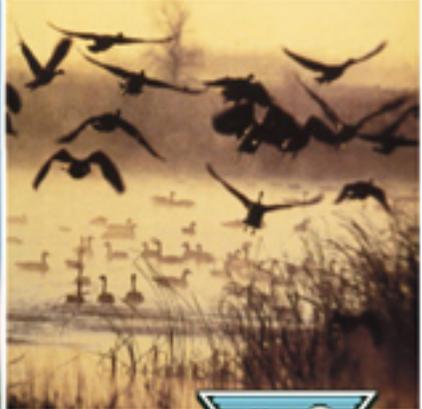
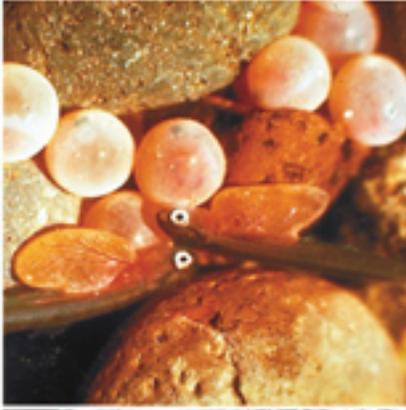


# Evaluation of Salmon Spawning below the Four Lowermost Columbia River Dams

Annual Report 2004 - 2005

February 2006

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# **Evaluation of Salmon Spawning Below the Four Lowermost Columbia River Dams**

**Annual Report**

**October 2004 – September 2005**

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Chapter 3:

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## Foreword

Since FY 2000, scientists at Pacific Northwest National Laboratory (PNNL) have conducted research to assess the extent of spawning by chum (*Oncorhynchus keta*) and fall Chinook (*O. tshawytscha*) salmon in the lower mainstem Columbia River. Their work supports a larger Bonneville Power Administration (BPA) project aimed at characterizing the physical habitat used by mainstem fall Chinook and chum salmon populations. Multiple collaborators in addition to PNNL are involved in the BPA project—counterparts include the Washington Department of Fish and Wildlife (WDFW), U.S. Fish and Wildlife Service (USFWS), Pacific States Marine Fisheries Commission (PSMFC), U.S. Geological Survey (USGS), and Oregon Department of Fish and Wildlife (ODFW). Data resulting from the individual tasks each agency conducts are providing a sound scientific basis for developing strategies to operate the Federal Columbia River Power System (FCRPS) in ways that will effectively protect and enhance the chum and fall Chinook salmon populations—both listed as threatened under the Endangered Species Act.

## Background

Fall Chinook salmon, thought to originate from Bonneville Hatchery, were first noted to be spawning downstream of Bonneville Dam by biologists from the WDFW in 1993. Known spawning areas include gravel beds on the Washington side of the river near Hamilton Creek and Ives Island. Limited spawning ground surveys were conducted in the area around Ives and Pierce islands during 1994 through 1997. Based on these surveys, fall Chinook salmon were believed to be spawning successfully in this area. In addition, chum salmon have been documented spawning downstream of Bonneville Dam.

In FY 1999, BPA Project No. 1999-003 was initiated by the WDFW, ODFW, and the USFWS to characterize the variables associated with physical habitat used by mainstem fall Chinook and chum salmon populations and to better understand the effects of hydropower project operations on spawning and incubation. Pacific Northwest National Laboratory was asked to join the study in FY 2000, during which its initial efforts were focused on 1) investigating the interactions between groundwater and surface water near fall Chinook and chum salmon spawning areas and 2) locating and mapping deepwater fall Chinook salmon spawning areas. In FY 2001, an additional task was added to provide support to the WDFW for analysis of juvenile salmon stranding data. The work PNNL has conducted since then continues to address these same three issues. The overall project is subdivided into a series of tasks, with each agency taking the lead on a task; WDFW leads the adult task, ODFW leads the juvenile task, and the USFWS leads the habitat task. All three tasks are designed to complement each other to achieve the overall project goal. Study results from PNNL's work contribute to all three tasks.

## Report Scope

This report documents the studies and tasks performed by PNNL during FY 2005. Chapter 1 provides a description of the deepwater redd searches conducted adjacent to Pierce and Ives islands and documents the search results and analysis of findings. Chapter 2 documents the collection of data on riverbed and river temperatures, from the onset of spawning to the end of emergence, and the provision of those data in-season to fisheries management agencies to assist with emergence timing estimates. Technical assistance provided to the WDFW in evaluation of stranding data is summarized in Chapter 3.

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# Chapter 1

## Deepwater Spawning of Fall Chinook Salmon (*Oncorhynchus tshawytscha*) near Ives and Pierce Island of the Columbia River, 2004

*Robert P. Mueller*

### Summary

Pacific Northwest National Laboratory conducted video-based boat surveys to identify fall Chinook salmon (*Oncorhynchus tshawytscha*) spawning areas located in deep water (greater than 1 m) downstream of Bonneville Dam in fall 2004. This report documents the number and extent of Chinook salmon spawning near Ives and Pierce Islands of the Columbia River and is the sixth in a series of reports prepared since 1999. The main objectives of this study were to find deepwater spawning locations of fall Chinook salmon in the main Columbia River channel, collect additional data on physical habitat parameters at spawning sites, and provide estimates of adult spawners in the surveyed area. The primary search area was adjacent to the upper portion of Pierce Island, and the secondary search zone was downstream of this area near the lower portion of Pierce Island. A secondary objective was to document the occurrence of any chum salmon (*O. keta*) redds in the deeper sections downstream of Hamilton Creek (slough zone search area).

Fall Chinook salmon redd numbers were down slightly from the record number found during 2003. The number of fall Chinook redds found in the Ives–Pierce Island complex (river km 228.5) during 2004 was 293, which does not include the number of shallow water redds found by visual observation by boat by the Oregon Department of Fish and Wildlife. The redds encompassed an area of 14.6 ha occurring adjacent to the lower part of Ives Island and Pierce Island. Peak spawning activity, based on redd counts and live fish seen near redds, was on or near November 16, 2004. An expanded redd count based on percentage video coverage in the primary and secondary search zones was 3,198 fall Chinook salmon redds at water depths exceeding approximately 1.0 m (approximately 125 kcfs) with an estimated spawning population of 10,800. Fall Chinook salmon redds were found at water depths from 1.07 to 7.6 m and were constructed predominantly of medium cobbles ranging in size from 7.6 to 15.2 cm in diameter. Near-bed water velocity readings taken in the secondary search ranged from 0.04 to 0.98 m/s (median 0.45 m/s). No chum salmon redds were found in a limited area within the relatively deeper sections of Hamilton Slough below Hamilton Creek. No additional salmon or chum redds were found in other areas searched, including near Woodward, Tanner, and McCord Creeks.

## Introduction

Since 1993, fall Chinook salmon (*Oncorhynchus tshawytscha*) have used Ives and Pierce Islands downstream of Bonneville Dam for spawning (Hymer 1997). Two stocks of fall Chinook salmon spawn in the area—lower river or Tule, currently listed as threatened (Good et al. 2005), and upriver bright stock, most of which spawn in the Hanford Reach of the Columbia River (Huntington et al. 1996). The size of this population was estimated at 1,800 to 5,200 fish from 1994 to 1996 (Hymer 1997). More recently, an adult population of 1,881 adult fish was estimated in 2002 (van der Naald et al. 2004) and 1,533 in 2003 (van der Naald et al. 2005). These estimates are based on carcass tagging and recoveries near shallow water and do not take into account fish that spawn nearer the main river channel in water depth exceeding approximately 2 m.

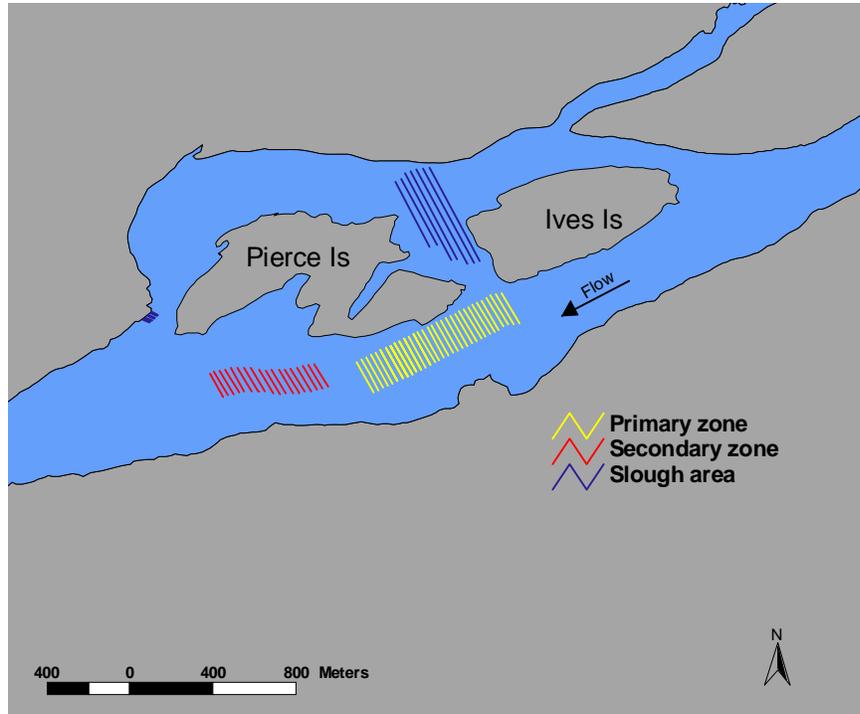
Pacific Northwest National Laboratory (PNNL) has conducted underwater video surveys from 1999 through 2004 downstream of Bonneville Dam. The primary objectives in 2004 were to locate and map deepwater (greater than 1 m) spawning areas of fall Chinook salmon near the main Columbia River channel and to collect additional data on the physical habitat at spawning sites. The secondary objective was to map any chum salmon (*O. keta*) redds located in deeper sections in and around Ives and Pierce Islands.

## Methods

The survey area consisted of three different search zones approximately 3.5 km downstream of Bonneville Dam near river km 228.5. The primary zone (125,000 m<sup>2</sup>) along the main channel side of Pierce Island was segmented into regularly spaced transects, 20 m apart and 160 m long (37 total), running perpendicular to the shoreline. An additional eight transects were run at 20-m spacing immediately upstream of the primary zone during the 2003 surveys. The secondary zone (60,350 m<sup>2</sup>) was at the lower end of Pierce Island and consisted of 18 additional transects, 25 m apart and 120 m long. The third search zone (slough area) consisted of two separate areas. The first was at the lower end of Pierce Island, and the second was within Hamilton Slough between Ives and Pierce Islands (Figure 1-1). These areas were established based on previous surveys that documented fall Chinook and chum salmon redd occurrences (Mueller and Dauble 2000; Mueller 2001, 2002, 2003, 2004).

Two separate underwater video boat surveys were conducted in late November and early December 2004. The surveys were conducted just after November 16, the peak spawning date for fall Chinook salmon. This date was based on visual observations of adult fish by the Oregon Department of Fish and Wildlife (ODFW).

The boat-deployed video system consisted of a high-sensitivity remote camera (DeepSea Multi-SeaCam<sup>®</sup> Model 1050) attached to a weighted platform or sled. The camera was positioned at a slight angle forward from vertical so that redd characteristics (bed elevation) could be detected more easily. Recordings were made using an 8-mm digital recorder (Sony Model GVD 7000) situated on the survey vessel; two high-resolution monitors for real-time viewing of the video obtained by the remote camera also were aboard the survey vessel. An integrated video/tow cable attached to a manual winch with slip ring mechanisms was used to raise and lower the sled to the desired depth. The presence of disturbed cobble indicated by changes in background contrast as well as “tail-spill” piles were the primary criteria used to determine spawning activity.



**Figure 1-1.** Location of Search Zones in Relation to Ives and Pierce Islands

The coverage area varied throughout the survey period and was influenced by ambient light levels, water clarity, boat speed, and, to a lesser extent, bottom slope and composition. The distance from the camera lens to the substratum averaged approximately 1.2 m, providing an effective coverage area of approximately 2.5 m<sup>2</sup> at any one location along each transect. The approximate vertical coverage along each transect was 1.2 m.

An on-board, real-time differential global positioning system (DGPS) (Trimble Pathfinder<sup>®</sup> Pro XR) was used to collect positional data and to navigate on preset transect grids during the surveys. The integrated DGPS beacon receiver and antenna provided DGPS corrections to calculate accuracy to below approximately 0.5 m. The system software (ASPEN) displayed a background map of the study site on a personal computer so that researchers could navigate to site locations on a predetermined transect line and visually verify data accuracy in the field. Both the DGPS and video system were synchronized via a time stamp. When a redd was encountered, the time was noted in the logbook; the notation was later associated with a GPS position. Further analysis and verification of redds was performed at PNNL in Richland, Washington. The location of any new redds also was mapped to an Arc/View<sup>®</sup> geographic information system (GIS).

The type and size of the substratum were determined with underwater red lasers (C-Map Systems Model HL6312G). The lasers provided a reference scale within the camera image. The distance from the camera lens to the substratum ranged from 0.9 to 1.4 m, providing an effective view path of approximately 2.5 m<sup>2</sup> along each transect. Grain size was determined by digitizing the image when the camera was positioned near the center portion of the redd and processing the image using an imaging software program (Optimas<sup>®</sup>). Three rocks were measured (long axis diameter) that constituted the dominant substrate size for each digitized image. An average of the three measurements was used to determine the

actual substrate category for each redd. The substrate size for each redd was classified according to five general size categories (Table 1-1). Using the substrate category, we expanded these points, based on association with the nearest substrate type, to predict the substrate category where no data points were collected. We projected the GPS positions into the GIS (ArcView) and then used a script (Thiessen Polygons) to connect a series of point locations with line segments, erecting perpendiculars to those line segments at their midpoints, and then extending those perpendiculars until they intersected.

**Table 1-1.** Substrate Categories Used for Spawning Habitat Classification (modified from Platts et al. 1983)

Category	Sediment Classification	Long Axis Diameter of Individual Substrate (cm)
1	Fines, silt	<0.61
2	Gravel	0.6 – 7.6
3	Medium cobble	7.6 – 15.2
4	Large cobble	15.2 – 30.5
5	Boulder	>30.5

Near-bed water velocity point measurements were obtained with a Marsh-McBirney Flo-Mate flowmeter (Model 2000) positioned 20 to 22 cm above the substratum, with the weighted platform resting on the river bottom. A measurement was recorded after the display stabilized. Point velocities were measured throughout the secondary survey zone, approximately four measurements per transect (Appendix A). GIS maps were created using Thiessen Polygons to connect the point velocity locations with line segments, erecting perpendiculars to those line segments at their midpoints, and then extending those perpendiculars until they intersected. Mean near-bed velocities ranging from 0.1 to 2.0 m/s are considered to be favorable for fall Chinook salmon spawning activity (Groves and Chandler 1999).

To eliminate the possibility of counting a redd more than once during the two survey periods, we omitted any redds that fell within a 1.8-m radius of a nearby redd. This distance was based on an overall redd size of 10 m<sup>2</sup>, which is indicative of fall Chinook salmon redds within the Columbia River (Burner 1951; Chapman et al. 1983; Visser 2000). In addition, the cumulative number of redds found during both survey periods was extrapolated to estimate the total number of redds constructed within the primary search zone. These estimates were calculated by taking the total number of redds found during each of the surveys and expanding this number based on the percentage of coverage (assuming normal distribution) within the total search zone. The total fall Chinook salmon redd estimates do not include redds found by other researchers conducting visual redd observations by boat.

Water turbidity was recorded using a LaMotte turbidimeter (Model 2008). Recorded tapes were reviewed in detail at the PNNL computer laboratory using a high-resolution monitor. Bathymetric data were obtained using a one-dimensional, unsteady river flow and water quality computer model, MASS1 (Modular Aquatic Simulation System 1D), developed at PNNL.

## Results

A total of 293 fall Chinook salmon redds were found and mapped during surveys conducted in November and December 2004 (Figure 1-1). Initial deepwater redd surveys of the main channel near Ives and Pierce Islands were completed on November 22 and 24, 2004, shortly after the peak spawning date of November 16 for fall Chinook salmon (FPC 2004). River flows recorded at Bonneville Dam were quite variable, ranging from 121 to 170 kcfs (Table 1-2). The majority of the redds were mapped on November 22 and 23 when flows averaged 126.1 kcfs. A total of 193 fall Chinook redds were located and mapped within all surveys zones. This total includes 124 within the primary search zone, 63 in the secondary zone, and 6 additional redds found upstream of the primary search zone near the lower portion of Ives Island (Table 1-3). A separate survey was conducted in the slough zone downstream of Hamilton Creek. A total of seven transects were run within this zone, with water depths ranging from 0.6 to 2.7 m. Flows during this survey were near 127 kcfs (staff gage 1 = 0.98 ft), which precluded boat access in the area between Ives and Pierce Islands. Several chum carcasses were observed, but no confirmed redds were found during the limited search.

