SUMMARY REPORT

Adult Fishway Water Temperatures

At Bonneville, The Dalles, and John Day Dams

1994 - 1998

by

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Executive Summary

USACOE Fisheries Field Unit personnel monitored water temperatures and surveyed the forebays, fish ladders, and tailraces at various depths for temperature differences in the adult fish ladders at Bonneville, The Dalles, and John Day dams from 1994 through 1998. During the five years of monitoring, water temperatures were 20 °C or higher 28 to 75 days a year at Bonneville Dam, 51 to 82 days a year at The Dalles Dam, and 65 to 92 days a year at John Day Dam. Because no temperature differences were found in fish ladders at Bonneville and The Dalles dams fish ladders in 1994 through 1996, only one location in each ladder was monitored there in 1997 and 1998. At John Day Dam temperature differences within the fishways equal to or greater than 0.28 °C were found each year. Above John Day Dam, beginning in 1996, the Columbia and John Day river temperatures were surveyed to locate sources of the warm water flows that cause temperature differences in the John Day Dam fish ladders. Warm water flowing from the John Day River appears to flow to the south end of the John Day Dam forebay and into the John Day Dam south ladder. This surface water flows into the south ladder exit and mixes with auxiliary water added at two areas in the ladder. This auxiliary water is pulled from depth, which tends to be cooler, and this appears to be causing the temperature differences in the ladder there. Surface warming of the forebay above the John Day Dam north ladder exit could account for the temperature differences that occur in the north ladder.

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Introduction

The Corps of Engineers began monitoring hourly water temperatures within the fish ladders at the three lower Columbia River Corps projects (John Day, The Dalles, and Bonneville dams) in the 1994 fish passage season and continued monitoring through the end of the 1998 fish passage season. The monitoring was in response to NMFS Biological Opinion Incidental Take Statement 18 that the water temperature of the adult fishway systems be monitored and evaluated (NMFS 1994).

At each of the dams, one of the goals of the temperature monitoring program was to determine when temperatures were present that may interfere with fish passage (20 °C and higher). The upper end of the optimal migration range for summer chinook has been put at 20 °C (Bell, 1991). A second goal of the monitoring was to determine whether or not there were temperature differences in and around the adult ladder systems that may interfere with fish passage. Bell (1991) has stated that fish are capable of sensing a temperature differential of less than 0.28 °C. A third goal of the monitoring was adopted in 1996. After temperature differences were discovered in the John Day Dam fish ladders, we positioned temperature probes at locations and depths above John Day dam so that we could attempt to determine the source of the temperature differences seen in the ladders.

Methods

Data logger/temperature probe systems (16 in 1994, 27 in 1995, 47 in 1996, 30 in 1997, and 40 in 1998) were used for monitoring fishway, forebay, John Day River, and Columbia River temperatures. The data loggers were battery-powered, automatic data-gathering units capable of gathering data at remote unmanned locations. The temperature probes were accuracy rated at ± 0.2 °C and long-range stability rated at ± 0.15 °C. The actual working accuracy of the probes was within ± 0.10 (post-season calibration is explained in Appendix A).

The data loggers were set to store water temperature information in a buffer every 15 seconds and log the average of 240 temperatures, providing a temperature average for each hour of each day throughout the monitoring period each year, which was from March through November. The data loggers were typically downloaded once a week or once every two weeks. However, a few remote sites were downloaded only once every several months. We downloaded as often as practical; both to supply up-to-date temperature information to the projects and to check for problems with the data logger/temperature probe systems.

A written description of where and when temperature probes were used can be found in Appendix B.

Results

Bonneville Dam

At Bonneville Dam in 1994, we monitored temperatures in the Bradford Island ladder at the counting station, in the B-branch entrance area, and in the powerhouse 1 collection channel. In 1995 we began monitoring at the ends of the Bradford Island ladder in the forebay above the ladder exit and in the tailrace below the collection channel. In 1996, these five locations were monitored and the powerhouse 1 forebay was monitored at three depths. No temperature differences ≥ 0.28 °C were present between contiguous temperature probes in the ladder or between contiguous temperature probes in the forebay. No temperature differences ≥ 0.28 °C were present between the forebay and the tailrace at the ends of the Bradford Island ladder in the two years we monitored them. No temperature differences ≥ 0.28 °C were present between the shallowest forebay temperature probe and the deepest during the year we monitored forebay depths. Because we found no temperature differences in the comparisons we made these three years, we monitored temperatures at only one location in this ladder, at the counting station in 1997 and 1998.

