Estimates of the stilling basin residence time and lateral distribution of passage of juvenile Chinook salmon passing through the spillway of The Dalles Dam, 2001

Final Report of Research during 2001
Contract W66QKZ10805878

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September 15, 2003

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Executive Summary

In 2001, the U.S. Army Corps of Engineers (COE) contracted with the U.S. Geological Survey (USGS) to determine fish residence time and lateral distribution during passage of yearling and subyearling juvenile Chinook salmon (*Oncorhynchus tshawytscha*) passing through the spillway at The Dalles Dam (TDA). To this end, the stilling basin residence time and lateral distribution of passage through the stilling basin of radio-tagged fish released through spill bays 4 (north site), and 9 and 11 (south sites) were determined.

Monitoring System: Separate aerial and underwater telemetry systems were used to detect tagged fish traveling through the stilling basin. The underwater system was a prototype design with dipole antennas mounted underwater slightly downstream of the end sill. The aerial system used was a slight modification of the aerial system used for past USGS fish passage efficiency studies at TDA.

Dam Operations: Spill began at TDA on 16 May 2001 and continued 24 h/d until 15 June 2001. During the period of fish and drogue releases for this study (20 May through 02 June), the mean discharge was 139.3 thousand cubic ft/s (45% of the 10-year average), the mean spill proportion was 30.5%, and the mean tailwater elevation was 77.3 ft. Due to drought conditions, spill did not occur during the subyearling Chinook salmon out-migration period, so passage of subyearling Chinook salmon was not studied.

Number of Fish Released and Detected: From 20 May 2001 through 30 May 2001, we radio-tagged and released 514 yearling Chinook salmon into the spillway at TDA. The aerial antenna array detected 72.4% of the released fish and the underwater array detected 18.4%.

Lateral Distribution within the Stilling Basin: Few fish from spill bay 4 exhibited lateral movements in the stilling basin, but many fish from spill bays 9 and 11 did. Based on aerial array detections, 26% of the 173 fish detected from spill bay 4 releases moved

laterally to the north and 12% moved to the south prior to exiting the stilling basin. Aerial detections of the fish released from spill bays 9 and 11 (pooled) indicated 49% (79 of 161) of the fish moved north while in the stilling basin. No southern movements occurred in fish released from spill bays 9 and 11.

Stilling Basin Residence Times: Including all fish regardless of their lateral movements, median residence times estimated from aerial array detections were 1.6 min (range 0.2 to 24.7 min, N =173) for fish released from spill bay 4 and 1.9 min (range 0.2 to 31.4 min, N = 161) for fish released from the spill bays 9 and 11 (pooled). Fish released from bays 9 and 11 that did not exhibit a northward lateral movement had a median residence time of 1.7 min (range 0.2 to 31.4 min, N = 82), whereas those that did exhibit such movements had a median residence time of 1.9 min (range 0.4 to 12.9 min, N = 79).

Drogue Releases: To further characterize tailrace flow conditions that may be encountered by fish passing through the TDA stilling basin, 19 aluminum drogues equipped with global positioning systems were released near the southern edge of the spill pattern (bays 9, 10 and 13) from 21 May 2001 to 02 June 2001. Sixty-eight percent of the drogues moved north at least one spill bay after release and 26% were transported laterally at least four bays. All lateral transport of drogues occurred between the base of the spillway ogee and the baffle blocks.

Introduction

The purpose for studying the egress characteristics and survival in the stilling basin at The Dalles Dam (TDA) is the relatively low survival of fish passing the spillway at this dam relative to others. For example, survival of radio-tagged yearling Chinook salmon passing via the spillway was estimated at 92.7% in 2000, which is several percentage points lower than at most Columbia and Snake River dams studied (Counihan et al. 2002).

One possible explanation for this low survival may be extended residence times in the stilling basin and/or increased injury of fish passing through the stilling basin in the lateral flow created by the juvenile spill pattern. The juvenile spill pattern is designed to avoid passing fish through the southern portion of the spillway to reduce their subsequent passage near the shallow areas and islands near the southern area of the tailrace. These areas contain habitat preferred by the northern pikeminnow (*Ptychocheilus oregonensis*; Shively et al. 1996, Martinelli et al. 1998), a predatory fish known to consume significant numbers of juvenile salmonids (Rieman et al. 1991). In an effort to prevent fish passage through these areas, proportionally more water is spilled in northern spill bays (i.e., closer to the Washington shore) than southern spill bays. One consequence of this spill pattern is the formation of northward lateral movement of water in the stilling basin, which may result in increased fish residence time and reduced survival in this turbulent area.

This study was designed to determine if fish are entrained in the northward flow in the stilling basin created by the juvenile spill pattern, and to quantify the extent of such movements in terms of their distance and effect on residence time within the stilling basin. To this end, a prototype underwater detection system was designed and installed in the stilling basin with the aid of engineers from the COE Portland District office to act as an exit array with which to determine the lateral distribution and residence time of fish exiting the stilling basin. We also redesigned the existing aerial array used to monitor fish in the spillway tailrace for other ongoing passage studies to increase its efficiency in detecting fish moving through this area.

Methods

Study Site

The Dalles Dam is located on the Columbia River at river km 307 (Figure 1). The dam consists of a single powerhouse of 22 turbine units and a single spillway of 23 tainter gates. The powerhouse is oriented parallel to river flow, but the spillway is perpendicular to river flow. A non-overflow wall oriented parallel to general river flow connects the powerhouse and spillway. A navigation lock is located at the north end of the dam.

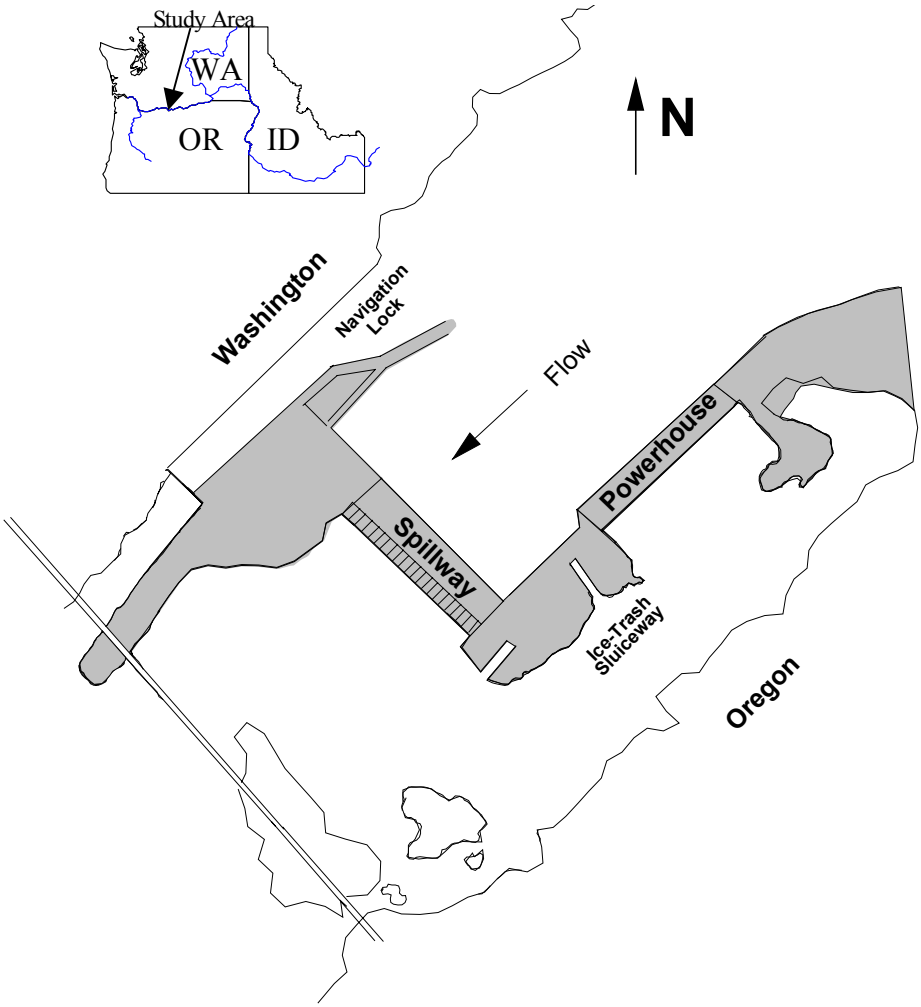

Figure 1. The Dalles Dam (river km 307) study site on the Columbia River and map indicating study site relative to the States of Washington (WA), Oregon (OR) and Idaho (ID).

Radio Transmitters and Fixed Receiving Equipment

Pulse-coded transmitters were implanted in yearling Chinook salmon allowing each individual fish to be uniquely identified. The radio transmitters were Lotek Wireless model MCFT-3KM (Lotek Wireless, Newmarket, Ontario, Canada[1]), which were 7.3 mm (diameter) X 18 mm and weighed 1.4 g in air and 0.8 g in water. The frequency range of the transmitters was between 150.320 and 150.760 MHz. The prototype underwater antenna array consisted of two lateral arrays of 32 half-wavelength dipole antennas each, with a combined coverage area along approximately 25 m of the end sill from spill bays 1 through 16 (Figure 2) and was monitored by a Multiprotocol Integrated Telemetry Acquisition System (MITAS; Grant Systems Engineering, King City, Ontario, Canada).

Figure 2. The Dalles Dam stilling basin during dam construction, with insert depicting approximate detection area of the underwater antenna array. Photo courtesy of the U.S. Army Corps of Engineers.

[1] Use of trade names does not imply endorsement by the U. S. Government.

A description of the underwater dipole antenna design is in Beeman et al. (In Press). The placement of these antennas relative to the stilling basin and end sill is indicated in Figure 3.

The existing spillway aerial array was modified from that used in past studies of fish passage at TDA (Beeman et al. 2001), by replacing the four-element Yagi antennas with 22-element corner-reflector antennas. The corner-reflector antenna has a radiation pattern with reduced side and back lobes, compared to a Yagi antenna, which reduces the effects of ambient radio noise, which is prevalent in the tailrace of The Dalles Dam. Mounted on the railing of the pier nose platform, the antennas were directed downward approximately 30 degrees and toward the north shore approximately 30 degrees. Antennas were positioned in this manner to better cover the stilling basin area between the ogee and the end sill. The spillway aerial array was monitored by a second MITAS. Antennas were mounted on the piernoses between spill bays 1 and 2, 3 and 4, 5 and 6, 7 and 8, 9 and 10, 11 and 12, 13 and 14, 15 and 16, 17 and 18, 19 and 20, 21 and 22, and on the southern edge of spill bay 23.

