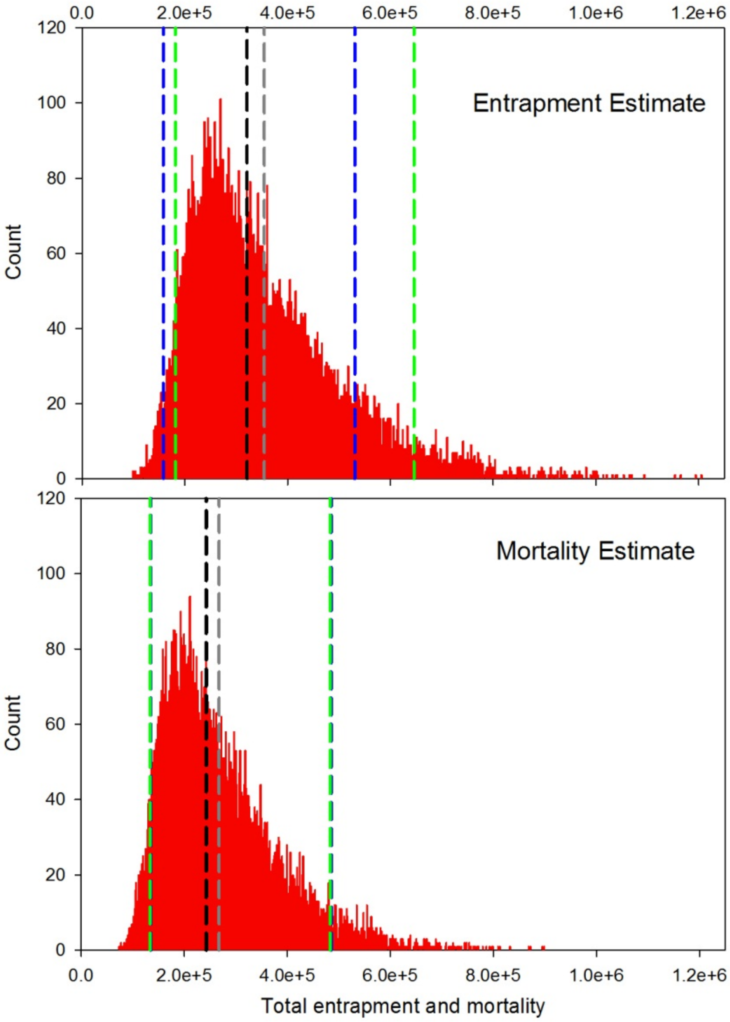

Figure 20 **Histograms of 10,000 bootstrap samples of the total estimated number of entrapped Chinook salmon (top) and the estimated number of Chinook salmon entrapment mortalities (bottom) in the Hanford Reach, 2013. The vertical lines denote the bias corrected bootstrap means (grey), medians (black), and percentile-based, 95% confidence intervals (green) and non-bias corrected confidence intervals (blue).**

Entrapment lethality rates varied by sampling period and river section strata and ranged between 10 and 100% (Table 26). Entrapment lethality over all samples was 77% with no consistent spatial patterns. However, strata with the highest and lowest mortality rates (i.e., 10 or 100%) contained fewer than ten sampled entrapments (Figure 21).

Table 26 **Estimates of entrapment lethality rates for juvenile fall Chinook salmon aggregated by sampling period and river section in the Hanford Reach, 2013.**

	Sampling Period							
Section	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Upper	0.86	0.93	0.71	0.85	0.69	0.89	0.73	0.87
Middle	0.88	0.10	0.88	0.71	0.81	0.74	0.31	1.00
Lower	0.86	0.56	1.00	0.89	1.00	1.00	1.00	0.40

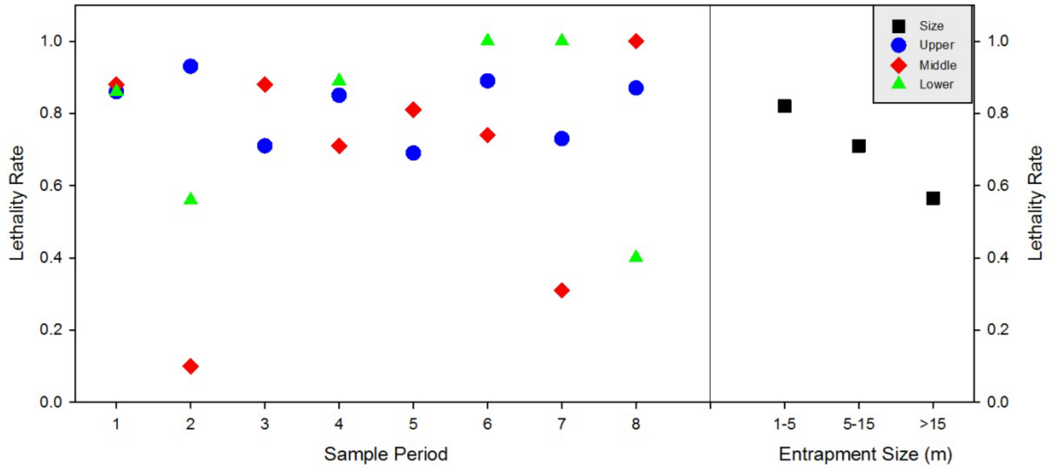

Figure 21 Estimates of mean entrapment lethality rates (y-axis) for juvenile fall Chinook salmon by sampling period in the Upper (circles), Middle (diamond), and Lower (triangles) river sections, as well as entrapment size (squares). Strata with fewer than five samples were not included.

After combining estimates of entrapped Chinook salmon and entrapment lethality rates, the greatest number of mortalities (67,944) occurred during sampling period six (May 8–21) in the Middle section (Table 27). Relatively consistent entrapment lethality rates cause patterns of mortality estimates to be nearly identical to those of estimates of the number of fish entrapped. Sampling period two in the Middle section was the exception, which had a moderate number of entrapped fish and the lowest lethality rate. Seventy-five percent of the estimated entrapment mortalities occurred during sampling periods four through six (April 10–May 21). After accounting for sampling frequency and the two-stage sampling design, we estimate that there were 267,453 juvenile fall Chinook salmon entrapment mortalities, with percentile-based, bias-corrected, 95% confidence interval bounds of 134,851 and 485,225 (Figure 20, lower panel).

Table 27 Estimates of the number of entrapped Chinook salmon mortalities aggregated by sampling period and river section of the Hanford Reach, 2013 (without two-stage bootstrap analyses).

	Sampling Period								
Section	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
Upper	0	1,730	14,370	16,661	19,548	24,519	9,644	0	**86,472**
Middle	268	1,119	7,643	27,352	5,128	67,944	0	0	**109,453**
Lower	2,060	775	0	21,557	0	2,452	22,544	0	**49,387**
Total	**2,328**	**3,624**	**22,013**	**65,570**	**24,676**	**94,915**	**32,188**	**0**	**245,313**

5.0 Discussion

The 2013 assessment of stranding and entrapment of juvenile fall Chinook salmon in the Hanford Reach used the updated study design that was first employed the previous year. Sampling crews were directed to sampling locations by a redesigned 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 transect (i.e., quadrant boundary). As in 2012, a 9.9-m (32.4-ft) or greater decrease in the wetted width over the previous 24 hours was used to identify candidate transects, and their associated quadrants for sampling. Stranding crews were able to sample 79% of the quadrants visited in 2013, relative to the 51% rate in 2011 and similar to the 86% rate in 2012. Modifying the sampling plan in 2012 and 2013 to align more stranding plots along the wetted perimeter of the river (see Section 3.2.1), also led to a large improvement in sample size. Fewer transects were visited to sample for stranding in 2013 than 2012 or 2011. While the sample area also dropped relative to 2012, (49,092 m^2 to 33,432 m^2) there this was still 45% more area sampled in 2013 than 2011 (22,997 $m^{2)}$.

