U.S. Army Corps of Engineers
Portland District

Development of Surface Flow Bypasses at Bonneville Dam: A Synthesis of Data from 1995 to 1998 and a Draft M&E Plan for 2000

FINAL REPORT

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Preface

This study was undertaken as part of the Corps of Engineers, Portland District's (CENWP) surface bypass program at Bonneville Dam. BioAnalysts, Inc. performed the work under subcontract to the CH2M-Hill/Montgomery Watson, Joint Venture who were contracted by CENWP (contract no. DACW57-97-D-0004, Task Order Case No. 10). The products of this study were three reports. The draft reports were referred to as 60% and 90% products. The 60% report was reviewed internally (Corps and researchers). The 90% report was available for external, regional review. A draft monitoring and evaluation (M&E) plan for 2000 was developed as part of this project. It appears as an appendix in the 100% report, although eventually it will be developed further and produced as a separate document. Submittal dates for the various reports were:

- 60% Preliminary Draft Report March 29, 1999
- 90% Draft Final Report August 13, 1999
- 100% Final Report October 8, 1999

Acknowledgments

We thank the researchers who reviewed the report and delivered specific data for it: G. Ploskey (USACE Waterways Experiment Station) and H. Hansel (USGS-Biological Resources Division). We also thank the following Portland District staff who reviewed the report: L. Broderick, B. Buchholz, D. Clarke, M. Hansen, and R. Lee. And, we especially appreciate the critical contributions of B. Ebberts and K. Kuhn.

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1.0 Introduction

Surface flow bypass (SFB) is being investigated as a possible strategy to increase smolt survival at Bonneville Dam. A surface bypass provides a non-turbine passage route that extends from the reservoir surface to some depth. The upper portion of the water column is where smolts are naturally distributed in most forebays (see reviews by Johnson et al. 1997 and Dauble et al. 1999). The intent of a surface bypass is to provide a "normative" smolt bypass (Bisson et al. 1999), such as that at Wells Dam. The Wells surface bypass, which has five deep slots (16 ft wide by 70 ft deep), passed an estimated 89% of the smolts arriving at the dam in spring and summer during the 1990-1992 evaluation of total project bypass efficiency (Skalski et al. 1997). The success of surface bypass at Wells Dam created renewed regional interest in these types of systems. At Bonneville Dam, the goal of the surface bypass program is to *"…develop and evaluate surface bypass and collection prototype concepts that will lead, if justified by prototype test results, to permanent systems for improving survival of juvenile salmon…"* (USACE 1995).

In their Biological Opinions on operation of the Federal Columbia River Power System (NMFS 1995, 1998), the National Marine Fisheries Service (NMFS) mandated development of surface bypasses at Bonneville Dam. NMFS did this because fish guidance efficiency (FGE) and smolt survival associated with turbine intake screens has been substandard at Bonneville Dam (e.g., Dawley et al. 1992; Gilbreath et al. 1993; Monk et al. 1999). NMFS (1995, 1998) also indicated the need to evaluate the merits of extended-length submersible bar screens at Bonneville Dam. The year 2001 is scheduled for the Region to decide which complement of smolt passage devices to emphasize for long-term smolt protection at Bonneville Dam.

At Bonneville First Powerhouse (B1), surface bypass investigations started decades ago. In the late 1960s, the 1970s, and early 1980s, researchers investigated the ice-trash sluiceway as a non-turbine passage route for smolts. It was found to be quite efficient (~40%) given the small amount of sluiceway flow (~1,500 cfs) (e.g., Willis and Uremovich 1981). Performance of the sluiceway as a smolt bypass, however, was constrained by the limited amount of total sluiceway flow and, possibly, the proximity of turbine intakes to the sluiceway (intake ceilings are ~6 ft deep at the trashracks). Because sluiceway performance was not sufficient to act as a stand-alone system, standard-length submersible traveling screens (STS) were installed in the turbine intakes. The B1 sluiceway is currently operated as a supplemental smolt bypass to the B1 STS bypass system. Section 5.1 contains an in-depth review of surface bypass research at the B1 sluiceway.

With the NMFS mandate for surface bypass at Bonneville Dam in 1994, surface bypass development was renewed at Bonneville Dam in 1995, and is currently ongoing. In 1996, trashrack blockages to increase sluiceway passage at B1 were tested. Under direction of the Portland District, Harza and ENSR (1996a) investigated surface bypass alternatives for B1. One of the designs for B1 was called Alternative A, which spanned the full front face on the powerhouse with deep vertical slots. To test some of the hydraulic variables that would influence design of such a production facility, a test structure was conceived. This prototype surface collector (PSC) was designed to test hydraulics and fish response to various entrance configurations. In 1998, the PSC was constructed, installed, and evaluated at Units 3-6. (1998 tests occurred at Units 3 and 5 only because Units 4 and 6 were off-line for rehabilitation.) The PSC is currently the focus of surface bypass research at B1.

At Bonneville Second Powerhouse (B2), there have been two phases to surface bypass development. First, in the 1980s, the ice-trash sluice chute was studied as a non-turbine passage route (e.g., Magne 1987a). This research was motivated by the substandard fish guidance efficiency achieved by the STS bypass system at B2 (e.g., Monk et al. 1999). Magne's evaluations were inconclusive, in large part due to poor monitoring conditions for hydroacoustics at the sluice chute entrance. Second, in 1997 and 1998 the sluice chute once again was operated for research using improved monitoring methodology to re-evaluate its passage potential. Based on forebay hydraulic patterns and fish distribution estimates, a strategy was developed to use the sluice chute as a prototype corner collector (PCC). A "corner collector" is a particular configuration of surface bypass that has entrance(s) in a localized terminal area where smolts are known to be concentrated horizontally. Under direction of the Portland District, Harza and ENSR (1996b) identified a number of surface bypass alternatives for B2. Then, INCA et al. (1997) studied biological, hydraulic, and engineering aspects of the sluice chute as a PCC. Consideration was also given to a physical guidance device at the beginning of the B2 forebay channel (CH2M-Hill et al. 1998). Today, the B2 PCC is the focus of surface bypass research at B2. It is a complement to the STS system for smolt protection at B2.

In 1998, smolt passage efficiency was evaluated at the B1 PSC and the B2 PCC. The results were promising (see Section 5). These surface bypass routes are also appealing because they can be considered "normative" smolt bypasses, based on the characterization by Bisson et al. (1999). Accordingly, the goal of this report is to critically assess available biological and hydraulic information relevant to surface bypass development at Bonneville Dam. Our objectives are to:

1. Summarize and integrate existing hydraulic and biological information.
2. Identify critical information that is needed to advance surface bypass development.
3. Identify surface bypass prototype configurations that could be evaluated in the near-term (2000-2001).
4. Discuss the potential for effective surface bypass systems at B1 and B2.
5. Develop a draft Monitoring and Evaluation Plan for 2000.

This report will survey a broad array of studies that are related to surface bypass issues at Bonneville Dam. These will include B1 sluiceway work conducted in early 1970s and B2 sluice chute work in 1980s. However, we will emphasize investigations conducted at the B1 PSC and B2 PCC during 1995-1998. All components of surface bypass (collection, conveyance, and outfall) will be treated. Research regarding fish guidance efficiency of turbine intake screens, however, is not within the scope of this project.

The report contains six main sections. Section 1 constitutes the introduction. A conceptual framework for surface bypass development is presented Section 2. Section 3 describes the study site. Sections 4 and 5 synthesize information and results presented in a broad spectrum of hydraulic and biological investigations, respectively. Key questions regarding the utility of and insights derived from the collective information are discussed and recommendations and conclusions made in Section 6. Appendix A contains a list of existing hydraulic model studies and field data relevant to the Bonneville surface bypass program. Appendix B is the draft M&E plan for 2000.

2.0 Framework for Surface Bypass Development

The conceptual framework for surface flow bypass (SFB) in this report is based on that presented by Dauble et al. (1999). This surface bypass framework evolved from that originally offered by Johnson et al. (1997), and modified by Erho and Johnson (1998). The new framework encompasses surface bypass from forebay collection to egress in the tailrace. Dauble et al. (1999) also updated the surface bypass premises and redefined the "zones" of interest in the forebay based on biological and hydraulic information obtained in recent years. This section of our Bonneville report includes surface bypass components and terminology, forebay zones, SFB premises, and specific performance measures.

2.1 Components and Terminology of Surface Bypass

There are three main components to a surface bypass: a forebay collection structure with an entrance(s), a conveyance channel, and an outfall structure downstream of the dam (Figure 1). The forebay collection structure provides smolts a surface entrance to a non-turbine passage route. It should be located in areas where appreciable numbers of smolts will encounter it. It is commonly held that if suitable hydraulic conditions can be established at the opening, then smolts will readily enter it; exactly what constitutes "suitable" has yet to be clearly defined. Inside the fish collection structure there is a transition to the conveyance channel. The transition can be abrupt or subtle. The conveyance channel transfers smolts from the forebay to an outfall located downstream of the dam. Smolt passage through this route should be injury-free and quick. The outfall structure should be configured and sited to deposit smolts safely into the tailrace and at a location where they can move readily downstream minimizing exposure to predatory fish. The normative nature of high flow surface bypasses, i.e., without dewatering, minimizes physical and physiological impairment during passage through the dam and into tailwaters.

2.2 Forebay Zones

At Bonneville Dam, surface bypass evaluations have emphasized the forebay component because of the strategy to demonstrate successful smolt collection before embarking on conveyance and outfall development. The forebay component includes Approach, Discovery, and Decision zones (Figure 1) as described by Dauble et al. (1999). Forebay zones cover smolt migration from the point they enter the forebay until they pass into the fish collection structure. The forebay zones are defined as:

- Approach Zone -- where smolts enter the forebay and begin to approach the dam.
- Discovery Zone -- where smolts can find or encounter surface bypass flownet(s).
- Decision Zone -- where smolts accept or reject a surface bypass flownet.

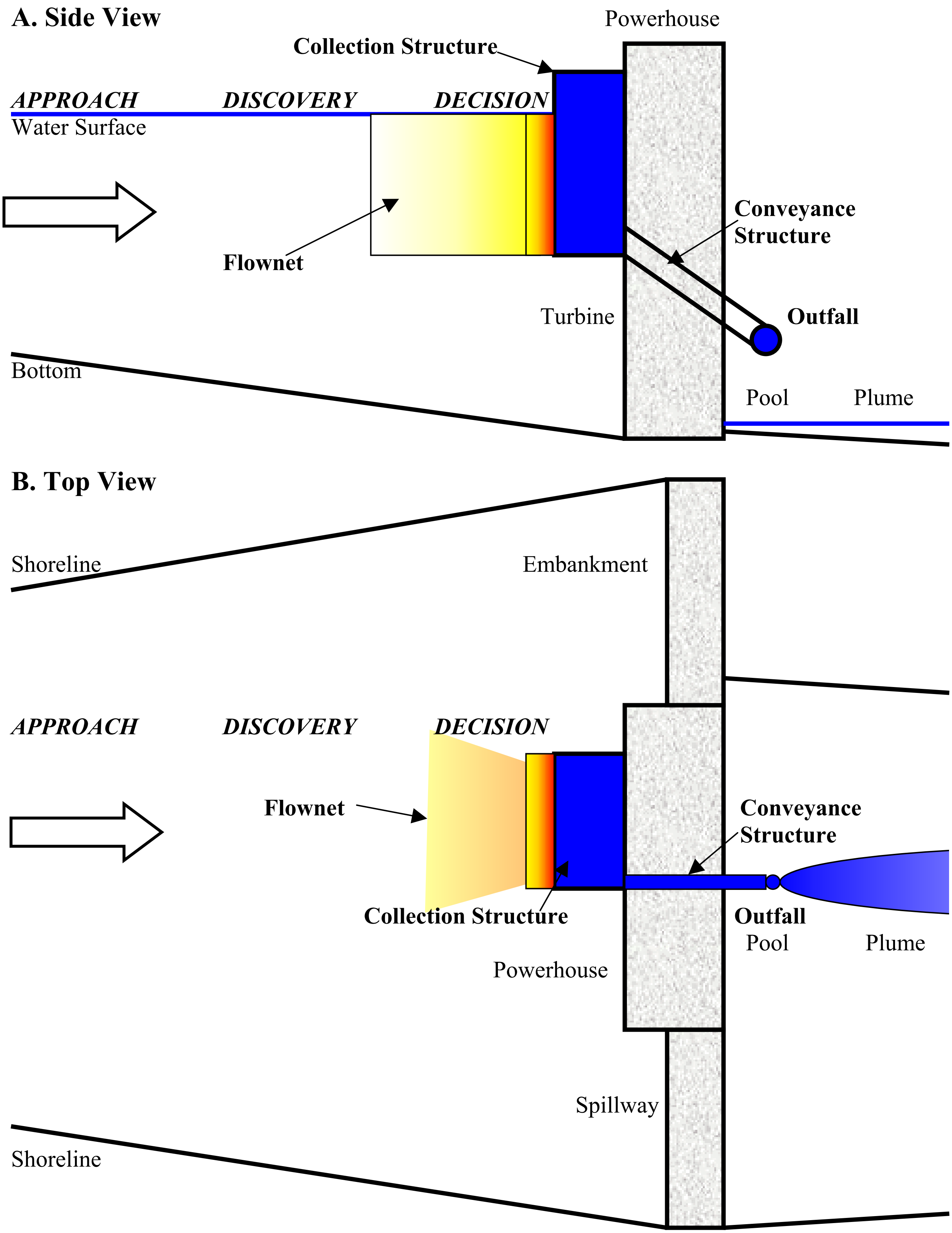

Figure 1. Surface flow bypass schematic (modified from Dauble et al. 1999). Not to scale.