**Table 1-2.** Average River Flow and Elevation Conditions Recorded During the Underwater Video Survey Period

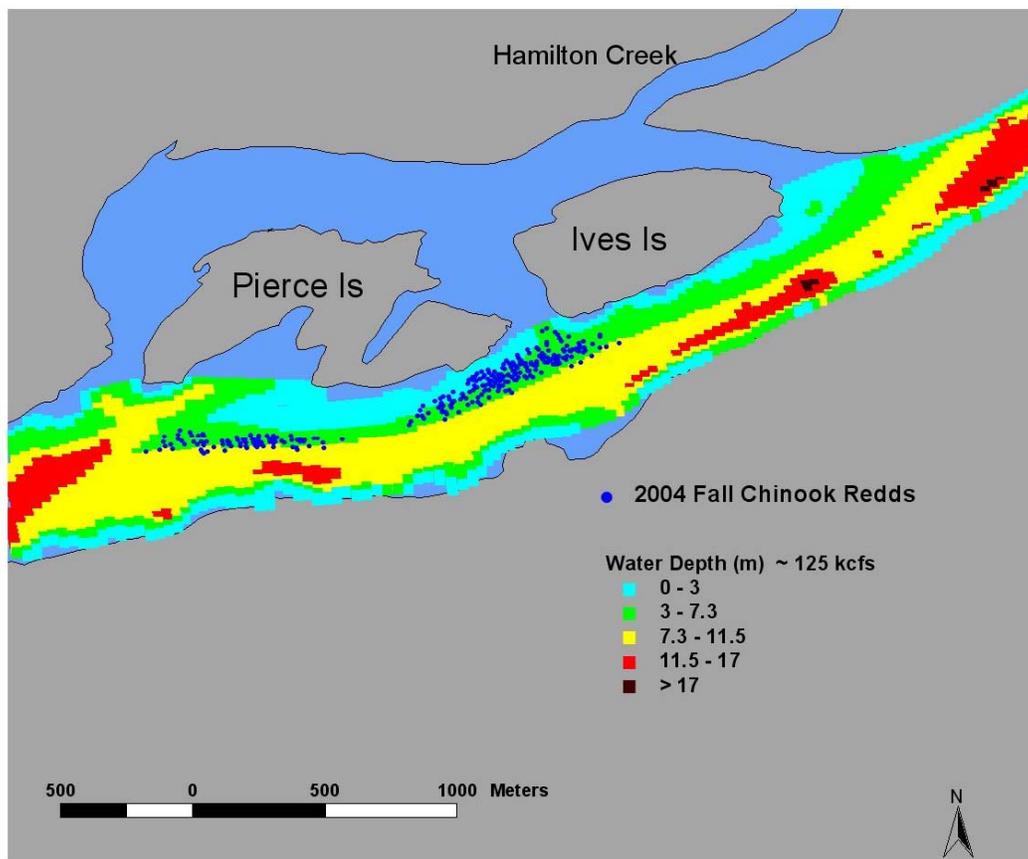
Date	Discharge at Bonneville Dam (average kcfs)	Ives Island Staff Gage 1 (ft)
November 22, 2004	126.7	0.88
November 23, 2004	125.5	1.0
November 24, 2004	170.0	3.7
December 8, 2004	151.8	3.4
December 9, 2004	102.8	1.6

**Table 1-3.** Number of Fall Chinook Redds Found in Primary and Secondary Search Zones 2004

Survey Date	Primary Zone (includes redds found at lower Ives Island)	Secondary Zone
November 22 through 24	130	63
December 8 and 9	72	28
Total	202	91

The second deepwater fall Chinook salmon redd survey was completed on December 8 and 9, 2004. River discharge at Bonneville Dam during the survey period ranged from 151.8 kcfs on December 8 and fell to 102.8 kcfs on December 9; water turbidity averaged 3.4 NTU. A total of 100 additional redds were found, including 72 in the primary search zone and 28 in the secondary zone. The maximum depth at which redds could be detected was 8.5 m during both surveys.

The location of all redds (n = 293) found during surveys conducted in 2004 is shown in Figure 1-2. The MASS1 model was superimposed on the river layer to illustrate the redds in relation to water depth at a river flow of 125 kcfs at Bonneville Dam.

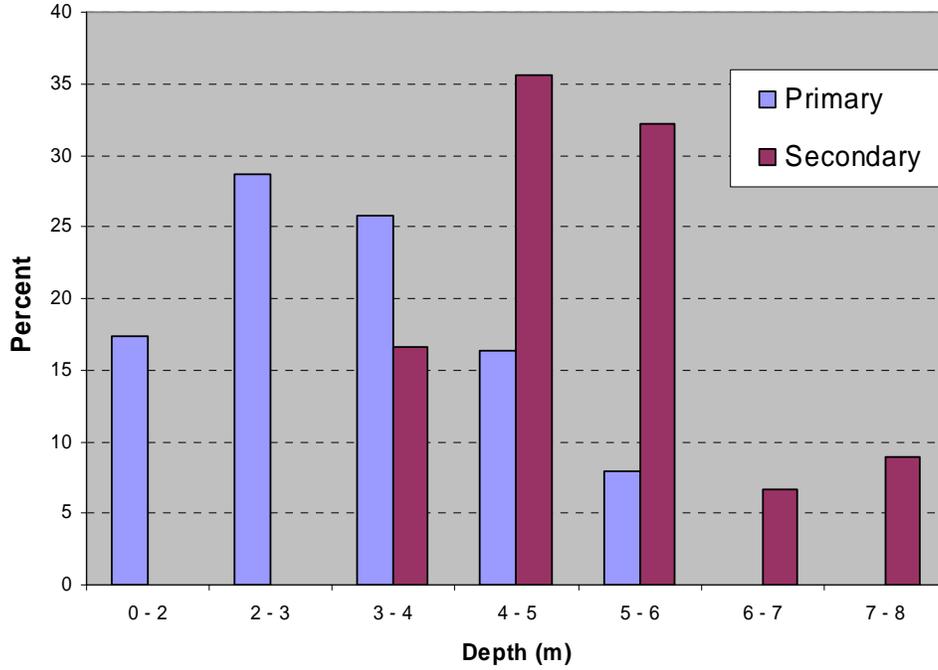


**Figure 1-2.** Location of Fall Chinook and Chum Salmon Redds (n = 293) in the Mainstem of the Columbia River Below Bonneville Dam in 2004

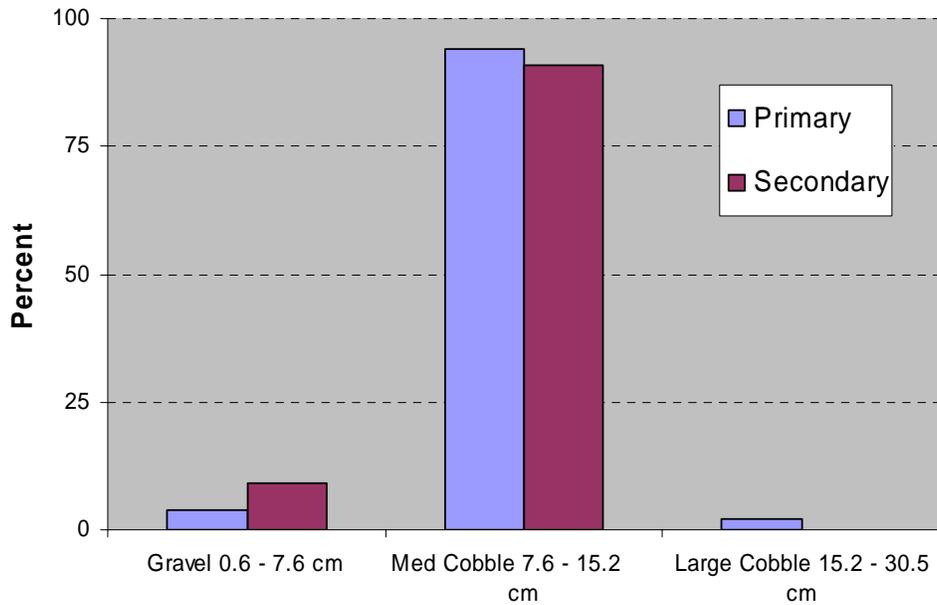
Water depths at redd locations ranged from 0.3 to 6.7 m (median = 3.0 m) in the primary and 3.0 to 7.92 m (median = 4.8 m) in the secondary zone at a river flow of approximately 123 kcfs (Figure 1-3).

Dominant substrate measurements were measured from the majority of the redds found using the lasers for scaling. The long axis diameter from 120 redds found in the primary search zone ranged from 7.0 to 18 cm (median = 10.0 cm) and 6.9 to 13.2 cm (median = 9.0 cm) in the secondary zone (n = 61). The substrate sizes were fairly uniform throughout the primary and secondary spawning zones and mostly fell into the medium cobble category (Figures 1-4 and 1-5). Only 16 redds were found in the gravel category and 2 in the large cobble category.

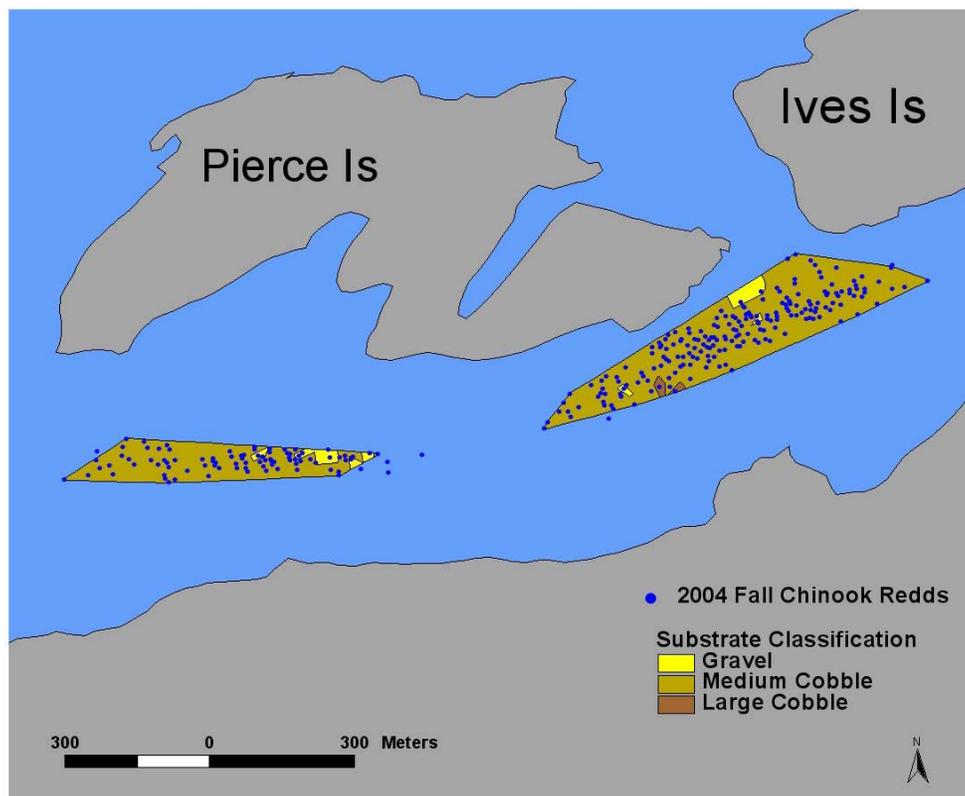
The Hamilton Slough survey was conducted on November 23, 2004. Low water elevation precluded surveys in the channel between Ives and Pierce Islands. A total of four carcasses were found, but no redds were observed. Additional chum or coho (*O. kisutch*) salmon carcasses were found at the mouth of Woodward Creek. We did not find any salmon redds during limited surveys at the mouths of Woodward, McCord, and Tanner Creeks.



**Figure 1-3.** Distribution of Fall Chinook Salmon Redds (n = 292) Relative to Water Depth During the November and December 2004 Surveys in the Primary and Secondary Search Zones (flow approximately 123 kcfs)



**Figure 1-4.** Dominant Substrate Classification of Fall Chinook Salmon Redds (n = 186) in the Primary and Secondary Search Zones



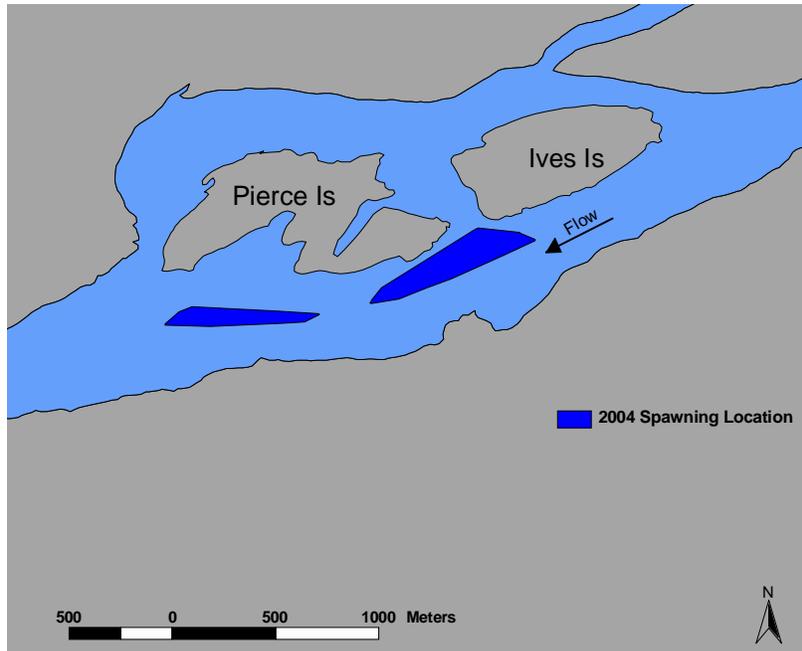
**Figure 1-5.** Substrate Composition Within the Fall Chinook Spawning Zones and Redds Found in 2004

The total area used by fall Chinook salmon for spawning was calculated by drawing a boundary line around the redd locations within the primary and secondary zones. A maximum convex polygon was created from points recorded above all salmon redds at both the upper and lower spawning areas. The radius of the polygon was then buffered 3 m to account for the redd areas that defined the polygon vertices. This buffer was then combined with the convex polygon, and the area was calculated. The area where redds were found encompassed 9.74 ha in the primary and 4.92 ha in the secondary zone (Figure 1-6). Additional maps showing how the spawning area has changed over the period from 1999 through 2004 are shown in Appendix B.

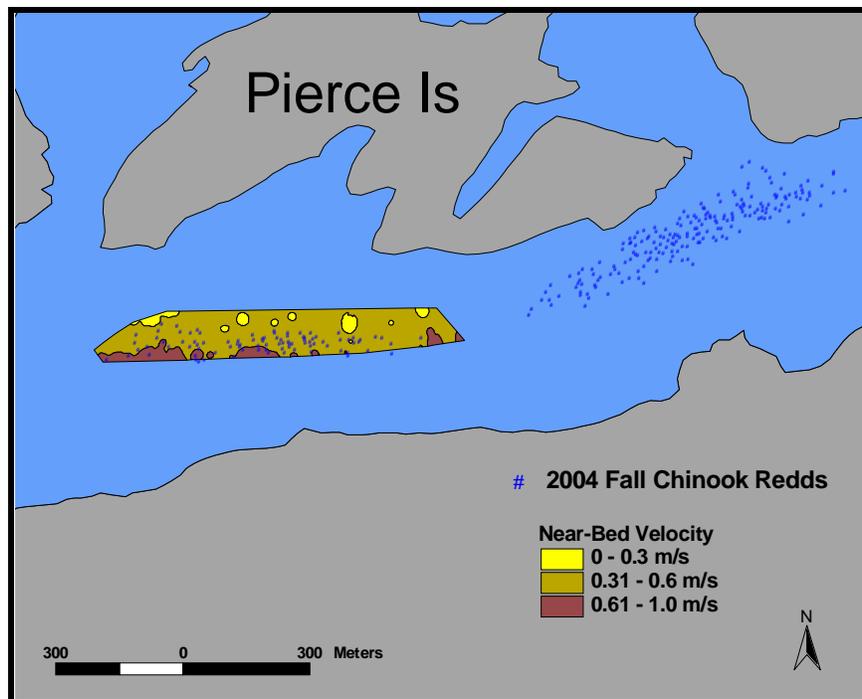
Near-bed water velocity readings were measured on December 9 at a river discharge of 105 kcfs. The water velocities ranged from 0.04 to 0.98 m/s (median 0.45 m/s). The interpolated map shows the majority of the redds were found where velocities were 0.3 m/s or greater. Velocities increased to near 1.0 m/s along the southern part of this zone nearest the main river channel.

During the past 4 years of deepwater redd surveys by PNNL, a total population of spawning fish was estimated by extrapolating the redd count based on the portion of the area surveyed by video camera. The average vertical coverage along each transect line was estimated to be approximately 1.2 m. This measurement was averaged during the two survey periods. Because the boat route varied somewhat along the line of each transect, the distance traveled along each transect varied. The actual redd count was used to estimate the total number of redds that may be present in the overall survey zone, assuming equal distribution throughout the two zones. Approximately 6.5% of the primary and 5.2% of the secondary zone were surveyed by the video camera. To estimate the total spawning population within the spawning

zones (Figure 1-7), a multiplier of 3.4 adult fish for each redd was used (Visser 2000). Using this multiplier, approximately 10,800 fish were present during the peak spawning period in mid-November 2004 (Table 1-4).



**Figure 1-6.** Fall Chinook Salmon Spawning Area for Redds Found During 2004



**Figure 1-7.** Near-Bed Water Velocity Measurements Taken December 9, 2004 (secondary zone), and Redd Locations (river flow approximately 105 kcfs)

**Table 1-4.** Estimated Number of Fall Chinook Salmon Redds Occurring in the Primary Search and Secondary Zone near Ives and Pierce Islands near the Peak Spawning Period, November 22 and 23, 2004

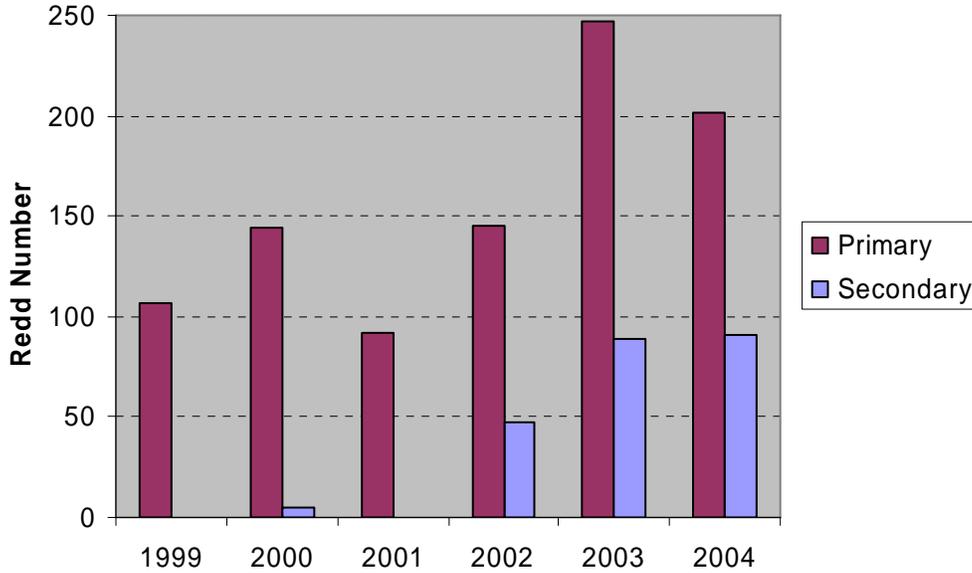
Location	Total Area Surveyed (m <sup>2</sup> ) <sup>(a)</sup>	Video Coverage (%)	Number of Redds Found	Extrapolated Redd Estimate	Adult Population Estimate
Primary	6,614	6.5	130	1,985	6,749
Secondary	2,958	5.2	61	1,152	3,115
Total	9,572		191	3,137	9,864
(a) Area encompassed the survey boat track and average transect length in each survey zone based on a 1.2-m video field view along each transect.					