Fish Tagging, Handling, and Release

Yearling Chinook salmon to be implanted with radio transmitters were obtained from the juvenile collection and bypass facility at John Day Dam. Fish to be implanted were typically held 24 h prior to tagging to allow for gut evacuation. Fish were considered suitable for tagging if they were free of injuries, severe descaling, external signs of gas bubble trauma, or other abnormalities.

Transmitters were gastrically implanted following the methods of Martinelli et al. (1998). Following tagging, fish were held in recovery tanks at The Dalles Dam for approximately 24 h. Tagged fish were transported to the spill bays for release after holding tanks were checked for mortalities and regurgitated tags.

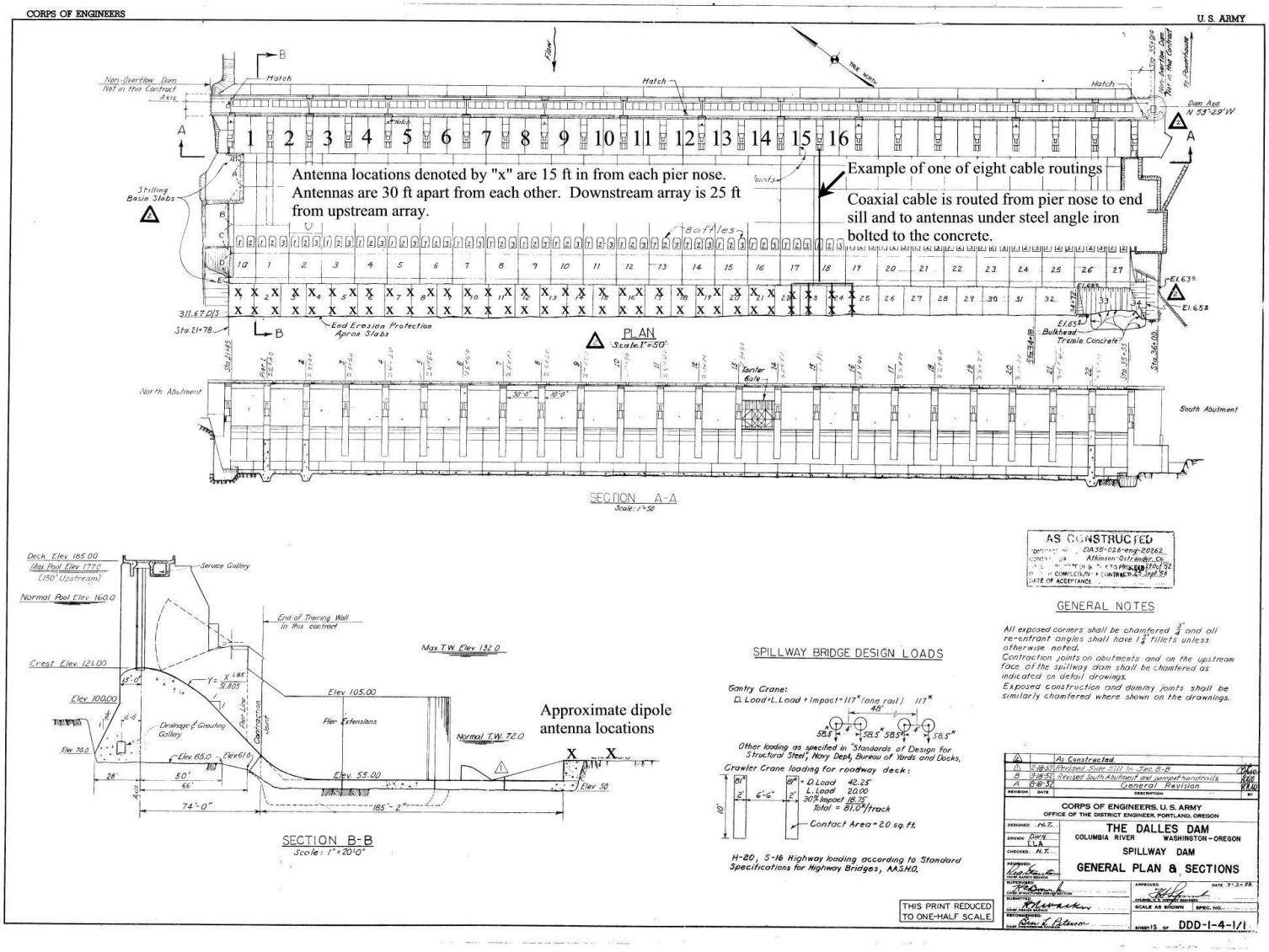

Figure 3. Schematic of The Dalles Dam stilling basin indicating locations of underwater antennas (X). Original schematic courtesy of the U.S. Army Corps of Engineers.

The release system was designed and installed by Normandeau Associates, Inc. for concurrent research being conducted from the TDA spillway (Normandeau Associates 2001). Release platforms were built parallel to the parapet wall on the spillway deck at spill bays 4, 9, and 11. The release mechanism was installed on both spill bays 9 and 11 so fish could be released near the southern edge of the spill pattern during various spill conditions. Upon each platform was a release tank supplied with water from the forebay via a submersible pump at a rate of approximately 200 L/min. Prior to placing fish into the release tanks, the tanks were filled until water flowed through the release hose to eliminate any air pockets in the release mechanism. The fish were released from the tank by removing a standpipe, allowing the fish to discharge with the water volume of the tank. A 10-cm diameter release hose was connected to the lower end of the release tank, and the hose extended through an opening on the spillway deck and was routed to the center of the spill bay. One or two radio-tagged fish were placed into the north and south release tank and released simultaneously, whenever possible. Water from the submersible pump was flushed through tanks and hoses to ensure the fish exited the hose. The design allowed us to simulate fish passing the TDA spillway via a northern and southern route, during the same flow conditions.

Drogue Releases

Aluminum drogues were used to study the large-scale hydraulic trends encountered by juvenile salmon in the TDA spillway between 21 May 2001 and 02 June 2001 using methods described in Liedtke et al. (1999). With lateral movement as our primary focus, drogues equipped with global positioning system (GPS) receivers were released on the south end of the spill pattern. Release locations were one bay north of the southern-most open bay to minimize "edge effect". Due to changing dam operating conditions, releases were conducted at spill bays 9, 10, and 13. All drogues were equipped with Trimble GeoExplorer II GPS units and collected spatial data as they drifted through the tailrace. Since GPS signals cannot break the air-water interface, GPS-equipped drogues do not record spatial coordinates when their GPS antenna is submerged, which occurs periodically in areas of extreme turbulence. To account for this potential loss of data, visual observations were recorded from release to the Route 197

Bridge. Boats were used to verify positions and to retrieve drogues. All GPS data were post processed to ensure 1-to-3 meter accuracy and entered into ArcView software (Environmental Research Systems Institute, Inc., Redlands, California USA) for geographic information system (GIS) analysis.

Data Management and Analysis

Data from MITAS were typically downloaded every other day and were imported into SAS software for personal computers (SAS 1999) for subsequent proofing and analyses. Proofing eliminated non-valid records including background noise, single records of a particular channel and code, and records that were collected prior to the known release date and time.

Residence time in the stilling basin area was defined as the amount of time between release and last detection in the stilling basin by the aerial antenna system. These residence times are a minimum estimate of the actual time that radio-tagged fish spent in the stilling basin because fish may have been there for an unknown amount of time following their last detection.

In assigning an area of last detection by the aerial array it was common for radio-tagged fish to be detected on multiple aerial antennas at the same time, since the zones of coverage overlapped. To assign a last detection location, the detection with the highest signal strength was considered the best estimate of last location. The aerial antennas were angled to the north approximately 30 degrees to ensure the cone-shaped coverage area would include areas very near the dam. As a result, fish were likely further north in the stilling basin than the last assigned detection location, because the detection range of each antenna overlapped with one or more antennas from adjacent spill bays to the north. Median stilling basin residence times of groups of fish released at the north and south release sites were compared statistically using Kruskal-Wallis tests. Results were considered statistically significant when $P \leq 0.05$.

Results

Dam Operations

Water was released at the spillway 24 h/d between 16 May 2001 and 15 June 2001 via the juvenile spill pattern. During this period the mean project discharge was 138.8 thousand cubic feet per second (KCFS; range 76.0 to 222.8 KCFS) and the mean percent of the discharge as spill was 30.1% (range 21.5 to 41.3%; data from COE). The mean discharge and percent spill during the time fish were released for this study (20 May through 02 June) were 139.3 KCFS (range 109.3 to 163.6 KCFS) and 30.5%, (range 29.4 to 35.1%), respectively. The 10-year average discharge during these dates between 1991 and 2000 was 306.5 KCFS (range 299.4 to 316.8 KCFS). The status of spill bay gates open and closed during fish releases is listed in Appendix A1 (data from COE).

Tailwater elevations were lower than in recent years due to the 2001 drought. The mean tailwater elevation from 20 May 2001 1100 h through 02 June 1200 h, the time period between the first and last fish and/or drogue release, was 77.3 ft (range 75.3 to 78.8 ft). Tailwater elevations in 2000 were an average of 79.6 ft (range 75.2 to 82.0 ft) and those during the high-flow year of 1997 were 87.7 ft (range 85.8 to 89.6 ft).

Fish Released and Detected

From 20 May through 30 May, we radio-tagged and released 514 yearling Chinook salmon into spill bays at TDA (detailed summaries of all releases are presented in Appendices A2 and A3). The morning release on 30 May was omitted from analysis due to the absence of detections by either the aerial or underwater arrays. We believe these data are missing due to equipment failure during the period that encompassed this release activity. Analysis was performed on the remaining seven releases, which comprised 474 yearling Chinook salmon. The 474 fish released were divided between the north and south release sites, with 236 fish being released into spill bay 4, and 238

fish released into spill bays 9 and 11. Most (202 of 238) of the south release site fish were released into spill bay 9.

Analyses were based on the aerial array data only due to the low detection percentages of the underwater array. Of the 236 fish released into spill bay 4, 74.2% (N = 175) were detected by the aerial antenna array and 14.0% (N = 33) were detected on the underwater antenna array (Tables 1 and 2). Aerial detections of fish released at spill bays 9 and 11 were similar, with 168 of the 238 (70.6%) fish being detected. The underwater array detection rate was higher for fish released into the south release sites, with 54 of the 238 (22.7%) fish detected. Two of the spill bay 4 fish and seven of the spill bay 9 and 11 fish detected by the aerial array exhibited post-release behavior indicative of dead, or preyed-upon fish (e.g., long residence times in one place, or detections on many antennas in a short time period), and were excluded from further analyses.

Lateral Distribution

Fish released into spill bay 4 generally did not show lateral movement in the stilling basin area (Figure 4). From aerial antenna detections, 26% of the 173 fish detected from spill bay 4 releases moved laterally to the north and 13% moved to the south; most fish (61%) showed no lateral movement. Due to the northward angle of the aerial antennas, it is normal for some fish near spill bay 4 to be detected on antennas south of this location. No fish released at spill bay 4 were detected with aerial antennas south of spill bay 11.