Estimates of the dewatered area for 2013 indicated a large decrease relative to 2012 (51%) and a moderate one for 2011 (29%). Along with the large drop in dewatered area, relative to 2012, there were 55% fewer entrapments created in 2013. The highest amount of dewatered area occurred in the Upper section (47%), and 31% occurred in the Middle section. More area was estimated to have been dewatered during the middle of the sampling season, April 24 – May 21. This is similar to the temporal and spatial distribution observed in 2012, though much less area was estimated to have been dewatered in 2013.

The results of field sampling for stranded juvenile fall Chinook salmon during 2013 were different from those observed in 2012, and similar to those found in 2011. In 2013, the majority of the stranded fish were found in the Middle section (27 of 50), with sub-equal numbers found in the Upper and Lower sections. This pattern is different from 2012 but similar to the one in 2011(Figure 22), 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). However, spatial and temporal patterns are weak across years. The pattern in 2013 was somewhat unique because most of the stranded juvenile fall Chinook salmon found in the Middle section were found during a single time period (May 8 – May 21;Figure 22). During other time periods, the numbers of stranded fall Chinook tended to be much lower.

The 51% decrease in the estimates of dewatered area for 2013, relative to 2012, translated into a large decrease in the bootstrap estimates of stranding loss in the Hanford Reach. The mean bootstrap estimate for 2013 of 160,824 stranded juvenile fall Chinook salmon is much lower than the 345,208 mean bootstrap estimate for 2012. There was a 25% decrease in the number of stranded Chinook salmon found in 2012, but this increase was spread over a somewhat smaller sampled area. The density of stranded Chinook salmon was slightly lower (0.0014 vs. $0.0015/m^2$) during 2012, so the decrease in dewatered area appears to be the major cause of the large decrease in the estimate of stranding losses during 2013.

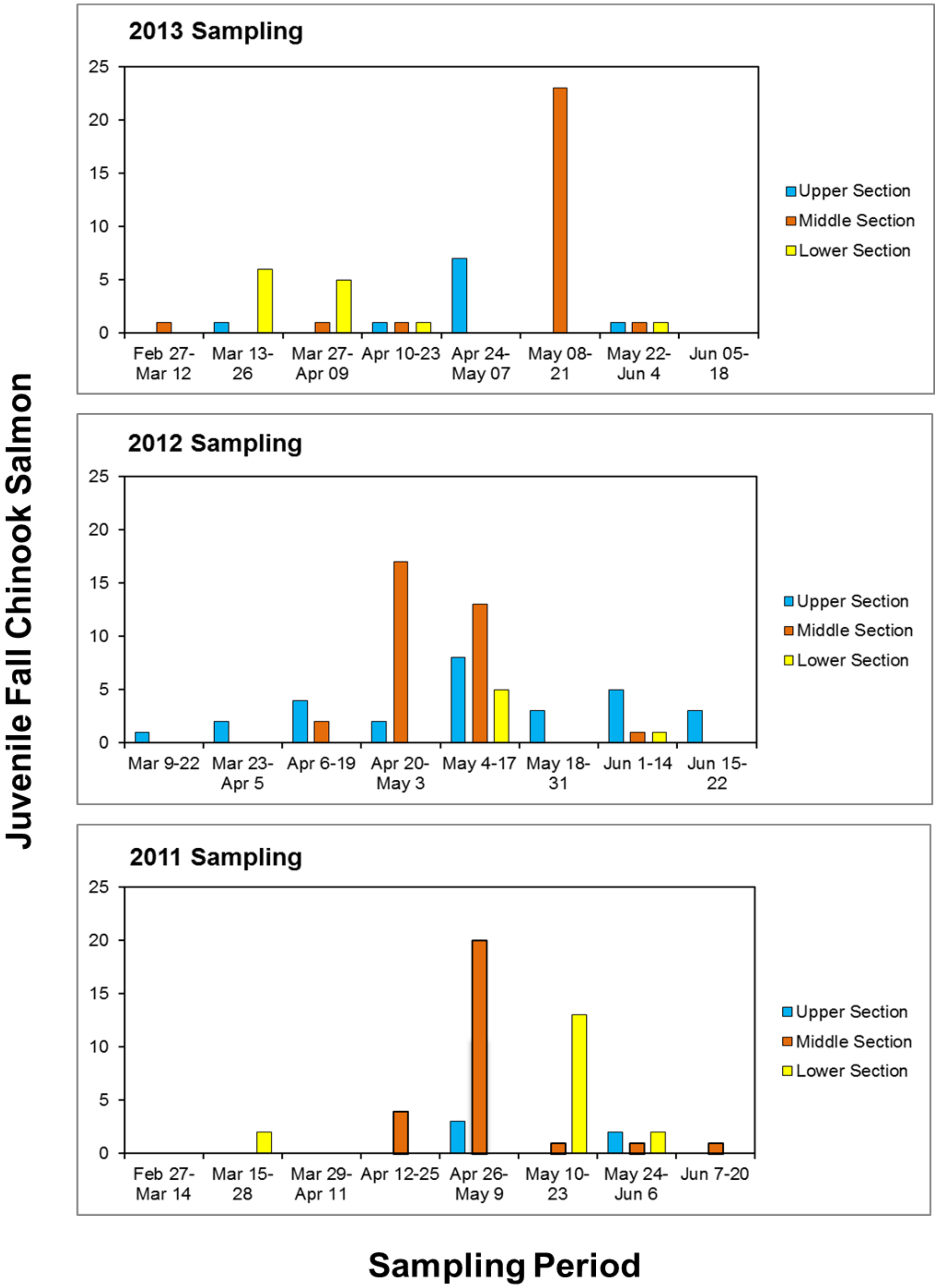

Figure 22 **Counts of fall Chinook salmon found in stranding surveys in the Hanford Reach during 2013, 2012, and 2011. Approximately 3.3, 4.9, and 2.3 ha of dewatered shoreline were sampled in 2013, 2012, and 2011, respectively.**

As in previous years, there were a number of two-week strata for which no stranded fish were found, and they were distributed over all three sections of the study area (Upper, Middle, and Lower). As an alternative estimate, we constructed combined strata to attempt to ensure all spatial strata contained at least one sample in which stranded juvenile fall Chinook salmon where found. However, no stranded fall Chinook were found anywhere in the Hanford Reach during the last time period, so the estimate for that time period defaulted to zero. During other time periods, 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 14% higher than the standard bootstrap estimate. This is larger than the 7% increase found for the combined strata bootstrap estimate in 2012, and similar to the 16% increase found using the same approach 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 2013 was 279,797, compared to intervals of 393,917 in 2012 and 668,703 in 2011. The large decrease seen in 2013 relative previous years is probably due, in part, to the changes in sampling design that allowed for greater sample sizes.

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. More efficiency trials were conducted during 2013, but the number was still relatively low (n=29) considering the variation in vegetation and substrate composition. Given that data on the distribution of vegetation and substrates throughout the Hanford Reach are limited and the number of efficiency tests conducted was relatively low, we elected to provide the sampling efficiency estimates (i.e., mean of 73%) for context and not to adjust the loss estimates. Therefore, the loss estimates presented should be considered to be minimum estimates of stranding loss for juvenile fall Chinook salmon in the Hanford Reach in 2013.

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 was able to collect sufficient data to make comparisons between years feasible. Beginning in 2011, the project participants expanded to include Grant PUD and Battelle. Contracts and staff were in place and sampling was able to begin at or near the estimated start of emergence during the past four study seasons (i.e., 2007, 2011, 2012, and 2013).

Chinook salmon were present in 21% of the entrapments sampled during 2013. This was the highest annual mean during the seven years that entrapment studies have been conducted in the Hanford Reach. However, the percentage of entrapments containing Chinook salmon within individual sampling periods has been much higher in previous years (Figure 23). The mean number of Chinook salmon collected per entrapment was 3.1 (bias-corrected bootstrap estimate of 3.7) in 2013. This was slightly lower than the estimate for 2012 and is the third lowest estimate of Chinook salmon per entrapment of the seven years of studies specifically targeting entrapment in the Hanford Reach. In contrast to 2013, the percentage of entrapments containing fish were similar during 2003 (18%) but Chinook salmon densities were much greater (35.5 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 (Harnish et al. 2012). Given that monitoring did not begin until well after the estimated start of emergence during years prior to 2007, those mean annual loss estimates may be biased low. However, trends within each section were similar for all seven study years. The Middle section had higher percentages of entrapments with Chinook salmon present and, with the exception of 2012, significantly higher numbers of Chinook salmon per entrapment (Table 28). The Lower section had the highest number of Chinook salmon per entrapment in 2012, but the value was strongly influenced by low sample rates and a single entrapment that contained 43% of the fish collected throughout the entire Hanford Reach.