At Bonneville Dam in 1994, we monitored temperatures in the Washington shore ladder at the counting station, in the powerhouse 2 collection channel, near the top of the Cascades Island ladder, and in the Cascades Island ladder entrance area. In 1995 we began monitoring at the ends of the Washington shore ladder in the forebay above the ladder exit and in the tailrace below the collection channel. In 1996, the powerhouse 2 collection channel was not monitored but the diffuser where water is added into the Washington shore ladder at the Adult Collection and Monitoring Facility ladder exit was monitored. No temperature differences ≥ 0.28 °C were present between contiguous temperature probes in this ladder system these three years. Only a few hours of temperature differences ≥ 0.28 °C were present at the ends of the Washington shore ladder after we began monitoring them in 1995. For 2 of 4642 hours in 1995 the Cascades Island ladder entrance area was 0.28 °C and 0.29 °C higher than the powerhouse 2 forebay. For 2 of 6010 hours in 1996, the powerhouse 2 forebay was 0.29 °C and 0.31 °C higher than the Cascades Island ladder entrance area. Because we found only these few hours of temperature differences in the comparisons we made these three years, in 1997 and 1998 we monitored temperatures at only one location in this ladder, which was at the counting station.

The Bonneville Dam temperature highs and the numbers of hours ladder temperatures reached or exceeded 20.0 °C are shown in Table 1. In Appendix C, the dates temperatures reached or exceeded 20.0 °C are shown.

Table 1: Water temperature highs and numbers of days and hours water temperatures were 20 °C or higher in the Bonneville Dam fish ladders during the study years, 1994 through 1998.

Year	*High*	*20 °C or Higher*
1994	22.4 °C on July 23	on 33 days for 685 hours
1995	21.8 °C on August 5	on 28 days for 839 hours
1996	21.1 °C on August 10-11	on 40 days for 811 hours
1997	21.9 °C on August 13-14	on 49 days for 1135 hours
1998	23.4 °C on August 14	on 75 days for 1766 hours

Figure 1 is a chart of the daily average temperatures, 1994 through 1998, at Bonneville Dam.

The Dalles Dam

In 1994, we monitored temperatures at the counting station and in the entrance area in the east ladder at The Dalles Dam. In 1995, two additional locations in the east ladder were monitored. These were the forebay above the ladder exit and the tailrace below the entrance area. In 1996, these four locations were monitored and the forebay was monitored at two deeper locations. No temperature differences ≥ 0.28 °C between contiguous temperature probes were present in the ladder or in the forebay these years. No temperature differences ≥ 0.28 °C were present between the forebay and the tailrace at the ends of the east ladder in 1995. A temperature difference of 0.30 °C was present between the ends of the east ladder for 1 of 6600 hours in 1996. No temperature differences ≥ 0.28 °C were present between the shallowest forebay temperature probe and the deepest during the year we monitored forebay depths. Because we found no temperature differences in the comparisons we made these three years, in 1997 and 1998 temperatures were monitored at one location in the ladder, which was at the counting station.

In 1994, we monitored temperatures at the counting station and in the entrance area in the north ladder at The Dalles Dam. In 1995, two additional locations in the north ladder were monitored. These were the forebay above the ladder exit and the tailrace below the entrance area. In 1996, these four locations were monitored, as were locations at the uppermost diffuser pool of the lower ladder diffusers and the tailrace portion of the navigation lock channel. No temperature differences ≥ 0.28 °C between contiguous temperature probes were present in the ladder these years. Temperature differences ≥ 0.28 °C were present between the forebay and tailrace ends of the north ladder 6 of 2484 hours in 1995. Four times the tailrace temperature rounded to just over 0.28 °C higher than the forebay temperature in the early morning hours. Twice the forebay temperature rounded to just over 0.28 °C higher than the tailrace temperature during midday hours. We were unable to determine whether or not there were temperature differences at the ends of north ladder in 1996 because the tailrace temperature probe became unstable and failed early in the 1996 monitoring year. Because we found only a few hours of temperature differences in the comparisons we made these three years, in 1997 and 1998 temperatures were monitored at one location in the ladder, which was at the counting station.

The Dalles Dam temperature highs and numbers of hours ladder temperatures reached or exceeded 20.0 °C are shown in Table 2. In Appendix C, the dates temperatures reached or exceeded 20.0 °C are shown.

Table 2: Water temperature highs and numbers of days and hours water temperatures were 20 °C or higher in The Dalles Dam fish ladders during the study years, 1994 through 1998.

Year	*High*	*20 °C or Higher*
1994	22.3 °C on July 28	on 76 days for 1734 hours
1995	22.0 °C on August 4	on 74 days for 1510 hours
1996	21.1 °C on Aug 13, 23, 29	on 51 days for 1034 hours
1997	22.1 °C on August 12	on 52 days for 1199 hours
1998	23.7 °C on August 13	on 82 days for 1947 hours

Figure 2 is a chart of the daily average temperatures, 1994 through 1998, at The Dalles Dam.