Almost half (49%; N = 79) of the detected fish released from spill bays 9 and 11 moved laterally toward the north, but the remaining 51% (N = 82) passed through the stilling basin without lateral movement (Figure 4). A total of 42% (N = 67) of the fish detected by the aerial array traveled northward at least three spill bays, as indicated by their detections at antennas monitoring the area north of spill bay 6.

Table 1. Aerial antenna array detection rates and residence time statistics of fish released during spring, 2001.

Release date	North release site (spill bay 4)						South release sites (spill bays 9 and 11)					
	Fish released	Fish detected(%)	Median residence time(min)	Mean residence time(min)	SD	Range	Fish released	Fish detected(%)	Median residence time(min)	Mean residence time(min)	SD	Range
5/20/01	37	27(73.0)	1.0	1.4	1.6	0.4-8.5	40	34(85.0)	0.8	0.9	0.6	0.2-2.8
5/22/01	48	8(16.7)	0.7	0.8	0.4	0.5-1.8	48	5(10.4)	0.8	0.9	0.4	0.4-1.4
5/24/01	68	67(98.5)	1.6	2.3	3.3	0.2-24.7	26	26(100)	2.8	5.2	7.0	0.7-31.4
5/26/01	23	23(100)	2.5	2.7	1.3	1.0-7.4	66	66(100)	2.0	2.4	1.2	0.7-7.6
5/28/01am	20	19(95.0)	1.7	2.0	1.1	0.8-5.1	20	20(100)	1.8	2.2	1.5	0.8-7.5
5/28/01pm	30	29(96.7)	1.7	2.0	1.1	0.8-6.1	9	9(100)	6.5	7.3	2.9	4.3-12.9
5/30/01	10	2(20.0)	1.1	1.1	0.1	1.0-1.2	29	8(27.6)	2.1	3.2	2.9	1.0-8.0
Total	236	175(74.2)	1.6	2.1	2.3	0.2-24.7	238	168(70.6)	1.9	2.7	3.4	0.2-31.4
All Bays Combined	474	343(72.4)	1.7	2.4	2.9	0.2-31.4						

Table 2. Underwater antenna array detection rates and residence time statistics of fish released during spring, 2001.

Release date	North release site (spill bay 4)						South release sites (spill bays 9 and 11)					
	Fish released	Fish detected(%)	Median residence time(min)	Mean residence time(min)	SD	Range	Fish released	Fish detected(%)	Median residence time(min)	Mean residence time(min)	SD	Range
5/20/01	37	3(08.1)	1.3	1.3	0.3	0.1-1.7	40	19(47.5)	0.5	0.7	0.7	0.1-2.6
5/22/01	48	1(02.1)	2.2	2.2			48	7(14.6)	0.3	0.3	0.1	0.2-0.5
5/24/01	68	18(26.5)	1.3	1.4	0.7	0.4-2.9	26	4(15.4)	2.3	3.8	4.5	0.5-10.1
5/26/01	23	3(13.0)	1.4	1.4	0.2	1.2-1.6	66	17(25.8)	1.0	1.4	1.4	0.1-6.0
5/28/01am	20	5(25.0)	1.3	1.3	0.6	0.8-2.1	20	3(15.0)	0.8	1.2	0.8	0.7-2.4
5/28/01pm	30	3(10.0)	0.6	0.6	0.2	0.5-0.8	9	2(22.2)	5.5	5.5	0.4	5.2-5.8
5/30/01	10	0(00.0)					29	2(06.9)	3.9	3.9	3.1	1.7-6.1
Total	236	33(14.0)	1.3	1.4	0.7	0.4-2.9	238	54(22.7)	0.7	1.4	1.9	0.1-10.1
All Bays Combined	474	87(18.4)	0.9	1.4	1.6	0.1-10.1						

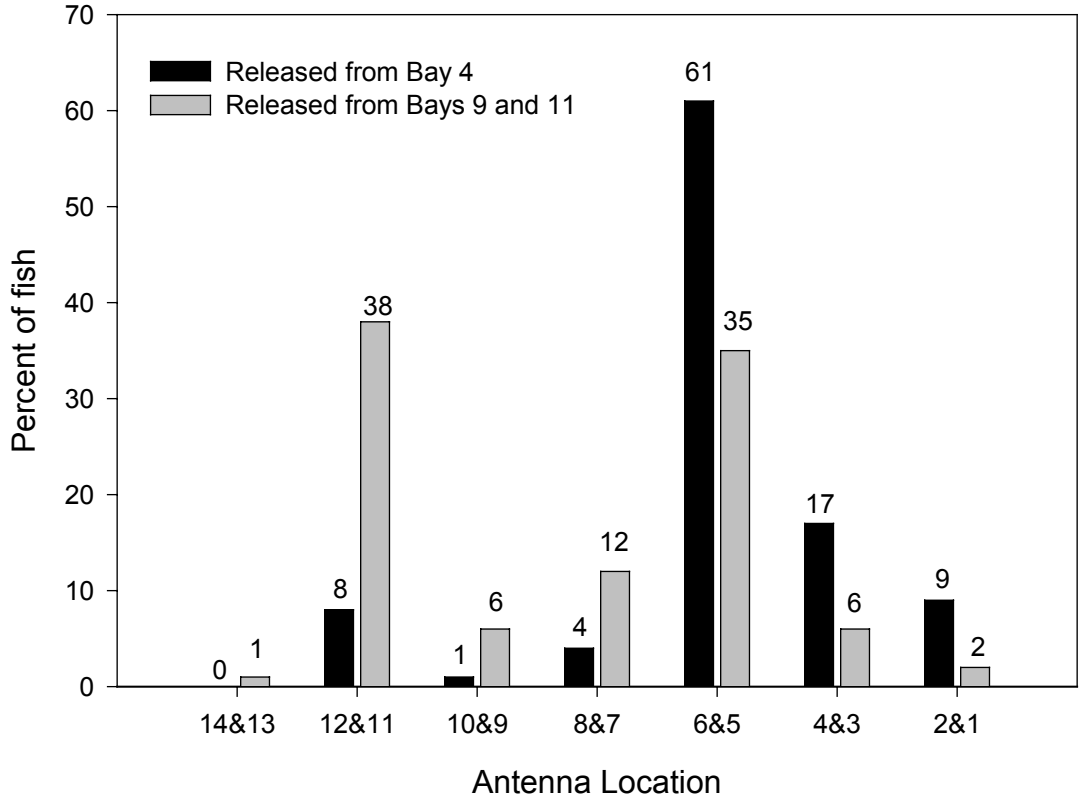

Figure 4. Location of last aerial antenna detections of fish released at spill bay 4 (*N* = 175 detections) and spill bays 9 and 11(pooled, *N* = 168 detections). Lateral movement northward (to the right in figure) is indicated in spill bay 9/11 fish last detected north of the antenna between bays 10 and 9 and in those from spill bay 4 north of the antenna between bays 6 and 5. No fish were last detected on antennas south of the piernose between spill bays 14 and 13. Numbers above bars indicate the percentages they represent.

Evidence of lateral movement is also available from detections at the underwater array, though few fish were detected by this system. During the first release, 6 of the 19 detected fish from the spill bay 9 group moved laterally to the north. Of these, five fish were detected passing the end sill downstream of spill bays 5 and 6. Additionally, 2 of the 3 fish detected from the spill bay 4 group also moved northward, being detected by underwater antennas monitoring directly downstream from spill bays 1 and 2.

Residence Time

The median residence times calculated from aerial detections of fish released through spill bay 4 were slightly shorter than those of fish released into spill bays 9 and 11. Based on aerial antenna detections, fish released from spill bay 4 had a median residence time of 1.6 min, ranging from 0.2 to 24.7 min (Figure 5). The fish from the pooled spill bay 9 and 11 releases had a median residence time of 1.9 min, with a range of 0.2 to 31.4 min. The difference in median values is statistically significant (Kruskal-Wallis test, DF = 1, P > Chi-Square = 0.0311).

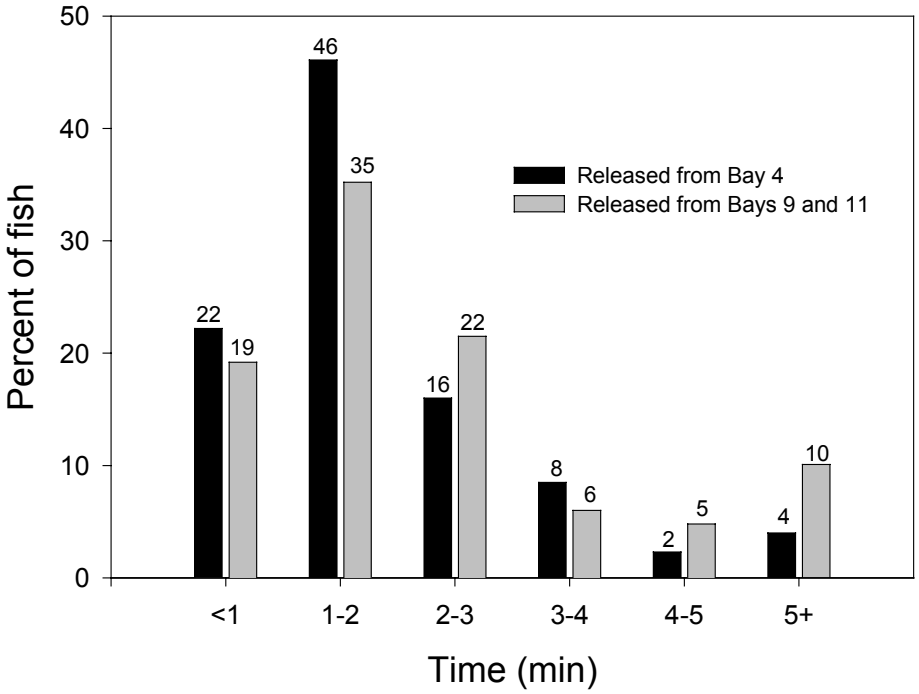

Figure 5. Stilling basin residence times of fish released from spill bay 4 and spill bays 9 and 11 (pooled). Residence times were estimated using aerial antenna detections. Numbers above bars indicate the percentages they represent.

The residence times of fish detected by the underwater array were shorter than the residence times calculated from aerial detections. However, due to the poor performance of the underwater antenna array throughout the spill season, we analyzed only the detection history of this array for the first release, which had the highest rate of detection

of fish released from spill bay 9 (47.5%). Based on the underwater antenna detections, the median residence time of spill bay 9 fish from this release was 0.5 min (range 0.1 to 2.6 min, $N = 19$). The data from these 19 individuals based on the aerial system indicated a median residence time 0.8 min (range 0.0 to 2.6 min), indicating the aerial array had a slightly larger range from the dam than the underwater array. Using the underwater detections from this single release, the residence times of fish released from spill bay 4 were longer (median 1.3 min, range 0.1 to 1.7 min, $N = 3$) than those released from spill bay 9. However, only 3 of 37 released through spill bay 4 were detected.