In addition to the deepwater surveys conducted by PNNL during 2004, personnel from ODFW counted a total of 111 fall Chinook salmon redds on November 9 through 16, 2004, by wading or boat in water depths less than 2 m. These redds were located at the upper part of Pierce Island and in the shallow channel between Ives and Pierce Islands (FPC 2004).

## Discussion

A total of 293 fall Chinook salmon redds were found to occur near the vicinity of Ives and Pierce Islands downstream of Bonneville Dam in 2004. This number is slightly lower than the record number of redds found in 2003 when 336 redds were found. We continue to observe a larger portion of redds in the lower portion of Pierce Island (secondary zone) as the percentage of the total redds found increased from 3% in 2000 to 31% in 2004 (Figure 1-8). The overall spawning area was also the highest observed for 2004, growing from 4.0 ha in 1999 to 14.6 ha in 2004 (Table 1-5). No chum redds were found during our limited surveys. ODFW personnel documented chum spawning near the mouth of Hamilton Creek, one fall Chinook salmon in the slough area near the north river bank, and 37 redds in the channel between Ives and Pierce Islands.

The maximum water depths at which redds were detected during 2004 was 7.9 m. At 3.4 NTU, water turbidity was higher than what we experienced during surveys in previous years. Ideal turbidity levels for visual detection would be in the 1- to 2-NTU range. Turbidity values exceeding 4 NTU can limit the ability to detect redds in water depths greater than 6 m (Dauble et al. 1999). Mean near-bed water velocity measurements within the suitable regions were generally on the very low end of the preferred criteria scale (0.45 m/s). All redds mapped within the secondary zone were located in areas where water velocities exceeded 0.31 m/s. Groves and Chandler (1999) reported mean substrate level velocities of 0.88 m/s on 164 fall Chinook redds below Hells Canyon Dam from 1993 through 1995. Water velocity measured near the bed within the secondary zone showed an increasing value toward the main river channel. River flows were consistent during the first survey period at approximately 126 kcfs and varied from 151 to 102 kcfs during the second survey.



**Figure 1-8.** Historical Perspective of Redd Proportions in the Primary and Secondary Search Zones near Pierce Island, 2004

**Table 1-5.** Fall Chinook Redd Counts and Approximate Spawning Areas from 1999 Through 2004 near Ives and Pierce Islands

Year	Redds (n)	Approximate Spawning Area (ha)
1999	64	4.0
2000	76	6.3
2001	43	4.9
2002	192	9.3
2003	336	13.7
2004	293	14.6

### Acknowledgments

The author thanks Scott Titzler, Fenton Khan, Corey Duberstein, and Nate Phillips of Pacific Northwest National Laboratory for their assistance in conducting the surveys, preparing geographic information system maps, and analyzing the videotapes.

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## Appendix A

### Near-Bed Water Velocity Point Measurements, 2004

#### Bed Velocity Coordinate Description

Projection	Stateplane
Zone	WA South 4602
Datum	NAD27
Units	US Survey feet

No.	Northing	Easting	Depth (m)	Bed Velocity (m/s)
1	107142.173	1614581.397	3.4	0.41
2	107072.576	1614687.607	5.0	0.81
3	107056.633	1614705.198	5.3	0.79
4	107056.366	1614585.334	5.2	0.33
5	107153.685	1614545.487	3.2	0.53
6	107247.403	1614507.000	2.1	0.54
7	107308.505	1614486.912	1.4	0.48
8	107280.202	1614386.289	1.4	0.04
9	107126.036	1614439.031	3.0	0.64
10	107040.844	1614458.288	5.3	0.69
11	107019.798	1614474.421	6.4	0.98
12	107006.141	1614367.311	6.1	0.25
13	107063.410	1614374.179	4.6	0.52
14	107067.494	1614367.561	4.3	0.58
15	107204.698	1614309.647	2.4	0.50
16	107132.824	1614208.007	3.0	0.32
17	107081.723	1614279.598	4.1	0.48
18	107010.763	1614261.129	5.8	0.50
19	106991.520	1614142.887	6.7	0.54
20	107017.252	1614148.393	5.5	0.41
21	107074.928	1614160.566	4.1	0.36
22	107192.287	1614135.965	1.8	0.28
23	107184.162	1614004.306	2.1	0.30
24	107100.313	1614078.092	3.4	0.53
25	107012.679	1614041.504	5.0	0.52
26	106976.179	1614036.650	6.1	0.36

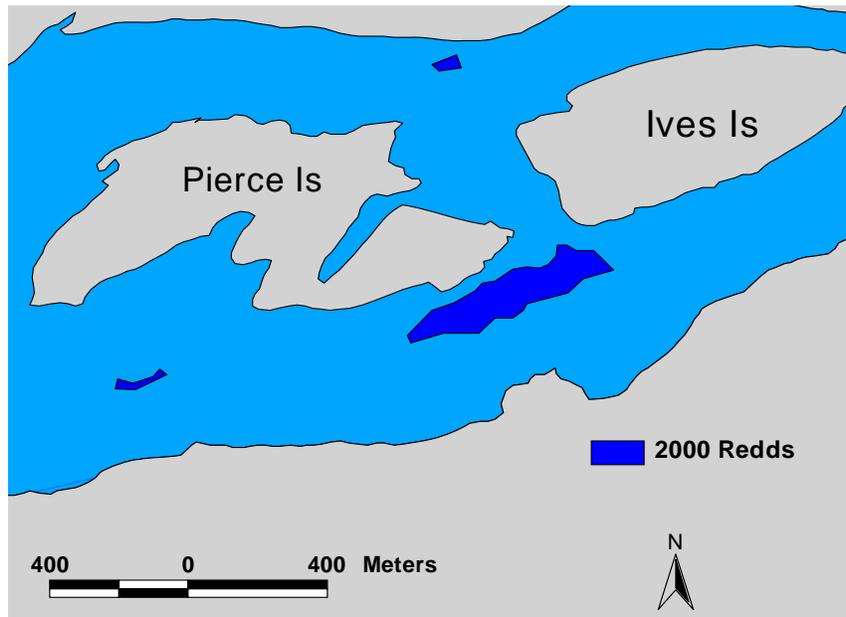
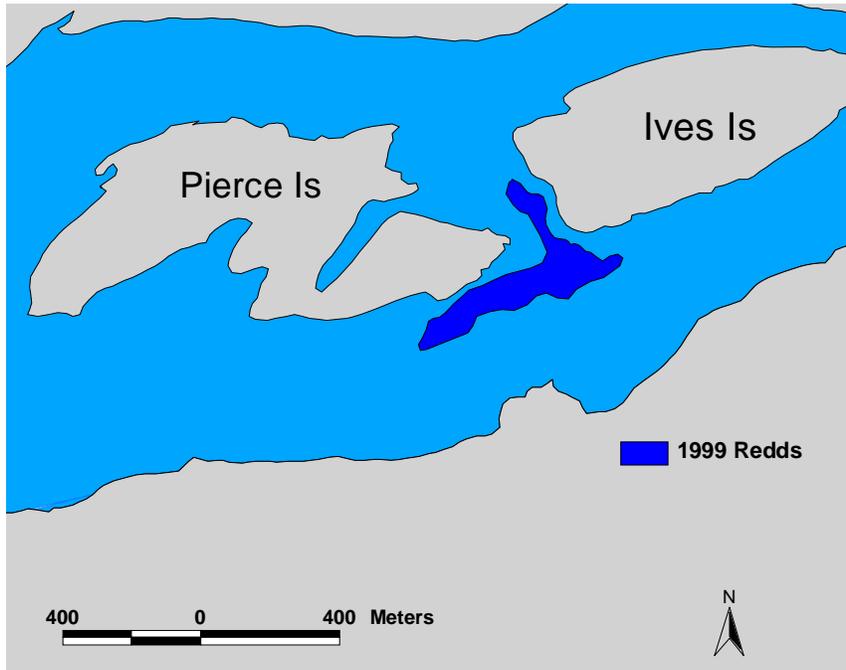
No.	Northing	Easting	Depth (m)	Bed Velocity (m/s)
27	106996.882	1613989.175	6.6	0.50
28	107050.626	1613973.056	4.6	0.51
29	107137.692	1613977.545	3.0	0.32
30	107102.877	1613874.221	3.4	0.32
31	107051.632	1613918.252	4.3	0.45
32	106999.520	1613926.514	5.8	0.32
33	106960.039	1613913.719	7.0	0.43
34	106970.891	1613811.448	6.4	0.38
35	107053.401	1613815.297	5.2	0.30
36	107046.601	1613822.610	4.4	0.28
37	107159.098	1613808.252	3.0	0.18
38	107065.277	1613778.912	4.1	0.30
39	106998.575	1613765.985	5.6	0.49
40	106967.136	1613783.094	6.1	0.65
41	106963.131	1613699.319	0.0	0.38
42	106995.687	1613703.906	5.6	0.41
43	107071.183	1613707.971	4.3	0.35
44	107161.812	1613667.987	2.9	0.38
45	107136.812	1613560.530	3.4	0.31
46	106976.871	1613656.600	6.1	0.49
47	106991.494	1613586.236	5.9	0.52
48	107160.752	1613488.330	2.7	0.31
49	107139.594	1613453.294	2.7	0.42
50	107060.646	1613512.972	4.7	0.35
51	106957.242	1613547.093	6.7	0.72
52	106945.170	1613497.069	6.7	0.55
53	107019.987	1613474.782	5.6	0.38
54	107071.626	1613455.280	4.3	0.41
55	107236.759	1613373.091	2.1	0.28
56	106930.539	1613383.867	7.0	0.65
57	106934.197	1613340.188	6.7	0.59
58	107190.012	1613229.959	3.4	0.27
59	107181.734	1613099.487	3.8	0.38
60	107090.968	1613165.019	4.3	0.49
61	107000.693	1613207.738	5.8	0.54
62	106942.117	1613189.863	6.9	0.75
63	106969.179	1613110.905	6.4	0.70

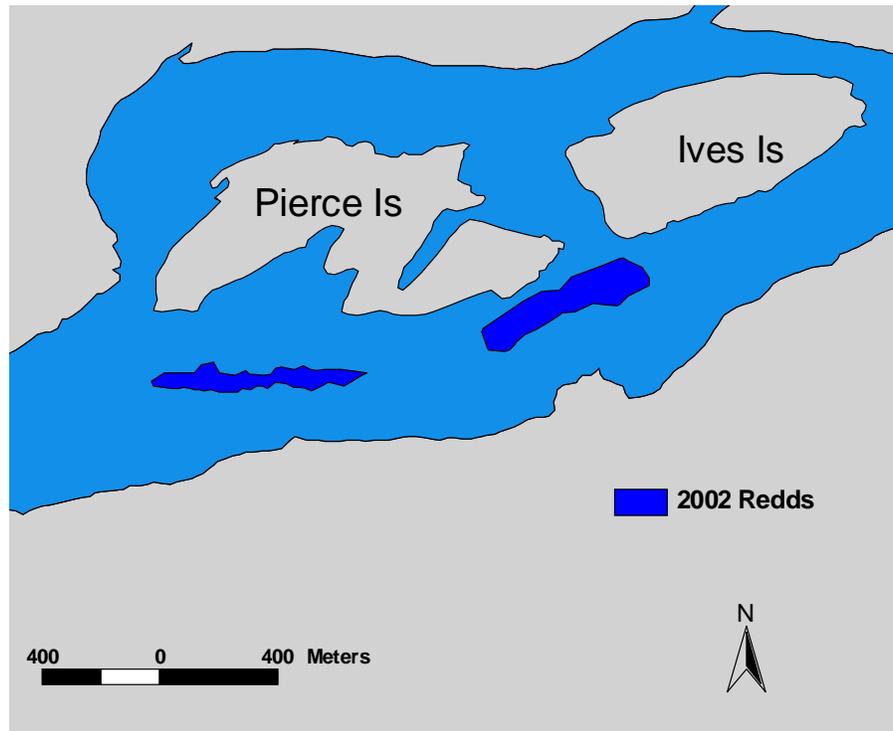
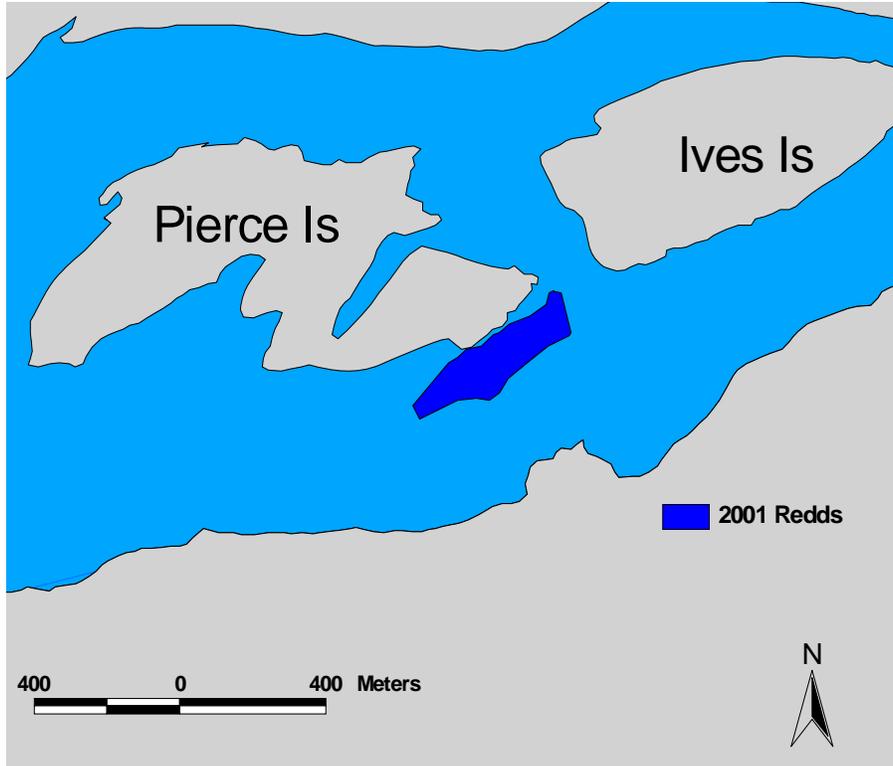
*Deepwater Spawning of Fall Chinook Salmon*

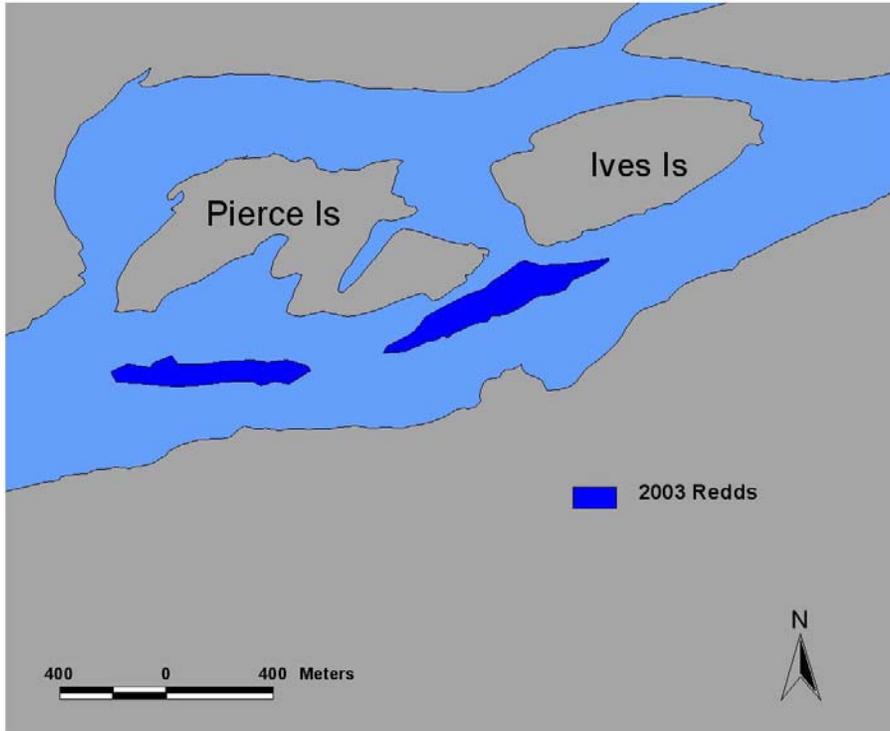
No.	Northing	Easting	Depth (m)	Bed Velocity (m/s)
64	107126.203	1613076.430	5.0	0.54
65	107126.542	1613077.411	4.4	0.20
66	107208.891	1612994.995	3.4	0.21
67	107196.121	1612853.221	3.5	0.33
68	107071.211	1612950.669	5.2	0.52
69	106941.481	1612999.982	7.0	0.83
70	106925.917	1612900.867	7.0	0.62
71	106992.027	1612882.550	6.4	0.41
72	107150.016	1612847.649	4.3	0.25
73	107238.962	1612793.333	3.0	0.37
74	107243.421	1612603.978	2.7	0.32
75	107162.025	1612692.624	3.8	0.37
76	107042.659	1612772.954	5.5	0.35
77	106985.858	1612805.807	6.1	0.39
78	106949.220	1612740.842	7.0	0.65
79	107254.697	1612584.944	3.0	0.39
80	107274.869	1612460.092	3.5	0.27
81	107171.242	1612539.561	3.2	0.45
82	107021.000	1612627.426	5.6	0.44
83	106963.958	1612636.390	6.4	0.71
84	107027.255	1612534.087	5.6	0.56
85	107115.241	1612547.847	4.0	0.37
86	107284.616	1612399.415	4.0	0.26
87	107203.436	1612330.838	3.8	0.29
88	107137.953	1612382.578	4.1	0.37
89	107047.439	1612424.547	5.2	0.37
90	106982.622	1612477.830	6.2	0.65
91	106915.787	1612464.982	7.6	0.68
92	106979.217	1612425.647	6.4	0.61
93	107040.646	1612376.735	5.0	0.70
94	107128.625	1612347.534	3.5	0.48
95	107198.545	1612291.420	4.3	0.19
96	107194.986	1612235.313	4.6	0.22
97	107202.315	1612142.726	5.5	0.20
98	107113.939	1612193.670	4.6	0.43
99	107096.020	1612243.684	4.1	0.46
100	106968.824	1612251.065	5.5	0.60

No.	Northing	Easting	Depth (m)	Bed Velocity (m/s)
101	106936.828	1612254.261	6.7	0.77
102	106926.741	1612184.106	7.3	0.76
103	106965.444	1612152.831	5.6	0.50
104	107018.400	1612165.440	5.0	0.58
105	107093.801	1612164.160	4.6	0.56
106	107103.851	1612167.730	4.6	0.59
107	107104.218	1612119.999	5.0	0.41
108	107111.960	1612005.709	6.1	0.30
109	107050.874	1612050.554	5.6	0.46
110	107017.878	1612094.738	5.2	0.42
111	106916.792	1612106.337	7.0	0.72
112	106899.699	1612022.021	7.9	0.78
113	106940.653	1612010.695	6.4	0.70
114	106994.634	1611999.311	5.2	0.50
115	107055.265	1611991.594	5.8	0.42
116	107044.178	1611911.143	6.7	0.32
117	106971.474	1611911.407	5.8	0.56
118	106943.881	1611905.322	6.2	0.67
119	106886.417	1611904.144	7.3	0.88
120	106983.321	1611838.557	6.6	0.51

**Appendix B**  
**Maps Illustrating Fall Chinook Salmon Redd Spawning**  
**Areas, 1999 Through 2003**









## Chapter 2

### **Summary of Temperature Data Collected to Improve Emergence Timing Estimates for Chum and Fall Chinook Salmon in the Lower Columbia River**

*Evan V. Arntzen, Timothy P. Hanrahan, Kathleen E. McGrath, Christopher J. Murray,  
Yi-Ju Chien, Susan L. Thorsten*

#### **Summary**

From 1999 through 2005, Pacific Northwest National Laboratory (PNNL) collected temperature data from within chum (*Oncorhynchus keta*) and fall Chinook (*O. tshawytscha*) salmon spawning gravels and the overlying river at 21 locations in the Ives Island area approximately 5 km downstream from Bonneville Dam. Sample locations included areas where riverbed temperatures were elevated, potentially influencing alevin development and emergence timing. The study objectives were to 1) collect riverbed and river temperature data each year from the onset of spawning (October) to the end of emergence (June) and 2) provide those data in-season to fisheries management agencies to assist with fall Chinook and chum salmon emergence timing estimates.