2.3 Surface Bypass Premises

There are five main premises for a successful surface bypass (Dauble et al. 1999). If these premises are not true, performance of the surface bypass may be compromised to some extent. In Sections 5 and 6, we assess the validity and implications of these premises relative to data acquired at the B1 PSC and B2 PCC. The premises are:

1. Approach – Smolts follow the bulk flow as they approach the dam.
2. Discovery -- Smolts can discover the surface bypass flownet.

For this to be true, the following characteristics of the discovery process also need to be true (modified from Dauble et al. 1999):

- Smolt migration has some active component.
- Vertical distribution of smolts is surface-oriented (upper third to half of the water column).
- Horizontal distribution of smolts is in the proximity of surface bypass entrance(s).
- The surface bypass flownet is distinct in terms of acceleration/deceleration from the ambient flow field.
- Smolts have the sensory capabilities to discern the surface bypass flownet from ambient surface or turbine flow.

3. Decision: Surface bypass entrance conditions do not elicit an avoidance response.
4. Conveyance: Smolts stay within the collector and pass through the conveyance structure safely.
5. Outfall: Smolts readily exit the outfall, safely enter the tailrace, and quickly migrate downstream with little risk from predation.
   - Smolt migration has some active component.
   - Physical and physiological fitness of smolts is maintained.

2.4 SFB Performance Measures

Surface bypass performance can be expressed using a suite of passage-related efficiency estimates. The relationship or linkage among those efficiencies can be used to establish the overall effectiveness of any surface bypass system. Stevenson et al. (1997) first applied this approach at Rocky Reach Dam in 1997. They expressed the overall effectiveness of the prototype corner collector as the product of smolt encounter, entrance, and retention efficiencies, which were estimated separately. Here we expand on that approach by redefining some terms with respect to prevailing hydraulic conditions, including all components of the bypass from the forebay through egress in the tailrace.

Overall surface bypass efficiency (OSBE) spans a broad series of events from where smolts first enter the forebay to a terminal site well downstream from the outfall. It is broader than "surface bypass efficiency" as presented in other investigations, because it incorporates the conveyance and outfall components, in addition to the forebay components. Furthermore, OSBE also reflects mortality incurred at certain locations in the system. The equation has various performance measures as its factors. The suite of individual probabilities or efficiencies that comprise OSBE are (modified from Dauble et al. 1999):

1. <u>Discovery efficiency</u> (DE) is the proportion of all smolts within the forebay that discover (encounter) the surface flow bypass (SFB) flownet.
2. <u>Entrance efficiency</u> (EE) is the proportion of smolts within the SFB flownet that ultimately enter the SFB collection structure.
3. <u>Conveyance efficiency</u> (CE) is the proportion of fish entering the SFB that move through the outlet of the conveyance structure alive.
4. <u>Egress efficiency</u> (GE) is the proportion of fish exiting the outlet that survive a specified distance downstream.

OSBE then is the proportion of all smolts entering a forebay that locate and pass through the surface collector and survive to a prescribed location downstream from the outfall. OSBE can be expressed as:

$$OSBE = DE * EE * CE * GE$$

A subset of OSBE is <u>forebay collection efficiency</u> (FCE):

$$FCE = DE * EE$$

The surface bypass efficiency relationships are an alternative means for formulating the framework. Some, but not all, of these efficiencies are readily estimable, using hydroacoustic or telemetry technologies. Forebay collection efficiency has been estimated at a number of prototype surface bypasses, such as those at Rocky Reach, Lower Granite, and Bonneville dams (e.g., Mosey et al. 1999, Johnson et al. 1998, and Ploskey et al. 1998a, respectively). Although it has often been referred to in different terms, e.g., passage efficiency (Stevenson et al. 1997), specific methods to estimate conveyance and egress efficiencies have not yet received much attention. The surface bypass framework, as proposed herein, might be helpful in standardizing some aspects of surface bypass research. This would expedite performance comparisons between years and sites.

3.0 Study Site Description

This section contains data on Bonneville Dam's main structures and features, prototype surface bypass structures, bathymetry, river conditions, dam operations, and biological conditions. Elevations are referenced to the National Geodetic Vertical Datum (NVGD); NGVD and mean sea level are virtually the same.

3.1 Main Structures and Features

Bonneville Dam is a complex set of concrete structures and islands approximately 146 miles from the mouth of the Columbia River (Figure 2). Moving from the Oregon shore to the Washington shore (south to north), the concrete structures include a large navigation lock, a small lock (out of service, but not decommissioned), Bonneville First Powerhouse (B1), a spillway, and Bonneville Second Powerhouse (B2). Bradford Island separates B1 and the spillway. Cascades Island separates the spillway and B2. Adult fishways (ladders) are located at the northern ends of B1 and B2 and the northern and southern ends of the spillway (4 total fishway entrances). Exits from the adult fishways are located on Bradford Island and the Washington shore. Surface bypass structures are described in Section 3.2.

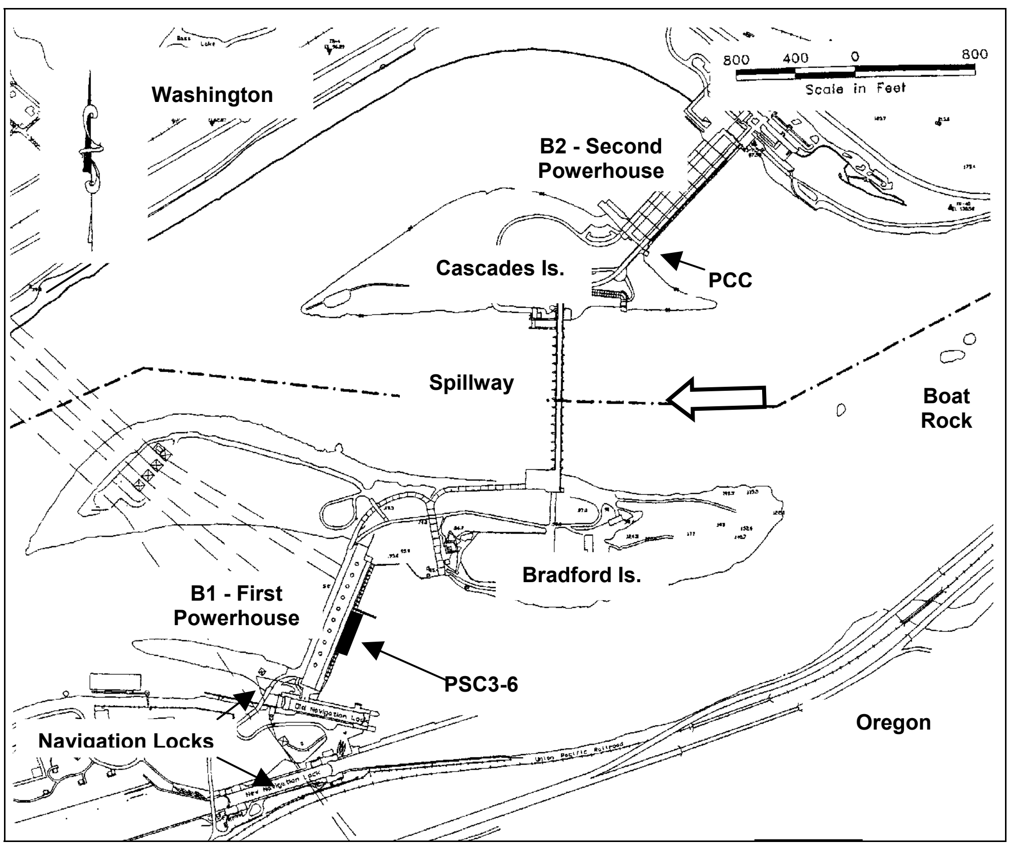

Figure 2. Plan view of Bonneville Dam showing navigation locks, B1 with PSC, Bradford Island, spillway, Cascades Island, and B2 with PCC.

The project is located in a natural and man-made braided channel area (Figure 2). Upstream of the dam about 1 mile, the river channel is narrow (~1,000 ft wide). Then, the river splits into three main channels: B1, spillway, and B2. B1 is at the end of a relatively narrow forebay channel and is thus largely isolated from the other passage routes. The B2 forebay is influenced more by spillway operations than the B1 forebay because of B2's proximity to the spillway. At the dam, the river is about 1 mile wide. Approximately 1 mile downstream, the three channels have merged and the river is relatively narrow again (~1,200 ft wide). ENSR et al. (1998) provided a description of geological features at Bonneville Dam.

B1 has ten turbine units with a generating capacity of 532 MW and a hydraulic capacity of 140,000 cfs under normal head and full load. Turbine units at B1 are numbered 1-10 from south to north. At normal pool elevation, turbine intake ceilings at the trashracks are about 6 ft deep (El. 68 ft) and intake floors are 76 ft deep (El. –2 ft) (Figure 3). A wing-wall extends 150 ft upstream at the junction of Units 6 and 7. An ice-trash sluiceway extends along the surface of the forebay side of the B1 powerhouse. There is a leaf gate above each turbine intake. Flow through sluice gates is strongly influenced by forebay elevation. Maximum total capacity of the sluiceway is about 2,100 cfs. A gate at the south end of the sluiceway controls sluiceway channel flow. At this point, flow plunges into a raceway, which turns downstream and discharges into the tailrace at the south end of the powerhouse. Submersible traveling screens are installed within each intake at B1 to divert fish from turbines into a juvenile bypass system. See Section 3.2 for a description of the prototype surface collector at B1.

Figure 3. Side view of B1. Modified from Michimoto and Korn (1969).

The spillway has 18 bays numbered 1-18 from north to south. Flow through a given spill bay is controlled by a vertical lift gate. The spillway ogee is at El. 25 ft, which is 49 ft below normal pool elevation (El. 74 ft). Each bay is 60 ft wide. The entire spillway structure is about 1,450 ft long.

B2 has eight turbine units with a generating capacity of 558 MW and a hydraulic capacity of 160,000 cfs at the rated head and full load. Typical unit discharge, however, is about 12,000-14,000 cfs. Turbine units at B2 are numbered 11-18 from south to north. Turbine intake ceilings at the trashracks are about 37 ft deep (El. 37 ft) and intake floors are 96 ft deep (El. –22 ft) (Figure 4). The intakes are 26 ft wide. Two fish turbine units located on the north side discharge 3,400 cfs each at the rated head and full load. An ice-trash sluice chute is located at the south end of the powerhouse. (See next section for a description of the sluice chute as a prototype surface bypass.) STSs are also installed in each intake at B2 to divert fish from turbines into a juvenile bypass system. Turbine intake extensions (TIEs) are installed at every other intake during the spring migration season. The purpose of the TIES is to increase fish guidance efficiency of the STSs. A new JBS outfall system for B2 was installed for the 1999 migration. It carries fish in 30-50 cfs from the powerhouse collection system to a new outfall site approximately 2 miles downstream from the B2 powerhouse.

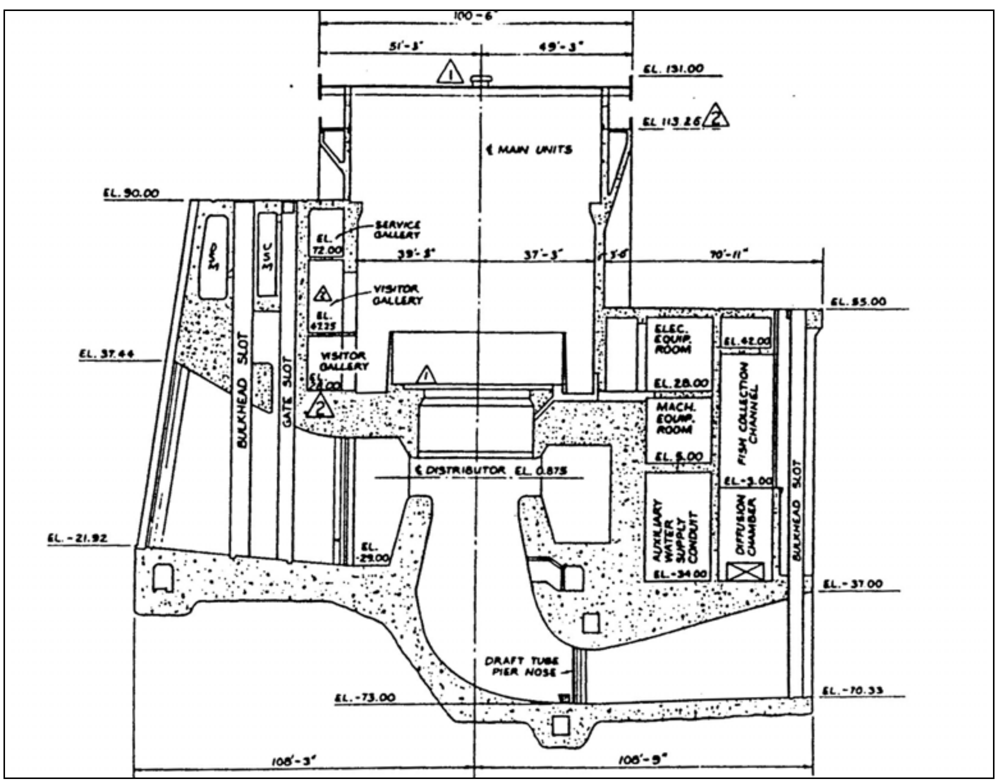

Figure 4. Side view of Bonneville Second Powerhouse. Modified from As Constructed drawings, Hydroelectric Design Center, NWP, Sheet 22 BDP 1-0-0/6.