John Day Dam South Ladder

In 1994, we monitored temperatures at the upper ladder diffuser pool and in the entrance area in the south ladder at John Day Dam. In 1995, three additional locations in the south ladder were monitored. These were the forebay above the ladder exit, the mid-ladder area at the 180° bend, and the tailrace below the entrance area. In 1996, these five locations were monitored, as were locations just above and just below the upper ladder diffuser pool, below the counting station, at the uppermost diffuser pool of the lower ladder diffusers, and the forebay was monitored at two deeper locations. As we came to understand where temperature differences were located in the south ladder, we dropped redundant temperature probes. In 1997, the temperature probes in the upper ladder diffuser pool, and below the counting station were dropped. In 1998, the temperature probes in the mid-ladder area and at the uppermost diffuser pool of the lower ladder diffusers were dropped.

Table 3 shows the amount of time temperature differences were present in the south ladder. For 27.7% to 36.5% of the time during the study years of 1994 through 1998, the temperature of the water at ladder locations in the south ladder above the lower ladder diffusers was 0.28 °C or more higher than the temperature of the water in entrance and tailrace areas.

Table 3: The percentages of hours temperature differences (0.28 °C or greater) were present in the John Day Dam south ladder during the study years, 1994 through 1998, the highest temperature differences, and the averages of the temperature differences during hours when temperature differences were present.

Year	*Start*	*End*	*% of Hours*	*Higher by*	*Average*
1994	Jun 11	Nov 30	34.3%	up to 3.22 °C	0.56 °C
1995	Mar 1	Oct 31	27.7%	up to 3.22 °C	0.89 °C
1996	Mar 15	Nov 30	36.5%	up to 3.56 °C	0.92 °C
1997	Mar 1	Nov 30	31.6%	up to 3.06 °C	0.68 °C
1998	Mar 1	Nov 30	32.8%	up to 4.04 °C	0.91 °C

Warmer water in the upper areas of the south ladder was present from mid-March to around the end of September, which was when the region was warming up in the spring and during the warm months of summer (Figure 3). The weather in the John Day region is characterized by wide differences in daytime and nighttime temperatures, with warm days and cool nights. Like the weather, temperature differences in the south ladder were much greater during mid-day and afternoon hours (Figure 4).

In 1996, 1997, and 1998, we monitored the temperature of the water above and below the upper ladder diffuser in the south ladder. During the hours when the average temperature in the upper ladder areas was 0.28 °C or more warmer than water temperature in the entrance and tailrace areas, the water above the upper ladder diffuser was occasionally 0.28 °C or more warmer than the water in the middle of the ladder. This condition was present 6.3% (396 of 6264 hours monitored) of the time in 1996, 4.2% (275 of 6600 hours monitored) of the time in 1997, and 11.5% (756 of 6600 hours monitored) of the time in 1998.

Figure 5 is a chart of the daily average temperatures, 1994 through 1998, in the south ladder at John Day Dam (entrance/tailrace areas and upper ladder areas shown separately).

Each year, March through November, the water temperature in the entrance and tailrace areas of the south ladder was higher than the water temperature in the entrance and tailrace areas of the north ladder some of the time (up to 10.3% of the hours), by up to 0.61 °C. The water temperature in the entrance and tailrace areas of the north ladder was higher than the water temperature in the entrance and tailrace areas of the south ladder some of the time (up to 9.0% of the time), by up to 1.24 °C.

John Day Dam North Ladder

In 1994, we monitored temperatures at the count station and in the entrance area in the north ladder at John Day Dam. In 1995, two additional locations were monitored. These were the forebay above the ladder exit and the tailrace below the entrance area. In 1996, these four locations were monitored, as were the highest diffuser pool of the lower ladder diffusers and the tailrace portion of the navigation lock channel. As we came to understand where temperature differences were located in the north ladder we dropped redundant temperature probes. In 1997, the forebay was monitored at two deeper locations, and the temperature probes in the tailrace and the tailrace portion of the navigation lock channel were dropped. In 1998, the temperature probe at the highest diffuser pool of the lower ladder diffusers was dropped.

Table 4 shows the amount of time temperature differences were present in the north ladder. For 5.2% to 9.9% of the time during the study years of 1994 through 1998, the temperature of the water at ladder locations above the lower ladder diffusers was 0.28 °C or more higher than the temperature of the water in entrance and tailrace areas.

Table 4: The percentages of hours temperature differences (0.28 °C or greater) were present in the John Day Dam north ladder during the study years, 1994 through 1998, highest temperature differences, and the averages of the temperature differences during hours when temperature differences were present.