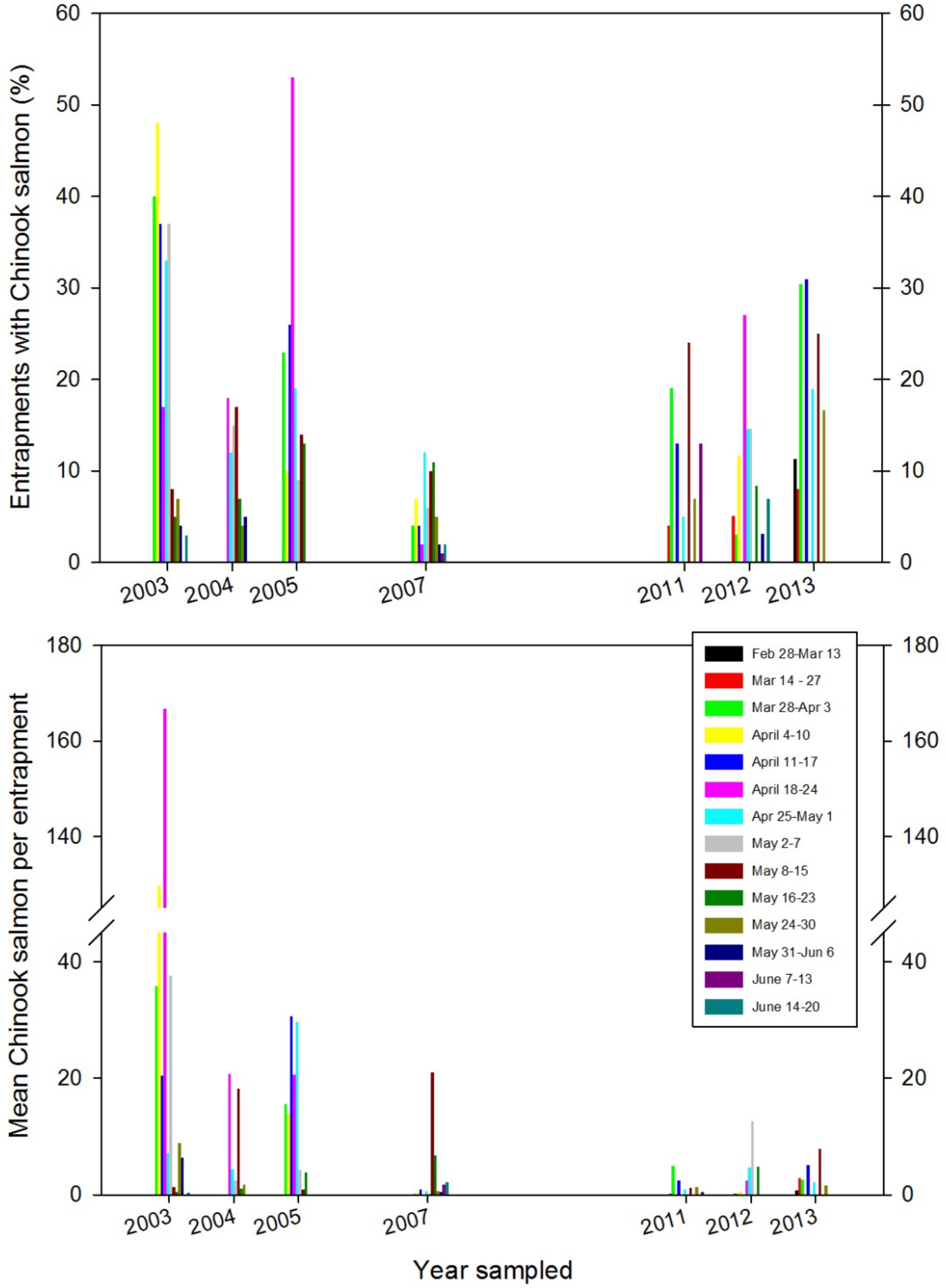

Figure 23 Percent of entrapments containing Chinook salmon (upper panel) and the mean number of Chinook salmon per entrapment in the Hanford Reach, migration years 2003 – 2013. Weekly time periods varied from year to year. Values are for the week closest to the dates indicated.

Table 28 **Entrapments with Chinook salmon and mean numbers of Chinook salmon per entrapment in the Hanford Reach, 2003 – 2013. 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 salmon (%)				**Number of Chinook salmon per Entrapment**				**Escapement**
Year	**Upper**	**Middle**	**Lower**	**Total**	**Upper**	**Middle**	**Lower**	**Total**	
2013	20	23	22	21	2.0	5.3	2.6	3.1	**51,774**
2012	9	12	5	9	1.3	4.0	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	**11.6**	**17.3**	**10.9**	**13.3**	**1.9**	**19.5**	**4.8**	**9.4**	**68,431**

Chinook salmon abundance in nearshore areas begins to decline shortly after the estimated end of emergence and coincides with declining numbers of stranded or entrapped fish in the upstream locations. 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; Hoffarth et al. 2013). 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).

The number of fall Chinook salmon fry per entrapment in the Hanford Reach were lowest in 2011 and greatest in 2003 (Table 28). 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). 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 (Langshaw and Hoffarth 2011). Assuming the availability of fall Chinook salmon fry to be stranded or entrapped 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 or stranded and spawner abundance.

The total number of entrapped Chinook salmon and their mortality rate is influenced by the characteristics of entrapments that are created throughout the season. Entrapment size influences lethality and Chinook salmon entrapment densities. Medium and Large entrapments comprised 34% of the entrapments sampled during 2013, yet they contained 63% of the fish collected. Larger entrapments are less likely to become lethal (dewatered or thermal; <69%) than medium (71.0%) or smaller (81.4%) entrapments (Table 29). Furthermore, monitoring during 2013 revealed that larger entrapments can be influenced by hyporheic flow. Water levels fluctuate and can even increase within entrapments that are disconnected from the river (Hoffarth et al. 2013a; Figure 24). Our methodologies for post-season fate assignment suggest the Island 1 entrapment should have been dewatered within 11 hours, yet live Chinook salmon were collected from that entrapment more than six days after the entrapment separated from the main channel. Hyporheic flow may also provide some thermal refugia, as live Chinook salmon were collected from entrapments where water temperatures exceeded lethal levels (Hoffarth et al. 2013a). Predation rates also appear to be reduced in larger entrapments. In a limited predation evaluation, a total of 180 marked Chinook salmon were released in six entrapments and only six were recovered (Hoffarth et al. 2013a). While these results suggest predation within entrapments could be significant, evidence from Chinook salmon that are naturally entrapped is less clear. The number of Chinook salmon collected in the intensively monitored entrapments decreased during repeated sampling but at a much slower rate (Hoffarth et al. 2013a).

Table 29 Estimates of entrapment fate, by size at arrival of sampling, in the Hanford Reach, 2013.