3.2 Prototype Surface Bypass Structures

Prototype surface bypass structures at Bonneville Dam include the B1 trashrack blockages, the B1 prototype surface collector, and the B2 prototype corner collector. Results of hydraulic and biological tests of these structures are presented in Sections 4 and 5, respectively.

3.2.1 B1 Trashrack Blockages

In 1996 at B1, trashracks at Units 3 and 5 were blocked to El. 33 ft (about 41 ft deep) as an inexpensive, preliminary surface bypass test. The purpose of the blockages was to occlude part of the intake entrance area to intensify and deepen the "zone of separation" between the turbine flow and surface sluiceway flow. The intent was to determine if surface-oriented smolts would exhibit an enhanced proclivity to resist sounding if a large zone of separation could be established.

3.2.2 B1 Prototype Surface Collector

The PSC test structure was retrofitted to the upstream face of B1 at Units 3-6 (Figures 2 and 5). Recall, its purpose was to investigate hydraulic and biological characteristics of a surface bypass at B1. Vertical slots in the PSC in front of Intakes 3B and 5B were configured to have 5-ft or 20-ft wide openings. These widths were chosen to maximize differences in flows and velocities between the configurations in an effort to increase the likelihood of detecting differential smolt behaviors. This information would be useful to help determine design criteria for surface bypass entrances. Entrance width was changed according to a randomized block experimental design to evaluate effects of slot width on PSC efficiency and effectiveness. PSC entrances were 40-46 ft deep depending upon forebay level (PSC floor was at El. 30.5 ft). The mean velocity at the entrance was about 7.2 fps for 5-ft slots and 4.3 fps for 20-ft slots. Flow through the entrances was about 1,500 cfs for 5-ft slots and 3,500 cfs for 20-ft slots. (PSC velocity and flow data have been updated based on information from turbine discharge tests in summer 1999.) Fish entering the PSC passed through the structure and into the turbine intake behind. The PSC was not designed to actually bypass fish during the test period. The intent was to use the PSC to examine entrance hydraulics and to examine the efficacy of surface bypass at B1 before building a large-scale prototype or full production surface bypass facilities at B1.

3.2.3 B2 Prototype Corner Collector

In 1998, the ice and trash sluice chute at B2 (Figure 2) was studied as a prototype corner collector (PCC) surface bypass. PCC configuration and operating characteristics are presented in Tables 1 and 2, respectively. Bottom and top weir gates (Figure 6) control flow into the sluice chute. The bottom weir gate rests on a concrete sill at El. 52

ft. It can be raised (undershot flow) to El. 61 ft. The top weir gate can be lowered (overflow) to El. 59.5 ft. Typically, the top gate is lowered to dog-off points that result in the weir crest at El. 61 or 68 ft. After passing over the weir gate, water drops about 45 ft to the channel floor at El. 29 ft (Figure 6). The chute channel bends 45^o to the right about 25 ft downstream of the weir gate. The radius of the turn in the 15-ft wide channel is about 32 ft, which corresponds to a curvature of about 2 diameters. The distance from the curve to the terminus of the chute (outfall) is about 400 ft.

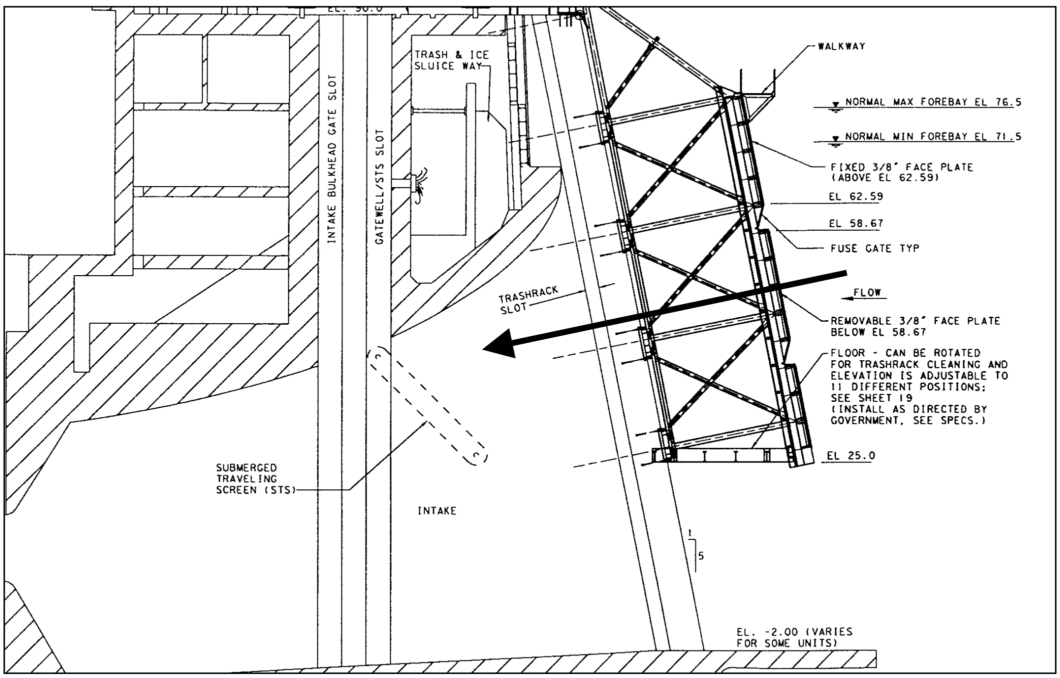

Figure 5. Side view of the PSC at B1. Arrow depicts flow into and through the PSC and into the turbine intake behind. PSC floor was actually installed at El. 30.5 ft, not 25.0 ft. Modified from Plate 4 in Harza and ENSR (1996a).

Table 1. Characteristics of B2 sluice. Modified from Table 1.1 INCA et al. (1997).

Parameter	Value (ft)
Lowered gate position (overshot flow):	
Initial opening elevation	76.5
Maximum opening elevation	59.5
Raised gate position (undershot flow):	
Initial opening elevation	52.0
Maximum opening elevation	61.0
Chute floor elevation	29.0
Chute length	430

Table 2. Prototype corner collector discharge (cfs) for various combinations of forebay elevation and PCC weir crest elevation. Modified from Table 1.1 in INCA et al. (1997).

	PCC Weir Crest			
Forebay Elevation	Elev. 68	Elev. 61	Elev. 52	Elev. 42
WS Elev. 71.5	400	2,000	4,000	----
WS Elev. 75.0	1,100	3,000	5,300	9,100
WS Elev. 76.5	1,500	3,600	5,600	10,000

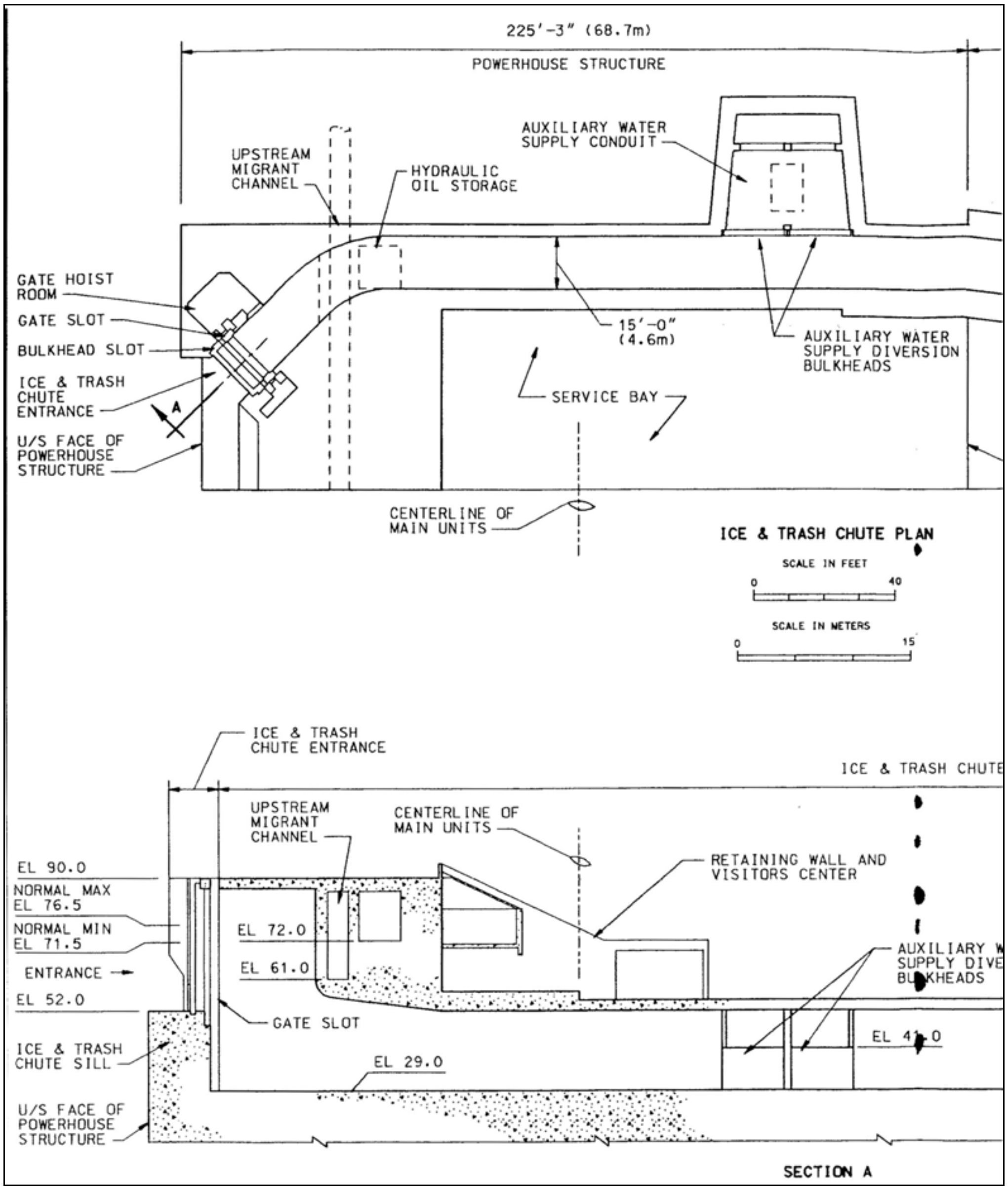

Figure 6. Top and side views of the sluice chute at B2. Modified from Plate 2 in INCA et al. (1997).

During 1998 tests, the weir crest was at El. 61 ft. Thus, the entrance was 15 ft wide and about 13 ft high, depending on forebay level. The approximate mean velocity upstream of the gate was 15.4 fps and PCC discharge was about 3,000 cfs. TIEs were removed at Units 11-14 to reduce turbulence at the PCC to allow hydroacoustic monitoring of fish passage there in 1998. TIE removal also made the southerly, lateral flow lines at the face of powerhouse Units 11-14 less variable and more uniformly directed to the south.

The existing sluice chute outfall was used during the 1998 PCC smolt passage test. The invert of the PCC outfall structure is fixed at El. 29. Tailwater elevation can vary widely, at times submerging the outlet. Mean tailwater elevation for 1994-1998 was less than El. 29 (Figure 7). But under high runoff conditions during 1996 and 1997, tailwater elevation regularly exceeded El. 29. In these instances, the outfall was submerged. Usually, though, at discharges less than about 330,000 cfs, the outfall jet plunges before entering the tailwater (Figure 8). During 1994-1998 the maximum mean plunge distance was 17 ft in late August. More details on the sluice chute outfall area can be found in INCA et al. (1997).