Year	*Start*	*End*	*% of Hours*	*Higher by*	*Average*
1994	Jun 11	Nov 30	5.3%	up to 1.00 °C	0.44 °C
1995	Mar 1	Oct 31	9.9%	up to 2.83 °C	0.72 °C
1996	Mar 1	Nov 30	5.2%	up to 1.89 °C	0.54 °C
1997	Mar 1	Nov 30	5.5%	up to 1.50 °C	0.49 °C
1998	Mar 1	Nov 30	8.6%	up to 2.59 °C	0.66 °C

As in the south ladder, warmer water in the upper ladder areas of the north ladder was present from mid-March to around the end of September. These differences, however, were minor compared to the presence of warmer water in the south ladder. Like the south ladder, the presence of warmer water in the upper ladder areas of the north ladder increased during the day and subsided at night, but again, only weakly.

Figure 6 is a chart of the daily average temperatures, 1994 through 1998, in the north ladder at John Day Dam (entrance/tailrace areas and upper ladder areas shown separately).

In contrast to the south ladder, water temperatures in the lower ladder area of the north ladder are frequently higher than water temperatures in the upper ladder areas, overall about 85 to 90 percent of the time. During the warmest water temperature months (July, August, and September), when the forebay temperatures are the highest, north ladder entrance area temperatures are warmer than upper ladder temperatures about 65% of the time. In contrast, in the south ladder, entrance area temperatures are warmer than upper ladder temperatures only about 20% of the time in July, August, and September. For three months in 1996 we had a temperature probe in-service in the tailrace entrance channel of the navigation lock channel, where water is pumped to the entrance area of the north ladder via the diffuser supply system. Temperatures in the navigation channel closely matched north ladder entrance temperatures and averaged slightly higher than the forebay temperatures above the north ladder.

High Water Temperatures

John Day Dam ladder water temperature highs and the numbers of hours these temperatures reached or exceeded 20.0 °C are shown in Table 5. In Appendix C, the dates temperatures reached or exceeded 20.0 °C are shown.

Table 5: Water temperature highs and numbers of days and hours water temperatures were 20 °C or higher in the John Day Dam fish ladders during the study years, 1994 through 1998.

Year	*High*	*20 °C or Higher*
1994	23.5 on July 21	on 87 days for 1965 hours
1995	23.5 on July 17	on 82 days for 1709 hours
1996	23.6 on August 9	on 65 days for 1281 hours
1997	23.8 °C on August 11	on 67 days for 1293 hours
1998	25.5 °C on August 4	on 92 days for 2054 hours

Figures 7 through 11 are charts of the John Day Dam upper ladder temperatures compared to the John Day Dam entrance and tailrace temperatures, The Dalles Dam temperatures, and Bonneville Dam temperatures. These charts show only days when the daily average temperatures somewhere in the ladders were at 20 °C or higher. Times at John Day Dam when water temperatures were 20 °C or higher typically started and ended in the John Day Dam south upper ladder.

John Day Dam, Forebay

In 1996 and 1997, we monitored the John Day Dam forebay water temperature at the south ladder exit at elevations 256, 242, and 228 feet mean sea level (msl). In 1998, we monitored the John Day Dam forebay water temperature at the south ladder exit at elevations 256, 211, and 194 feet msl (we lost our probes at 242 and 228 in 1998 and we were unsuccessful at collecting temperature data at 177). Table 6 shows the percentages of time the forebay temperatures were the same as (within 0.28 °C) or cooler than the south ladder entrance and tailrace temperatures these years.

Table 6: Percentages of time the forebay temperatures were the same as (within 0.28 °C) or cooler than the south ladder entrance and tailrace temperatures in 1996, 1997, and 1998.

	el. 256	el. 242	el. 228	el. 211	el. 194
March	79-89	92-99	92-100		
April	52-78	83-84	85-93*		
May	54-76	77-78	84-94		
June	53-77	79-91	93-94	98*	100*
July	30-64	56-79	69-82	78	97*
August	52-64	65-74	69-85	96	100
September	70-81	90-94	92-99	96	99
October	90-97	98	97-100	100	100
November	98-100	99-100	100	100	100

* The forebay temperature at elevation 228 feet msl was more than 0.28 °C cooler than entrance and tailrace temperatures 2% of the time in April 1996. The forebay temperature at elevation 211 feet msl was more than 0.28 °C cooler than entrance and tailrace temperatures 6% of the time in June 1998. The forebay temperature at elevation 194 feet mean sea level was more than 0.28 °C cooler than entrance and tailrace temperatures 10% of the time in June 1998 and 12% of the time in July 1998.