Entrapment Size at Arrival	N	Entrapment Fate		
		Dewatered	**Thermal (>27°C)**	**Reflooded**
1–5	431	77.3%	4.2%	18.6%
>15	52	51.9%	5.8%	42.3%
>15 NS	19	57.9%	10.5%	31.6%
Total	**678**	**71.5%**	**5.0%**	**23.4%**

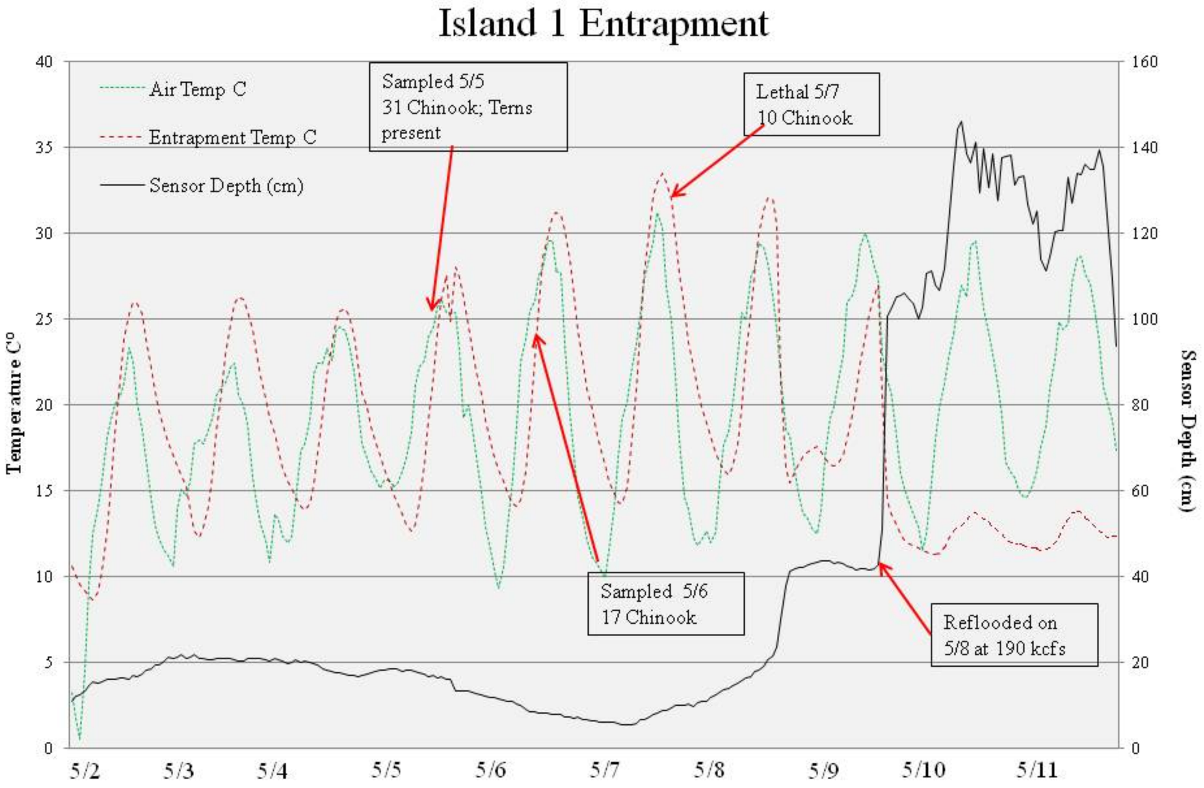

Figure 24 Event history over a 10 day period for the Island 1 entrapment in the Hanford Reach, 2013 (Figure 8 from Hoffarth et al., 2013).

River flow in the Hanford Reach during the 2013 emergence and rearing period for fall Chinook salmon was slightly higher than the mean since the interim Fall Chinook Protection Program began in 1999 (Table 30). The HRFCPPA allows larger daily discharge fluctuations at higher flows and the mean daily fluctuation in discharge from Priest Rapids Dam is highly correlated with mean daily discharge ($R^2 = 0.82$ and $R^2 = 0.91$, Figure 25). However, the relationship between dewatered shoreline and mean daily discharge ($R^2 = 0.52$) or mean daily fluctuation ($R^2 = 0.49$) is less strong because of differences in channel bathymetry. Lower elevations tend to have lower gradient profiles, which can disproportionately influence changes in river stage and dewatered shoreline. In general, fluctuations in river elevation at higher flows tend to dewater less shoreline than fluctuations at lower elevations, so relative entrapment and stranding risk may be reduced under higher discharge conditions (Figure 25).

Table 30 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.

	March	**April**	**May**	**June**	**Mean**
2013	80.9	160.3	197.2	175.1	**156.0**
2012	121.0	177.9	226.9	251.6	**194.4**
2011	134.0	158.8	224.4	296.0	**203.3**
2007	134.3	169.3	175.4	164.9	**161.0**
2006(a)	94.8	156.1	181.3	214.6	**161.7**
2005	98.4	90.0	131.8	135.9	**114.0**
2004	77.3	95.4	128.0	141.3	**110.5**
2003	89.0	115.6	144.6	150.2	**124.8**
2002	76.1	128.3	150.6	227.0	**145.5**
2001	81.7	70.2	64.1	93.8	**77.4**
2000	110.2	160.0	166.2	134.1	**142.6**
1999	140.0	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

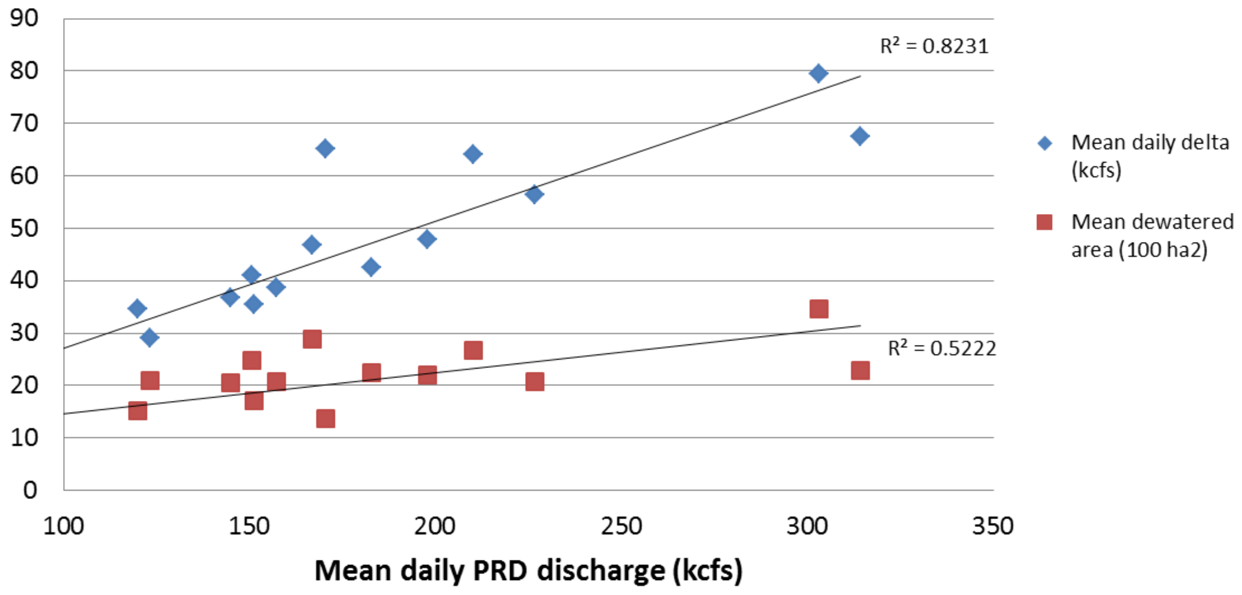

Figure 25 **Mean Priest Rapids Dam discharge, daily discharge fluctuation (delta), and dewatered area in the Hanford Reach during each sampling stratum during 2012 and 2013. Discharge constraints were not required for much of the eighth sampling period in 2013. When this stratum is excluded, the relationship between discharge and daily delta becomes stronger (R^2=0.91).**

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 resulted in fewer entrapments that could be sampled due to dense vegetation, and likely reduced collection efficiencies. Sampling conditions were not as difficult during 2013, as the period of higher discharge was relatively short. To address uncertainties associated with entrapment detection and enumeration, area-based methodologies were developed for estimating entrapment creation (see Methods section). While, the area-based method is reasonable to estimate the number of entrapments that were created in area that are not well surveyed, it is unknown whether the entrapment density is consistent across elevations. The area-based estimate of entrapments was 14,089 higher than the entrapment-based estimate, but was used during 2013 to maintain consistency across years.

Providing context is a critical component of any research or monitoring project. The most relevant 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 combine stranding and entrapment loss estimates and provide a range of estimates for historical production.