Fish from spill bays 9 and 11 exhibiting northward lateral movements had slightly longer median residence times than those that did not show lateral movements. The median residence time of those showing lateral movements was 1.9 min (range 0.4 to 12.9 min, $N = 79$), whereas those without lateral movements had a median residence time of 1.7 min (range 0.2 to 31.4 min, $N = 82$). The difference in the median values was statistically significant (Kruskal-Wallis test, DF = 1, $P = 0.0494$). Some fish without northward lateral movements tended to remain within the detection area of the aerial antennas near the south edge of the spill pattern for long periods (perhaps in areas without spill), which contributed to the large range in residence times and increased the overall median.

Drogue Releases

Nineteen drogues were deployed to characterize tailrace flow patterns in the TDA stilling basin between 21 May and 02 June 2001. As seen in 2000 (Allen et al. 2000) most spillway drogues moved laterally from south to north in the stilling basin. All lateral transport occurred between the base of the ogee and the baffle blocks; this was primarily determined by visual observation, because the GPS antenna was often underwater in this area. Thirteen of 19 (68%) drogues moved one or more bays to the north and 5 of 19 (26%) drogues were laterally transported at least four bays to the north. The elapsed time from drogue release to arrival at the Route 197 bridge ranged from 3 min 29 s to 1 h 1 min 25 s (Appendix A4). The elapsed time from release to a point 6 km downstream from the dam (i.e., Exit Station) ranged from 17 min 49 s to 1 h 20 min 28 s,

though few drogues reached this destination; many ran aground and some were simply retrieved prior to this point. Figure 6 illustrates the paths of drogues released on 02 June 2001 at spill bay 10, which are generally representative of the data from other dates. Paths of all individual drogues with GPS data are presented in Appendix A5.

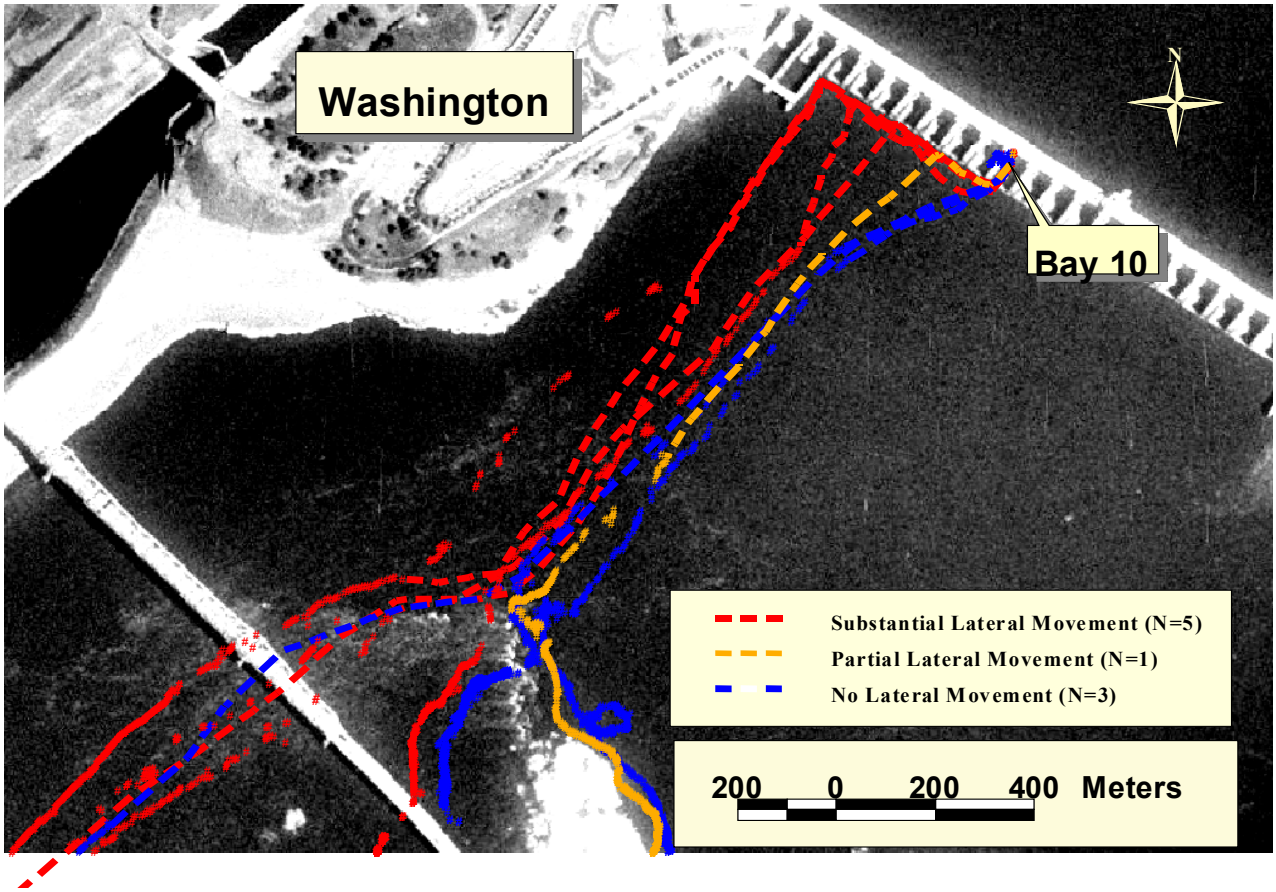

Figure 6. Paths of GPS-equipped drogues released from The Dalles Dam spill bay 10, on 02 June 2001 ($N = 9$). Observed paths (dashed lines) were used to supplement GPS data (dotted lines). Drogue paths are depicted in three groups: drogues depicted in red moved four or more spill bays to the south, drogues depicted in orange had up to 4 spill bays of lateral movement, and drogues depicted in blue had no lateral movement between the spillway ogee and end sill.

Discussion

A northward lateral movement through the stilling basin was common in yearling Chinook salmon released through the spillway near the southern edge of the juvenile spill pattern during spring, 2001. Approximately 50% of the fish released through spill bays 9 and 11 exhibited northward lateral movement, with about 40% of the fish detected via the aerial array moving at least three spill bays prior to their exit from the stilling basin. Fish released from spill bay 4 appeared to have less lateral movement during passage than those from spill bays 9 and 11, though northerly movement from bay 4 is limited by its proximity to the Washington shoreline. Results from the underwater antenna array, which detected few fish overall, indicated that fish from the first release at bay 9 traveled several bays north prior to passing the end sill and two of the three fish detected from the first release at bay 4 passed the end sill directly downstream of bays 1 and 2.

Data from drogues indicate that the hydraulic characteristics encountered by fish in the stilling basin is a logical explanation of the increased residence time and lateral movement of fish passing via the south spill bays. Most drogues (68%) moved laterally northward, with 26% moving at least four spill bays, which is similar to results from 2000 (Allen et al. 2000). All lateral transport of drogues occurred between the base of the ogee and the baffle blocks.

The results of this and concurrent studies of direct mortality and the hydraulic environment indicate that fish passing via spill bays 9 and 11 experienced a more deleterious route through the stilling basin than fish passing via spill bay 4. Despite the damage to the underwater detection array, our results from the GPS-equipped drogues and the aerial detection array indicate that lateral gradient of water velocity indeed occurs due to the juvenile spill pattern and that 42% of the detected fish released from spill bays 9 and 11 were transported at least three spill bays north in this gradient. Results of a pilot study of direct mortality based on balloon-tagged fish indicated that injury rates of rainbow trout were much greater among those released from spill bay 9 (14%; 8 of 58 fish) than spill bay 4 (2%; 1 of 54 fish; Normandeau Associates 2001). In addition,

Normandeau Associates (2001) reported results of data from several sensor packages (i.e., "sensor fish") released by Battelle Pacific Northwest Laboratories, which indicated greater velocity vector differences (i.e., changes in velocity indicative of turbulence or strike) in those released through spill bay 9 than spill bay 4. These results indicate that fish released through spill bays 9 and 11 experienced a more turbulent environment and greater proportion of injuries than those passing through spill bay 4. Results from our study suggest this is due to the northward lateral movements of fish that likely occur between the spillway and baffle blocks, based on the location of drogue movements. However, the paths of the drogues are likely not indicative of exact fish paths, due to the differences in surface area and mass of the drogues and fish. Results from a concurrent study of overall fish passage at TDA indicate that 45% of the radio-tagged fish released upstream of TDA that passed via the spillway did so between spill bays 9 and the southern end of the spill pattern (Beeman et al. Preparation). This suggests that a significant proportion of volitionally passing fish experience the lateral movement, extended residence times and other indications of poor downstream passage noted in fish, drogues and sensor packages released specifically through bays 9 and 11.

River discharge during 2001 was among the lowest on record (45% of the 10-year average), resulting in lower spillway discharges and tailwater elevations than during most years, which may have affected the results of this and the other concurrent studies in the stilling basin of TDA. For example, low tailwater elevations may have increased the direct injury and mortality estimates and produced different hydraulic conditions than normal, resulting in atypical results from the studies of the physical environment and the lateral movements of fish in the stilling basin.

The prototype underwater array was to be the primary method of data collection due to the high spatial resolution of underwater antennas, but structural damage reduced the detection proportions dramatically. The underwater array functioned acceptably during the first release, but detections decreased as the study period progressed. On 05 September 2001, a post-spill dive inspection was conducted to evaluate the condition of the antenna array. Divers noted either structural damage to, or the disappearance of, 59

of the 64 dipole antennas. In addition, the angle iron bolted to the concrete broke free in the area of the base of the spillway ogee in four of the eight arrays, severing transmission cables between the antennas and receiving system. Damage was more prevalent near the north end of the stilling basin where the spill was greatest. We were unable to determine exactly when or how much damage occurred prior to our first release of fish, because spill began four days prior to that date. However, the data indicate the quantity and quality of detections decreased throughout the study period. During the first release (20 May), 22 of the 77 (29%) fish released into the spill bays were detected by the underwater array. By the last release on 30 May, only 2 of the 39 (5%) fish released were detected by the underwater antenna array.