Three systems were used to collect the data. The first consisted of temperature sensors deployed inside piezometers that were screened to the riverbed or the river within chum and fall Chinook salmon spawning areas. These sensors required direct access by staff to download data and were difficult to recover during high river discharge. The second system consisted of a similar arrangement but with a wire connecting the thermistor to a data logger attached to a buoy at the water surface. This system allowed for data retrieval at high river discharge but proved relatively unreliable. The third system consisted of temperature sensors installed in piezometers such that real-time data could be downloaded remotely via radio telemetry. After being downloaded, data were posted hourly on the Internet. Several times during the emergence season of each year, temperature data were manually downloaded and provided to management agencies. During 2003 and 2004, the real-time data were made available on the Internet to assist with emergence timing estimates.

Examination of temperature data reveals several important patterns. Piezometer sites differ in the direction of vertical flow between surface and subsurface water. Bed temperatures in upwelling areas are more stable during salmon spawning and incubation than in downwelling areas. Bed temperatures in downwelling areas generally reflect river temperatures. Chum and fall Chinook salmon spawning is spatially segregated, with chum salmon in upwelling areas and fall Chinook salmon in downwelling areas. Although these general patterns remain similar among years, differences also exist that are dependent on interannual flow characteristics.

## **Introduction**

From 1999 to the present, the Bonneville Power Administration (BPA) has funded BPA Project No. 1999-00301 to quantify fall Chinook and chum salmon spawning downstream from Bonneville Dam, the timing of spawning, emergence and rearing, characteristics of their spawning habitat, and flows necessary to ensure their long-term survival. The primary location of this study is near Ives Island, an off-channel spawning area located approximately 5 km downstream from Bonneville Dam. During 1999, Pacific Northwest National Laboratory (PNNL) identified areas where relatively warm subsurface water upwelled through chum spawning gravels in the Ives Island spawning complex (Geist et al. 2002).

Since 1999, PNNL has monitored river and bed temperatures in the Ives Island channel to assist the Oregon Department of Fish and Wildlife (ODFW) with emergence timing predictions for fall Chinook and chum salmon. The objective of this report is to chronologically summarize the methods used and temperature data obtained by PNNL from 1999 through 2005 to improve emergence timing estimates for Chinook and chum salmon. A digital appendix containing all temperature data collected for emergence timing estimation is included in this report. We do not attempt to analyze the data here; subsequent reports will examine relationships between hydrosystem operation and riverbed temperatures.

## **Background**

Although historically abundant, run sizes of chum salmon and fall Chinook salmon to the Columbia River had decreased dramatically by the 1950s as a result of habitat degradation, water diversion, overharvest, and artificial propagation (National Marine Fisheries Service 1998). Populations of both species spawning downstream from Bonneville Dam are currently listed as threatened under the Endangered Species Act (National Marine Fisheries Service 1999).

Spawning surveys conducted at Ives Island since 1998 indicated that chum salmon and fall Chinook salmon spawn in spatially distinct clusters (U.S. Fish and Wildlife Service (USFWS) and ODFW, unpublished data). This clustering suggests that these species may select specific, and different, spawning habitat features within the study area (Geist and Dauble 1998). Understanding the spatial distribution of subsurface temperature variation is critical to accurate emergence timing estimation and establishment of meaningful minimum flows for the protection of spawning habitat in this area.

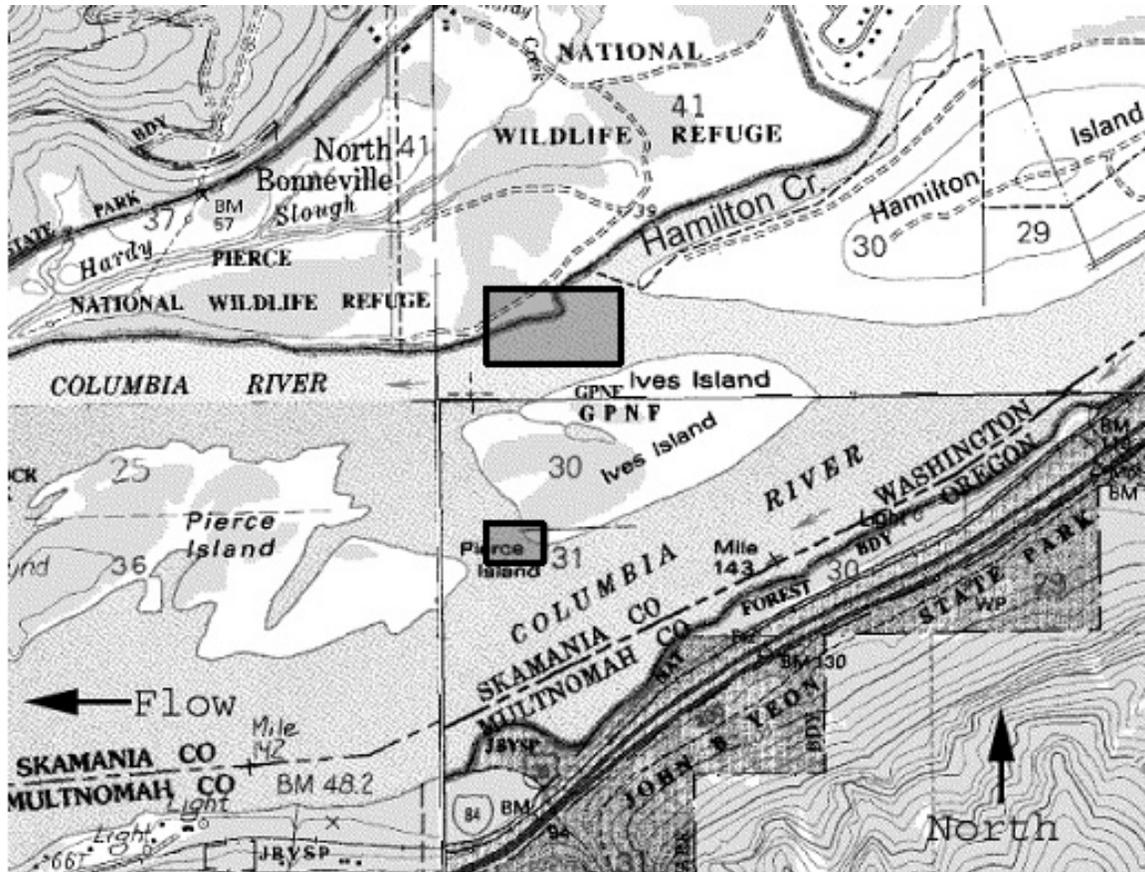
## **Study Site**

Data were collected from spawning areas downstream of the mouth of Hamilton Creek between Ives Island and the U.S. Fish and Wildlife Service Pierce Wildlife Refuge and in an area between Ives and Pierce islands (Figure 2-1). The location coordinates of all sensors used to collect data presented in this document are included in Appendix A. Various types of sensors and deployment techniques were employed each year from 1999 to 2005, and summaries of the methods used during each year are included.

## Methods

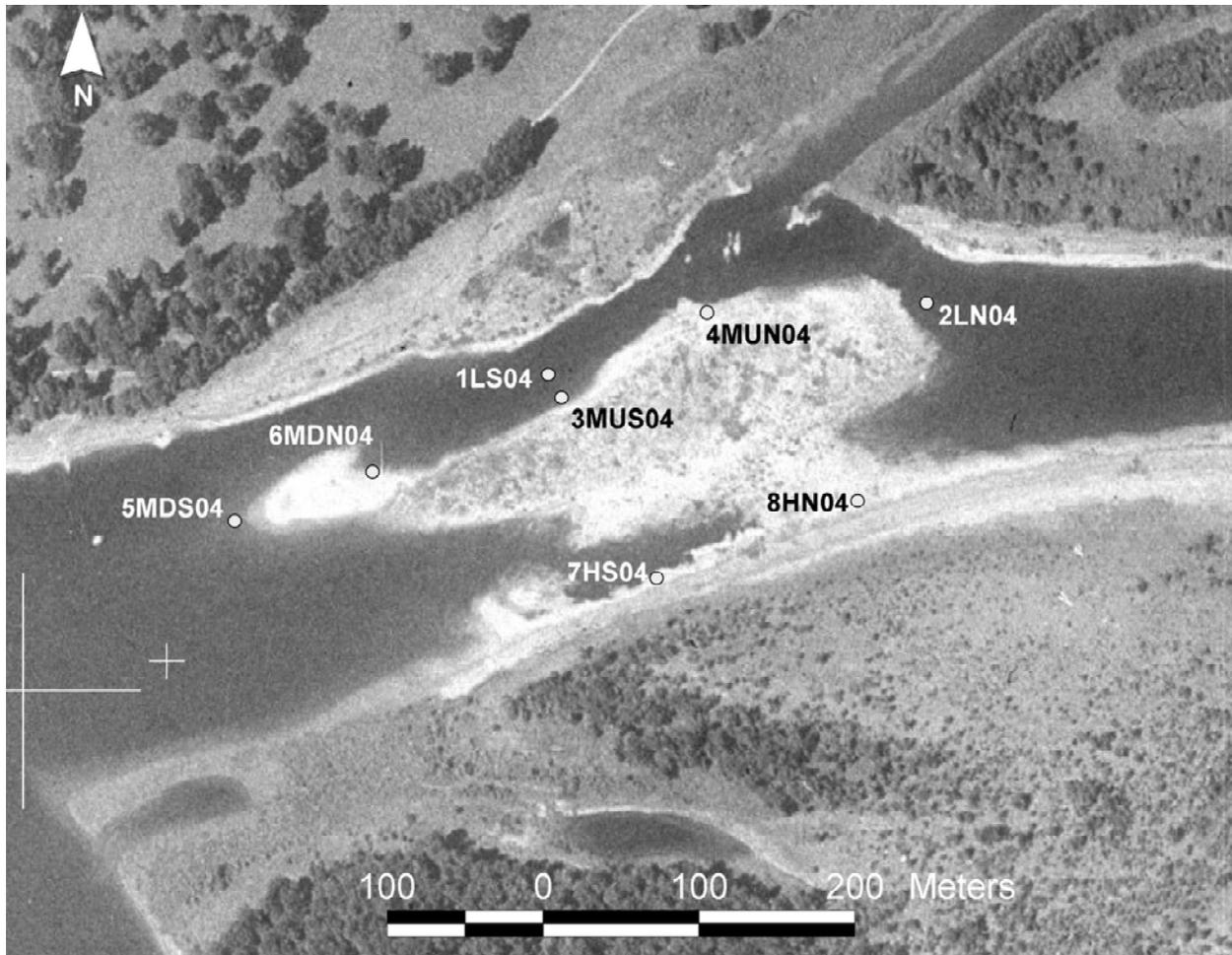
1999

Temperature sensors were deployed at various depths below the riverbed surface within fall Chinook and chum salmon spawning areas. Sensors were also deployed within non-spawning locations for comparison. Work was concentrated in the spawning areas downstream from the mouth of Hamilton Creek in the vicinity of Ives Island (Figure 2-1).



**Figure 2-1.** Location of Fall Chinook and Chum Salmon Spawning Areas Focused on in This Study, Below Bonneville Dam (shaded boxes)

On October 20, 1999, eight piezometer clusters were established (Figure 2-2). Each cluster site was classified as either spawning or non-spawning. Nineteen piezometers were installed, 8 in non-spawning areas and 11 in spawning areas. The distinction between spawning and non-spawning area was made based on existing spawning distributions data (USFWS, ODFW, unpublished data).



**Figure 2-2.** Location of piezometers Installed During 1999 (circles). The labeling scheme provides the cluster number (1–8), discharge range (L = 125 kcfs, M = 145 kcfs, H = 165 kcfs), location (U = upriver, D = downriver), and piezometer length (3, 4, 5 ft) for each site.

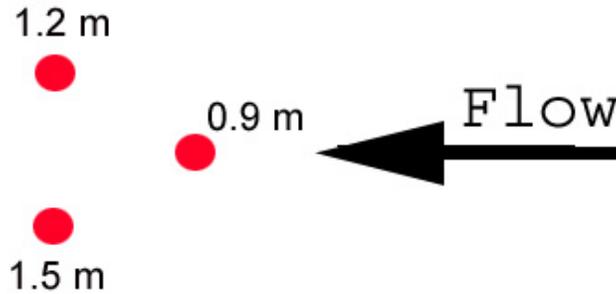
Cluster locations in both spawning and non-spawning habitat were established at several different vertical elevations to allow sampling over a wide range of Bonneville Dam discharges, including three targeted flow bands (where kcfs denotes thousand cubic feet per second): 125–140 kcfs (low), 140–150 kcfs (medium), and 150–160 kcfs (high). Two clusters were placed in the low, four clusters in the medium, and two clusters in the high flow bands. At each cluster, we attempted to install piezometers to approximate depths of 0.9 m, 1.2 m, and 1.5 m, respectively, below the riverbed. Five piezometers were broken during installation, leaving some clusters with only two piezometers (Table 2-1). At each cluster, piezometers were arranged in a triangular pattern within approximately 1 m of each other (Figure 2-3). Coordinate location data for each cluster were recorded with a Trimble ProXL GPS receiver. These data were post-processed with correction files from the Portland State University Geology Department Community Base Station. After post-processing, the coordinate location accuracy is  $\pm 1.0$  m. The location coordinates for 1.2-m piezometers from each cluster are included in Appendix A.

**Table 2-1.** Piezometer Cluster Data Summary

Cluster	Discharge Range	Habitat Designation	Piezometer screen depth (cm)		
			0.9 m	1.2 m	1.5 m
1	Low	Spawning	40.0	72.0	98.5
2	Low	Non-spawning	32.2	64.0	*
3	Medium	Spawning	42.2	70.0	*
4	Medium	Non-spawning	42.4	71.2	*
5	Medium	Spawning	41.9	72.2	103.7
6	Medium	Non-spawning	41.1	71.1	*
7	High	Spawning	41.3	67.4	98.8
8	High	Non-spawning	37.4	67.3	*

\* Piezometer broken during installation. See text for description of discharge ranges.

Piezometer screens were constructed of slotted stainless steel Johnson screen (0.038 cm slot size) with a 31.0-cm screened interval and a 3.2-cm inside diameter (Figure 2-4a). The screen was welded on one end to a 12-cm drive point and on the other end to a variable-length section of galvanized steel pipe (3.2-cm inner diameter) threaded on top. Piezometers were installed by inserting a solid steel drive-rod into the piezometer and pounding the rod with a post pounder or pneumatic hammer until the desired depth below the riverbed surface was achieved (Geist et al. 1998; Figure 2-4b). Once piezometers were in place, the internal drive-rod was removed and the piezometer was developed by removing fine sediment (<0.38 mm) with a hand pump.



**Figure 2-3.** Piezometer Cluster Configuration

Temperature-recording data loggers (Onset Optic Stowaway) were installed in the 1.2-m piezometer at each cluster. The depth below the riverbed where the temperature measurement was recorded ranged from 64 to 72 cm (Table 2-1). Temperature data were collected hourly beginning on October 21, 1999. Each data logger was National Institute for Science and Technology (NIST) -certified with an accuracy of  $\pm 0.2$  °C.