Combining the bias-corrected mean estimates of stranding and entrapment resulted in an estimated loss of 0.45 million juvenile fall Chinook salmon during 2013. 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 0.2 to 1.0 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; Harnish et al. In press). 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 26). 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 as adults, an estimate for brood year 2012 cannot be completed for until at least 2016. While these methods for estimating pre-smolt abundance do not account for all sources of error and we have not generated an estimate for brood year 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.

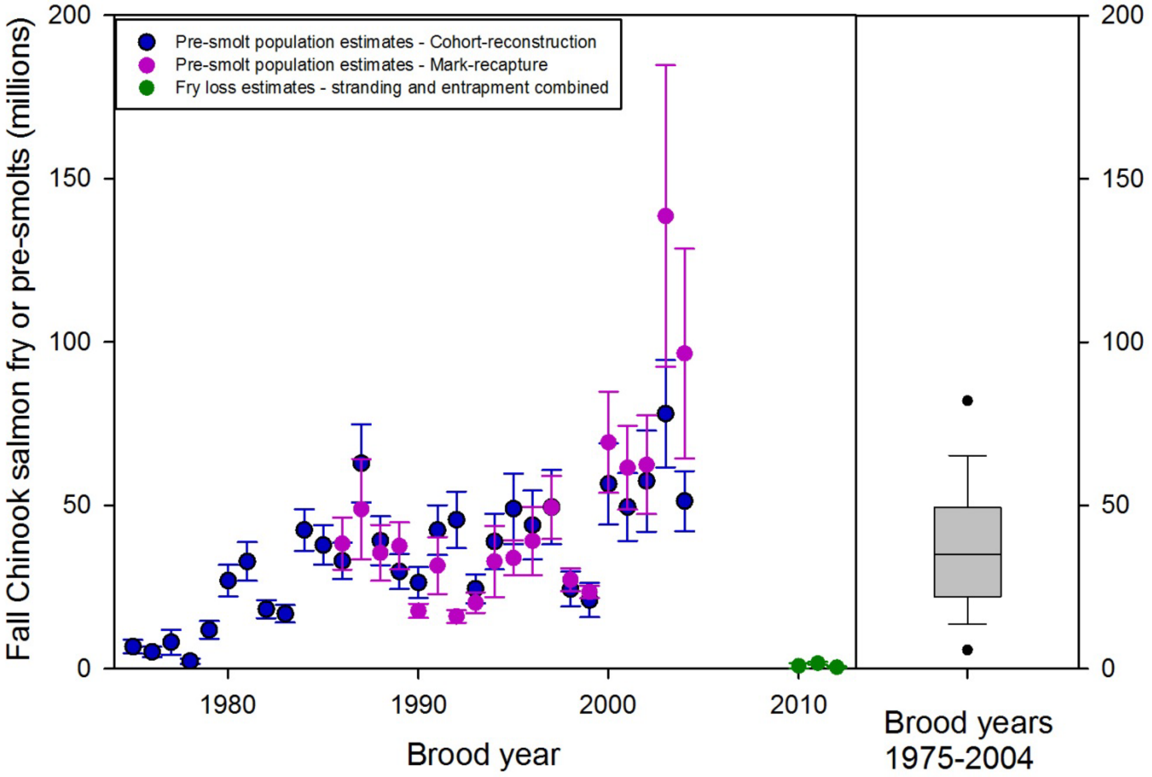

Figure 26 **Hanford Reach fall Chinook salmon pre-smolt population estimates based on cohort-reconstruction and mark recapture methodologies (with one standard deviation). The box plot was generated with mean and error estimates from the cohort reconstruction and mark recapture methodologies. The estimates 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
Evaluation of the Effect of Streamflows and Streamflow Fluctuations on Entrapment and Stranding of Juvenile Fall Chinook Salmon in the Hanford Reach of the Columbia River

Scope of Work
February 11, 2013

Hanford Reach Stranding and Entrapment Protocol, 2013 Field Sampling Methods

Updated for 2013 sampling by: P. Hoffarth (WDFW), R. Langshaw (GCPUD),

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	

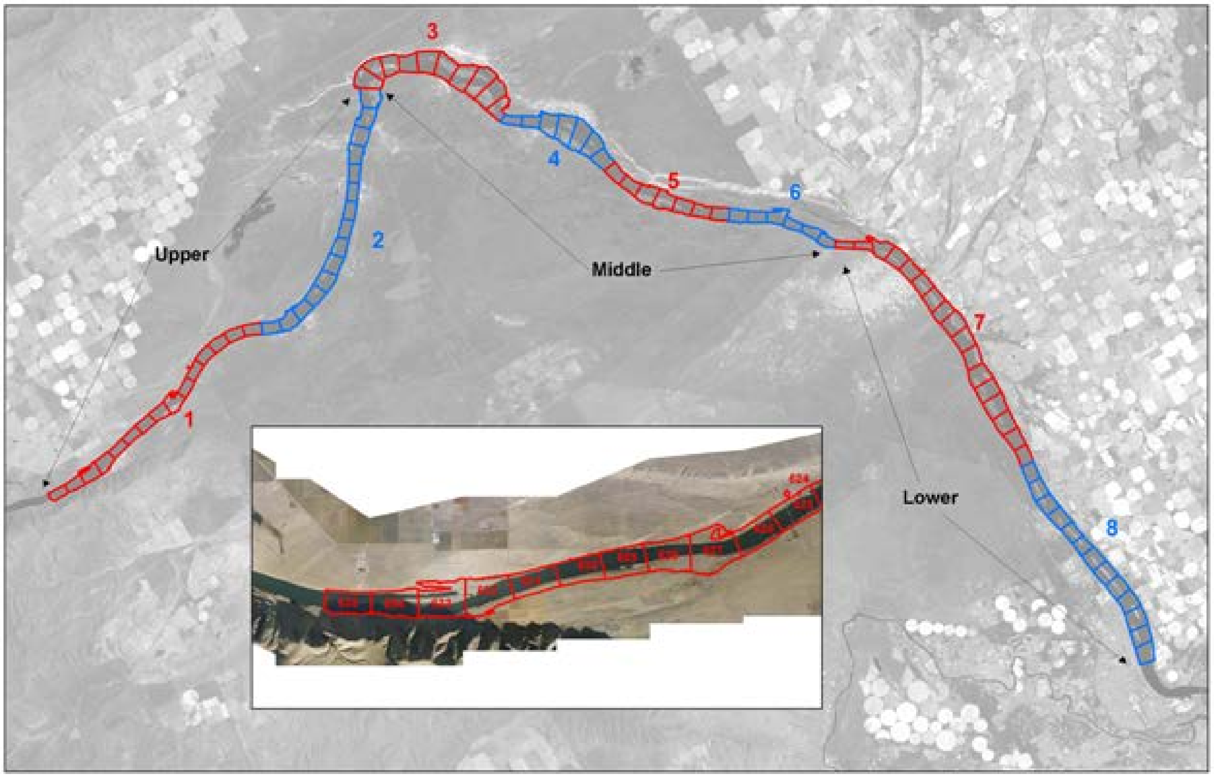


Figure 2. Spatial strata for the 2011-13 evaluation of stranding and entrapment of juvenile fall Chinook in the Hanford Reach.

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 Stranding/Entrapment Site Selection Model (SESSM) using the Modular Aquatic Simulation System in one dimension (MASS1).