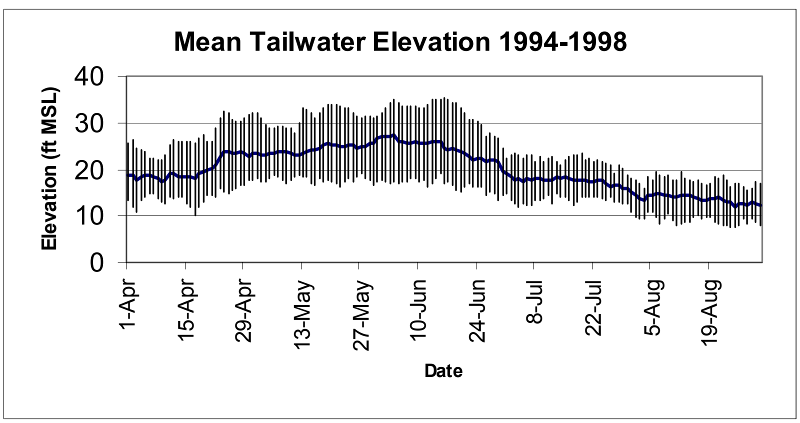

Figure 7. Maximum, mean, and minimum daily tailwater elevations (ft NVGD) at Bonneville Dam for the period April 1 to August 31, 1994-1998. Data provided by J. Cress, University of Washington.

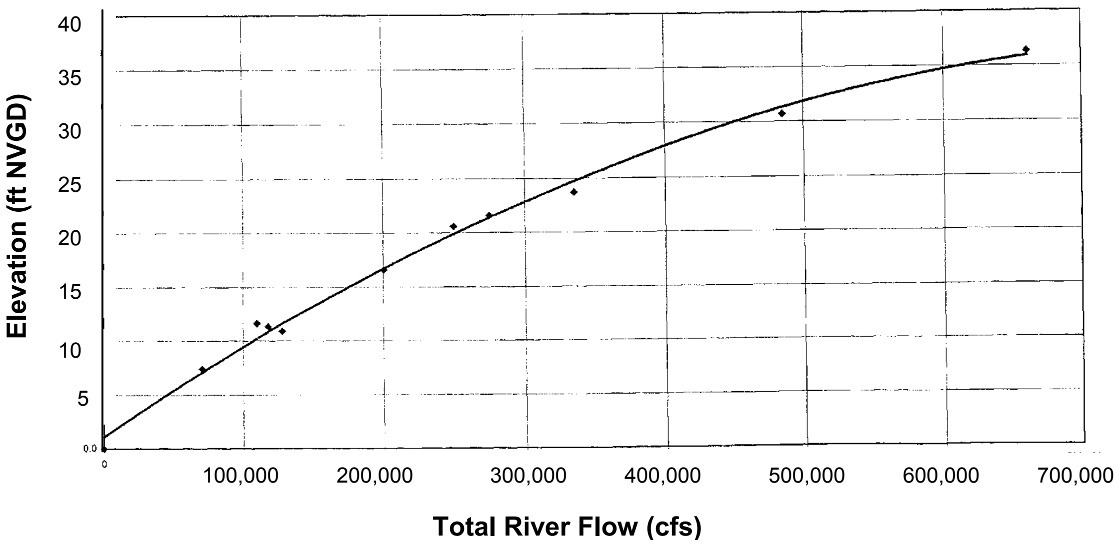

Figure 8. Tailwater rating curve for B1. Grade elevation for the tailrace near the B2 PCC outfall is about El. –25 ft NVGD. Modified from Plate 3-6 in ENSR et al. (1998).

3.3 Bathymetry, River Conditions, and Dam Operations

Bathymetry at Bonneville Dam is comprised of both old river channel (the thalweg) and newly excavated areas. At B1 and the spillway, forebay bathymetry reflects the split in the thalweg that occurred at Bradford Island. The thalweg at B1 intersects the dam at Units 1-6; the forebay of Units 7-10 is relatively shallow (Figure 9). At B2, the forebay is man-made. The B2 forebay, an excavated area, is about 40-44 ft deep where it branches off from the spillway forebay (Figure 10). Near B2, bottom depth abruptly increases for water to enter the turbine intakes (Figure 10).

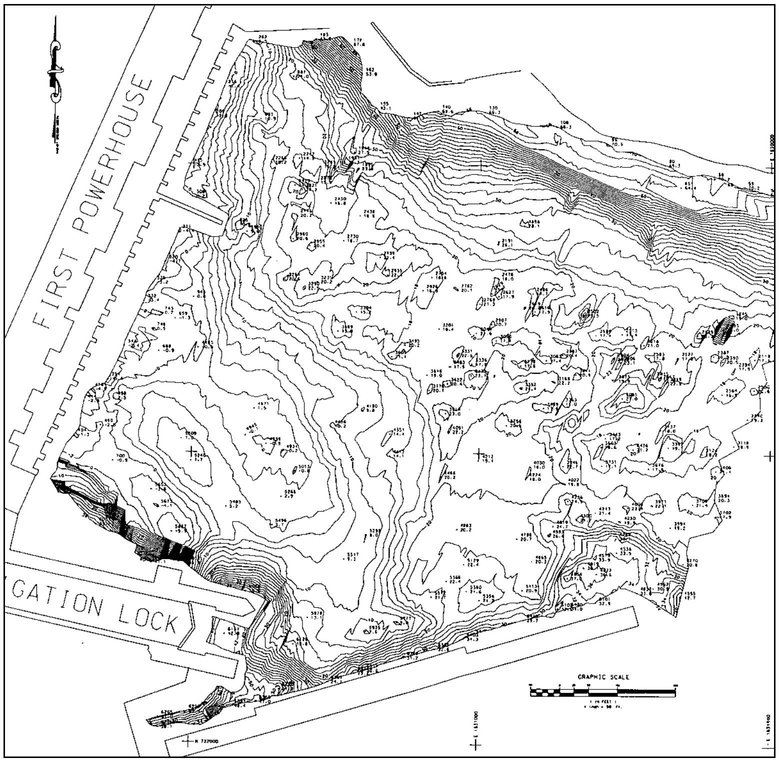

Figure 9. General depiction of bathymetry at the B1 forebay. Data are from hydrographic survey in December 1998 by Minister-Glaeser Surveying, Inc.

Figure 10. General depiction of bathymetry at the B2 forebay. Data are from hydrographic survey in December 1998 by Minister-Glaeser Surveying, Inc.

River discharge at Bonneville Dam typically increases steadily from April through May and peaks in June (Figure 11). Spill discharge follows a similar pattern (Figure 11). In 1994-1998, maximum discharge at Bonneville Dam was 557 kcfs on June 16, 1997. River discharge decreases from June through August (Figure 11). From April through July, temperature increases steadily from about 8 °C to about 21 °C (Figure 12). During the April-August period, turbidity ranges between 2 and 7 NTU (Figure 12). Highest turbidity levels at Bonneville Dam are usually in August.

Water is spilled involuntarily at Bonneville Dam to pass flows in excess of powerhouse capacity. It is spilled voluntarily to increase fish passage efficiency and smolt survival through the project. In the last five years, the daily average percentage of water spilled has ranged from 37% to 48% (Table 3). In 1996 and 1997, involuntary spill occurred above normal fish spill because of high runoff conditions.

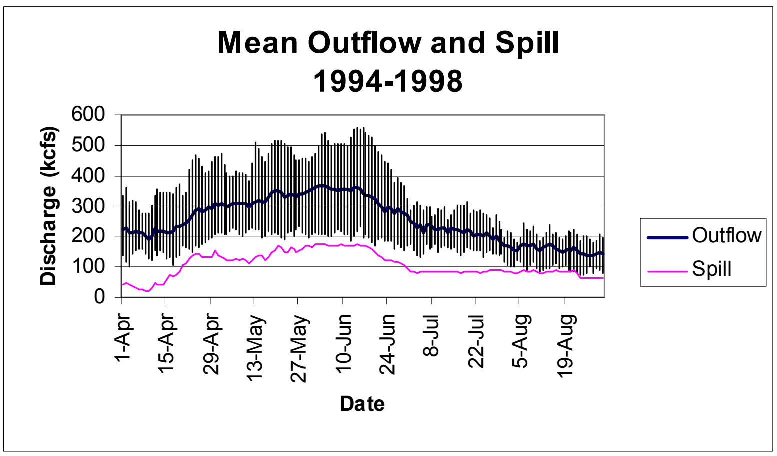

Figure 11. Daily average outflow and spill (kcfs) for the period April 1 to August 31, 1994-1998. Data are from DART (http://www.cqs.washington.edu/dart/).

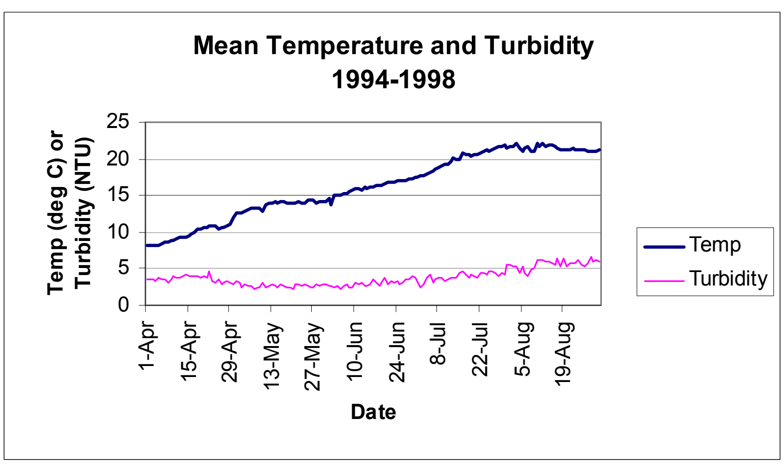

Figure 12. Mean temperature (°C) and turbidity (NTU) for the period April 1 to August 31, 1994-1998. Data are from DART.

Table 3. Daily average outflow and spill (kcfs) and proportion spill at Bonneville Dam for the April-August time period in 1994-1998. Data are from DART.

Mean (April-August)	1994	1995	1996	1997	1998
Outflow	161	219	300	350	235
Spill	60	83	134	168	90
Proportion spill	0.37	0.38	0.45	0.48	0.39

Turbine unit priority during the juvenile fish passage season (April-August) is based on considerations for adult passage and the need for flushing flow past the existing juvenile bypass system outfall at B1.

3.4 Biological Conditions

In this section we describe adult passage, smolt species composition and run timing, and predator distribution and abundance.

3.4.1. Adult Passage

Adult salmon and steelhead migrate upstream through Bonneville Dam mainly from March to November. There are runs of chinook salmon (*Oncorhynchus tshawytscha*) in spring, summer, and fall. The largest upstream migration is typically by fall chinook salmon. Steelhead (*O. mykiss*) move upstream in summer and fall. Sockeye (*O. nerka*) are summer migrants and coho (*O. kisutch*) are fall migrants. With regard to surface bypass development, there is concern about adult fallback through a forebay collection structure, false attraction to a bypass outfall, and masking of the fishway attraction flows by high flows from a bypass outfall.

3.4.2 Smolt Species Composition and Run Timing

Juvenile chinook salmon, coho salmon, sockeye salmon, and steelhead trout migrate downstream through Bonneville Dam. All have stream-type life histories, i.e., they migrate downstream as yearling fish. In addition, there are ocean-type chinook salmon that migrate downstream as subyearlings. The subyearlings have the highest daily passage indices from the Smolt Monitoring Program 1994-1998 (Figure 13). Sockeye salmon are the least abundant juvenile salmonid at Bonneville Dam. The migration of yearling fish occurs from early April until late June (Figure 13). Peaks in run timing vary, but are usually in late April or May (Figure 13). Migration magnitude generally declines in late May and June (Figure 13). The migration of subyearling fish begins with the major release from the Spring Creek hatchery in April (Figure 13). Another peak in subyearling passage can occur in late May. Subyearling fish migrate through Bonneville Dam until late July or early August (Figure 13). Surface bypasses at

Bonneville Dam will need to address all downstream migrant species and life history types.

3.4.3 Predator Distribution and Abundance

Predators are abundant in the forebays and tailraces of Bonneville Dam (e.g., Ward et al. 1995). Northern pikeminnow (*Ptychocheilus oregonensis*) consumption of juvenile salmonids is generally higher in tailraces than forebays, and higher in summer than spring (Ward et al. 1995). Predation is a concern at surface bypass entrances, in the conveyance structure, and at outfalls. In Section 5.3.8 we review predator studies that focused specifically on impacts to surface bypass performance.