In 1998, we monitored the John Day Dam forebay water temperature at elevation 256 feet mean sea level in the following locations: the south ladder exit, turbine 1, between turbines 3 and 4, between turbines 8 and 9, between turbines 13 and 14, turbine 18, and the north ladder exit (Table 7). During hours when temperature differences were present in the south ladder warmer forebay water can be seen halfway across the forebay face of the powerhouse.

Table 7: Monthly average forebay water temperatures (°C) at the south ladder exit, turbine 1, between turbines 3 and 4, between turbines 8 and 9, between turbines 13 and 14, turbine 18, and the north ladder exit in July through October 1998.

	s. exit	t1	t3/t4	t8/t9	t13/t14	t18	n. exit

Jul	21.8	21.7	21.6	21.3	21.0	21.0	21.2
Aug	23.4	23.4	23.3	23.1	22.9	22.8	23.0
Sep	22.5	22.4	22.3	22.1	21.9	21.9	22.0
Oct	17.6	17.6	17.4	17.4	17.2	17.2	17.3

John Day Dam Reservoir and John Day River

Day to day stream flow in the John Day River, which empties into the Columbia River 1.8 miles above the dam, varies widely (Figure 12) due to the weather in the John Day River basin. Day-to-day John Day River temperatures also vary widely.

In 1996 through 1998, we monitored the water temperatures in the mouth of the John Day River at LePage Park (Figures 13 through 15). LePage Park is located on the west side of the mouth of the John Day River, only a few hundred yards from where the John Day River joins the Columbia River. We found that the water temperature of the John Day River at LePage Park was much higher than the temperature of the water in the south upper ladder from March through mid-July. In 1997 (Figure 14) we monitored the temperature of the water in the John Day River at Phillipi Park. Phillipi Park is located about four miles up the John Day River, very near to where the free flowing river meets the reservoir. We found that the water temperature at LePage Park was much cooler than at Phillipi Park to the end of September. In 1998 we conducted transects of the forebay during June, July, August, and September, starting within the mouth of the John Day River at LePage Park and then going back and forth across the Columbia River to John Day Dam (Figures 16 through 19). We found that a plume of warm water flows directly out of the mouth of the John Day River more than halfway across the Columbia River and a stream of warm water flows from the mouth of the John Day River along the Oregon shore of the Columbia to the south end of John Day Dam. Although the water temperature of the John Day River cools rapidly as it combines with Columbia River water, the cooling seems to slow as the temperatures near equilibrium, enough so that warm water can be seen along the Columbia's south shore line, all the way to the dam.

The water temperature of the John Day River at LePage Park closely matched the temperature of the water in the south upper ladder from mid-July through the end of September ($r = .83$ in 1996, $r = .76$ in 1997, and $r = .82$ in 1998). Water from the John Day River appears to be the primary source of the warmer water in the south upper ladder this time of the year. In 1997 we monitored the water temperature in the main flow of the Columbia River from a buoy approximately 1.5 miles above the mouth of the John Day River. The correlation between the buoy temperature and the south upper ladder temperature, mid-July through the end of September, at $r = .53$, was weaker than the LePage Park/south upper ladder relationship.

In October and November, the water temperature in the Columbia River was the same as the water temperature in the south upper ladder (using a temperature probe at a buoy located in the Columbia River approximately 1.5 miles above the mouth of the John Day River). Figures 13, 14, and 15 all show the water temperature in the mouth of the

John Day River at LePage Park as almost always cooler than Columbia River or south upper ladder temperatures in October and November. According to limnologists, a flow of cooler water entering a body of warmer water tends to descend down into the warmer water. Therefore, in the reservoir above John Day Dam, John Day River water should not be at the surface in October and November. Consistent with the idea that the water from the John Day River is the primary source of the warmer water in the south upper ladder, temperature differences between the upper and lower portions of the south ladder are rare in October and November each year.

Discussion

Water temperatures higher than the upper end of the optimal migration range for salmon (20 °C) are present in the Columbia River in July, August, and September each year. Whether or not these river water temperatures are high enough to threaten salmon runs is unknown.

Migrating salmon do not encounter temperature differences in the fish ladders at Bonneville and The Dalles dams. Migrating salmon, which are capable of detecting temperature differences of as little as 0.28 °C, encounter slightly warmer water at the bases of the overflow portions of the fish ladders at John Day Dam from mid-March through September each year. Water temperatures at the surface in the John Day Dam forebay are often warmer than water temperatures in the John Day Dam tailrace, especially at the south end of the forebay where John Day River water collects and flows into the south fish ladder. The water temperature at approximately 50 feet below the surface of the forebay at the south ladder exit (at elevation 211 feet mean sea level) is probably most equivalent to south ladder entrance and tailrace temperatures. The impact of temperature differences in the John Day Dam fish ladders on the migrating adult salmonids is unknown.