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

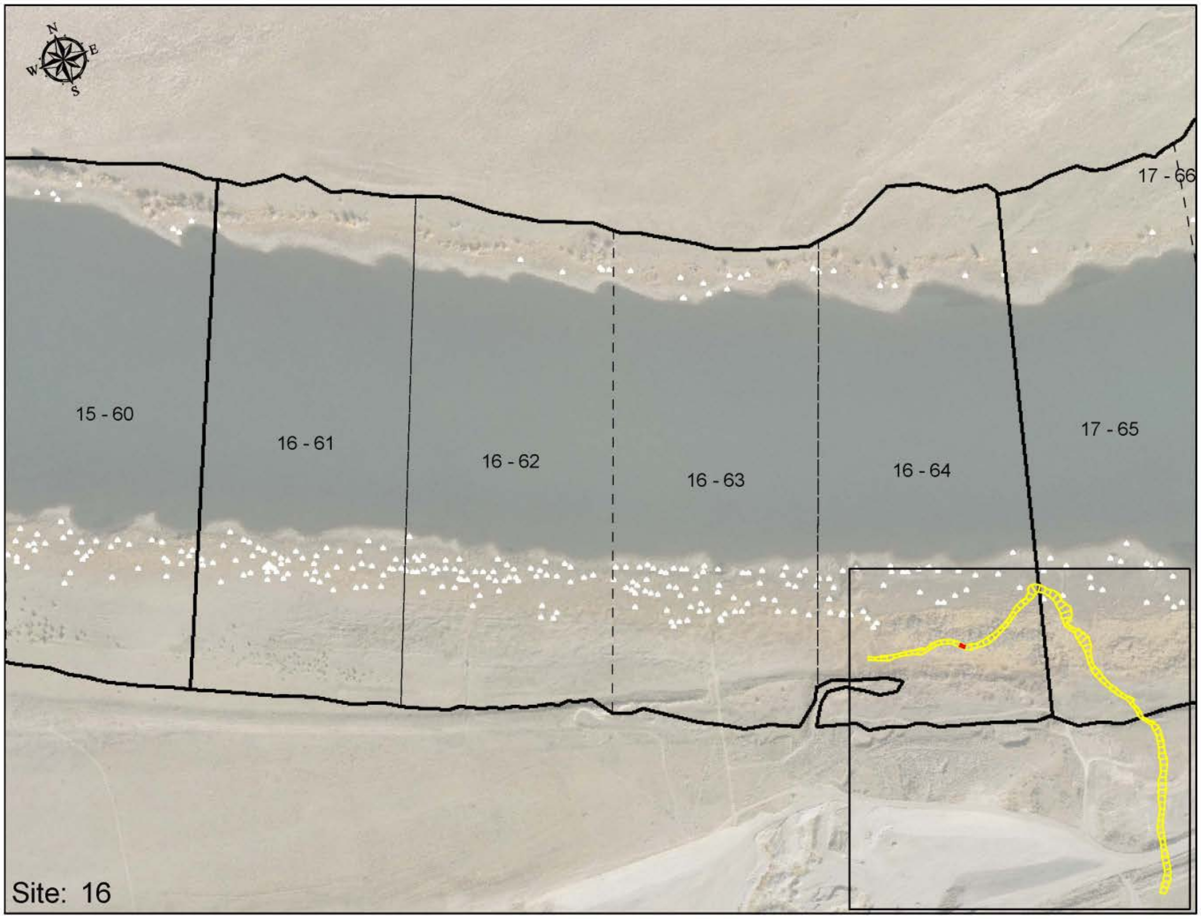


Figure 3. Example of an individual sample site (Site 16), quadrants (16.1-16.4), and entrapments (white dots).

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 sampled 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 dominant and sub-dominant 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 (SESSM) 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 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. SESSM 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. SESSM 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 transects lines. Several factors will determine the number of randomly selected transects and sites 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 days 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 transects 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.
- Transects selected will be reviewed prior to leaving the office. Where more than two shorelines are present in a transect (islands/peninsulas present) the next closest transect with only two shorelines will be reviewed through the SSEM Model to ensure the presence of a 10 meter flow band. Where the top width band is less than 10 meters the transect will be discarded and returned not sampled.

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 the ten sampling locations for the day. The list name should read as follows: crew ID followed by the four digit date (e.g. A0402). The crew will navigate to the first transect selected by the model. A coin toss will be used to determine the shoreline to be sampled first, left or right (facing downstream). When islands are present along the transect, a coin toss will be used to determine whether the island(s) or the shorelines are sampled first.

Task 2.1) The second entrapment crew (Crew C) scheduled for the day will compare the first transect selected by the SESSM to the first location selected for the first crew (Crew A). If the first transect selected by the model is within the same section (Lower, Middle, Upper) as Crew A, Crew C will select the first transect on the list outside of this area as the first transect to be sampled. If no transects are generated by the model outside of this area Crew C will use the first transect on their list.

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) As stated above, shoreline sampling order is determined by flipping a coin marked right shore/left shore. This will randomize the sampling order to eliminate bias caused by time constraints associated with shift period and changes in flow. Crews will continue to move from shoreline to shoreline along the transect until all shorelines are sampled.

Task 6.1) After completing sampling at the first transect, crews will proceed to the next closest transect on the list.

2.0 Entrapment Sampling

Physical and biological sampling of entrapments will be conducted by two, three person crews, 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.

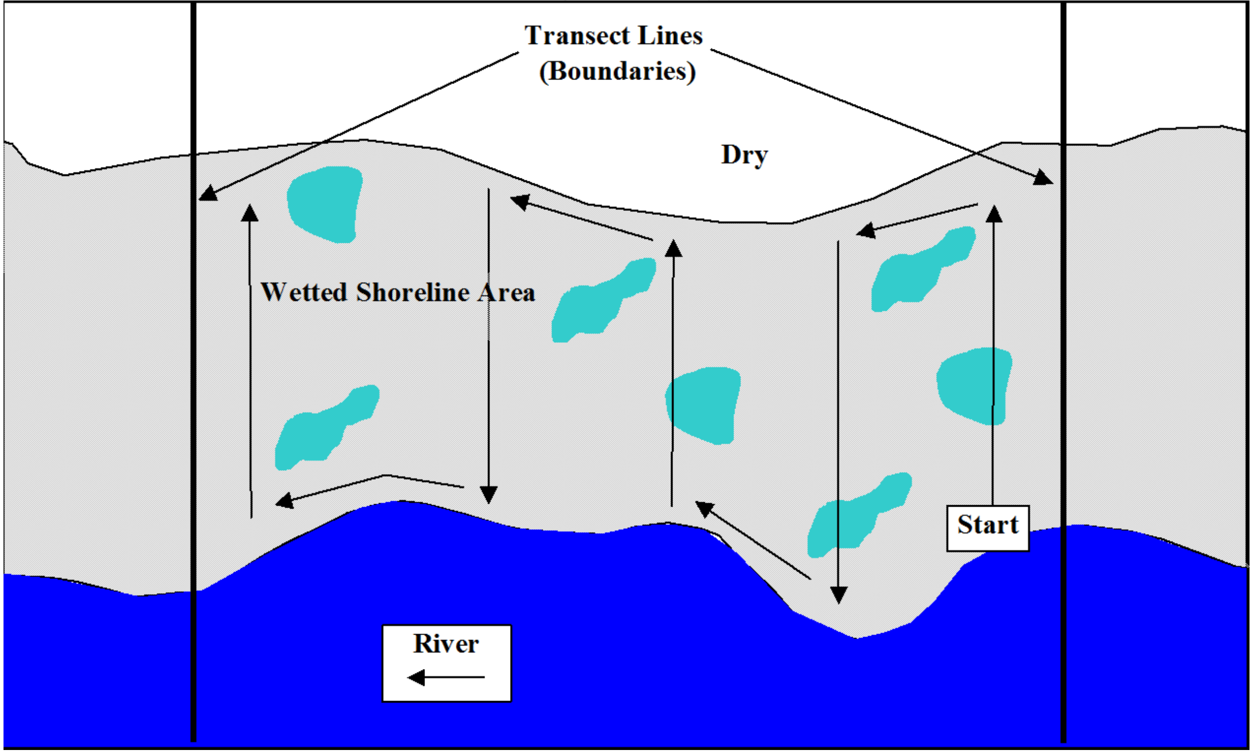


Figure 4. Search pattern for sampling entrapments.

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.

5) loosely aggregated
6) moderate
7) little space
8) 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 sampleable 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 these elevations. The proportion of lethal entrapments will be used to estimate mortality for fall Chinook in the Hanford Reach rather than the mortality of Chinook sampled in the entrapments. This greatly increases the sample size and provides sufficient data to segregate the expansions into two week time periods that better reflect the changes in abundance, air and water temperatures, and river elevation. Entrapment fate is based on the effects of drainage, water temperature, and reflooding as defined below:

Lethal (drained): Entrapment drained prior to sampling, during sampling or through *a posteriori* determination.