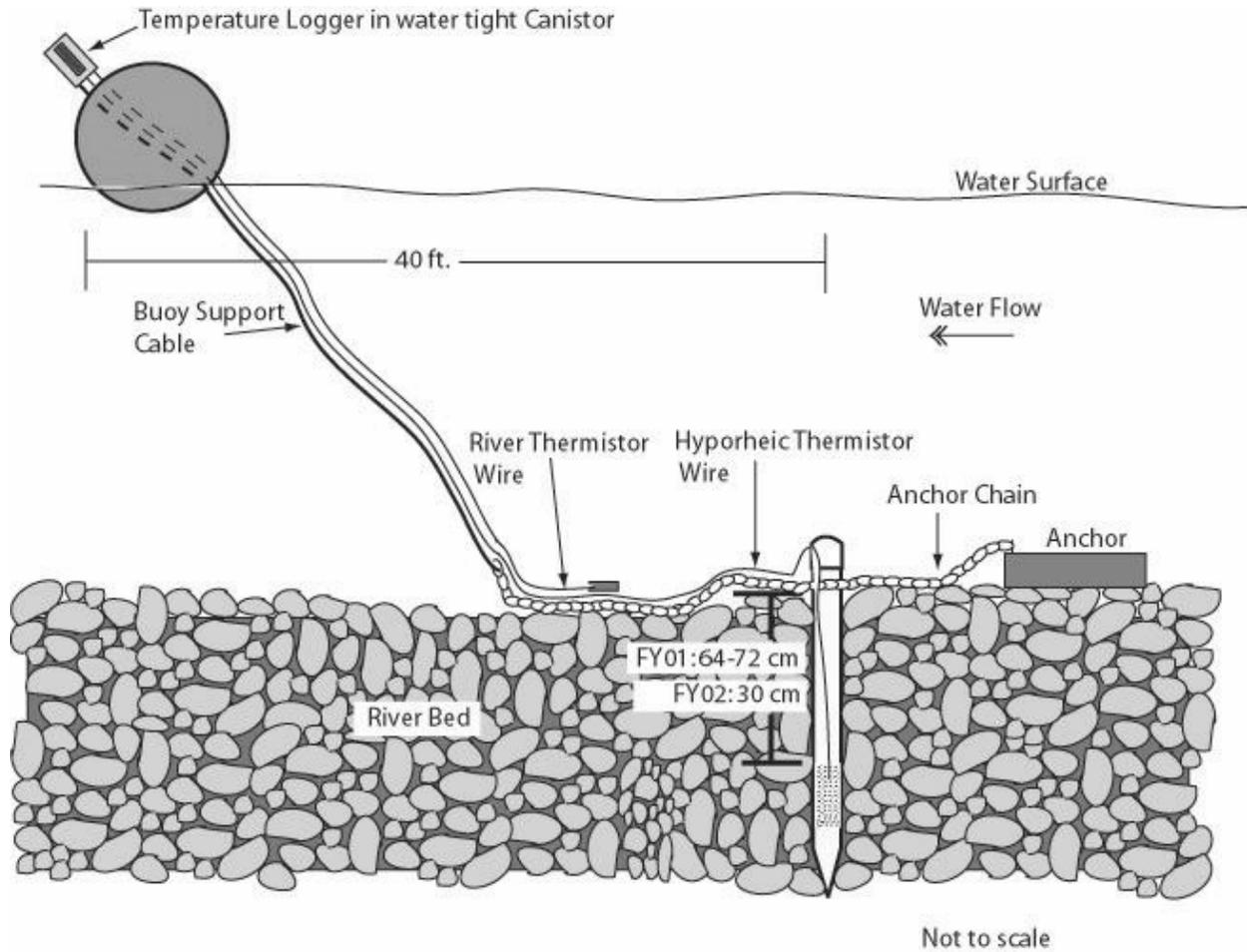
**2000**

On November 6 and 7, 2000, temperature sensors attached to buoys were deployed in the 1.2-m piezometers at clusters 1LS04, 4MUN04, and 7HS04. The buoy systems were designed to allow sampling at high river discharge so data could be provided to agencies earlier rather than after high spring flows had subsided. The buoys were spatially distributed to include spawning areas in low and high discharge ranges and a non-spawning area at medium discharge. To make room for the thermistors, Onset data loggers were removed from the 1.2-m piezometers where the buoys were installed. At



**Figure 2-4.** Johnson 3.2-cm-diameter Piezometer (a) and Its Installation Using Drive Rod and Pneumatic Hammer (b)

clusters 1 and 7, the Onset data loggers were moved into the 1.5-m piezometers. At cluster 4, the 1.5-m piezometer was not installed; the 0.9-m piezometer had filled with sand and was not useable, so the Onset data logger was removed. At all three clusters, thermistors were placed inside the 1.2-m piezometer with the temperature sensor at the top of the screen (Figure 2-5). A second thermistor was attached to the piezometer and deployed in the river adjacent to the riverbed to record river temperature. Thermistor wires were routed through approximately 12 m of polyethylene tubing that was zip-tied to approximately 3 m of 0.95-cm-diameter anchor chain and then to approximately 9 m of steel cable. The anchor chains were shackled to 30-kg weights of scrap iron. The weights were deployed approximately 1.5 m upstream of the piezometer clusters, and cable ends were attached to mooring buoys. The polyethylene tubing was routed into a watertight canister attached to each buoy. Data loggers were attached to the wires inside each canister, allowing the data to be downloaded by wading or from the deck of a boat.

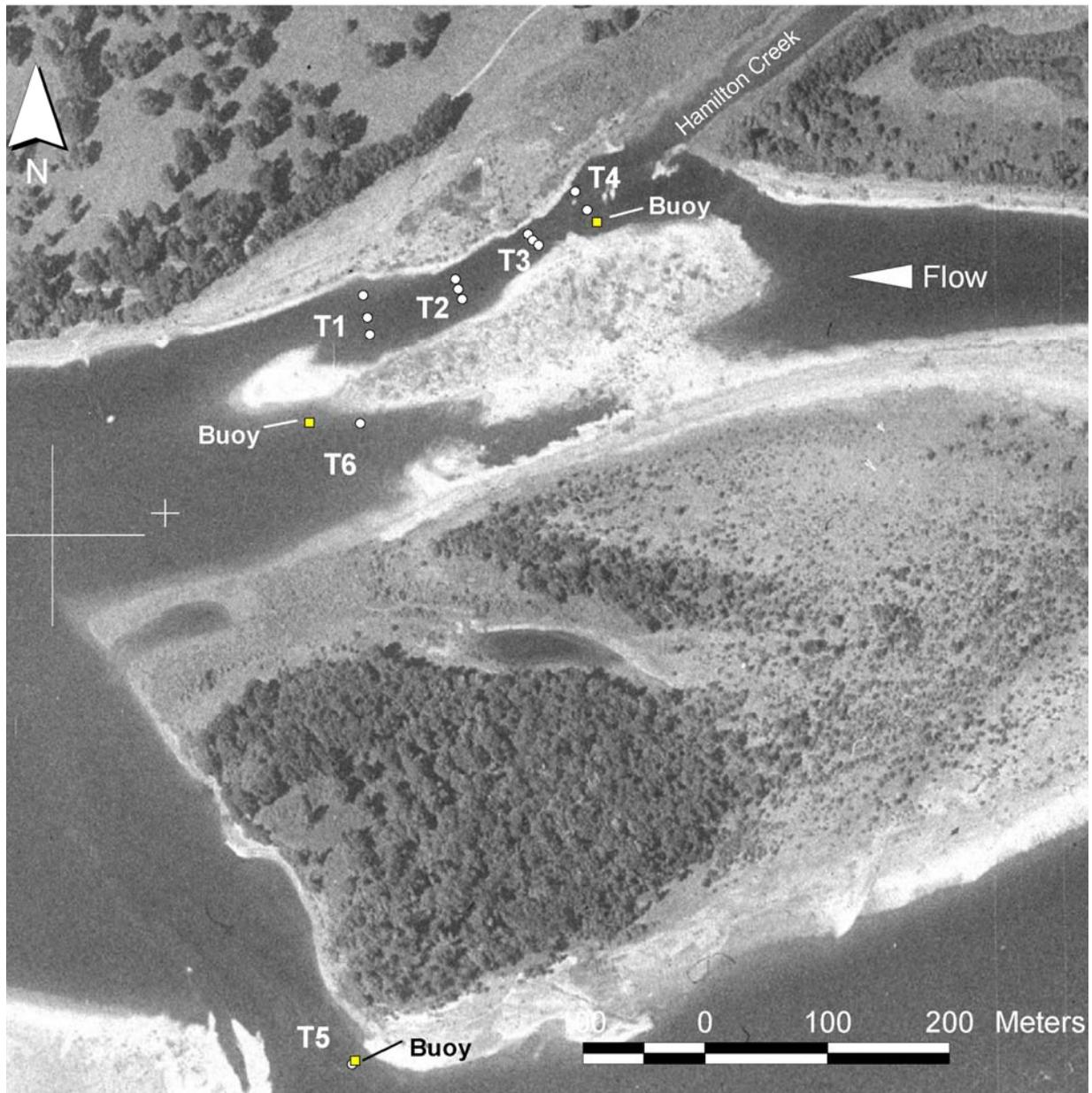


**Figure 2-5.** Configuration of Buoyed River and Riverbed Temperature Sampling System

## 2001

On November 27 and 28, 2001, 14 additional piezometers were installed at the site to augment in-season temperature data provided to government agencies for emergence timing estimation and for other project purposes associated with groundwater–surface water interactions (Figure 2-6). Equipment and methods used in piezometer installation were similar to those in 2000. Piezometer locations were selected based on separate project activities that identified areas of warm upwelling water associated with chum spawning, and established that bed and river temperatures maintained continuity for approximately 60 m in the direction of flow (Geist et al. 2002). Additional factors influencing piezometer location included the expected range of discharges from Bonneville Dam and the availability of sensors (see below). Transects T1, T2, and T3 were located in chum spawning areas, and transects T4 and T5 were located in fall Chinook salmon spawning areas. At locations T1 to T4 and at T5, two piezometers were installed at the mid-channel location (MC), one screened to the riverbed (top of the screen 20 cm below the riverbed) and the other to the river. A Solinst Model 3001 LT levelogger was deployed in each MC piezometer to record temperature differences between bed and river. All data loggers were installed with the sensors at the middle of the screen (30 cm below the riverbed). Solinst LT data loggers record temperature differences with an accuracy of  $\pm 0.1$  °C.

We randomly selected additional piezometers to instrument with temperature data loggers because an insufficient number were available to instrument all piezometers installed in 2001. The right bank (RB) locations on transects T1, T2, and T4 were instrumented with Onset data loggers. At T3, the locations on the right bank (RB) and left bank (LB) were instrumented, and at T5, a second piezometer on the right bank (RB) was instrumented using Onset data loggers. One piezometer at T6 was instrumented similarly. At each location, a data logger was placed in the riverbed piezometer 30 cm below bed and also in a PVC sleeve screened to the river and attached to the piezometer. The Onset data loggers were similar to those installed during 1999 and 2000.



**Figure 2-6.** Location of Piezometers Installed During 2001 (white circles). Yellow squares show piezometers that were later equipped with buoy systems to access bed and river sensors at high discharges.

At the same time that these piezometers were installed, three additional piezometers were installed on transects T4 (LB), T5, and T6 for future deployment of buoy systems. The 2001 buoy piezometers were installed with screen depths of 30 cm to reflect egg pocket conditions. The buoy systems successfully produced temperature data during various time periods while they were deployed. However, by Spring 2001, all the buoy systems installed in 2000 had been removed due to problems with water infiltration through the polyethylene tubing or vandalism.

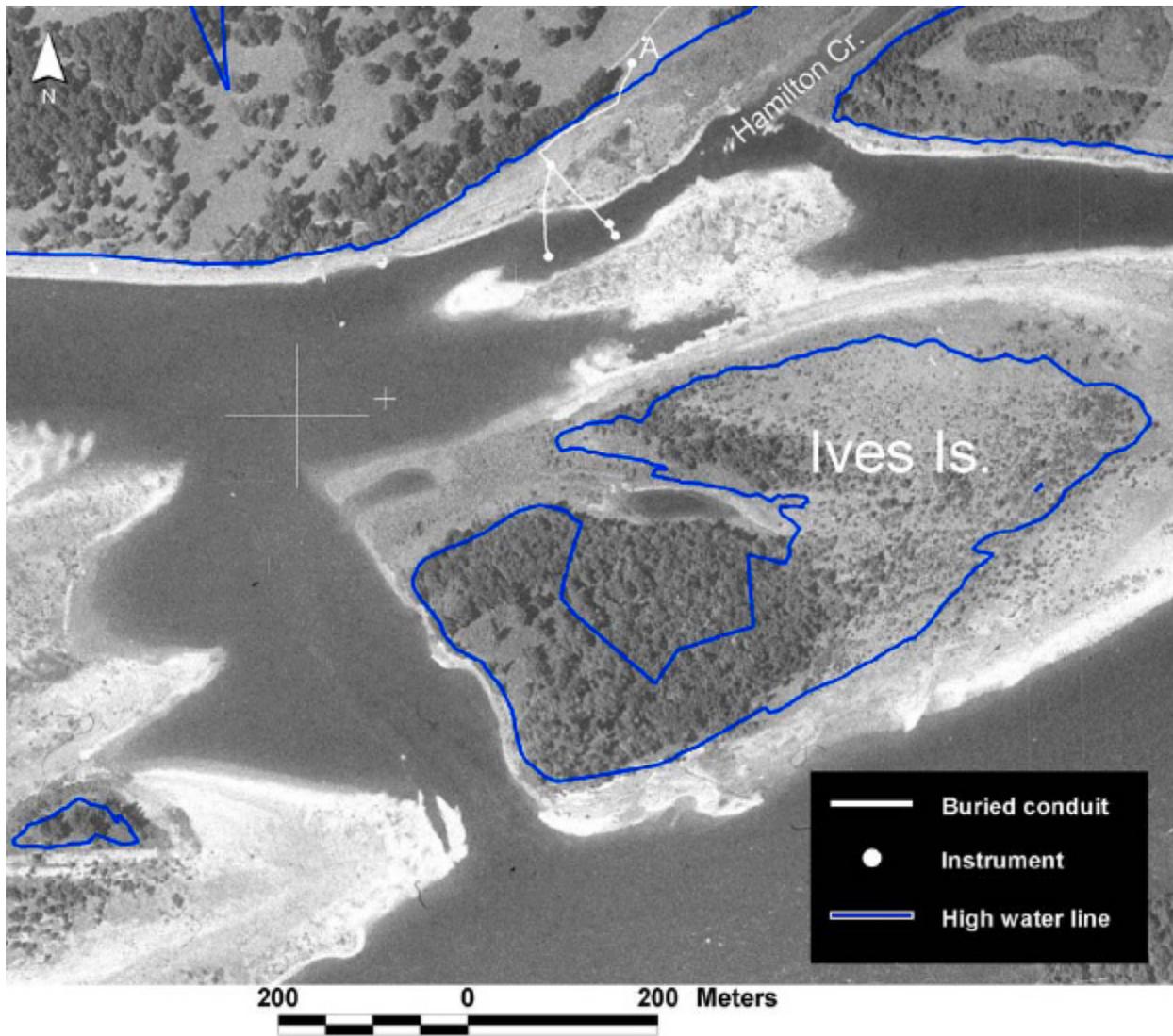
## **2002**

Buoys were deployed at T4LB on January 25 and at T5 and T6 on February 13, 2002. These buoy systems were similar to those installed in 2000, except that sensor depth was reduced from 64 cm to 30 cm below the riverbed to more accurately reflect egg pocket depth. The buoy systems were used to provide in-season emergence timing temperature data to the agencies during winter and spring 2002. Other sensors installed during 2000 and 2001 were maintained and downloaded, and temperature data were archived when field conditions allowed access.

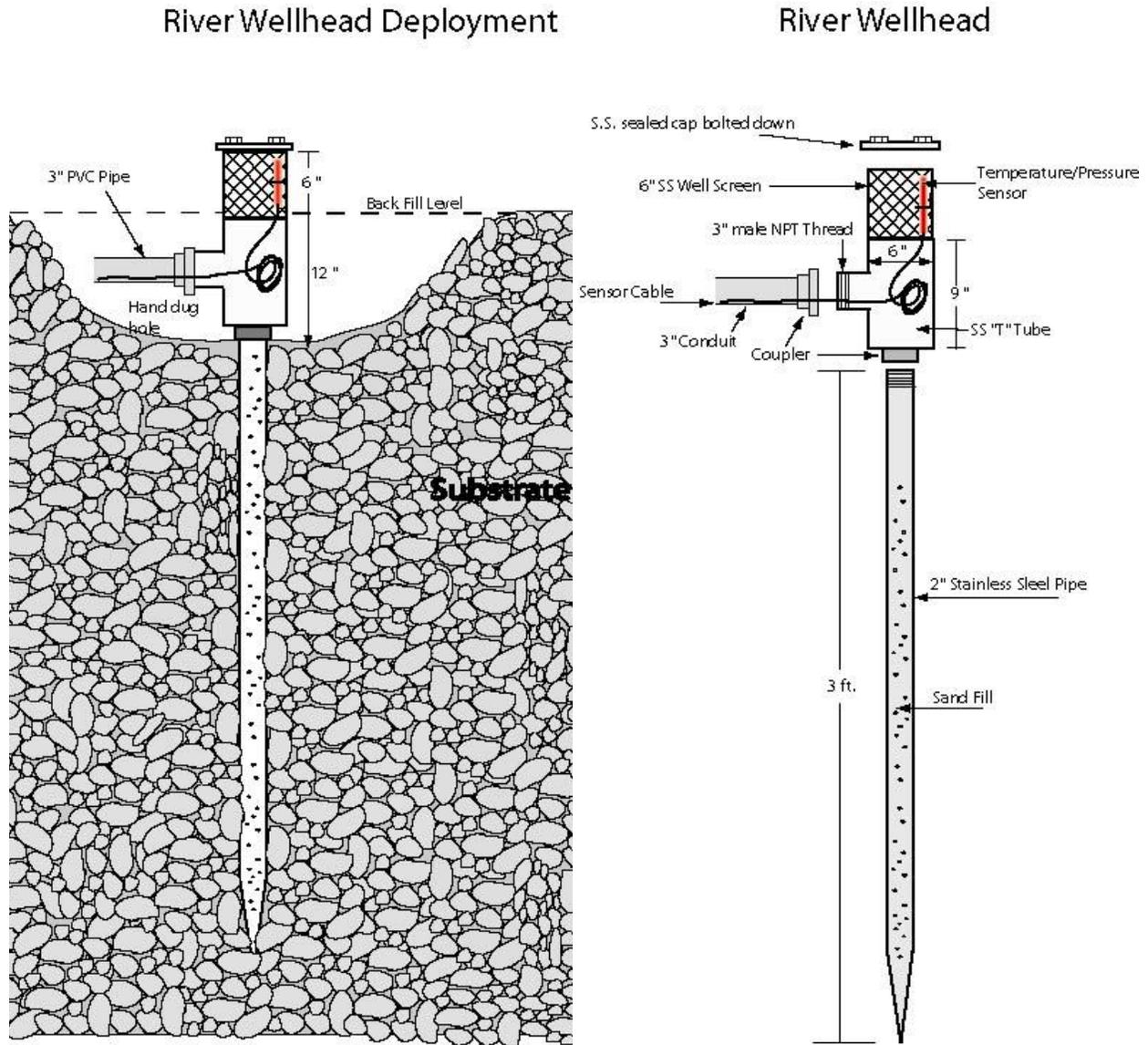
## **2003**

On September 6 through 9, 2003, a real-time temperature collection system was deployed in the north channel at the study site to provide real-time river and riverbed temperature data within chum salmon spawning areas. One riverbed sensor and one river sensor were installed at T1LB, T2LB, and T2MC (Figures 2-7 and 2-8). These sites were selected because transects T1 and T2 were associated with chum spawning and habitat modeling suggested that although high-quality habitat was available throughout the channel at low flows (104 kcfs), spawning habitat at higher flows (125-150 kcfs) was located primarily along the left bank (Garland et al. 2003).