Careful study of the radio tracking data currently being collected at Bonneville, The Dalles, and John Day dams by University of Idaho researchers has the potential to help clarify the possible impacts on salmon runs of these two temperature parameters, high summertime water temperatures in the Columbia River and fish detectable temperature differences in the John Day Dam fish ladders.

Recommendations

1. We recommend further examination of both ladder fish counts and radio tracking data being collected at John Day Dam in order to determine if the temperature differences observed in the John Day Dam ladders are affecting fish passage.
2. If uniform temperatures in the John Day Dam ladders are desired, then we recommend the evaluation and development of ways to supply cooler water to the upper ladder sections of the John Day Dam ladders. For example, cooler water could be supplied by pumping it up from deeper in the forebay to the ladder exit and the upper ladder diffuser.
3. To continue to assess the temperatures of the water in the fish ladders, as well as the temperatures along the routes fish travel in the Columbia River and its tributaries, we recommend extending temperature monitoring to other Corps projects beyond Bonneville, The Dalles and John Day dams. By monitoring the temperatures of the water as far up the Columbia River as Chief Joseph Dam, monitoring the temperatures of the water at the four Snake River Corps projects, and monitoring water temperatures below Bonneville, we could provide a full river system temperature profile.

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Appendix A

In December each year, we gathered all of our temperature probes for calibration testing. At the end of 1994, none of the probes (0 of 16) failed testing. At the end of 1995, 7% of the probes (2 of 27) failed testing. At the end of 1996, 4% of the probes (2 of 47) failed testing. At the end of 1997, 17% of the probes (5 of 30) failed testing. At the end of 1998, 20% of the probes (8 of 40) failed testing. Our experience with the temperature probes and conversations with our probe vender led us to the following conclusions about the temperature probes that we used. The temperature probes failed calibration testing because water leaks sometimes developed at the seal between the probe and its connecting wire or in the wire itself. When water leaks were present, probe readings were too high. The temperature probes also failed calibration testing because of corrosion in the connecting wires. When corrosion was present, probe readings were too low. Probes deeper in the water were prone to water leaks. Probe systems with exposed wiring (array probes that have three probes wired into one data logger) were prone to corrosion. Longer wires with splices in them were prone to both water leaks and corrosion.

We made minor changes to the calibration test we did each year, but the basic procedure was always the same. We tested for calibration by comparing individual temperature probes against all the others. The data loggers, which read and recorded the probe temperatures, were programmed to a compressed sampling schedule, usually to read one temperature sample every five seconds and to record the average of the readings once every five minutes. The probes were put in a five-gallon bucket of ice water for one to five days. We let the ice in the bucket melt, which allowed the water in the bucket to warm from temperatures near 0 °C to room temperatures of around 19 °C. This procedure allowed us to compare the probes at nearly the full range of temperatures found in the field.

From the calibration test data, bad temperature probes were found in two steps. First, each probe’s temperature readings were compared to the average and standard deviation of all the other probes. We defined the accuracy of a temperature probe’s readings as its average compared to the average of all the other probes. We defined the stability of a temperature probe’s readings as the standard deviation of the probe’s readings. The user’s manual for the temperature probes describe the probes as having an accuracy range of $\pm$ 0.2 °C and a stability range of $\pm$ 0.15 °C.

At the start of the second step, probes that were reading either high or low and probes that had a high standard deviation were separated from the others then the 5-minute temperature averages of the remaining good probes were recomputed. The suspect probe readings were then compared to the average readings of the remaining good probes. Probes that read 0.2 °C higher or lower than the average of remaining good probes and probes that had a standard deviation of 0.15 °C or more were declared bad and eliminated. As a precautionary measure we also removed from service probes that read

0.1 °C higher or lower than the average of remaining good probes. We recommend the use of a finely graduated mercury thermometer to compare with probe readings to increase the accuracy of future calibration tests.

We experimented with stirring during calibration testing at the end of 1996 and 1997. Stirring the water in the bucket during calibration testing increased the accuracy of the probe temperature readings. In stirring tests at the end of 1996, we found that stirring reduced the variability between five minute temperature averages, from 0.01°C-0.09°C without stirring to 0.00°C-0.02°C with stirring. In the 1996 test, 95% of the five-minute temperature readings of each probe were within +/- 0.14°C of the mean temperature of the 40 other remaining good temperature probes and 99% of the temperature readings were within +/- 0.18°C of the mean temperature. We recommend the use of a mechanized stirrer to increase the precision of future calibration tests.