Lethal (temperature): Entrapments with observed water temperatures greater than 27°C will be defined as lethal.

Non-lethal (reflood): Entrapment was observed or modeled to reconnect to river during sampling are considered non-lethal. Large-deep entrapments and short duration drops in surface water elevation will likely experience a high frequency of reflooding.

Unknown: If the fate of the entrapment cannot be determined in the field, the entrapment fate is classified as “Unknown”. All entrapments with unknown fates are re-visited prior to leaving the site to determine fate and drainage rate. If the 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.

Post Assigning Fate

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 2013. 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 5, 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.

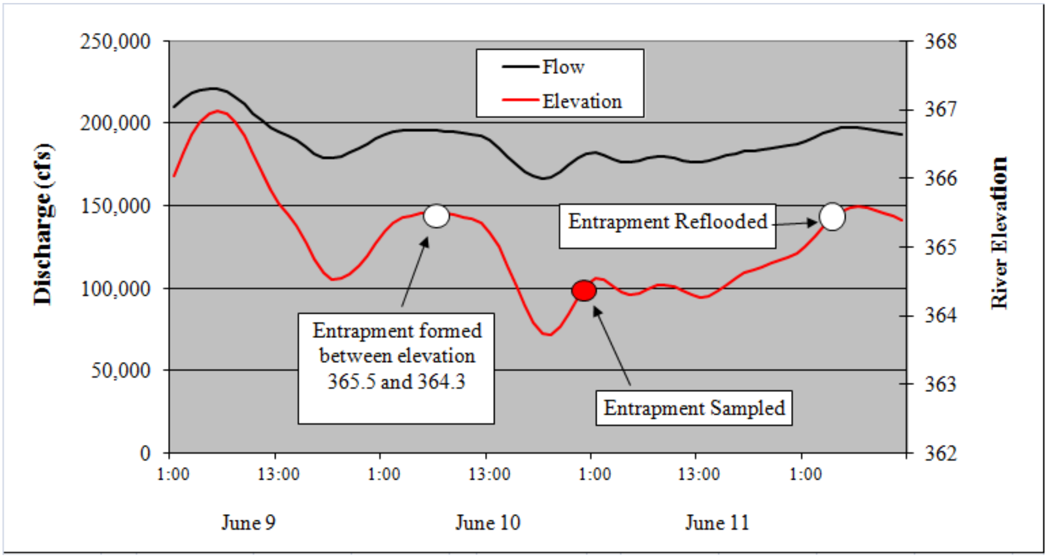


Figure 5. Example of river discharge (black line) and the water surface elevation data from MASS1 (red line) and the time an entrapment was isolated from the river and then reflooded and reconnected to the river (white circles) in reference to when it was sampled in the field (red circle).

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 2013. Where the duration between depth measurements was too brief (less than 30 minutes), the median drainage rate for entrapments from 2013 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. 2.0 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.

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 field observations, data collected on-site and water surface elevation information provided by the MASS1 hydrodynamic flow model.

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 will be conducted on the first entrapment sampled with Chinook present by each crew each day. 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.

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 below. Instead of using the number of passes to evaluate effort, the recorded shock time from the initial capture event will be used.

Sampling Efficiency: All live fish collected by beach seine or electrofishing should be anesthetized and caudal clipped from the first entrapment with Chinook sampled by each crew each day. Hold the marked fish for 5 to 10 minutes after marking to assess mortality. Release the fish into the entrapment. A sufficient amount of time should be allocated for the fish to resume their natural distribution 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) or the same duration of time for electrofishing. Efficiency estimates will be evaluated and pooled based on sample method and habitat characteristics to estimate sampling efficiency.

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. 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 transects 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.

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 transects 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 Trimble 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. Based on the width of the wetted flow band along the transect determine how the plots will be sampled. For wide flowbands, greater than 50 meters, plots will be sampled as illustrated in Figure 6. When the wetted flow band is greater than 5 meters and less than 50 meters, staff will select the appropriate sampling scheme from Figure 7 below.

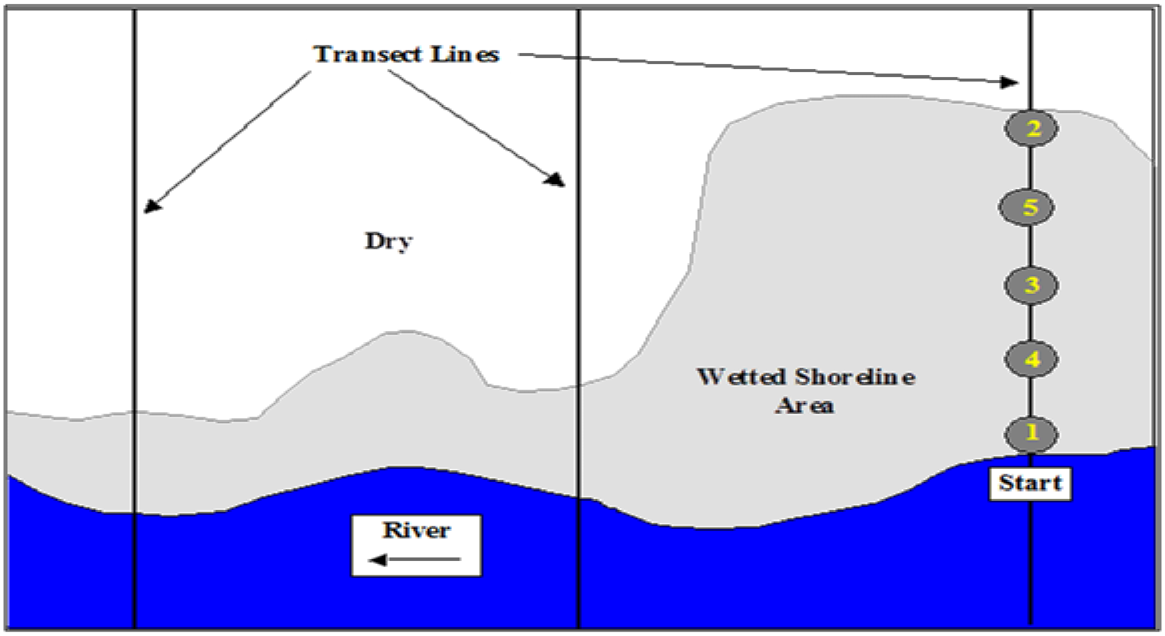
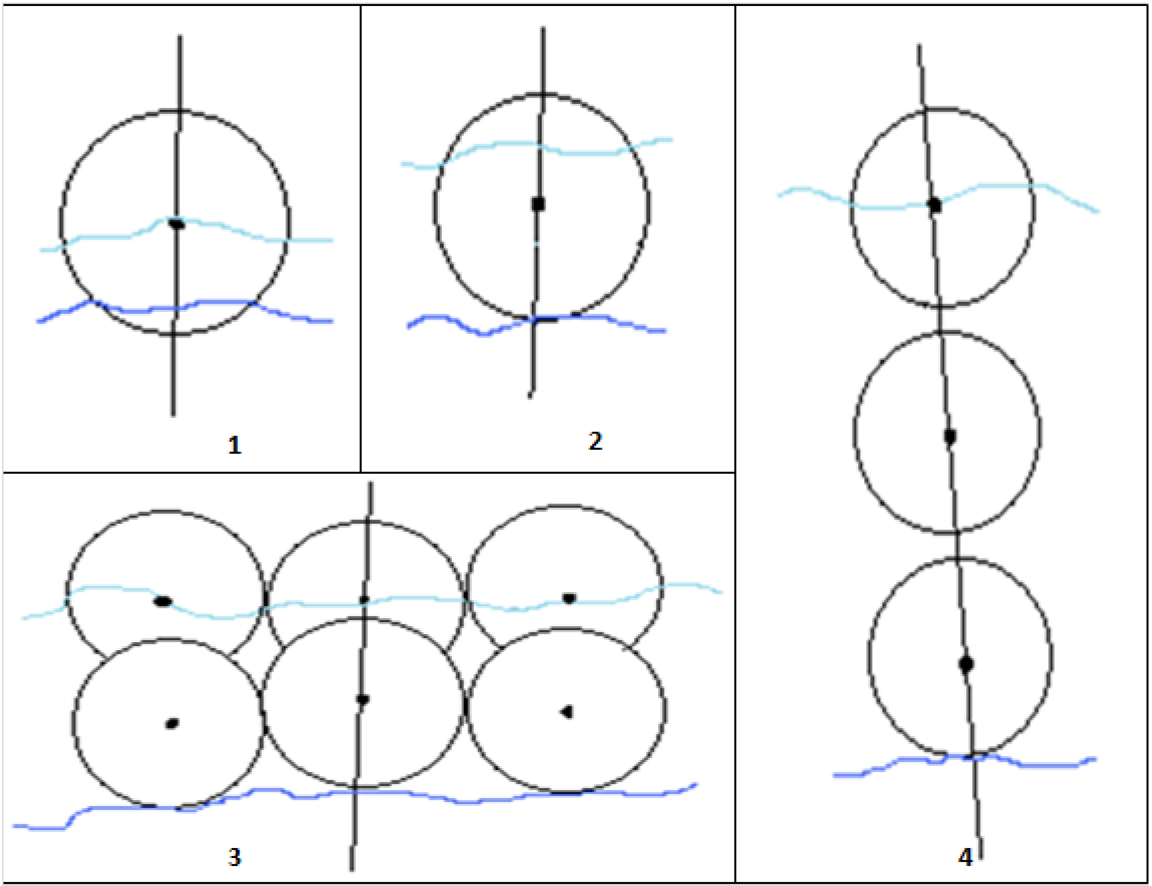