At all sites, 5-cm well points were installed and used to anchor constructed wellheads. The river piezometers did not have screens, and contact between the sensor and the river was made using a 15-cm PVC wellhead with a screen open only to the surface water column (Figure 2-8).



**Figure 2-7.** Location of Real-Time System Sensors (white circles). White lines show the locations of buried cables. The telemetry station is above the high water line at point A.



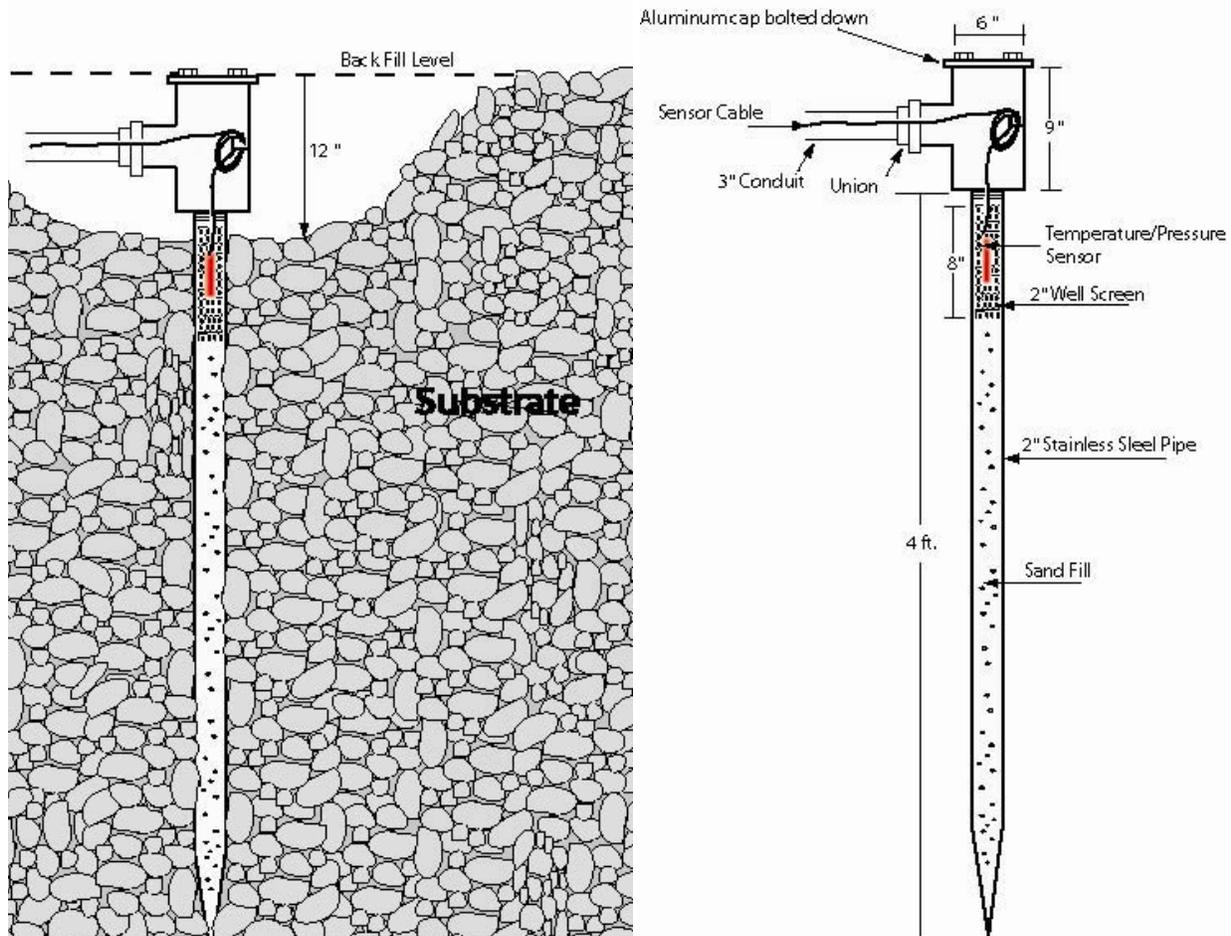
**Figure 2-8.** Real-Time System River Wellheads

The sensors monitoring bed temperatures were anchored by similar 5-cm well points, with 30 cm screened intervals near their tops. Piezometers were installed using installation methods similar to those of previous years. The riverbed wellheads were deployed with the tops of their screens 58 cm below the riverbed (Figure 2-9).

Rubber stoppers were used to prevent the movement of water from the riverbed wellhead into the screened interval and to prevent water movement from the conduit and the piezometer into the river wellhead. River and riverbed piezometers were filled with sand to help minimize artificially induced temperature gradients due to convection.

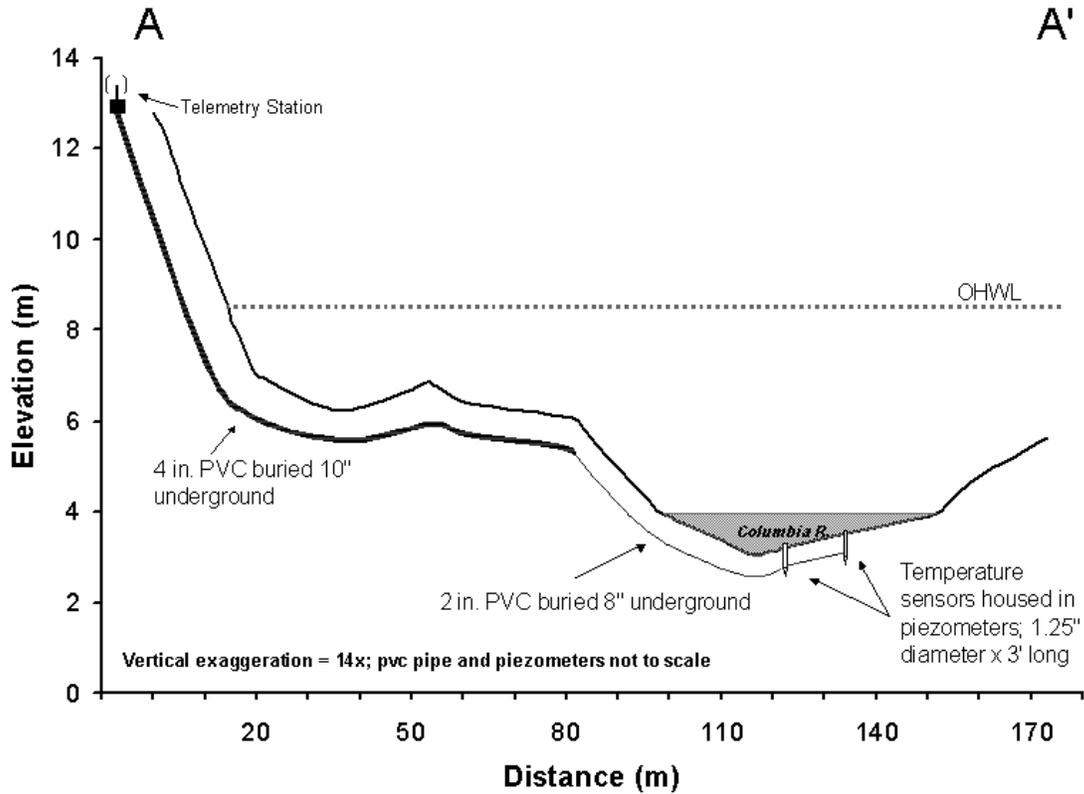
## Riverbed Wellhead Deployment

## Riverbed Wellhead



**Figure 2-9.** Riverbed Wellhead Schematic

Six Model PT2X sensors (Instrumentation Northwest, Inc.) were used for the real-time system, with each sensor recording absolute pressure and temperature. One additional barometric sensor was installed on the telemetry tower to record atmospheric pressure and temperature. The PT2X sensors were not vented, minimizing problems that can occur with desiccants under humid conditions and reducing cable expense and maintenance frequency. PT2X sensor temperature accuracy is 0.75°C with a resolution of 0.1°C. Sensors were connected to a telemetry tower via buried cables (Figures 2-7 and 2-10). The telemetry system uses solar-powered line-of-sight radio, and transmits to a station in North Bonneville approximately 2.4 km from the study site. The data are queried hourly and posted to an FTP server maintained by Instrumentation Northwest, Inc. (INW). The Fish Passage Center (FPC) retrieves the data from the INW FTP site and posts them at [http://www.fpc.org/ivesisland/ives\\_island\\_home.html](http://www.fpc.org/ivesisland/ives_island_home.html).



**Figure 2-10.** Columbia River Cross Section from A to A' (see Figure 2-7) Relative to Water Level at Approximately 13 ft. Bonneville Tailwater Elevation and the Ordinary High Water Line

**2004**

Temperature data were downloaded from sensors deployed during previous years. Additional Onset data loggers were deployed in piezometers adjacent to each real-time wellhead (T1LB, T2LB, and T2MC). Onset sensors were deployed 20–30 cm below the riverbed to collect temperature data at egg pocket depth and to calibrate temperature data collected from the deeper real-time systems.

**2005**

Temperature data from Onset and Solinst sensors were downloaded from locations in the Ives North channel at T1, T2, T4, and T5 (Figure 2-6). To provide improved emergence timing estimates to the water management agencies, PNNL collected additional multi-level temperature data in the riverbed and in the river adjacent to each of the three real-time wellheads. One goal was to refine salmon emergence timing estimates, which are made using accumulated temperature units (ATU). The ATU are computed as the cumulative sum of the daily average temperature, starting on the date the adult salmon spawned, using degrees centigrade. State agencies have traditionally used surface water temperatures to compute ATU values, which are typically representative of the temperatures at egg pocket depth (approximately 20 cm). However, in the Ives Island area relatively warm subsurface water discharges into spawning areas, which could influence temperature unit accrual and emergence timing estimates. It is also known that a seasonally variable but often significant temperature gradient exists between the local surface and

subsurface water at Ives Island. Because of this gradient, the temperature data we are collecting using the real-time wellheads (55-cm depth) may not be representative of egg pocket temperatures.

To relate the temperature at 55-m depth to the temperature at egg pocket depth, PNNL installed additional multi-level samplers at each of the three stations at depths of 15 cm, 30 cm, 45 cm, and 60 cm. The temperature data collected from the multilevel samplers are referred to as profiler data. The profiler data were collected at 10-minute intervals, while the real-time data were collected hourly. We selected the profiler data for each of the three locations that were collected at the start of each hour and matched those with the corresponding real-time data, so all data were put on an hourly basis. For each location, linear regression was performed between real-time 55-cm depth data and the profiler 15-cm depth data for the incubation and emergence period of November 11, 2004, through March 1, 2005. The regression coefficients were used to adjust the real-time data over the time period October 1, 2004 through March 31, 2005. Daily average temperatures were computed, and the resulting ATU for the time period were compared to actual salmon emergence. Although the adjusted temperature data seemed reasonable for much of the time period, the temperature gradient changed during March 2005, due presumably to seasonal changes in the temperature relationship between surface water and groundwater.

To improve estimates of egg pocket temperature, we regressed the profiler data against the deep bed temperature, the river temperature by itself, and a combination of both the deep bed temperature and the river temperature (multiple linear regression). The best approach used multiple linear regression to estimate the egg pocket temperature as a function of both real-time temperature (55 cm depth) and surface water temperature. This approach was attractive because it should better represent seasonal variation between surface water and ground water. The results of the regression analysis are shown in Table 2-2, including the regression coefficients for each model and the associated  $R^2$  values (correlation coefficients). For T1LB, the combination of both the river and bed temperature better predicts the profiler temperature than either the bed or river temperatures by themselves ( $R^2 = 0.84$  versus 0.74 or 0.73, respectively). For T2LB, the model with both variables has slightly better predictive ability than either variable by itself ( $R^2 = 0.89$  versus 0.82 or 0.83). For T2MC, the combination provides a better estimate than the bed temperature by itself ( $R^2 = 0.93$  versus 0.82) but is only marginally better than the estimate using just the river sensor ( $R^2 = 0.93$  versus 0.92).

**Table 2-2.** Linear Regression for Profiler Temperature with Bed and River Temperature at T1LB, T2LB, and T2MC from November 11, 2004, to March 2, 2005

Temperature At Profiler	Regression Coefficient			Model Correlation Coefficient ( $R^2$ )
	Constant ( $^{\circ}\text{C}$ )	Bed Temperature ( $^{\circ}\text{C}$ )	River Temperature ( $^{\circ}\text{C}$ )	
T1LB	-0.908	0.647	0.419	0.835
	-3.118	1.117	-	0.736
	3.875	-	0.748	0.728
T2LB	-7.491	0.841	0.710	0.888
	-12.657	1.623	-	0.823
	-0.400	-	1.279	0.832
T2MC	-3.933	0.355	1.019	0.925
	-11.342	1.502	-	0.817
	-1.166	-	1.276	0.916

Use of linear regression for estimating temperature at egg pocket depth is somewhat problematic because the temperature data are temporally autocorrelated, violating a fundamental assumption of linear regression. To better estimate temperature at egg pocket depth, an advanced time-series analysis that accounts for temporal autocorrelation should be used. The time-series analysis would be complicated by the non-stationary nature of the temperature data (i.e., the mean and variance of the different time series are not constant with time). For example, temperatures decrease in the fall and early winter for all three time series, with increasing values for the river and profiler temperatures in the later winter but not for the deep bed temperatures. In addition, there are strong diurnal fluctuations in the river temperature, and the relationship between the bed and surface temperature time series changes with time.

During 2006, we plan to develop a more rigorous estimation procedure that accounts for these complications. However, the use of a more complex estimation algorithm may not provide a significantly better estimate. Chatterjee and Price (1977) conclude that linear regression with autocorrelated data will provide unbiased estimates, but the standard errors of the regression coefficients will be underestimated. This suggests that although the estimates provided by our multiple linear regression equations will be unbiased, they should not be used for uncertainty analysis (e.g., to provide reliable confidence intervals for the estimated egg pocket temperatures).

## **Results and Discussion**

In this section, we present representative data plots, summaries of data availability, and general data trends to facilitate use by others. The time period during which bed and river data were successfully collected varied, as did the type of sensors used to collect the data. Data among sensor types are comparable, within the accuracy limits of the sensors. Location coordinates and sensor depths below the riverbed are included for each location where temperature data were collected (Appendix A). Temperature data availability is summarized in Appendix B. All temperature data collected from 1999 through 2005 are presented in Appendix C.

During 1999 through 2005, riverbed and river water temperatures were provided to the ODFW, WDFW, USFWS, and BPA to assist these agencies in estimating chum and fall Chinook salmon emergence timing. For this reason, we focus on data for which we have complete records during the spawning through emergence period (October 1–June 30). Data available for this period are summarized in Table 2-3 and discussed by time period in this section. We provide general comparisons of data between riverbed and river sensors and between sites used by chum and fall Chinook salmon. Data for this period, and only data from spawning locations, were used in temperature comparisons presented here. Comparative statistics are provided as general descriptions; more rigorous analyses should be conducted by and are the responsibility of data users.

Piezometers were located in either chum or fall Chinook salmon spawning sites or in areas not used by either species (Figure 2-11). Spawning associations were based on visual comparison of spawning count data for 2000-2004 (USFWS, ODFW, unpublished data) and piezometer locations within a geographic information system. Redd mapping efforts conducted since 1999 have demonstrated that several of our classifications at the time of equipment installation and as described in the Methods section were incorrect. Sites 1LS04 and 3MUS04 are associated with chum salmon spawning, 4MUN04 is associated with fall Chinook salmon spawning, and the remainder of sites in this coding system are not

**Table 2-3.** Availability of Complete Data Sets for the Spawning and Incubation Period (October 1-June 30)

Piezometer	Use	Year					
		99-00	00-01	01-02	02-03	03-04	04-05
1LS04	C	B <sup>1</sup>					
1LS05	C						
2LN04	N	B <sup>2</sup>	B	B			
3MUS04	C	B <sup>2</sup>	B	B	B		
4MUN04	FC	B <sup>2</sup>					
5MDS04	N	B <sup>2</sup>	B	B	B	B	
6MDN04	N	B <sup>2</sup>	B	B	B	B	
7HS04	N						
7HS05	N			B			
T1LB	C					B,R <sup>4</sup>	B,R
T1MC	C			B,R <sup>3</sup>	B,R	B,R	B
T1RB	C			R <sup>3</sup>		B	
T2LB	C					B,R <sup>4</sup>	B,R
T2MC	C					B,R <sup>4</sup>	B,R
T2RB	C			B,R <sup>3</sup>	B		
T3LB	C,FC			B <sup>3</sup>			
T3MC	C,FC			R <sup>3</sup>	R	B,R	
T3RB	C,FC			B <sup>3</sup>	B		
T4LB							
T4MC	FC			B <sup>3</sup> ,R <sup>3</sup>	B,R	R	
T4RB	FC			B <sup>3</sup> ,R <sup>3</sup>	B,R	B,R	R
T5MC	C,FC			B <sup>3</sup> ,R <sup>3</sup>	R	B,R	B,R
T6IL	C						

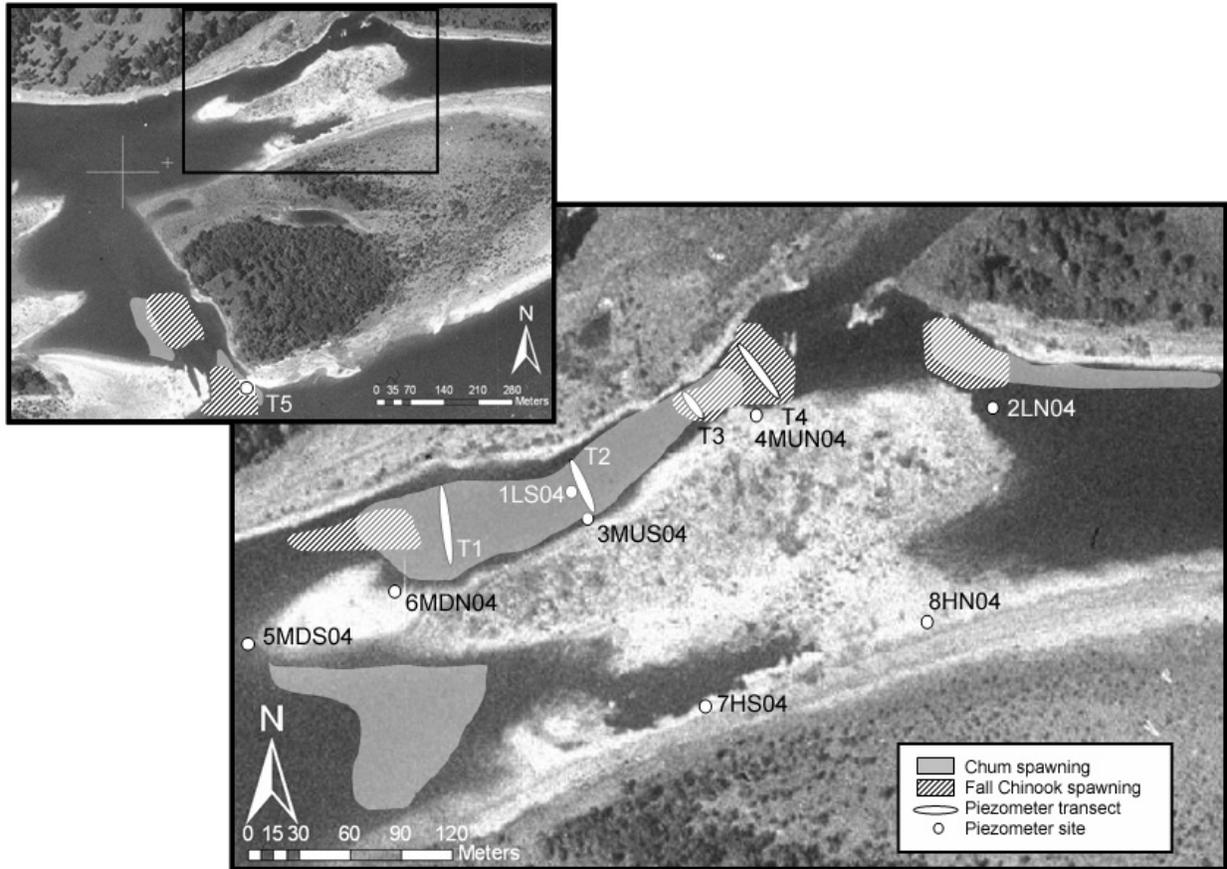
Use: C = chum, FC = fall Chinook, N = none.