We also checked all temperature data for suspicious hourly temperature averages. For example, it appeared to us that people working around our probes pulled them out of the water on several occasions over the five years of the study. When this happened, it was easy to spot because the probe's temperature average for the hour would jump or drop dramatically. We also checked all temperature data for temperatures that drifted high because of water leaks into the probes or probe wires. When a leak developed it was usually, but not always, discovered during calibration testing. Suspicious hourly temperature averages were eliminated from each year's data sets.

Appendix B

What follows is a written description of where and when temperature probes were in-service in and around the fish ladders at Bonneville, The Dalles, and John Day dams. As a rule, we always tried to place temperature probes at least five feet below the water surface, to avoid direct sunlight warming the probes. Occasionally, very low tailwater levels or other circumstances brought probes closer to the water surface than we wanted.

Bradford Island Ladder System at Bonneville Dam

Years	*Area*	*Location*
1994-1998	Main stem	Below the count station on the east wall of the ladder, three weirs down from the highest weir in the ladder, where the controlling stillwell for the ladder's auxiliary water supply valve, FV3-9, is located.
1994-1996	B-branch entrance	Along the north wall of the entrance about 40 feet from the deep slot entrance that faces north.
1994-1996	Collection channel	At diffuser FG2-18, a closed diffuser gate located approximately three-quarters of the way along the collection channel toward the north end of the collection channel.
1995-1996	Forebay	About ten feet from the Bradford Island ladder exit, half way between the exit and the intake to the ladder's auxiliary water supply valve FV3-9.
1995-1996	Tailrace	At the bottom of a tailwater stillwell at entrance gate no. 52 in the powerhouse 1 collection channel.
1996	Forebay	Near the upper end of the old navigation lock, on the forebay side of the lock, at elevation 65 feet mean sea level.
1996	Forebay	Near the upper end of the old navigation lock, on the forebay side of the lock, at elevation 45 feet mean sea level.
1996	Forebay	Near the upper end of the old navigation lock, on the forebay side of the lock, at elevation 25 feet mean sea level.

Washington Shore Ladder System at Bonneville Dam

Years	*Area*	*Location*
1994-1998	Upper ladder	Where the Cascades Island ladder joins the Washington shore ladder above the highest weir in the ladder, on the north wall of the ladder near the controlling stillwell for the ladder's auxiliary water supply valve FV6-9.
1994-1996	Collection channel junction pool	Along north wall of the junction pool.
1994-1996	Entrance to the upstream migrant transportation channel	At the set of picketed leads just above the picketed leads that divert fish into the upstream migrant transportation channel.
1994-1996	Cascades Island ladder entrance	Along the south wall of the entrance about 40 feet from the deep slot entrance that faces south.
1995-1996	Forebay	Near the Washington shore ladder exit, just inside the Washington shore ladder exit trashrack.
1995	Tailrace	Attached to the north-downstream entrance sliding tailwater staff gauge that is on the west face of the north-downstream entrance.
1996	Adult Fish Monitoring and Sampling Facility ladder exit	In the Washington shore ladder just outside the Adult Fish Monitoring and Sampling Facility ladder exit, over a diffuser. The diffuser is open when the entry and exit ladders to the Adult Fish Monitoring and Sampling Facility are watered up.

The East Ladder at The Dalles Dam

Years	*Area*	*Location*
1994-1998	Upper ladder	Just upstream from the count station on the north side of the fishway.
1994-1996	Junction pool	Along the west wall of the junction pool.
1995-1996	Forebay	Near the ladder exit at elevation 154 feet mean sea level.
1995-1996	Tailrace	Near the ladder entrance at elevation 68 feet

		mean sea level.
1996	Forebay	Near the ladder exit at elevation 137 feet mean sea level.
1996	Forebay	Near the ladder exit at elevation 120 feet mean sea level.
1996	Lower ladder	In the highest diffuser pool of the lower ladder diffusers.

The North Ladder at The Dalles Dam

Years	*Area*	*Location*
1994-1998	Upper ladder	Just upstream from the count station on the south side of the fishway.
1994-1996	Lower ladder	On the south wall of the fishway just inside the ladder entrance.
1995-1996	Forebay	Near the ladder exit at elevation 154 feet mean sea level.
1995-1996	Tailrace	Near the ladder entrance at elevation 68 feet mean sea level.
1996	Lower ladder	In the highest diffuser pool of the lower ladder diffusers.
1996	Tailrace	In the tailrace portion of the navigation lock channel.