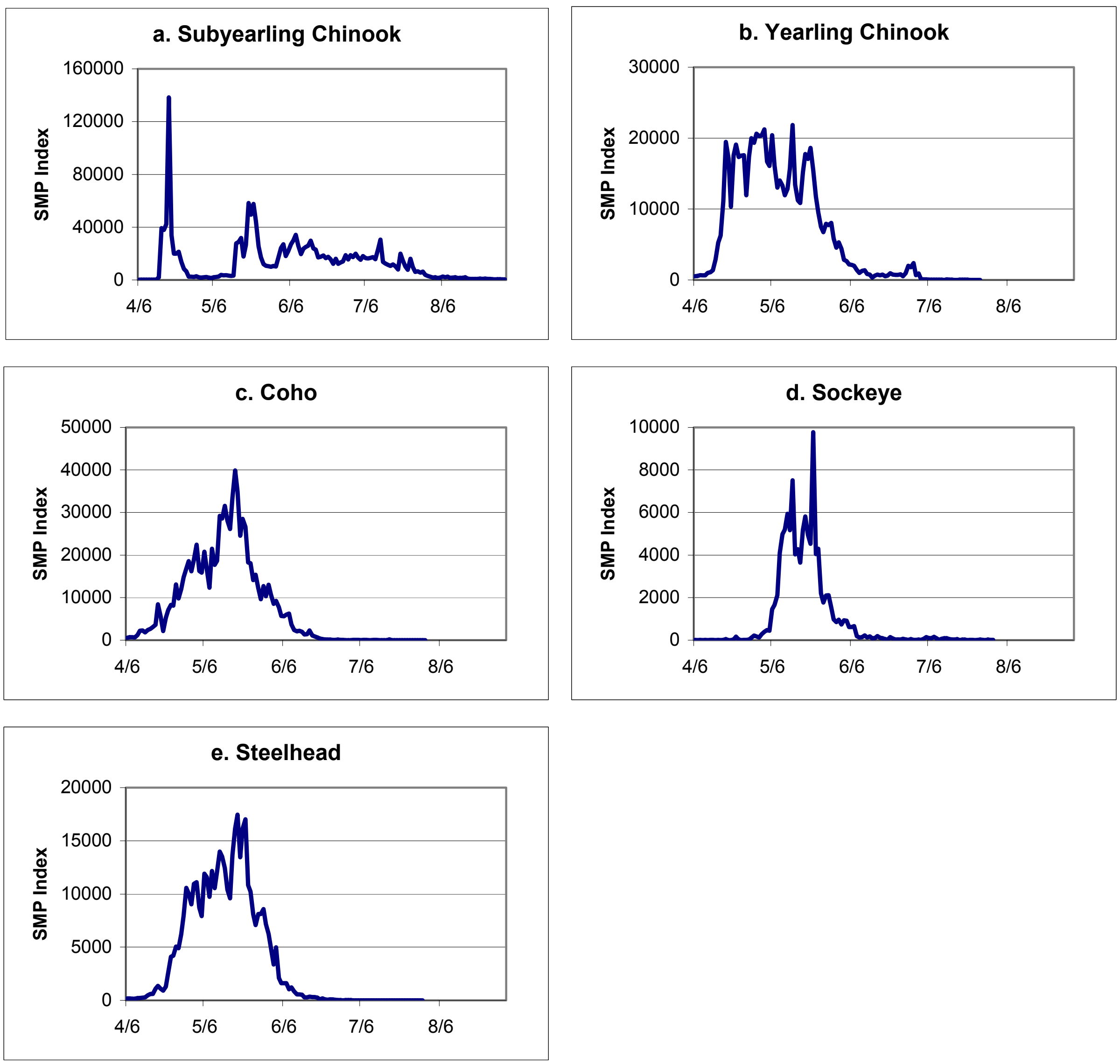

Figure 13. Average daily passage indices by species from the Smolt Monitoring Program at Bonneville Dam 1994-1998. Data are from DART.

4.0 Summary of Hydraulic Data

This section contains a summary of selected hydraulic information regarding general approach, B1 and B2 forebays and tailraces, B1 PSC, and B2 PCC. These characterizations are based on data obtained from field work at Bonneville Dam and from physical models at WES. The physical models used are the B1 forebay general 1:40 scale , B1 sectional 1:25 scale, B2 forebay general 1:40 scale , and Bonneville general 1:100 scale. The Bonneville general 1:100 includes forebays and tailraces of B1, the spillway, and B2. Depth averaged velocity data (generally 0-14 ft or 0-25 ft) and spot velocities for top, mid and bottom depths have been measured on the Bonneville 1:100 model. Additionally, several flow scenarios were investigated for the surface bypass program to characterize forebay and upriver flows, calibrate the 1:40 scale model, and compare with ADCP field data acquired in 1995 by WES. The field data were analyzed for various depths and include composite as well as vertical velocity vector cross-sectional plots. Hydraulic investigations that are relevant to the Bonneville surface bypass program are listed in Table A.1 in Appendix A. If the reader desires data not reported in this section, they should contact the Portland District, Hydraulics Branch. The following summarization is a general overview; specific hydraulic conditions are dependent on inflow and project operations.

4.1 General Approach Flows

Hydraulic conditions at Bonneville Dam are complicated and variable. Intricate bathymetry, structures, and islands complicate hydraulics. Inflow and operations of the two powerhouses and spillway that change with season, weather, power demand, and fishery management actions cause variability. Water coming into the forebay at the Bonneville Dam passes through a constriction in the river at the Bridge of the Gods about 3 miles upstream. Moving downstream, the channel splits at Boat Rock (also called "Decision Rock"), about 2/3 mile upstream of the spillway. Generally, flow to the south of Boat Rock goes to B1 and flow north of it goes to the spillway or B2.

4.2 Forebay Current Patterns

In the B1 forebay upstream of the new navigation lock, current direction is relatively straight toward the powerhouse (Figure 14). Typically, velocity is higher toward the center and northern part of the channel formed by Bradford Island and the Oregon shore than it is toward the Oregon shore. Eddies form in the south and north corners of the forebay at the B1 powerhouse across a broad range of project operations. The south eddy is generally larger and more distinct than the north eddy. Within 500 ft of the dam, current direction can become oblique (in the horizontal plane) depending on which units are operated. Velocity vectors tend to orient north for the vector data in front of Units 7-10 and south for vector data in front of Units 1-6. Because the turbine intakes are shallow (recall, ceilings at the trashracks are about 6 ft below the surface), forebay currents likely to not have a pronounced downward component at B1.

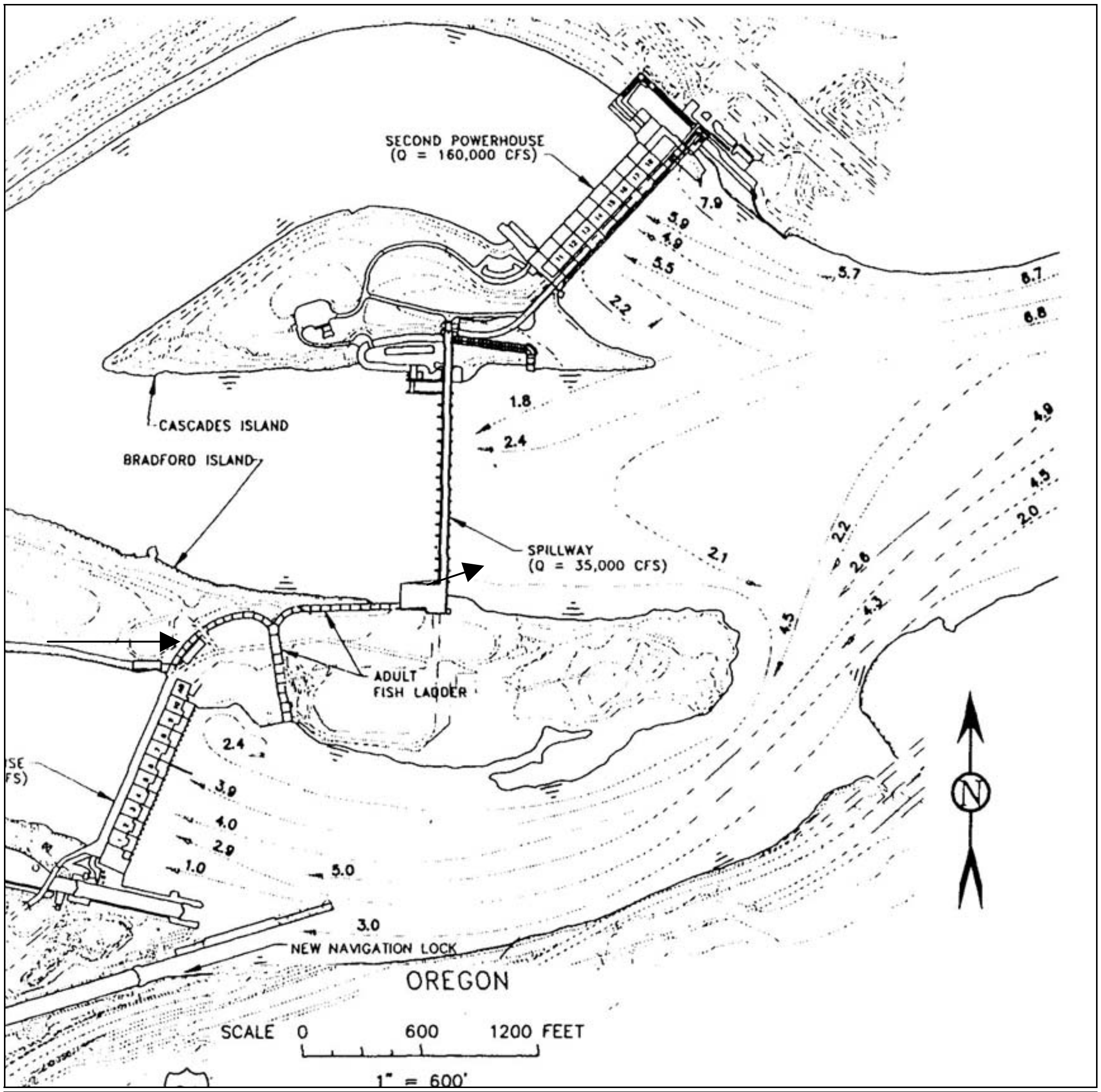

Figure 14. Example of forebay current patterns at Bonneville Dam. Velocities (fps) and directions obtained from WES 1:100 model with floats submerged to 14-ft draft. B1 Units 1-10 at 140,000 cfs, B2 Units 11-18 at 160,000 cfs, and Spill Bays 1 and 18 at 2,400 cfs and Bays 2-17 at 32,600 cfs. Total discharge 335,000 cfs. Modified from Figure 2-2 Harza and ENSR (1996b).

At B2, water generally feeds into the powerhouse from the central part of the forebay (Figure 14). As this flow encounters the powerhouse, momentum in the surface water is transferred to the south and north while deeper water continues into the turbines.

The southerly and northerly transfer of momentum causes noticeable eddies on the south and north corners of the B2 forebay, respectively. The sizes of these eddies depend on B2 powerhouse and spillway operations. In general, low spill creates the largest southern eddy and allows the approach velocity vectors at the entrance to the forebay orient more to the north. When spillway flow is increased, the southern eddy decreases in size and the approach velocity vectors orient more perpendicular to the powerhouse or even slightly to the south. For uniform turbine loading at B2, the south eddy is generally larger than the north eddy. Removal of the turbine intake extensions (TIEs) augments the surface flow that runs parallel to the B2 powerhouse. The lateral, southerly movement of surface water along the face of the B2 powerhouse toward the sluice chute and the subsequent eddy are the main hydraulic features that support use of the sluice chute as a prototype corner collector at B2.

4.3 Tailrace Current Patterns

Tailrace hydraulic conditions below each of the powerhouses and spillway are sensitive to tailwater elevation and the collective discharge at the dam. Tailwater elevation generally increases as project discharge increases. The five-year average (1994-1998) for April-August ranged between 12 and 27 ft NGVD, with a mean of 20 ft NGVD (Figure 7). At B1, the tailrace is about 2,000 ft long, extending to the tip of Bradford Island. At B2, the tailrace is about 3,700 ft long, extending to the tip of Cascades Island. B2 discharge merges with spill, then both water masses move downstream to merge with B1 discharge. Mixing of these water masses as the river progresses downstream is dependent on distribution of discharge between the spillway and two powerhouses.

In 1995, WES collected water velocity data in the field under two total river discharges, 128,300 cfs and about 283,000 cfs. Tailwater velocities (0-25 ft depth averaged) for both the 75,000 cfs and 61,000 cfs B1 powerhouse flows were about 2–4 fps. At B2, they were mostly 2–4 fps at the low flow (B2 at 59,000 cfs) and mostly 3-5 fps at the high flow (B2 at about 126,000 cfs). Also from field data, water velocities below where all three channels have merged were about 2.9-4.8 fps for a total river flow of 128,300 cfs and about 2.9-7.5 fps for about 283,000 cfs river flow. From model data for 70,000 and 485,000 cfs total discharges, water velocities (25 ft depth averaged) downstream of where all three channels have merged were about 1.5-3.6 and 2-14 fps, respectively (Figure 15, high flow). Localized tailwater velocities are highly dependent on unit operations and spill patterns.

In addition to the 1995 field data, many tailrace flow conditions have been modeled during various studies at WES (see Appendix A). These investigations included the navigation lock study, the spill pattern study, the low flow outfall study for the juvenile bypass systems at both B1 and B2, the high flow outfall alternatives study for B1, and current work on potential high flow outfalls for the B2 CC. These studies typically resulted in maps of depth averaged velocity vectors.