Data available: B = bed, R = river.

1 = October 22 start date; 2 = November 10 start date; 3 = November 27–28 start date; 4 = October 16 start date.

associated with salmon spawning. Transects T1 and T2 are associated with chum spawning, transect T4 is associated with fall Chinook salmon spawning, and transect T3 is a region of spawning overlap between these species.

The availability of calendar year data sets varies by sensor type, location (bed versus river), and applicability to chum versus fall Chinook salmon. For 1999 through 2001, most of the temperature data were collected from the riverbed. At least one calendar year of data is available for five sites (2LN04, 3MUS04, 5MDS04, 6MDN04, 7HS05). Less than one year of data is available from four additional sites (1LS04, 1LS05, 4MUN04, 7HS04). River data are limited to two sites (1LS04, 4MUN04) and to periods of six months or less. Beginning in 2002, full year data sets are available for more sites and include some sites with paired river and riverbed data. From 2002 to 2004, at least one calendar year of data is available for nine river sites (T1LB, T1MC, T1RB, T2LB, T2RB, T3MC, T4MC, T4RB, T5MC) and 13 riverbed sites (river sites plus 3MUS04, 5MDS04, 6MDN04, 7HS05). Several manual download sensors remain in place, and real-time sensors continue to transmit hourly data from the three real-time sites (T1LB, T2LB, T2MC). More detailed information regarding data availability is summarized in Appendix B and discussed by time period in this section.



**Figure 2-11.** Chum and Fall Chinook Spawning Location Relative to Temperature Data Collection Sites, in the Vicinity of Ives Island

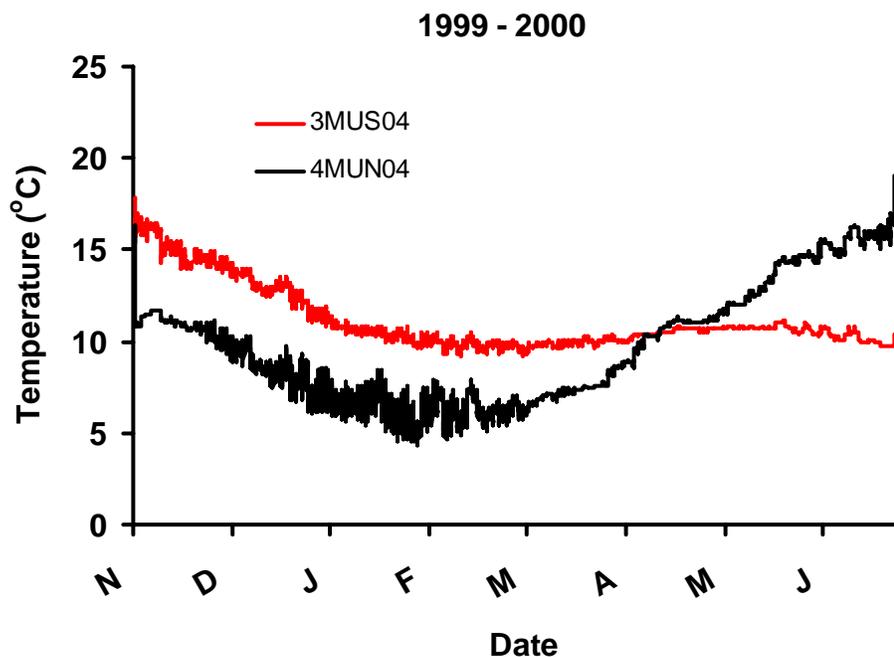
Data are unavailable or missing for a variety of reasons. In some cases, as described in the Methods section, we transferred sensors from one piezometer to another to collect higher-priority data. The most common sources of data loss were data logger malfunction and data logger loss. In numerous cases over the study period, data loggers could not be downloaded on-site and were returned to the manufacturer for data retrieval, with ultimate loss of data in most cases. We lost eight data loggers, of which three were found later on the riverbed. One Onset data logger, presumably washed from its piezometer during high river discharge, was ultimately found in Willapa Bay on the Pacific Ocean. Several data loggers were found at the bottom of their piezometers with the cable suspending them severed. One buoy system was vandalized, and other data logger losses were likely associated with vandalism as well. In some cases, there was evidence of damage to the piezometer, either from impact (e.g., by a passing boat) or from debris buildup and associated increase in drag on the piezometer during high flow. Data logger loss was more likely in piezometers sealed by test plugs (rubber caps with an internal thumb screw securing the plug) or slip PVC caps, which were more prone to failure than threaded PVC caps. Thus far we have experienced no problems with the real-time system, which was designed to withstand harsher conditions than the other deployments and to function for a longer duration. We hope our experiences will guide others with similar research needs.

**1999–2000**

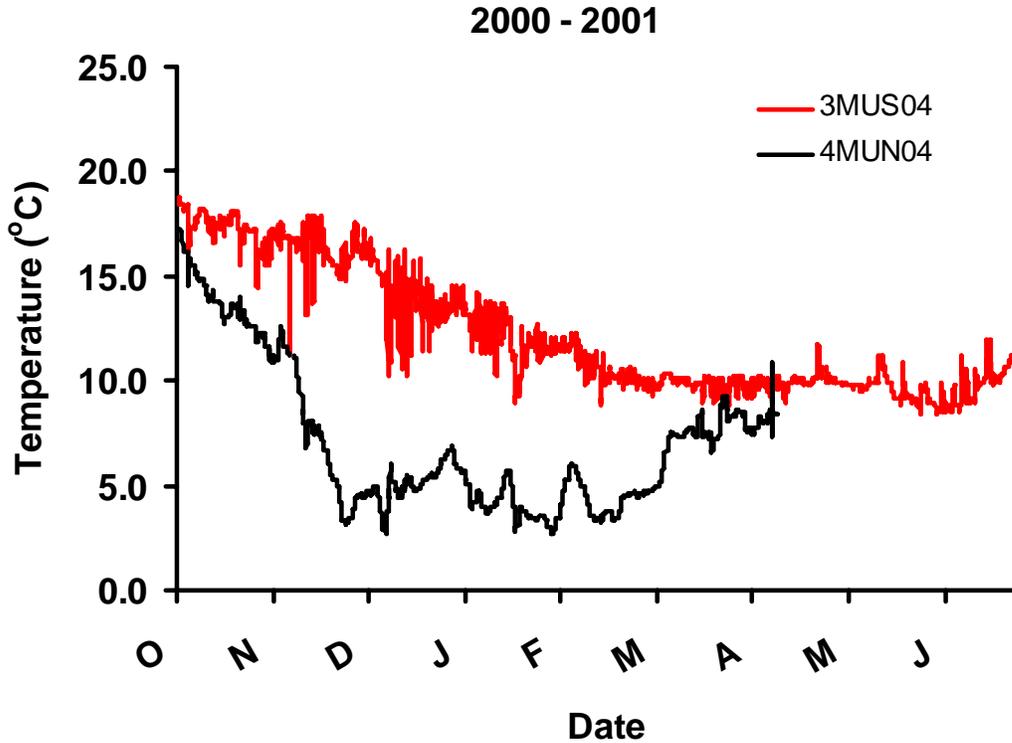
Initial project installation began on October 22, so no complete October 1–June 30 data sets are available for this year. Riverbed data are available for six sites beginning on either that date or November 10. Of these, 3MUS04 and 1LS04 are associated with chum salmon spawning. Combined mean (standard deviation (SD)) riverbed temperature for these sites was 11.1 (1.98) °C. Site 4MUN04 is associated with fall Chinook spawning. Mean (SD) riverbed temperature for this site was 9.8 (3.20) °C. Bed temperatures in chum salmon spawning areas were more stable through the period than in the fall Chinook salmon spawning area, and were warmer through April and cooler from April through June (Figure 2-12). Daily bed temperatures were also more stable in chum salmon spawning areas than in the fall Chinook salmon area from December through February. No river temperature data were collected during 1999–2000.

**2000–2001**

Complete bed temperature data sets were obtained at four locations—2LN04, 3MUS04, 5MDS04, and 6MDN04—as well as incomplete bed and river data for 4MUN04 (Figure 2-13) and several other sites not used for spawning. Location 3MUS04 was within chum spawning habitat, and 4MUN04 was within fall Chinook spawning habitat. Mean (SD) bed temperature for 3MUS04 and 4MUN04 for the period in which data are available for both sites (October 1–April 12) were 13.3 (2.96) °C and 7.1 (3.55) °C, respectively. Although bed temperatures were similar at the beginning of the period, they decreased significantly more at the fall Chinook salmon spawning site (4MUN04) than at the chum salmon spawning site (3MUS04) through March. Bed temperatures were also more stable at 3MUS04 across the period but generally more variable on a daily basis than at 4MUN04. Incomplete river temperature data sets are available for several sites (see Appendix B).



**Figure 2-12.** Bed Temperature Collected During 1999–2000 Within Chum (3MUS04) and Fall Chinook (4MUN04) Salmon Spawning Areas

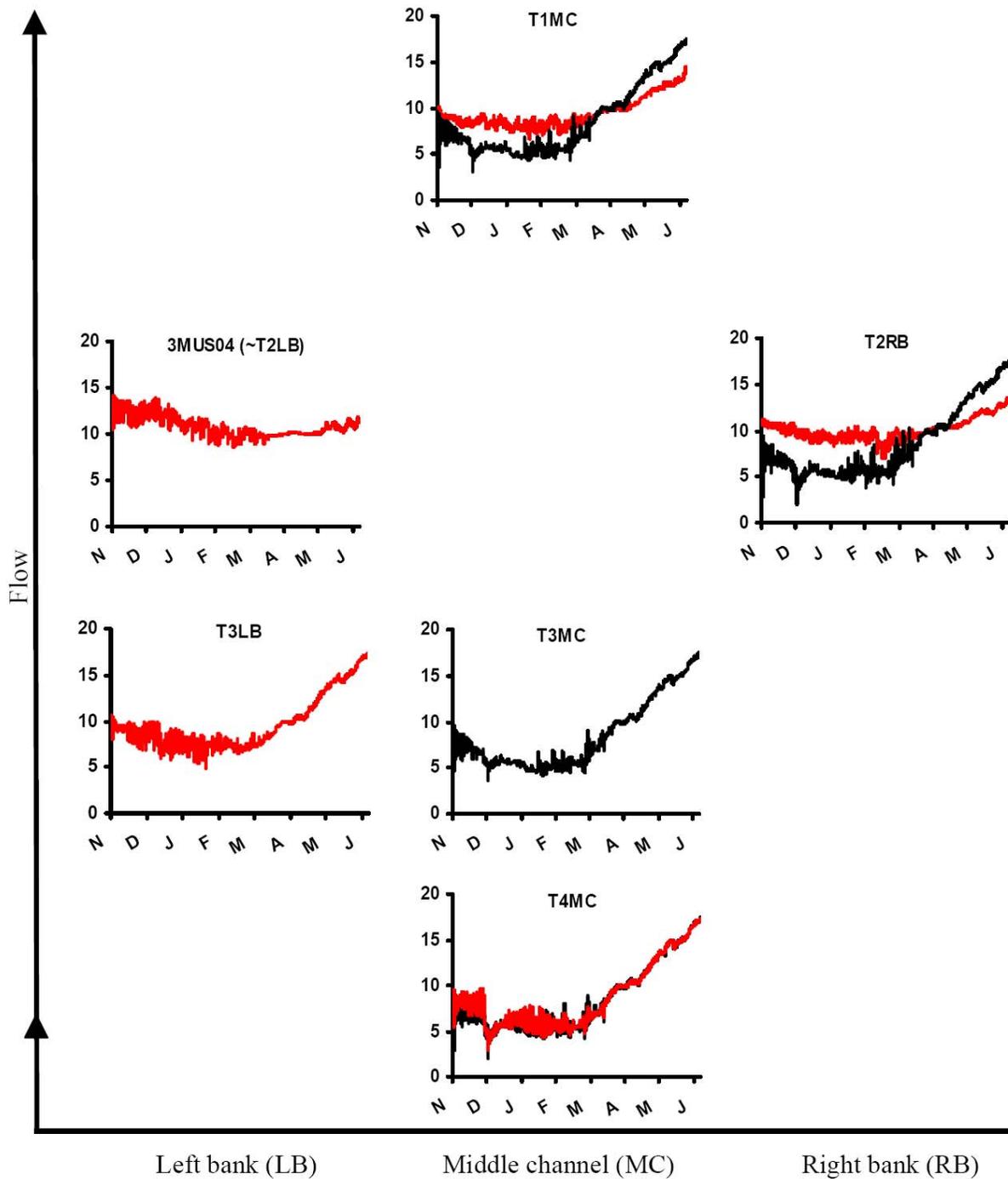


**Figure 2-13.** Bed Temperature Collected During 2000–01 Within Chum (3MUS04) and Fall Chinook (4MUN04) Salmon Spawning Areas

**2001–2002**

Considerable data were collected during this period from previously installed piezometers as well as the additional T1-T4 piezometers installed on November 27, including paired river and riverbed data from several T transect piezometers. Complete data sets were obtained for 10 riverbed and 5 river sites, including 3 sites for which both were obtained. Data for 6 sites in the channel north of Ives Island are presented in Figure 2-14, including the chum salmon spawning sites T1MC, T2RB, and 3MUS04 and the fall Chinook salmon site T4MC. For the period November 27–June 30, combined mean (SD) bed temperature for these chum salmon spawning areas and the fall Chinook salmon spawning area were 9.8 (1.44) °C and 8.7 (3.60) °C, respectively. Data from 3MUS04 were excluded from mean values because the sensor at 3MUS04 was located deeper within the riverbed than for T1MC and T2RB. Mean (SD) river temperature across the four sites in Figure 2-14 was 8.5 (3.76) °C.

Examination of the summary statistics and data plots in Figure 2-14 reveals a pattern of surface/subsurface interactions along this channel. Direction of flow between the bed and river is strongly upward from the subsurface at T2 and upward, although less strongly so, at T1. In contrast, flow is downward into the bed at T4. This pattern is reflected in the differing relationships between river and bed temperatures among these locations. At T1 and T2, bed temperatures are less variable over the period and on a daily basis than are river temperatures, reflecting the limited influence of river water on the bed environment. At T4, because river water flows into the bed, the temperature difference between river and bed water is reduced. Bed temperatures are more variable during the period and on a daily basis and reach lower fall temperatures and higher spring temperatures at T4 than at T1 or T2.



**Figure 2-14.** River (black line) and Riverbed (red line) Temperature, 2001–2002. Plots are arranged according to lateral and longitudinal site location within the channel north of Ives Island, with plots at the top farthest downstream and plots on the left along the left bank. In all plots, the x-axis is date, from November 27, 2001, to June 30, 2002, and the y-axis is temperature (°C).

In Fall 2001, in conjunction with the installation of the piezometers on transects T1–T4, some temperature sensors from the 1999–2000 installation series were moved from the 1.2-m to the 1.5-m piezometers, discontinuing data series at the shallower piezometers. Data from the 1999–2000 series and the transects installed in November 2001 are not directly comparable since temperature sensors are installed at different depths. Sensors installed during 1999–2000 were at 64–72 cm, whereas the sensors installed in 2001 were at 30 cm.