We expected the dipole antenna design used in this study to withstand the water velocities in the detection area, but a stronger design is clearly warranted. Data collected from the sectional model of The Dalles spillway at the Waterways Experiment Station (Cooper, date unknown), as well as that from the computational fluid dynamics model created by Battelle Pacific Northwest Laboratories (Marshall Richmond, Battelle Pacific Northwest Laboratories, personal communication) indicated the water velocities expected in the proposed detection area would be approximately 3 m/s. After this study, we developed and tested an armored dipole antenna design. The armored dipole antenna, used in conjunction with a steel deflector plate, survived an exposure of about 48 h in the juvenile bypass system at John Day Dam in water velocities of up to approximately 12 m/s, whereas the standard design used in this study withstood velocities of about 3 m/s, but was broken at velocities of about 6 and 12 m/s. The range of the armored version is similar to the original design (Beeman et al. In Press). The damage to the angle iron installation indicates a stronger, or alternative attachment method is required for this application.

The median residence times from aerial array detections were 0.3 min longer than those from the underwater array, indicating the range of the aerial system extended downstream beyond the underwater antennas. Assuming an average water velocity of 3 m/s (as described previously), the fish would have traveled a median of 54 m beyond the

range of the underwater antennas. Though this affected the residence times, it may have had little effect on the reported extent of lateral distribution if fish paths were similar to drogue paths, since nearly all lateral movement of the drogues was completed between the spillway and the baffle blocks. Data from this and concurrent studies of fish passage at the spillway of The Dalles Dam indicate further investigation into the effects of the lateral movements and extended residence times on the survival of passing juvenile salmonids is warranted.

Acknowledgements

We thank Mike Langeslay, Rock Peters, Miro Zyndol, and COE personnel at The Dalles and John Day dams for their efforts in managing the contract and assisting in the planning and completion of this research. This work would not have been accomplished without the efforts and technical assistance of Brady Allen, Ben Hausmann, Brad Liedtke, Leah Brown, Jill Begala, Brian Beardsley, Jodi Charrier, Tyler Hallock, Brad Herrick, Linda Kelley, John Kirby, Blair Paul, Joel Quennette, and Jacquelyn Schei, who tagged and released the fish used in this study. We also thank Rick Martinson and Greg Kovalchuk, of the Pacific States Marine Fisheries Commission, and the staff at John Day Dam's smolt monitoring facility for collecting and holding fish for this study.

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Appendix A1. Status of spill bay gates while fish releases were being conducted.

Spill Bay Gate	Release							
	1	2	3	4	5	6	7	8
	11:00-15:00	13:00-16:00	0:00-3:00	0:00-3:00	11:00-13:00	0:00-1:00	12:00-13:00	0:00-1:00
Spill bay 1	Open	Open	Open	Open	Open	Open	Open	Open
Spill bay 2	Open	Open	Open	Open	Open	Open	Open	Open
Spill bay 3	Open	Open	Open	Open	Open	Open	Open	Open
Spill bay 4	Open	Open	Open	Open	Open	Open	Open	Open
Spill bay 5	Open	Open	Open	Open	Open	Open	Open	Open
Spill bay 6	Open	Open	Open	Open	Open	Open	Open	Open
Spill bay 7	Open	Open	Open	Open	Open	Open	Open	Open
Spill bay 8	Open	Open	Open	Open	Open	Open	Open	Open
Spill bay 9	Open	Open	Transition	Open	Open	Transition	Open	Open
Spill bay 10	Open	Open	Transition	Open	Open	Transition	Open	Closed
Spill bay 11	Closed	Open	Transition	Open	Open	Transition	Open	Closed
Spill bay 12	Open	Open	Closed	Transition	Closed	Closed	Open	Closed
Spill bay 13	Transition	Open	Closed	Closed	Closed	Closed	Closed	Closed
Spill bay 14	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed
Spill bay 15	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed
Spill bay 16	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed
Spill bay 17	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed
Spill bay 18	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed
Spill bay 19	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed
Spill bay 20	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed
Spill bay 21	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed
Spill bay 22	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed

Appendix A2. Summary of number of radio-tagged yearling Chinook salmon released (N) from TDA spill bay 4 (north release site) and the mean, standard deviation (SD), and range of the fork length and weight.

Release date	Release time	N	Fork length (mm)			Weight (g)		
			Mean	SD	Range	Mean	SD	Range
5/20/01	1100	37	166	19	130-205	46.0	15.4	22.0-81.7
5/22/01	1300	48	171	16	140-209	47.5	14.4	23.9-89.2
5/24/01	2300	68	179	20	141-220	56.2	20.5	25.9-100.0
5/26/01	2300	23	165	16	128-193	42.5	12.8	18.4-74.4
5/28/01	1000	20	167	17	146-204	42.3	14.5	27.0-79.8
5/28/01	2300	30	166	19	140-203	43.5	16.1	23.9-79.0
5/30/01	1000	20	181	25	143-215	58.2	23.7	25.8-96.5
5/30/01	2200	10	168	18	140-200	45.8	15.9	24.2-70.5
Overall		256	172	20	128-220	49.0	18.1	18.4-100.0

Appendix A3. Summary of number of radio-tagged yearling Chinook salmon released (N) from TDA spill bays 9 and 11 (south release sites) and the mean, standard deviation (SD), and range of the fork length and weight.

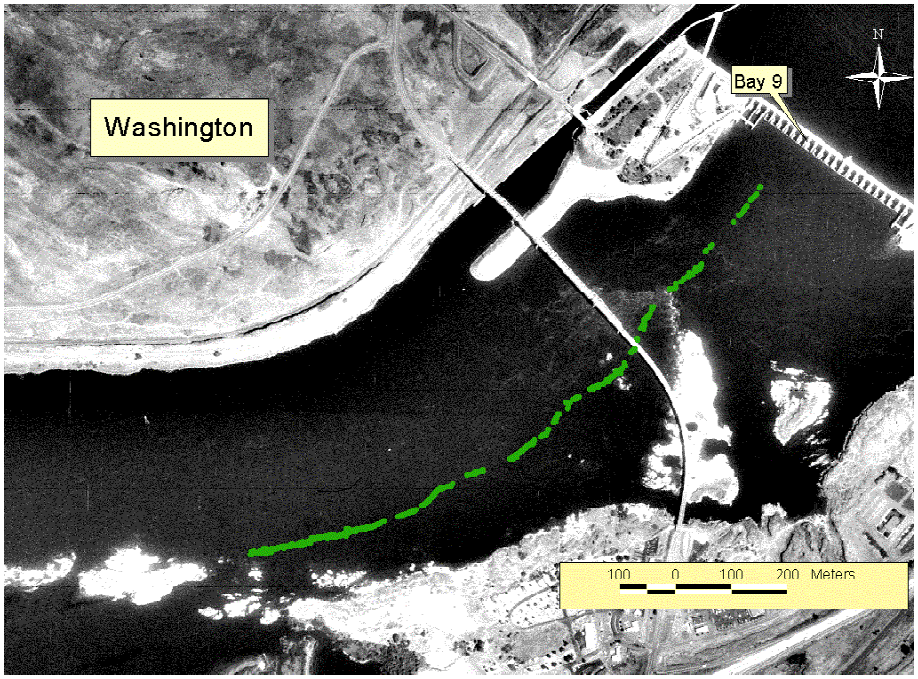
Release date	Release time	Release site	N	Fork length (mm)			Weight (g)		
				Mean	SD	Range	Mean	SD	Range
5/20/01	1100	SB9	40	163	15	145-197	42.2	13.3	27.9-80.3
5/22/01	1300	SB9	48	167	17	139-212	45.9	15.2	24.9-103.2
5/24/01	2300	SB9	26	179	20	141-223	55.0	19.9	26.4-110.1
5/26/01	2300	SB9	50	169	18	138-210	46.3	14.9	24.8-96.0
5/26/01	2300	SB11	16	174	16	149-199	51.0	16.3	31.5-82.1
5/28/01	1000	SB9	20	168	19	139-210	44.7	16.9	24.2-92.6
5/28/01	2300	SB9	9	161	10	140-177	36.8	7.6	22.8-49.5
5/30/01	1000	SB11	20	183	16	160-209	58.5	16.8	38.0-85.7
5/30/01	2200	SB9	29	184	19	138-216	60.1	19.0	24.8-101.9
Overall			258	171	19	138-223	48.7	17.0	22.8-110.1

Appendix A4. Summary of drogues released from TDA spillway in 2001 by release date (Date), deployment location (Location), deployment time (Deployment Time), elapsed time to the Highway 197 bridge (Time to Bridge), elapsed time to the exit (Time to Exit), total discharge at TDA (Total Discharge), and total spill at TDA (Total Spill). Where no data is reported for Bridge Time or Exit Time, the drogue did not complete the drift. Time format is hh:mm:ss.

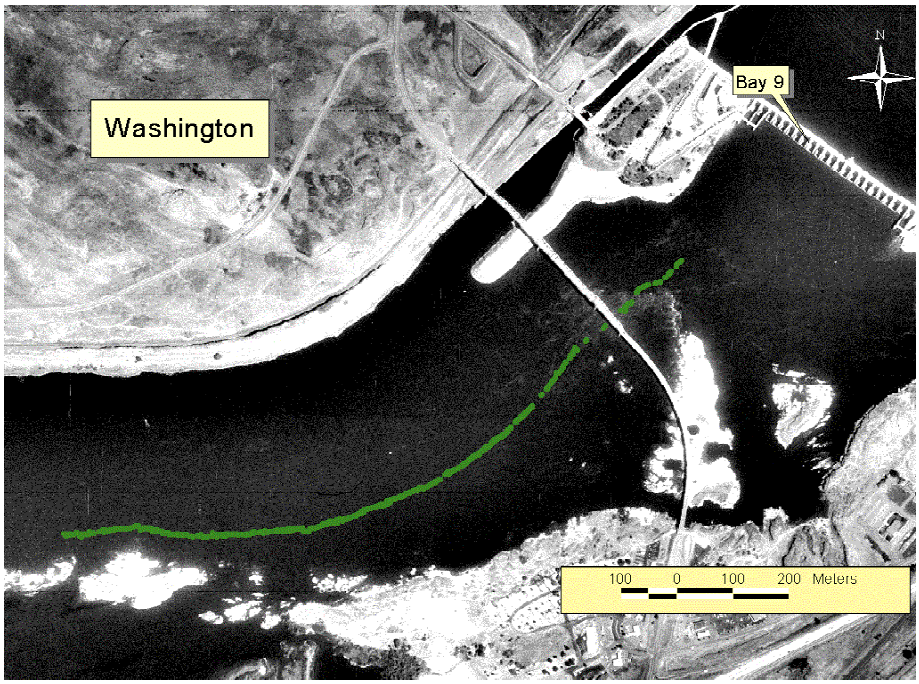
Date	Location	Deployment Time	Time to Bridge	Time to Exit	Total Discharge (kcfs)	Total Spill (kcfs)
5/21/2001	Spill Bay 9	12:08:52	00:07:21		155.7	46.0
5/21/2001	Spill Bay 9	12:33:57	00:03:51	00:36:18	154.8	46.0
*5/21/2001	Spill Bay 9	12:54:41	00:03:29	00:41:42	154.8	46.0
5/21/2001	Spill Bay 9	13:20:37	00:06:14		143.9	43.0
5/21/2001	Spill Bay 9	13:51:58	00:14:36		143.9	43.0
*5/23/2001	Spill Bay 13	15:12:00	00:11:38		179.2	69.0
5/23/2001	Spill Bay 13	15:24:36	01:01:25		180.5	69.0
*5/23/2001	Spill Bay 13	15:38:15	00:53:40		180.5	69.0
5/23/2001	Spill Bay 13	15:57:31	00:04:30	00:28:54	180.5	69.0
6/2/2001	Spill Bay 10	08:39:00			132.6	39.0
*6/2/2001	Spill Bay 10	08:52:29	00:06:50	01:20:28	132.6	39.0
6/2/2001	Spill Bay 10	09:02:22	00:05:09	00:38:19	132.4	39.0
6/2/2001	Spill Bay 10	09:18:41	00:11:09	00:17:49	132.4	39.0
6/2/2001	Spill Bay 10	09:40:32			133.5	39.0
6/2/2001	Spill Bay 10	11:32:21	00:04:39	00:41:39	130.3	39.0
6/2/2001	Spill Bay 10	11:48:11	00:05:35		130.3	39.0
6/2/2001	Spill Bay 10	12:01:05			130.0	39.0
6/2/2001	Spill Bay 10	12:17:21			130.1	39.0
6/2/2001	Spill Bay 10	12:27:28	00:06:12	00:36:59	130.0	39.0