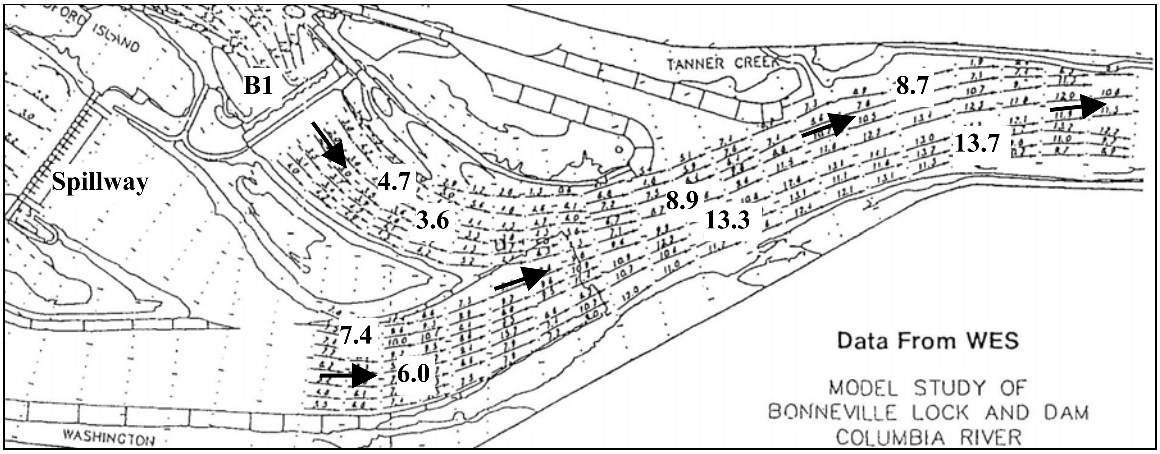

Figure 15. Example of tailrace current patterns at Bonneville Dam. Velocities (fps) and directions obtained from WES 1:100 model with floats submerged to 14-ft draft. B1 Units 1-10 at 140,000 cfs, B2 Units 11-18 at 160 kcfs, and Spill Bays 1 and 18 at 2.4 kcfs and Bays 2-17 at 182.6 kcfs, for a total of 485 kcfs. Modified from Plate 3-10 ENSR et al. (1998).

4.4 B1 PSC Hydraulics

Throughout the Portland District's surface bypass program, physical models have been used to investigate specific design elements in the development process. The physical models have also been used to obtain data for the specific purpose of integration with biological data. Whatever the original purpose, model data must be used within the context for which they were collected. Often, specific configurations modeled in the development process are not identical with those eventually biologically tested in the field. In 1998, physical hydraulic modeling was done after the field season specifically to integrate biological field data with hydraulic data. However, these data also have limitations as the hydraulic field conditions can vary (e.g., forebay elevations, turbine operations, sluiceway settings, etc.) throughout the biological test season. The configurations chosen for hydraulic modeling may represent only the average condition or a range of conditions. Hydraulic data from physical models must be applied and interpreted carefully.

In support of the surface collection program, several design elements were investigated on the B1 1:25 and 1:40 models. Limited three dimensional velocities in front of the blocked trashrack configuration were collected at the B1 1:40 model. Additionally, on the 1:40 model, three dimensional velocities were taken in the approach to the proposed 1998 PSC configuration (floor El. 25.0 ft) upstream about 50 ft and to either side about 20 ft of the slot. Also, although it has not been fully investigated, a hydraulic model of a full production surface collector has been constructed based on the Alternative A design (Harza and ENSR 1996a).

In the 1:25 sectional model, two-dimensional water velocities and flow patterns approaching, inside, and under the proposed PSC and near the blocked trashrack configurations were taken. Specific parameters such as slot widths (5 to 20 ft) and collector floor elevations (El. 25 to 57.5 ft) were investigated. Additionally, the 1:25 model was used to develop rating curves prior to the 1998 PSC test. The sluice gate configuration for the model data will result in more flow through the slot than occurred in the field. These data were later modified to estimate the velocity and flow data for the 5 ft. and 20 ft PSC openings presented in Section 3.2.2.

The B1 forebay model has also been used for "zone of influence" testing of the proposed PSC (El. 25 ft) in Units 3-6 using dye injection techniques. This testing attempted to determine the extent of the hydraulic influence (as defined by dye) of the PSC on the "working" slots, Units 3 and 5; recall, Units 4 and 6 were off-line during the 1998 test. For this test, the PSC floor was set at El. 25 ft and the slot openings on the PSC were 20 ft wide. Dye streams were used to view movement of flow. In general, researchers found that:

1. At mid-depth, the “zone of influence” extended approximately 140-160 feet upstream and 40-80 feet right (looking downstream) of each collector entrance, based on the fate of dye streams.
2. At 5 feet below the surface, the “zone of influence” extended approximately 100 feet upstream and 40-80 feet to the right (looking downstream) of each collector entrance.
3. The horizontal line of delineation of approximately 70% dye interception in the vicinity of the centerline of Unit 5 was used as an indicator of “vertical zone of influence.” It varied from about 45 ft deep within 15 ft of the collector face to 39 ft deep within 55 ft upstream, and about 31 ft deep up to about 135 ft upstream.

Another purpose for the B1 1:40 forebay model was to support a fish behavior study in the vicinity of the PSC (see Johnson et al. 1999b). The velocity data gathered from the 1:40 model were used to correlate fish movement data acquired during the 1998 test season. The hydraulic and fish behavior data will aid design of future modifications to the PSC, as well as potential prototypes or production surface bypass facilities. For this effort, the sample area was about 50 ft by 50 ft immediately in front of the PSC entrance at Unit 3. It extended from the surface to the bottom. For the present report, we used three-dimensional water velocities for the 5-ft and 20-ft PSC configurations. The plots we present, however, represent only the two-dimensional velocity vector information that is depicted in the plane of the figure.

For the 20-ft configuration, water velocity increased (accelerated) as it got closer to the PSC entrance (Figures 16 and 17). A zone of relatively low velocity in front of the PSC 3 entrance was apparent about 20 ft upstream. Velocity vectors were relatively flat in the vertical plane near the surface (upper 25 ft), but had a downward component (~30° off horizontal) in the lower part of the water column (Figure 16). Velocity magnitude was fairly uniform vertically in front of the PSC at Unit 3. In the top view of the 20-ft configuration (Figure 17), flow at the 4-m depth was oblique, directed at about a 45° angle to the south relative to the PSC. Transverse flow was observed in the model just upstream of the south side of the PSC 3 entrance. Water velocity 5-10 ft upstream of the 20-ft entrance at PSC 3 was about 1.8-3.1 fps (Figure 16). In conclusion, the main observations on water velocity for the 20-ft configuration were: (1) velocity increased as distance from the PSC entrance decreased; (2) vertically, the downward component of flow increased with both depth and proximity to the powerhouse and PSC, but velocity magnitude was fairly uniform vertically more than 20 ft upstream of PSC; and, (3) velocity vectors were noticeably oblique in the horizontal plane relative to the PSC entrances.

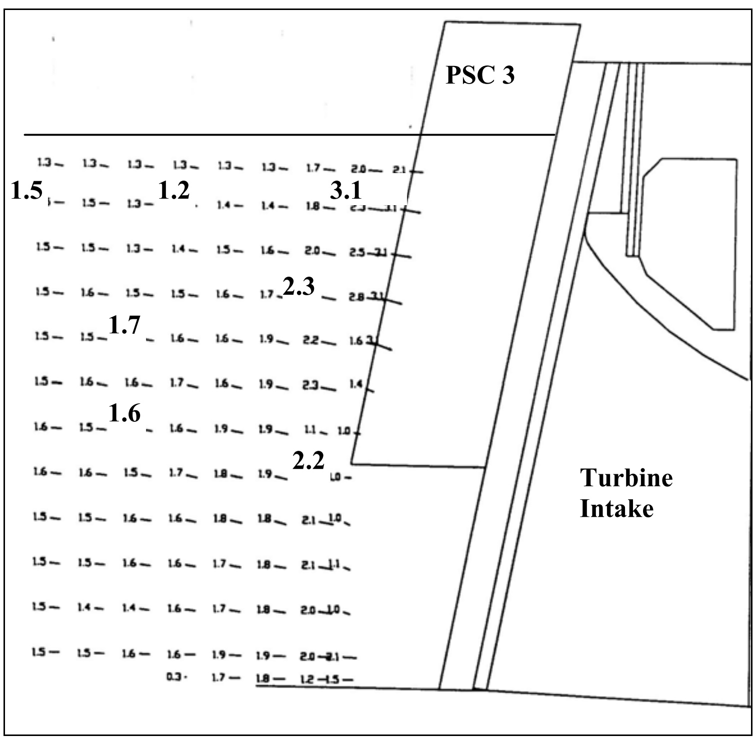

Figure 16. Side view of two-dimensional water velocities (fps) on the centerline of Unit 3 as measured in the 1:40 physical model of the PSC with the entrance 20-ft wide. Units 1-2 and 7-10 at 11.3 kcfs, Units 3 and 5 at 9.8 kcfs, and Units 4 and 6 off. Bottom of PSC was at El. 30.5 ft and pool elevation was at 74.5 ft.

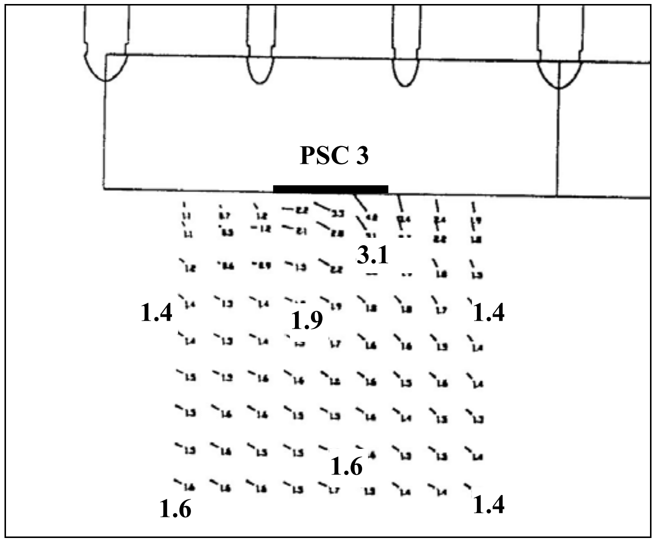

Figure 17. Top view of two-dimensional water velocities (fps) in the horizontal plane 4 m below the water surface in front of Unit 3 as measured in the 1:40 physical model of the PSC with the entrance 20-ft wide. Operations and elevations were the same as in Figure 16.

For the 5-ft configuration, water velocity decreased (decelerated) from 50 to 15 ft from the PSC (Figure 18). Then it increased (accelerated) from 15 ft away into the PSC entrance (Figure 18). The zone of relatively low velocity in front of the 5-ft PSC 3 entrance was about 30 ft deep (Figure 18). It was more prominent than the low velocity area upstream of the 20-ft entrance. Velocity vectors were relatively flat near the surface (upper 15 ft), but had a downward component (~30° off horizontal) below 15 ft deep (Figure 18). Velocity was not uniform vertically in front of the PSC at Unit 3; velocities near the bottom (~2.4 fps) were higher than those near the surface (~0.6 fps). Underneath the collector, velocity appeared to be increasing steadily as it approached the PSC. In the top view of the 5-ft configuration (Figure 19), flow at the 4-m depth was again oblique at a 45° angle to the south. Transverse flow was also observed in the model just upstream of the south side of the PSC 3 entrance, although not as strong as that for the 20-ft entrance. Water velocity 5-10 ft upstream of the 5-ft entrance at PSC 3 was about 0.6-1.8 fps. In conclusion, the main observations on water velocity for the 5-ft configuration were: (1) there was a zone of low velocity upstream of the entrance; (2) vertically, velocity vectors were relatively flat, especially in the water column above 15 ft; and, (3) velocity vectors were noticeably oblique in the horizontal plane relative to the PSC entrances.

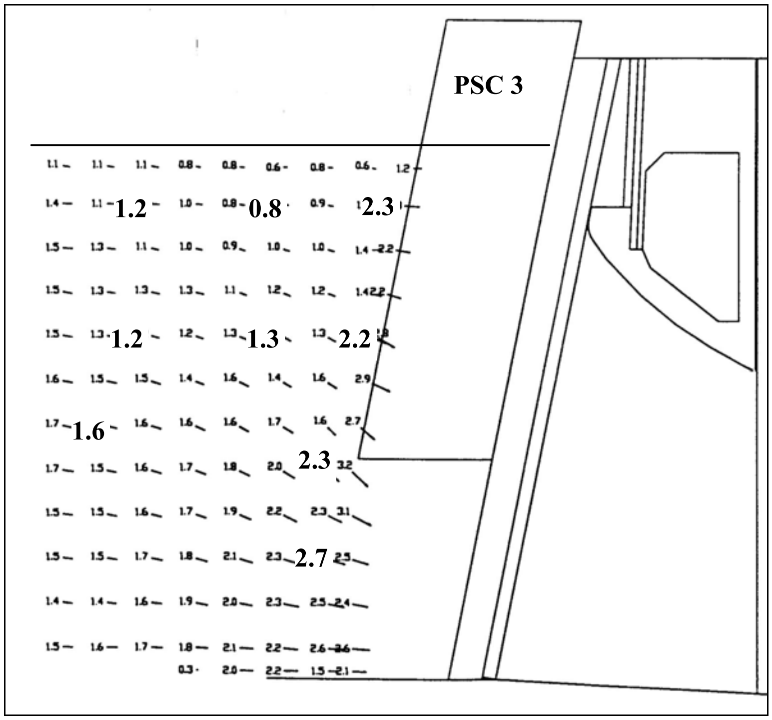

Figure 18. Side view of two-dimensional water velocities (fps) on the centerline of Unit 3 as measured in the 1:40 physical model of the PSC with the entrance 5-ft wide. Operations and elevations were the same as in Figure 16.