### **2002–2003**

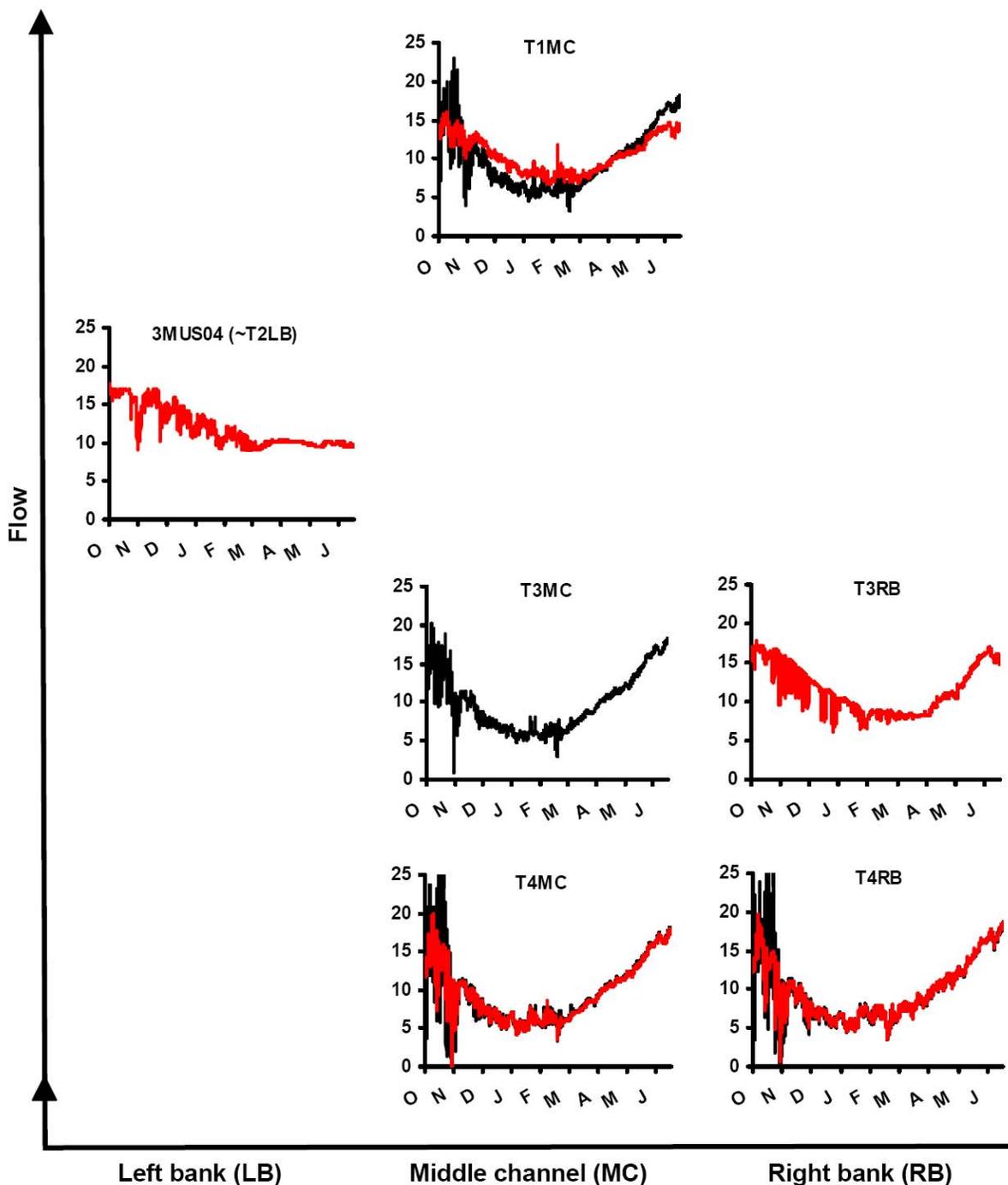
Considerable data at both river and bed locations were collected, including complete records for most sites during this period. Seven complete bed temperature records and four complete river records were collected, including three sites in spawning areas at which both bed and river data were collected (chum salmon: T1MC, fall Chinook salmon: T4MC, T4RB; Figure 2-15). Mean (SD) bed temperature for the chum salmon spawning area and combined mean (SD) bed temperature for the fall Chinook salmon spawning areas were 10.5 (2.32) °C and 9.6 (3.71) °C, respectively. Combined mean (SD) river temperature across the four sites in Figure 2-16 was 9.7 (3.86) °C. As in previous years, bed temperature was more stable across the period and on a daily basis, particularly early in the period, at the T1MC site than river or bed temperature at the T4 sites. Bed temperature at the T4 sites largely reflected river temperature.

### **2003–2004**

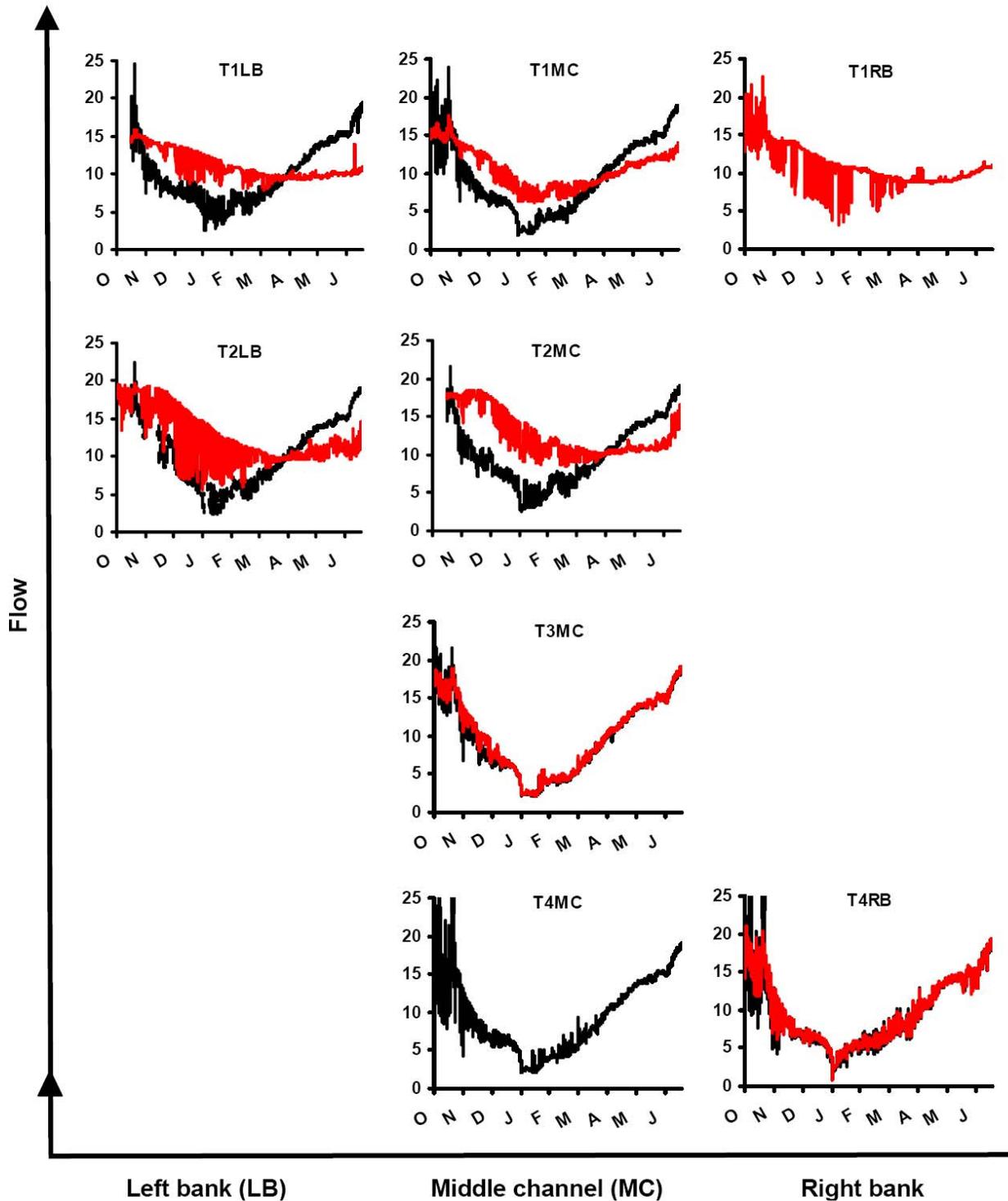
This period represents the most data-extensive period of the project. Complete or almost complete bed and river data sets were collected from nine and seven sites, respectively. Paired bed and river data sets are available at six sites. Although complete records are available at most sites, at the three real-time sites (T1LB, T2LB, and T2MC), some sensor records do not begin until October 16. Available data for eight sites in the channel north of Ives Island are presented in Figure 2-16. For the period October 16–June 30, combined mean (SD) bed temperature for the five chum spawning areas (T1, T2) and mean (SD) for the fall Chinook salmon spawning area (T4RB) were 11.4 (2.64) and 9.4 (4.19) °C, respectively. Mean (SD) river temperature across all seven sites in Figure 2-16 was 9.6 (4.36) °C. Patterns between bed and river and between chum and fall Chinook sites are similar to those of past years. At T1 and T2, bed temperatures are more stable than bed temperatures at T4 or river temperatures across the period and on a daily basis. There are exceptions, however. At T1RB and T2LB, bed temperatures are highly variable on a daily basis, particularly in the fall.

### **2004–2005**

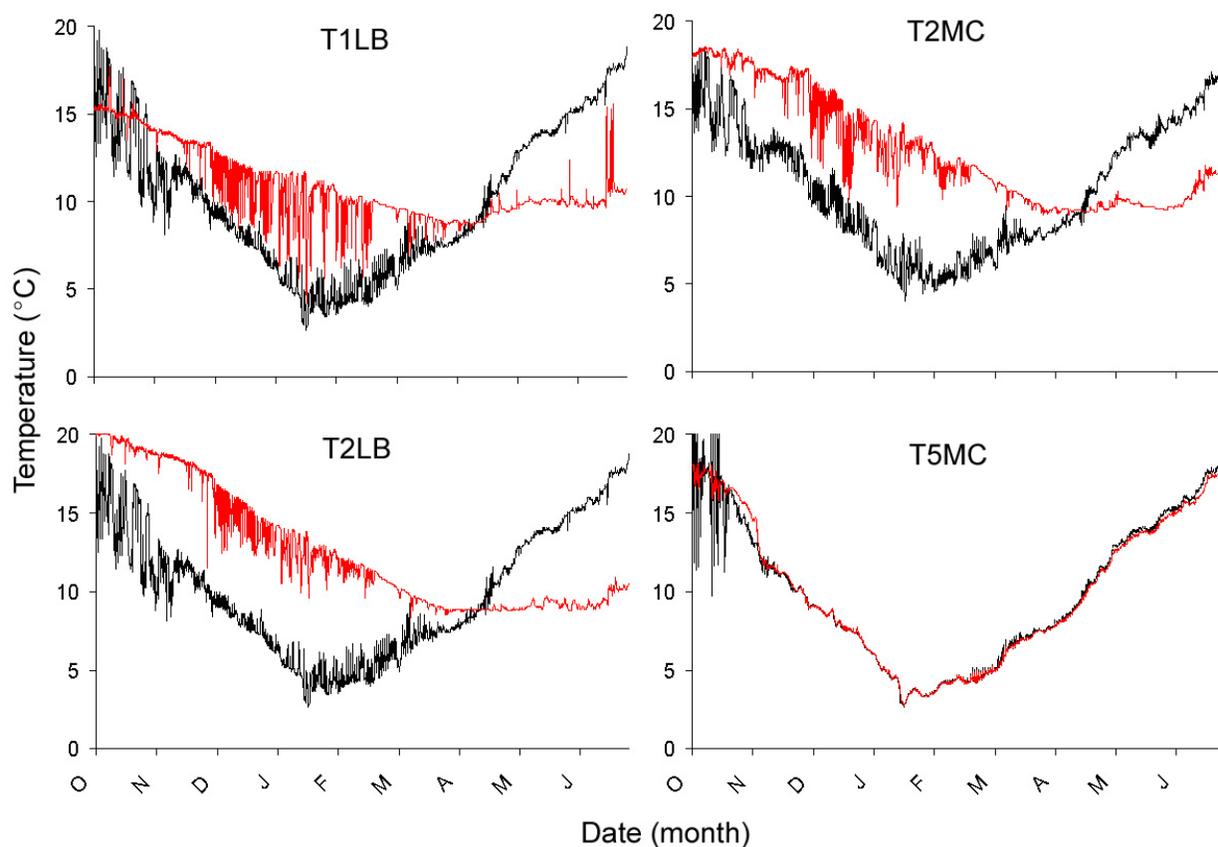
Paired bed and river data were collected for the entire period from the three real-time sensors in chum spawning locations (T1LB, T2LB, T2MC) and from one area used by chum and fall Chinook (T5, Figure 2-17). In addition, bed data were collected at T1MC, and river data were collected at T4RB. There were other locations where sensors were deployed but failed to produce any data (e.g., T4MC). Combined mean (SD) bed temperatures for October 1–June 30 for chum salmon spawning areas (T1 and T2) was 11.5 (3.03) °C. At T5, mean (SD) bed temperature was 10.0 (4.56) °C. The mean (SD) river temperature during the period was 10.1 (4.04) °C. The T2 sites show the pattern of warmer bed than river temperatures during the fall that was seen in previous years. At T1LB, average bed and river temperatures appear similar through October, although bed temperatures are more stable. Although bed



**Figure 2-15.** River (black line) and Riverbed (red line) Temperature, 2002–2003. Plots are arranged according to lateral and longitudinal site location within the channel north of Ives Island, with plots at the top farthest downstream and plots on the left along the left bank. In all plots, the x-axis is date, from October 1, 2002 to June 30, 2003, and the y-axis is temperature (°C).



**Figure 2-16.** River (black line) and Riverbed (red line) Temperature, 2003–2004. Plots are arranged according to lateral and longitudinal site location within the channel north of Ives Island, with plots at the top farthest downstream and plots on the left along the left bank. In all plots, the x-axis is date, from October 1, 2003, to June 30, 2004, and the y-axis is temperature (°C).



**Figure 2-17.** River (black) and Riverbed (red) Temperature from October 1, 2004, to June 30, 2005. T1LB, T2LB, and T2MC are located within chum spawning habitat. T5MC is located in an area used primarily by fall Chinook salmon.

temperatures at all three sites are more stable than river temperatures on a daily basis through mid-November, they are more variable than river temperatures during December. This is particularly the case for T1LB. This pattern has not been seen in previous years. During the winter months, all chum spawning locations had warmer bed temperatures than river temperatures, although this was more pronounced at the T2 locations than at T1. There was very little difference between bed and river temperatures at T5. This pattern is similar to previous observations in downwelling riffles where fall Chinook salmon spawn (T4).

Multiple linear regression was used to develop equations that can be used to improve the accuracy of acquired temperature unit (ATU) estimates made using data from the real-time system. The temperature gradient at each real-time system location (T1LB, T2LB, and T2MC) was evaluated and used to formulate the following relationships, which are more fully described in the Methods section:

$$\text{T1LB: EPT} = -0.908 + (0.647 \text{ BT}) + (0.419 \text{ RT})$$

$$\text{T2LB: EPT} = -7.491 + (0.841 \text{ BT}) + (0.710 \text{ RT})$$

$$\text{T2MC: EPT} = -3.933 + (0.355 \text{ BT}) + (1.019 \text{ RT})$$

where EPT = egg pocket temperature, BT = bed temperature (real-time system), and RT = river temperature (real-time system).

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## Appendix A

### Temperature Sensor Location Information

Name	Device <sup>1</sup>	$\Delta L^2$ (cm)	X <sup>3</sup>	Y <sup>3</sup>
1LS04	OS/T	77.0	578198	5053053
1LS05	OS	60.5	578198	5053053
2LN04	OS	63.0	578440	5053099
3MUS04	OS	66.0	578207	5053038
4MUN04	OS/T	67.2	578300	5053093
5MDS04	OS	69.2	577997	5052959
6MDN04	OS	66.0	578085	5052991
7HS04	OS	62.4	578267	5052923
7HS05	OS	63.8	578267	5052923
T1LB	OS	30.0	578126	5053019
T1LB	PT	58.0	578121	5053018
T1MC	SOL	30.0	578119	5053032
T1RB	OS	30.0	578115	5053051
T2LB	OS	31.0	578197	5053041
T2LB	PT	58.4	578197	5053041
T2MC	OS	31.0	578193	5053055
T2MC	PT	58.0	578193	5053055
T2RB	OS	30.0	578190	5053064
T3LB	OS	30.0	578258	5053092
T3MC	SOL	30.0	578254	5053096
T3RB	OS	30.0	578250	5053101
T4LB	T	35.5	578306	5053111
T4MC	SOL	36.0	578298	5053121
T4RB	OS	30.0 <sup>4</sup>	578288	5053136
T5MC	SOL	30.0 <sup>5</sup>	578106	5052412
T6IL	T	34.5	578113	5052944

<sup>1</sup> OS=Onset Stowaway temperature data logger, T=thermistor, SOL=Solinst temperature sensor, PT=Instrumentation NW PT2X temperature sensor

<sup>2</sup>  $\Delta L$ = depth of sensor below the riverbed

<sup>3</sup> Horizontal coordinate system UTM Zone 10 North, Datum NAD 83

<sup>4</sup>  $\Delta L$  changed to 38.0 cm on 9/7/03

<sup>5</sup>  $\Delta L$  changed to 24.2 cm on 10/10/02



**Appendix C**  
**Temperature Data Compendium**

[Click here for Appendix C \(2.41 MB pdf\)](#)

## Chapter 3

### Stranding and Entrapment Evaluation

*Christopher J. Murray*

During FY 2005, we completed Work Elements G, H, and I from the PNNL Statement of Work Report for BPA project 1999-003-01. This work scope provides technical support to the Washington Department of Fish and Wildlife (WDFW) for assessment of stranding of juvenile chum (*Oncorhynchus keta*), fall Chinook (*O. tshawytscha*), and coho (*O. kisutch*) salmon in the area below Bonneville Dam. We discussed the current sampling plan used for assessment of loss due to stranding and entrapment with WDFW and looked at the possibility of improving that plan. Given the lack of a real-time model for prediction of water levels at specific locations in the study area, we suggested that it would be necessary to continue with the current sampling plan.

As part of its work on the three work elements, PNNL performed a statistical analysis of fork length data for each of the three salmon species in order to determine whether or not there was a statistically significant difference between the fork length of entrapped and stranded juvenile salmon. This work was performed using a series of two-sample t-tests, and the results were included within the report being prepared by WDFW.

The main work performed for the three work elements included providing detailed evaluations and comments for the report produced by WDFW describing the field sampling of salmon stranding and entrapment for all three species as well as analysis of that data. Several drafts were reviewed and evaluated, and we provided both technical and editorial comments for each of the drafts. The final report on 2004 stranding and assessment was accepted by BPA and is available as follows:

Duston, Reed, and Jeremy Wilson. *2004 Evaluation of Chum, Chinook and Coho Salmon Entrapment near Ives Island in the Columbia River*. 2004 Annual Report, Project No. 199900301, 70 electronic pages (BPA Report DOE/BP-00004287-3). Accessed electronically on February 1, 2006, at <http://pisces.bpa.gov/release/documents/documentviewer.aspx?doc=00004287-3>.