The South Ladder at John Day Dam

Years	*Area*	*Location*
1994-1996	Upper ladder	In the upper ladder diffuser pool at the lower end of the flow control section.
1994-1998	Entrance	On the west wall of the fishway just upstream from the SE-1 entrance, under the old juvenile bypass outfall conduit.
1995-1996	Tailrace	Near the ladder entrance at elevation 154 feet mean sea level.
1995-1997	Mid-ladder	On the west wall of the fishway in the middle of the 180° bend.
1995-1998	Forebay	Near the ladder exit at elevation 256 feet mean sea level.

1996	Lower ladder	Several pools below the footbridge that crosses over the lower portion of the ladder.
1996-1997	Lower ladder	In the uppermost diffuser pool of the lower ladder diffusers.
1996-1998	Forebay	Near the ladder exit at elevation 242 feet mean sea level.
1996-1998	Forebay	Near the ladder exit at elevation 228 feet mean sea level.
1996-1998	Upper ladder	In the pool just above the upper ladder diffuser pool.
1996-1998	Upper ladder	In the pool just below the upper ladder diffuser pool.
1996-1998	Lower ladder	In the stilling basin, from which auxiliary supply water is pumped into the lower portion of the ladder. This probe was used as a substitute for the tailrace probe, which was taken out of service at the end of 1995.

The North Ladder at John Day Dam

Years	*Area*	*Location*
1994-1998	Upper ladder	Just upstream of the count station on the north wall of the fishway.
1994-1998	Entrance	On the south wall of the fishway just upstream from the first bend in the ladder.
1995-1998	Forebay	Near the ladder exit at elevation 256 feet mean sea level.
1995-1996	Tailrace	Near the ladder entrance at elevation 154 feet mean sea level.
1996	Tailrace	Along the north side of the tailrace portion of the navigation lock channel.
1996-1997	Lower ladder	In the highest diffuser pool of the lower ladder diffusers.
1997-1998	Forebay	Near the ladder exit at elevation 242 feet mean sea level.
1997-1998	Forebay	Near the ladder exit at elevation 228 feet mean sea level.

Air Temperature at John Day Dam

Years	*Area*	*Location*
1997-1998	John Day Dam	In the air below the walkway leading down to the north ladder count station. It was placed in a spot where it is always shady.

Forebay Temperature at John Day Dam*

Years	*Area*	*Location*
1997-1998	North end of the powerhouse	In the center of skeleton turbine bay #18 at elevation 256 feet mean sea level.
1997-1998	North end of the powerhouse	In the center of skeleton turbine bay #18 at elevation 242 feet mean sea level.
1997-1998	North end of the powerhouse	In the center of skeleton turbine bay #18 at elevation 228 feet mean sea level.
1998	South end of the powerhouse	Near the South ladder exit at elevation 211 feet mean sea level.
1998	South end of the powerhouse	Near the South ladder exit at elevation 194 feet mean sea level.
1998	South end of the powerhouse	Near the South ladder exit at elevation 177 feet mean sea level.
1998	Forebay face of the powerhouse	At the divide between the south monolith and turbine unit 1 at elevation 256 feet mean sea level.
1998	Forebay face of the powerhouse	At the divide between turbine unit 3 and turbine unit 4 at elevation 256 feet mean sea level.
1998	Forebay face of the powerhouse	At the divide between turbine unit 8 and turbine unit 9 at elevation 256 feet mean sea level.
1998	Forebay face of the powerhouse	At the divide between turbine unit 13 and turbine unit 14 at elevation 256 feet mean sea level.

*Six probes in the south ladder and north ladder lists, the probes used near the south and north ladder exits at elevations 256, 242 and 228 feet mean sea level, are also forebay probes but don’t appear in this list.

John Day Dam Reservoir and John Day River Temperatures

Years	*Area*	*Location*
1996-1998	John Day River	In the mouth on the boat docks at LePage Park at five feet below the surface of the water.
1996-1998	John Day River	In the mouth on the boat docks at LePage Park at 15 feet below the surface of the water.
1997	Columbia River	Two miles above the confluence of the Columbia and John Day rivers anchored in 111 feet of water along the south edge of the barge shipping lane at 5.6 feet below the surface of the water.
1997	Columbia River	Two miles above the confluence of the Columbia and John Day rivers anchored in 111 feet of water along the south edge of the barge-shipping lane at 22.2 feet below the surface of the water.
1997	Columbia River	Two miles above the confluence of the Columbia and John Day rivers anchored in 111 feet of water along the south edge of the barge-shipping lane at 33.3 feet below the surface of the water.
1997	Columbia River	Two miles above the confluence of the Columbia and John Day rivers anchored in 103 feet of water well north of the barge shipping lane at 5.6 feet below the surface of the water.
1997-1998	John Day River	On the boat docks at Phillipi Park at five feet below the surface of the water.