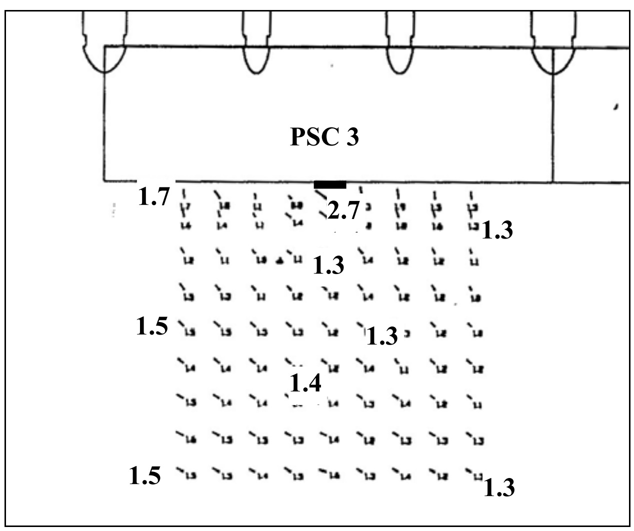

Figure 19. Top view of two-dimensional water velocities (fps) in the horizontal plane 4 m below the water surface in front of Unit 3 as measured in the 1:40 physical model of the PSC with the entrance 5-ft wide. Operations and elevations were the same as in Figure 16.

In general, we observed some differences and similarities in water velocities for the 5-ft and 20-ft configurations for the conditions studied. Approach velocity was higher for the 20-ft than 5-ft configuration, although mean entrance velocities at the PSC slot were higher for the 5-ft than 20-ft. The 5-ft and 20-ft entrances had zones of relatively low velocity in front of the PSC 3 entrance. Downward velocity components become pronounced deeper in the water column for the 20-ft than the 5-ft. However, given the particular turbine operations for the 1998 studies, both configurations had southerly oblique flow upstream of PSC 3.

4.5 B2 PCC Hydraulics

The following discussion focuses on hydraulics at the PCC entrance. Note that it was difficult to collect velocity data near the PCC entrance in both the field and the model due to complex hydraulics that developed through the southern eddy and the transverse southern flow along the B2 powerhouse. From qualitative observations, hydraulics in the area were fairly unsteady with eddies and boils appearing sporadically. The zone of presumed influence of the PCC was assessed using dye traces during brief observation of the model, not thorough testing, by INCA et al. (1997). It was about 200 ft into the forebay with the weir gate at El. 68 ft and approximately 900 cfs PCC flow. "Zone of influence" of the PCC was investigated further by WES during preliminary dye testing on the 1:40 model. This work focused on 2 areas: Local – an area 40-200 ft upstream of the collector and up to 120 ft to the north towards the center of the powerhouse; and Lateral -- an area parallel to the powerhouse up to 200 ft upstream. Generalized conclusions were:

- TIE removal seemed to increase dye capture into the PCC laterally to the north.
- Increasing sluice Q by lowering the gate affected mid depth flows by increasing local dye capture.
- Increasing powerhouse flows tended to decrease local dye capture at mid depth but appears to increase the lateral extent of dye capture to the north.

Limited water velocity measurements were available from physical model (1:40 general) or field work in the forebay near the PCC entrance. With the weir at El. 61 ft and forebay at El. 73 ft, calculated flow was about 2,800 cfs. Entrance velocity varied by depth; they were faster than shown at El. 67 and 70 ft and less for El. 64, 61, and 58 ft. Overall, entrance velocities ranged from 9 to 25 fps (e.g., Figure 20).

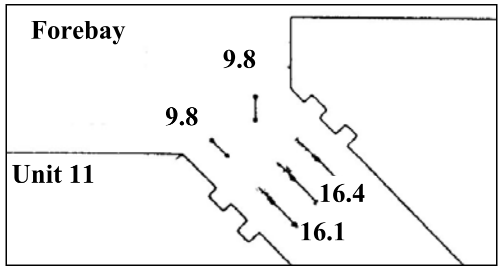

Figure 20. One-dimensional spot velocities (fps) as measured at the B2 PCC entrance in the 1:40 physical model at WES. Weir gate was at El. 61 ft, forebay was at El. 73 ft, and calculated PCC flow was at 2,800 cfs.

During model investigations, it was observed that distinctive hydraulic patterns developed with and without turbine intake extensions (TIEs). With the TIEs removed, lateral movement across the face of the powerhouse was smooth with minimal disruption before encountering the "zone of influence" of the collector entrance. With the TIEs installed, significant amounts of dye become entrained in eddies between adjacent TIEs and general turbulence levels increased. This was evident in 1998 when removal of half the TIEs in 1998 made possible the hydroacoustic evaluation of the PCC, as reported in Section 5.6.

Other B2 hydraulic model data are available from the Portland District for the interested reader. From the Bonneville 1:100 model, other B2 data include three tailwater scenarios in the near-B2 tailrace collected during low flow (100 kcfs and 110 kcfs total river discharge). From the B2 1:40 model, other data include: (1) dye injections to study the sensitivity of "zone of influence" of PCC to various scenarios (TIEs in/out, powerhouse operations, intake extensions, gate elevations, etc.); (2) one-dimensional spot velocities along centerline of chute at El. 71.25 ft; (3) one-dimensional spot velocities in front of Unit 11 at El. 71.25 ft at a horizontal plane location in the estimated zone of maximum transverse velocity; (4) rating curves for El. 52 and El. 42 ft; and, (5) one-dimensional spot velocities at various elevations at the entrance of PCC for gate El. 61 ft.

INCA et al. (1997) described hydraulics of the existing PCC conveyance channel and outfall (see summary data in Table 4). For conditions similar to those tested in 1998 (gate at El. 61 ft, forebay at El. 75 ft, approximate discharge 3,000 cfs), the impact velocity on the sluice chute floor was about 50 fps. Velocity at the outlet point was about 40 fps. Entry velocity for a tailwater El. 10 ft was about 53 fps. Under these conditions, the Cascades Island bank at the sluice chute outfall has noticeably eroded during PCC operations in 1996, 1997 and 1998. The following improvements are planned in the PCC's conveyance channel and outfall to produce a more fish-friendly passage route; (1) install an ogee insert at the weir gate to eliminate the free-fall to the floor of the chute; (2) slope the chute floor to minimize stranding when it is dewatered; and, (3) extend the outfall away from the Cascades Island bank to get better outfall pool and egress conditions. Engineering for a new B2 PCC conveyance channel and outfall is underway.

Table 4. B2 PCC hydraulic data from INCA et al. (1997).

PHASE 0 Gate at el 61.0								
	Crest Gate Overflow Computations							
Gate elev	61	(ft msl)						
Forebay =	75	(ft msl)						
Intake floor elevation=		52	(ft msl)	Sluice floor elevation=	29	(ft msl)		
Upstream intake width		30	(ft)	Intake entrance length	17.5	(ft)		
Gate width	15	(ft)		Forebay floor elevatio	-30	(ft msl)		
Gate width/entrance width =			0.5					
Gate width effective = G.W. + .01			15.01	(King and Brater)				
Head effective = Head + .003'			14.003	(King and Brater)				
P/H = (gate el.-intake floor el.)/Head effective				0.64				
Discharge coefficient effective =			3.84	(COE HDC 122-1/2)				
Discharge = $Ce^*We^*(He^{3/2})$			3020	(cfs)				
Critical depth ycritical			10.79	(ft)				
Critical velocity Vcritical			18.64	(fps)				
Plunge distance to sluice floor =			37.40	(ft)	(Gate elev + 1/2 ycrest - sluice floor el)			
Vertical comp. of plunge velocity			49.07	(fps)				
Resultant plunge velocity =			52.50	(fps)	(IMPACT VELOCITY ON SLUICE FLOOR)			
Resultant angle of impact (to hor.			69	(degrees)				
Station of impact point =			188.59					
Initial depth at impact =			3.83	(ft)				
Impact point Froude #	4.725386							
Bulked depth =	4.58	(ft)	(Plate 4-1, EM1110-2-1603)					
Bulked discharge (air+water) =			3604	(cfs)				
USE RESULTANT VELOCITY AND BULKED DEPTH								
FOR PROFILE COMPUTATION								
	Tailwater Plunge Impact Computations							
Tailwater elevation lo	10	(ft msl)						
Tailwater elevation hi	35	(ft msl)						
Depth at outfall	6.024833	(ft)						
Velocity at outfall	39.87697	(fps)						
Plunge dist. (max) to tailwater =			19.00	(ft)				
Vertical comp. of plunge velocity			34.98	(fps)				
Resultant plunge velocity =			53.05	(fps)				
Resultant angle of impact (to hor.			41	(degrees)				
Station of impact point =			-43.32	(ft beyond outfall)				

4.6 Bonneville High Flow Outfall Model Research

Hydraulic investigations for high flow (> 1,000 cfs) outfalls were conducted at WES using the Bonneville 1:100 scale general model (ENSR et al. 1998). Currently, outfall studies are planned or underway for B1 and B2 that build upon this work (e.g., see research plan for high flow outfalls in Johnson et al. 1999a). One purpose of the ENSR et al. (1998) study was to determine potential outfall locations associated with surface bypasses at B1. With the high volume of water anticipated for a B1 surface bypass (~15,000 cfs), hydraulic investigations were needed to assess optimum location(s) to deposit fish so that they quickly egress downstream. The modeling effort was intended to cover a range of outfall locations (mid-channel, shoreline, etc.). Thirty-five different scenarios using different combinations of outfall sites, powerhouse flows, total river flows and flow distributions among B1, B2, and the spillway were qualitatively investigated using dye plumes. From these preliminary model investigations, four locations were identified at B1 (ENSR et al. 1998).

1. The north side of Bradford Island near the spillway tailrace.
2. The tip of Bradford Island. This site was selected to take advantage of the existing topography on Bradford Island to allow at-grade construction.
3. A mid-channel site. The attractive feature of this site was that its location in mid-channel and alignment with mean flow direction made its performance relatively insensitive to variation in project operations.
4. The old navigation lock entrance channel site. This site provided the shortest length of the outfall alternatives. Observations on the model indicated it provided reasonable performance under limited variations in project operations.

4.7 Hydraulic Data Gaps

From the available data, we identified the following gaps in the hydraulic information base regarding surface bypass at Bonneville Dam.

- A central archive of existing model results apparently does not exist. Technical reports, memoranda-for-the-record, and trip reports from previous physical model work at WES should be part of the data archive.
- For the purpose of surface bypass development, it is not clear whether adequate hydraulic data have been collected and compiled for B1 and B2 forebays, PSC and PCC entrance vicinities, and B1 and B2 tailraces. This is important to understand PSC and PCC performance data and to aid design of the PCC outfall.
- Computational fluid dynamics (CFD) models for the B1 and B2 forebays and tailraces are not yet available. In addition, CFD models would be useful to improve

design efficiency, decrease data turn-around time, select operational scenarios for field tests, and integrate hydraulic and biological data sets. The available hydraulic data are essentially snapshots of certain conditions, to make more global inferences, a CFD model may be necessary.

- Quantitative integration of hydraulic and biological data has not been extensively conducted. A team of fish passage biologists and fisheries hydraulic engineers should perform this work.

5.0 Summary of Biological Data

Research on surface routes for smolt passage began at Bonneville Dam in 1969. With the advent of intake screens (e.g., STSs) in the 1980s, however, surface bypass research was abandoned. In 1995, the Corps re-initiated surface bypass research as interest in the approach grew regionally, and the STS bypass systems failed to meet expectations. Eleven biological studies directly related to surface bypass at Bonneville Dam have been performed over the last four years (Table 5). Evaluation techniques have included balloon tags, electrofishing, mobile and fixed hydroacoustics, mobile and fixed radio telemetry, and underwater video. In this section, we review that collective information, with emphasis on implications to surface bypass design and prototype performance at both powerhouses.

5.1 Sluiceway Research at B1 in the 1960s, 1970s, and 1980s

Three decades ago, Michimoto and Korn (1969) investigated the potential for passing smolts through the B1 sluiceway. Using mark-recapture techniques, they observed that sluiceway passage was higher during day than night. They estimated that hundreds of thousands of smolts passed the dam via the sluiceway. It was surmised that many more would have passed through the sluiceway had its flow been maximized at 1,500 cfs instead of 832 cfs necessary for their sampling operations. Michimoto and Korn (1969) concluded that sluiceway passage was more similar to spillway passage than turbine passage because of the hydraulic and physical characteristics of each passage route. They recommended full-time B1 sluiceway operation at 1,500 cfs during the downstream migration period.

Two decades ago, Uremovich et al. (1980) found that juvenile salmonid passage in spring and summer at the B1 sluiceway was significantly ($P < 0.01$) higher with “split” gates (4B, 6B, 7A, 10C) than with “adjacent” gates (6A, 6B, 6C). They observed highest concentrations of fish in gatewells where the intakes are near or adjacent to walls (6B, 7A, and 10C). This suggested that forebay walls or shorelines, and possibly associated vortices or eddies, might serve to guide and concentrate smolts.