* No GPS data available.

Appendix A5. Paths of GPS-equipped drogues at The Dalles Dam spillway from 21 May to 2 June 2001. Appendix A4 lists total and spill discharge for each drogue depicted. Drogues without GPS data are not presented. Background photo does not represent dam operating conditions during the study.



Release Date / Time: 05/21/01 12:08:52
Release Site: Spill bay 09



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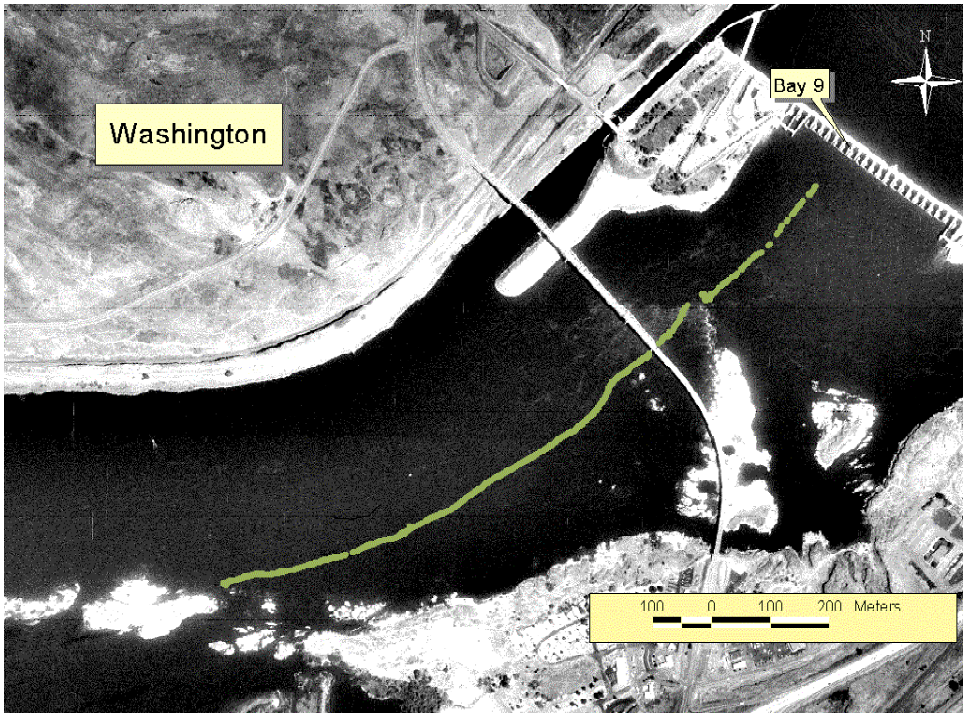
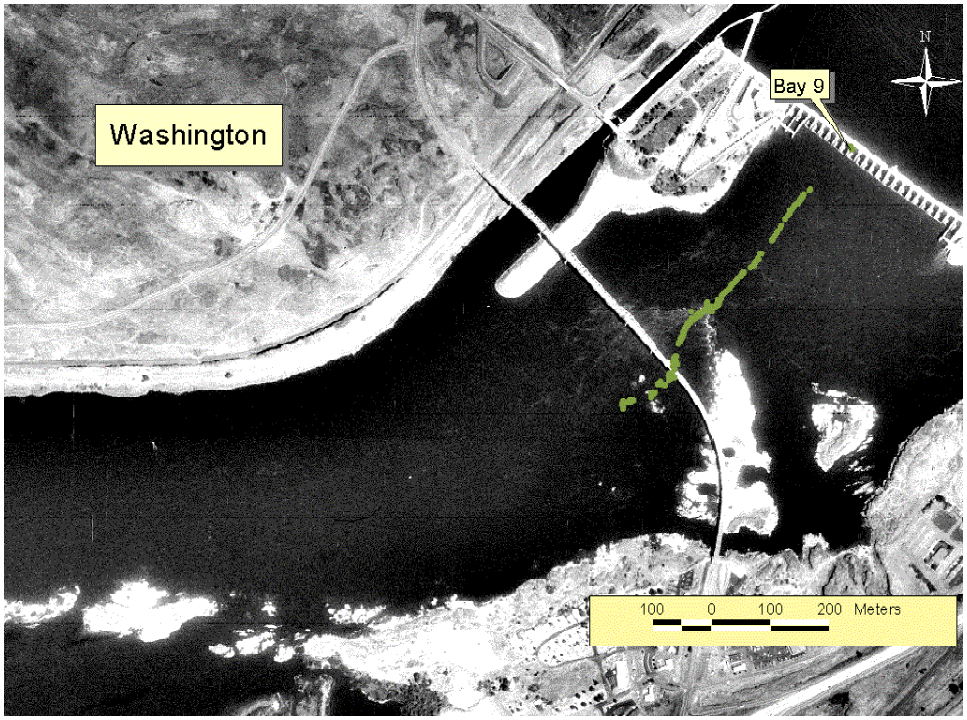
Release Site: Spill bay 9

Appendix A5 continued.

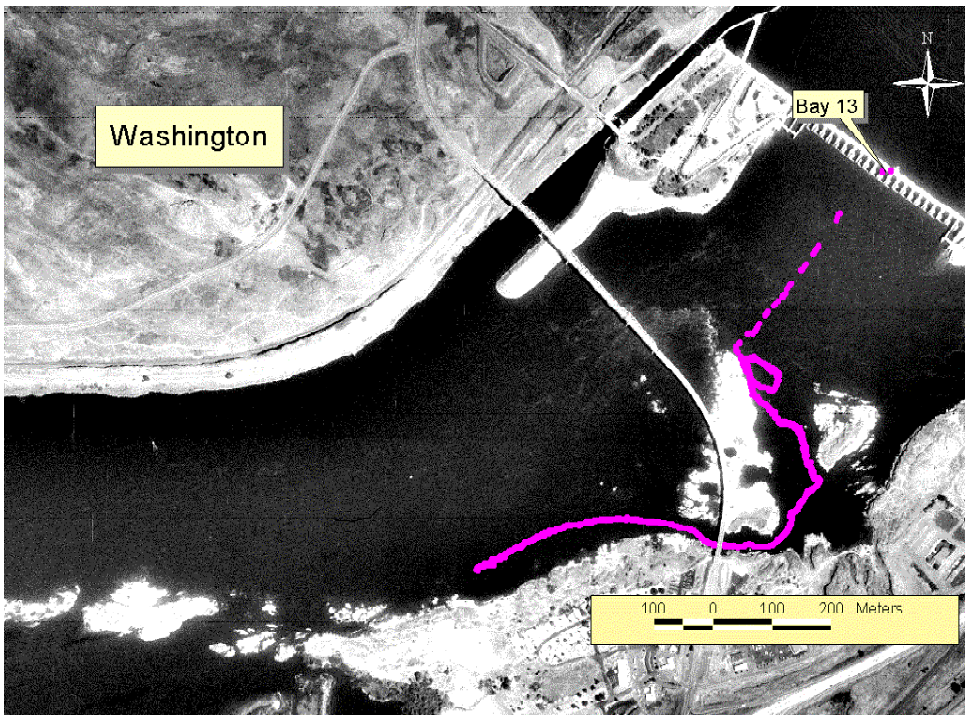


Release Date / Time: 5/21/01 13:20:37
Release Site: Spill bay 9

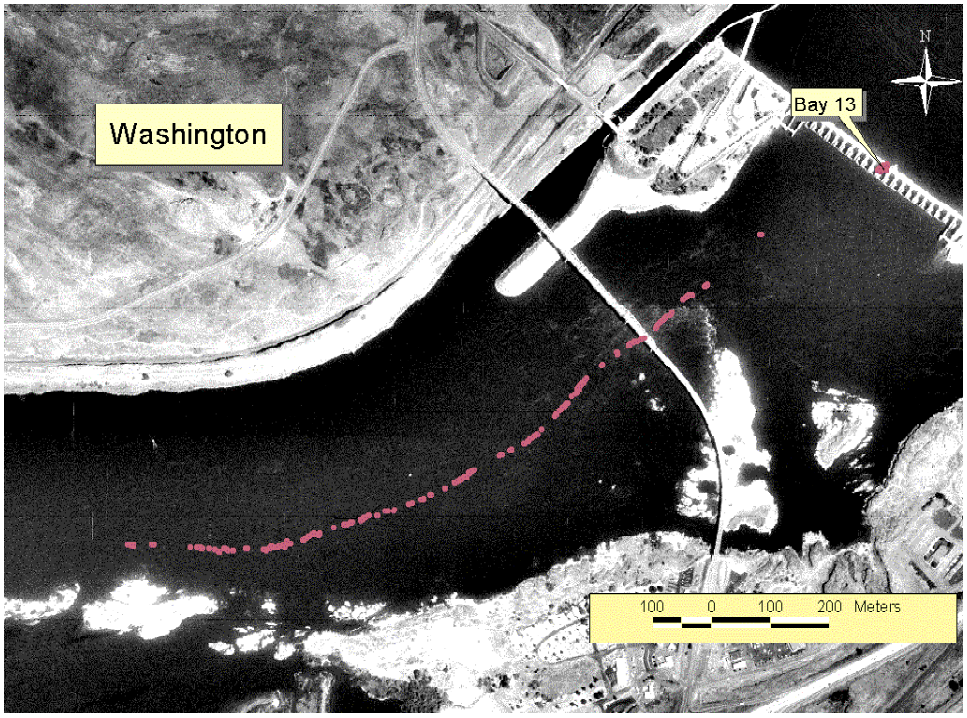


Release Date / Time: 5/21/01 13:51:58
Release Site: Spill bay 9

Appendix A5 continued.