Figure 6. Sampling scheme for stranding plots with wide flow bands.



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 8. Plot configuration for transects with narrow flow bans.

Task 3) 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. 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. 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.

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 0.5 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.

Task 6) If the sampling for a given transect is complete the crew will move to the next sampling transect provided by SESM. 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.

E) 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);

F) Vegetation density:

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

G) Entrapments Present: Record yes or no;

H) 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;

I) 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 Large Entrapment Sampling

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. Typically when large numbers of juvenile fall Chinook are encountered during entrapment sampling they are observed/collected in large entrapments. Large entrapments are defined as entrapments greater than 15 meters in diameter. Due to size and depth of the larger entrapments they are less likely to drain before the river level rises and refloods the entrapment. In addition the water temperatures are less likely to reach lethal levels. Determining the fate of these larger entrapments is also more difficult as they commonly drain over a period of days rather than hours.

In 2013, twelve large entrapments will be monitored for depth, temperature, fish presence, and mortality. Temperature/depth data loggers will be placed in these 12 large entrapments in March and the data will be recorded hourly during the field sampling season (March – June 15). Entrapment crews will also routinely sample these locations to determine fish presence, abundance, and mortality.

5.0 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 data forms will be compiled and stored in three ring binders 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.

6.0 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.

Substrate Size Chart

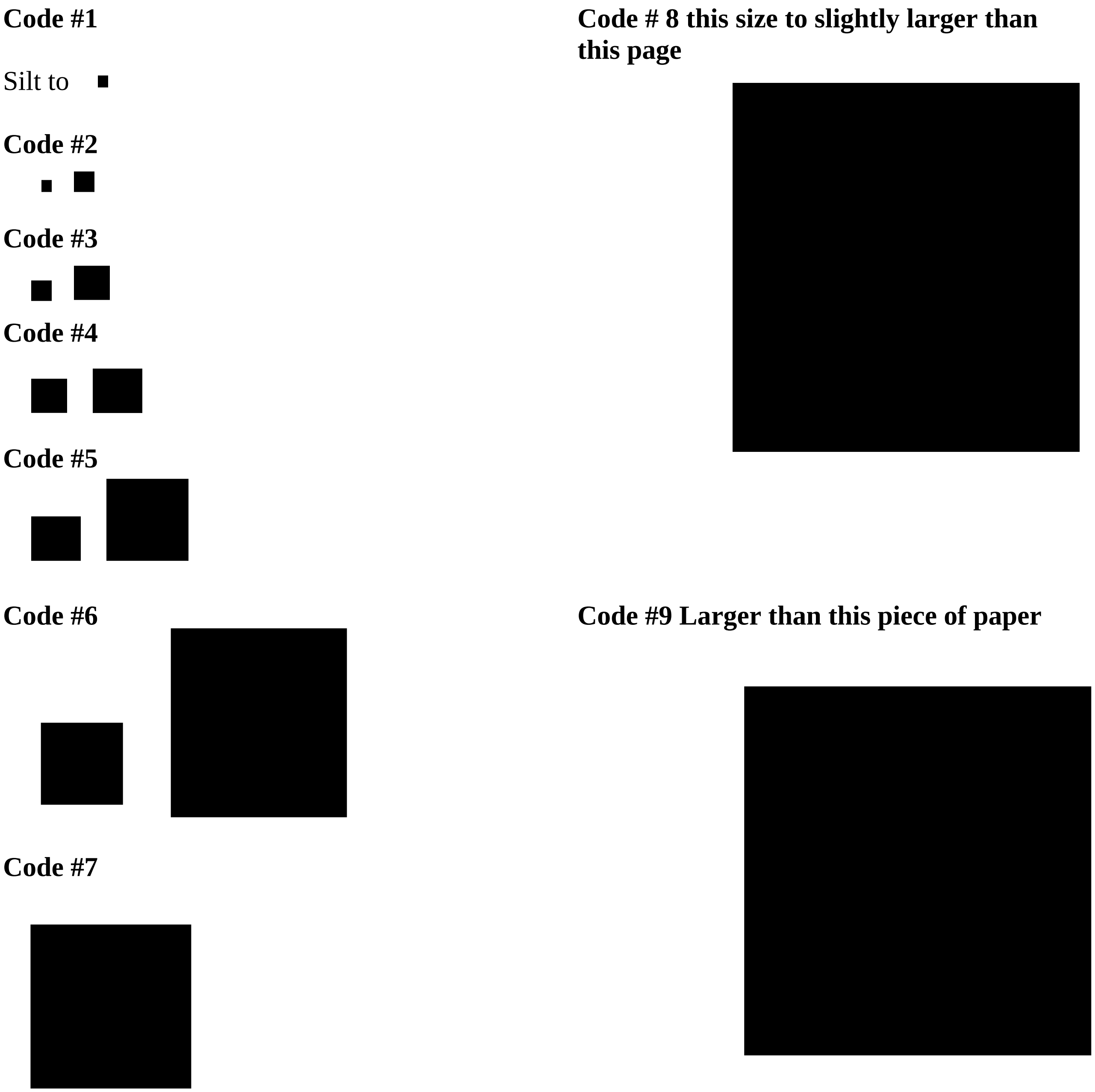


Figure 9 Substrate size classification adopted from the Wentworth code (Platts et al. 1983)

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
Grant County PUD Responses to Comments

From	Comment	Response
Alaska Department of Fish and Game – Email comments submitted 12/19/13	ADFG commended the authors on a quality report and noted that stranding and entrapment of fall Chinook salmon in the Hanford Reach appears to be a relatively insignificant mortality factor in their life history. Particularly, in relation to high mortality rates during migration that are presumed to result from predation.	We appreciate ADFG's timely review of the report, participation in the Fall Chinook Work Group, and contribution to this and other projects associated with the Hanford Reach.
Pacific Northwest National Laboratory – Written comments submitted 12/19/13 and 1/6/14	Editorial comments and suggestions for clarification.	Comments and edits were addressed before the report was finalized.
Washington Department of Fish and Wildlife – Written comments submitted 12/23/13	Editorial comments and suggestions for clarification.	Comments and edits were addressed before the report was finalized.
Fall Chinook Work Group - Discussion during the 1/7/14 meeting	Grant PUD provided a brief update of the final results presented in the report. No additional comments were provided and no one requested additional time to review the report.	We appreciate the FCWG's participation in all aspects of the project from initial development through final reporting.