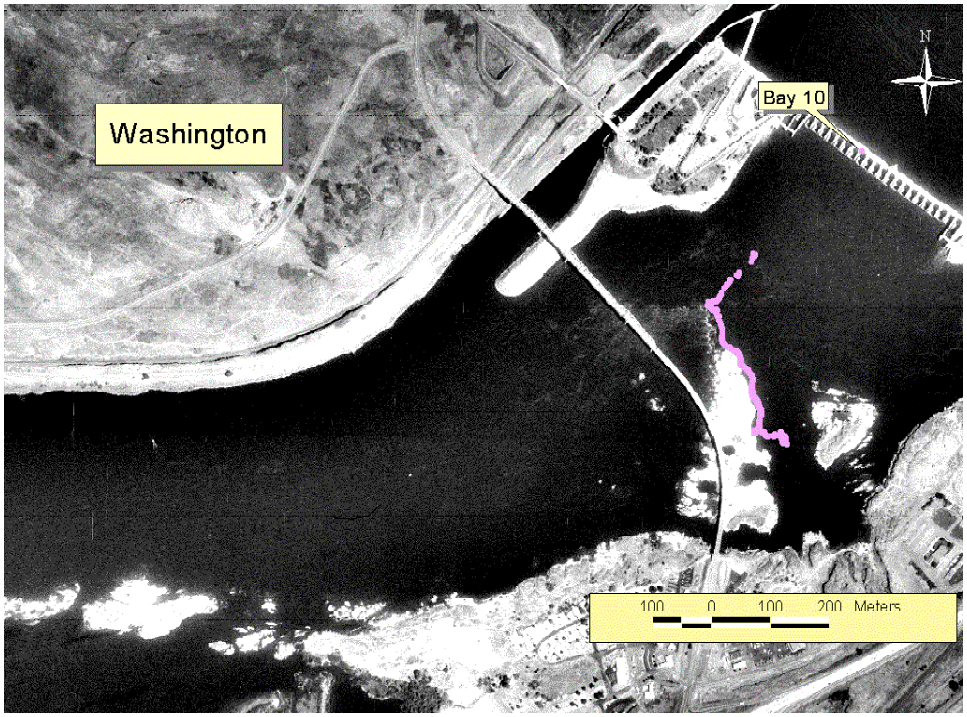


Release Date / Time: 5/23/03 15:24:36
Release Site: Spill bay 13

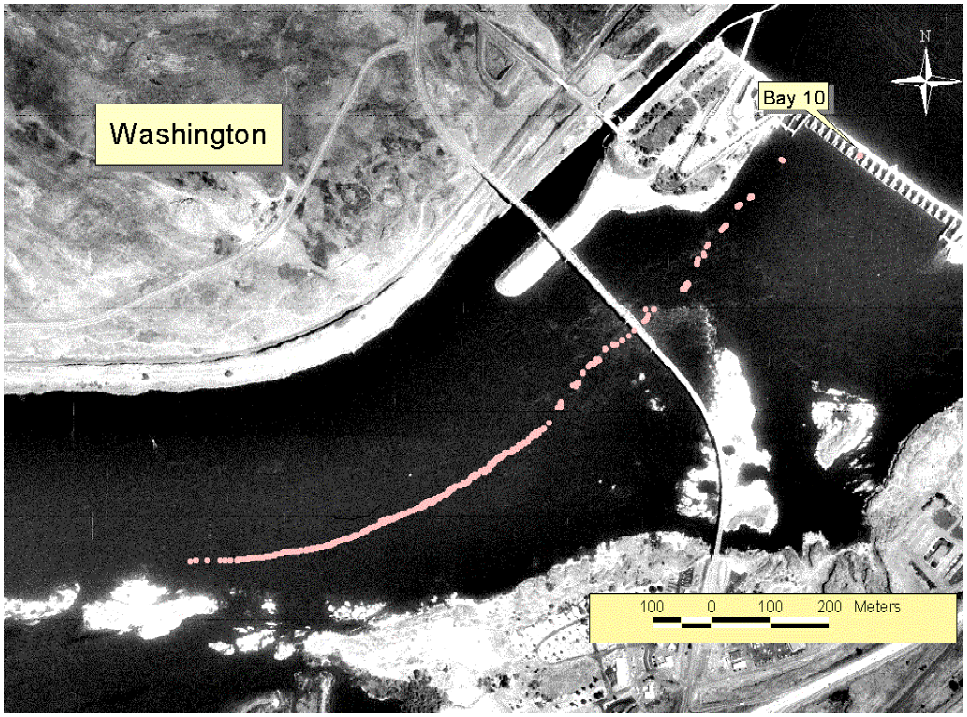


Release Date / Time: 5/23/03 15:57:31
Release Site: Spill bay 13

Appendix A5 continued.

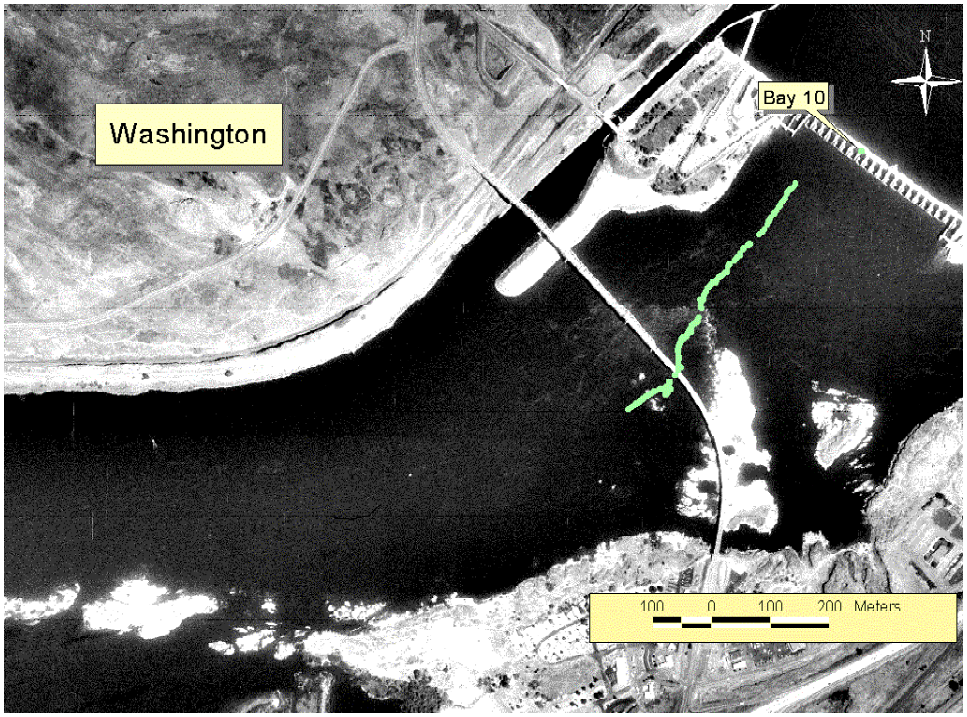


Release Date / Time: 6/2/01 08:39:00
Release Site: Spill bay10



Release Date / Time: 6/2/01 09:02:22
Release Site: Spill bay10

Appendix A5 continued.



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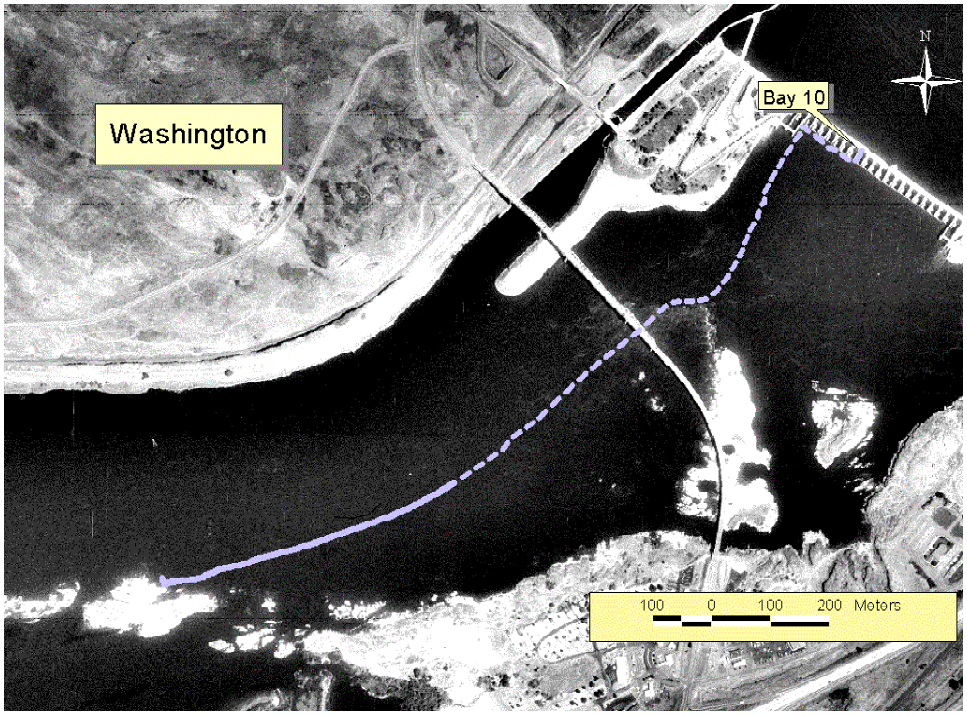
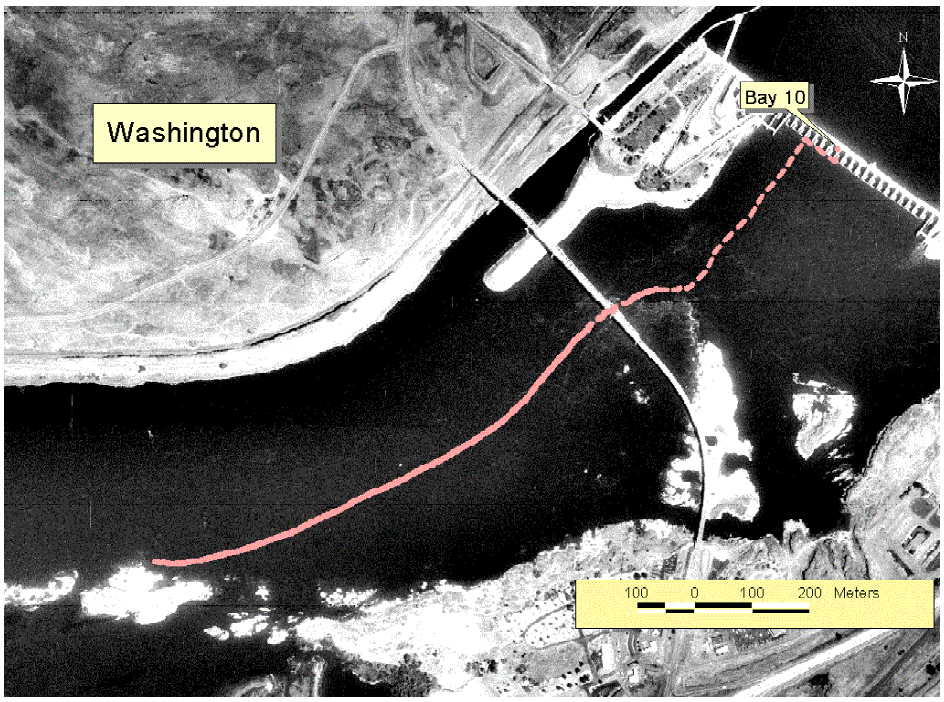


Release Date / Time: 6/2/01 09:40:32
Release Site: Spill bay10
*The dashed line represents visual observation supplemented for missing GPS data.

Appendix A5 continued.



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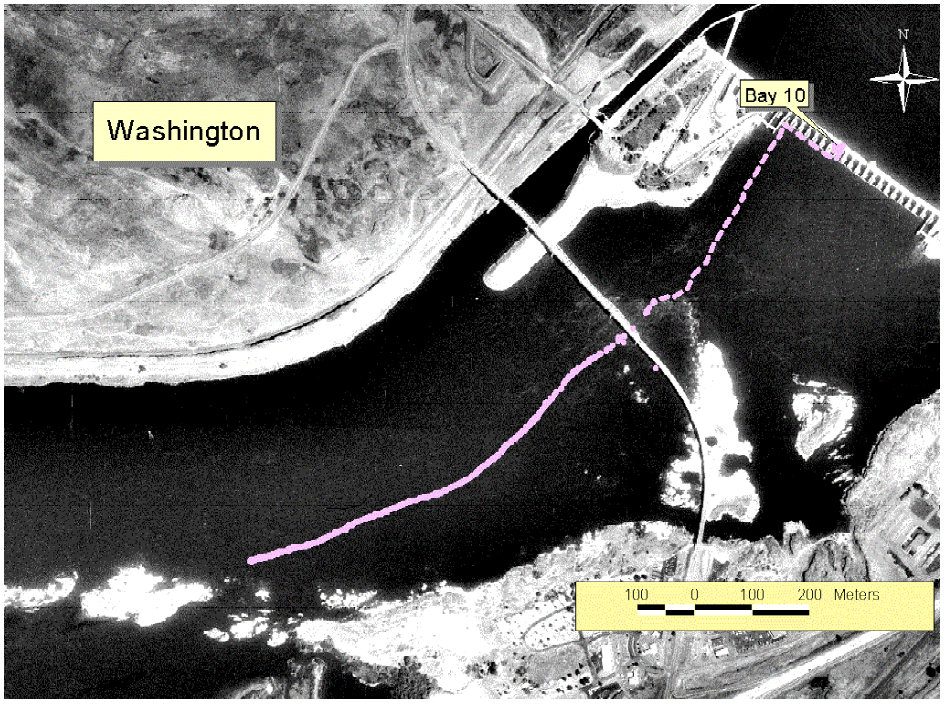
Release Site: Spill bay10
*The dashed line represents visual observation supplemented for missing GPS data.



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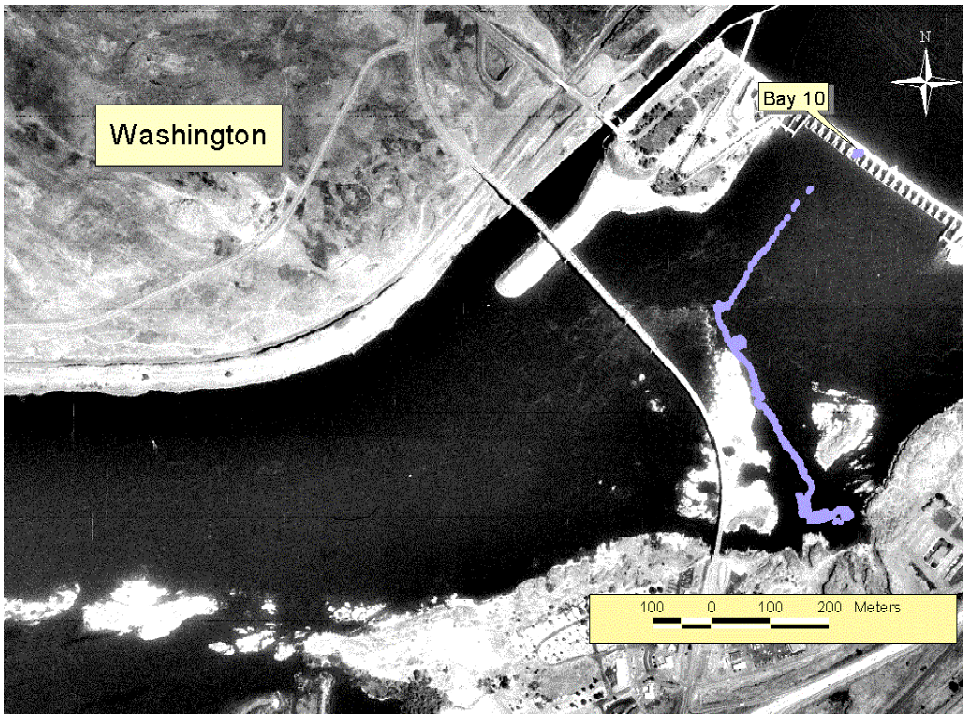
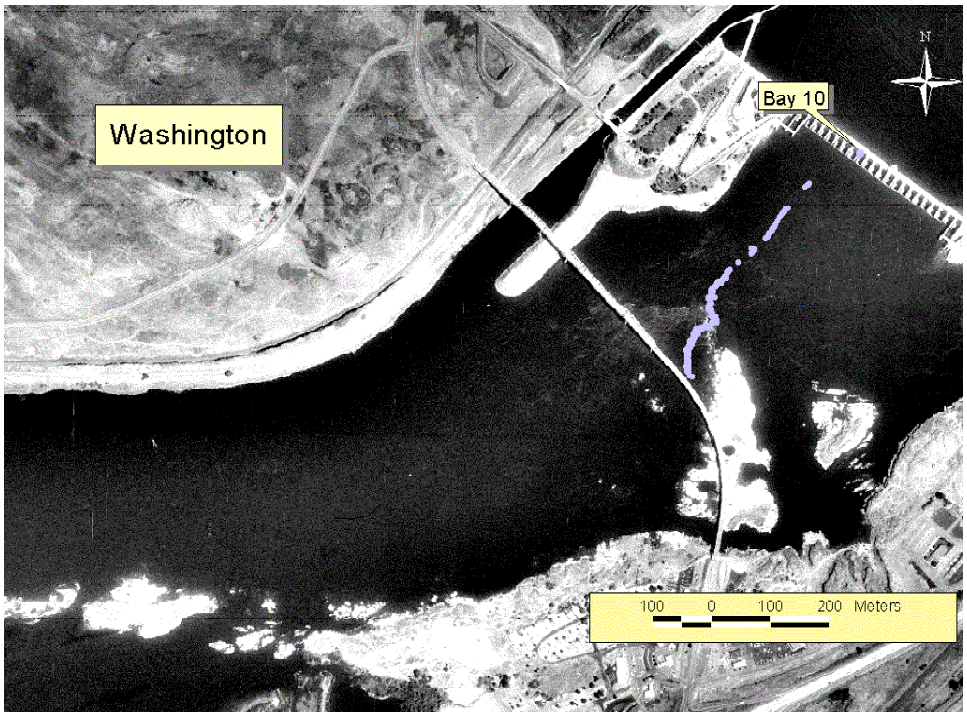
*The dashed line represents visual observation supplemented for missing GPS data.

Appendix A5 continued.

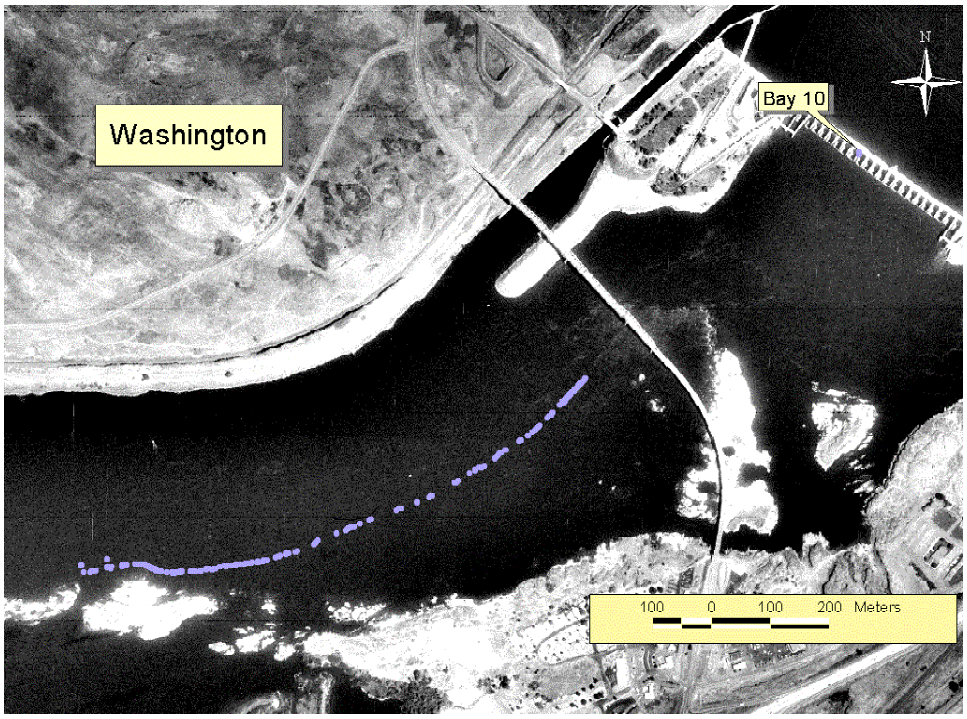


Release Date / Time: 6/2/01 12:01:05
Release Site: Spill bay10



Release Date / Time: 6/2/01 12:17:21
Release Site: Spill bay10

Appendix A5 continued.



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