Table 5. Biological studies related to surface bypass during 1995-1998 at Bonneville Dam.

	B1						B2			
Year	F-bay	Phs	Sluice	PSC	T-race	Spillway	F-bay	Phs	Sluice	T-race
1995			BAL [8]	n/a		BAL [8]			BAL [8]	
1996	MHA [9], MRT [5,7], EL [7]	FHA [9], FLRT [5,7]	FHA [9], FLRT [5], VID [9]	n/a	FLRT [11], MRT [11]	FLRT [5]	MHA [9], MRT [5,7], EL [7]	FHA [9], FLRT [5,7]	FHA [9], FLRT [5], VID [9]	FLRT [11], MRT [11]
1997	MHA [1], MRT [3]	FLRT [3]		n/a		FHA [1], FLRT [3]	MHA [1], MRT [3]	FHA [1], FLRT [3]	FHA [1], FLRT [3]	
1998		FHA [10], FLRT [2,4], FURT [2,4]		FHA [6,10], FLRT [2,4], FURT [2,4]		FLRT [2,4]		FHA [10], FLRT [2,4], FURT [2,4]	FHA [10], FLRT [2,4]	

<u>Key:</u>

BAL = Balloon tags
EL = electrofishing
FHA = fixed hydroacoustics
FLRT = fixed aerial radio telemetry
FURT = fixed underwater radio telemetry
MHA = mobile hydroacoustics
MRT = mobile radio telemetry
VID = video

<u>References:</u>

1. BioSonics, Inc. 1998 (Final 1997 mobile HA study)
2. Hansel et al. 1998. (Preliminary subyearling RT report 1998 Nov 6)
3. Hensleigh et al. 1999 (Final 1997 RT study)
4. Hensleigh et al. 1998. (Preliminary yearling RT report 1998 Sep 11)
5. Holmberg et al. 1996. (Draft 1996 RT study)
6. Johnson, R. L. et al. 1999 (Final 1998 Mbeam study at PSC)
7. Knutsen and Reeves 1996. (1996 predation study)
8. Normandeau et al 1996 (Oct. 1995 balloon tag study)
9. Ploskey et al. 1998b (Final 1996 HA study)
10. Ploskey et al. 1998a (Draft 1998 HA study)
11. Snelling and Mattson 1996. (Draft 1996 tailrace RT study)

Willis and Uremovich (1981) continued sluiceway research at B1 in 1981. Their goal was to provide estimates of sluiceway efficiency under their proposed optimum operating conditions. Fisheries managers considered this information when they decided which smolt bypass alternative was preferred (STS, sluiceway, or both). Willis and Uremovich (1981) found that passage per sluice gate at 6B and 7A, respectively, was 6.1 and 3.7 times higher at full flow (~475 cfs per gate) than at half flow (~240 cfs per gate). This implied that "fish attraction" was positively related to the amount of water entering a sluice gate. They estimated sluiceway bypass efficiencies (sluice passage divided by total powerhouse passage) to be 83% for steelhead, 58% for yearling chinook salmon, 50% for coho salmon, 42% for sockeye salmon, 10% for subyearling chinook salmon "migrating naturally", and 4% for hatchery subyearling chinook salmon. Given these results, Willis and Uremovich (1981) recommended the sluiceway at B1 be operated in conjunction with a STS bypass system. They felt a "hybrid" system would reduce delay and decrease turbine passage over either the STS or sluiceway as a stand-alone smolt bypass. A combination of sluiceway and STS has been operated routinely at B1 since the early 1980s.

Collectively, the early sluiceway research demonstrated that surface routes would pass appreciable numbers of smolts at B1. However, fisheries managers felt the sluiceway system was inadequate as a stand-alone system because intake flow was limited to about 2,100 cfs, and conveyance and outfall conditions needed improvement. This remains the case today.

5.2 Sluice Chute Research at B2 in the 1980s

INCA et al. (1997) summarized research conducted in the 1980s at the B2 sluice chute with respect to its potential as a surface bypass. Studies by Nagy and Magne (1986), Magne (1987a,b), Magne et al. (1989), and Stansell et al. (1990) documented that the B2 sluice chute passed substantial numbers of juvenile salmonids. None of these studies, however, was able to make a direct estimate of sluice chute efficiency (i.e., sluice chute passage relative to passage elsewhere at the B2 powerhouse) because of sampling difficulties. Clearly the potential was evident, but questions remained regarding forebay collection, conveyance, and outfall conditions. There was a hiatus in research on this topic between 1989 and 1995. In 1995 research efforts were renewed with establishment of the surface bypass program for Bonneville Dam.

5.3 Baseline Biological Data for Bonneville Dam in 1995-1998

Giorgi and Stevenson (1995) reviewed biological literature pertinent to surface bypass development at Bonneville Dam. They concluded that available biological information was not adequate to design and locate surface collector prototypes there. Specifically, information on the vertical and lateral distributions of smolts in forebay areas of both powerhouses and spillway was very limited. Therefore, beginning in fall 1995, baseline biological data were collected on migration pathways, forebay residence time, fish passage, fish distribution, fish injury at sluiceway outfalls, smolt movements in the tailraces, and predation. These data were used in the design process for the surface bypass prototypes at B1 and B2.

5.3.1 Migration Pathways

Smolt distribution in the narrow river channel between the Bridge of the Gods and Boat Rock was somewhat species-specific and always variable depending on river conditions (e.g., Hensleigh et al. 1998). Yearling chinook salmon and steelhead were generally distributed in the southern portion of the channel (Figures 21 and 22). Subyearling chinook salmon tended to migrate in the northern portion of the channel (Figure 23). Most radio-tagged smolts moved quickly downstream to Boat Rock where they branched into the three main forebay regions of Bonneville Dam. Lateral smolt distribution on approach to Bonneville Dam influenced whether the ultimate passage route was B1, the spillway, or B2 (e.g., Hensleigh et al. 1998).

In 1996, 1997, and 1998, investigators coupled data describing location of radio-tagged smolts upstream of Boat Rock with data identifying the location these tagged fish passed the dam (Holmberg et al. 1996, Hensleigh et al. 1998 and 1999, Hansel et al. 1998). Fish distributed to the south side of the channel were likely to pass the dam at B1 or the spillway (e.g., Figures 21 and 22). Fish distributed to the north side of the channel were likely to pass the dam at B2 or the spillway.

Migration pathways at Bonneville Dam may be summarized by data on the proportion of radio-tagged fish using B1, spillway, or B2 (Table 6). In 1996-1998, proportionately more fish passed over the spillway than through either B1 or B2. This was likely due to the relatively high river flows and the level of spill in these years. It may be possible to have different species composition at B1 and B2 prototype surface bypasses depending on species-specific approach patterns.

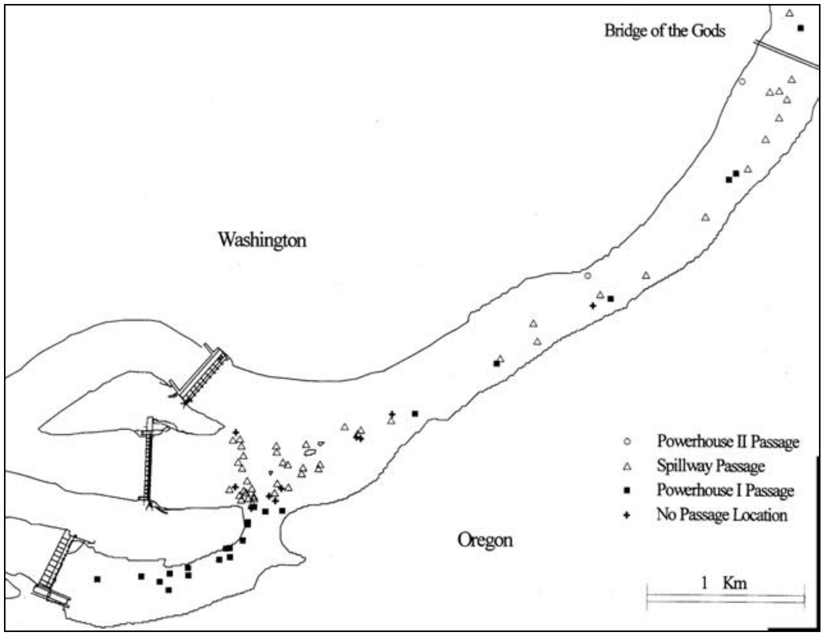

Figure 21. Approach locations and final passage routes of 70 radio-tagged hatchery steelhead at Bonneville Dam in spring 1997. During the study, flows were about 80 kcfs at B1, 110 kcfs at B2, and 100-365 kcfs at the spillway. Data are from Hensleigh et al. (Figure 17, 1999).

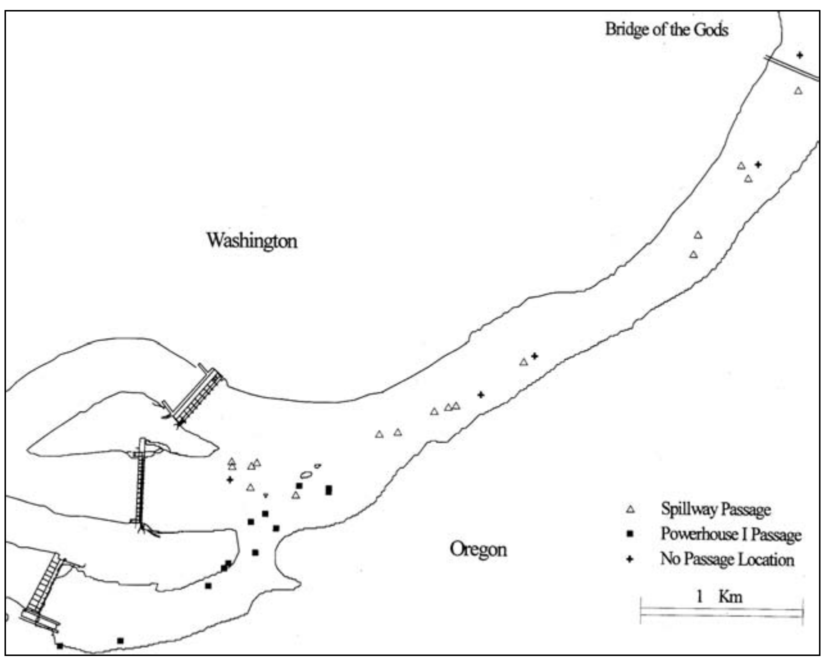

Figure 22. Approach locations and final passage routes of 46 radio-tagged yearling chinook salmon at Bonneville Dam in spring 1997. Spring 1997 flows were as described in Figure 21. Data are from Hensleigh et al. (Figure 18, 1999).

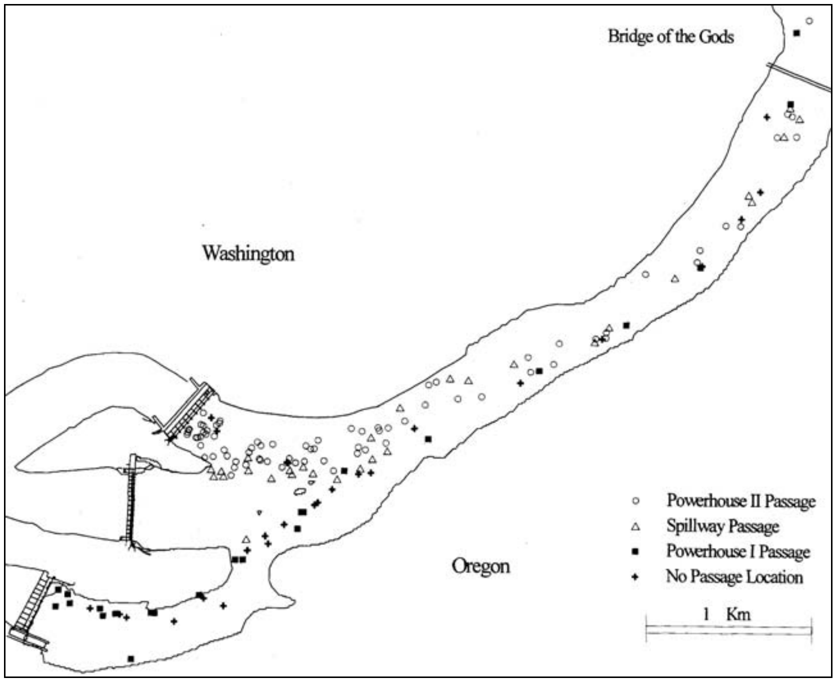

Figure 23. Approach locations and final passage routes of 77 radio-tagged subyearling chinook salmon at Bonneville Dam in summer 1997. During the study, flows were about 80 kcfs at B1, 110 kcfs at B2, and 85-120 kcfs at the spillway. Data are from Hensleigh et al. (Figure 19, 1999).

Table 6. Numbers and proportions of radio-tagged fish using the three migration pathways at Bonneville Dam (B1, spillway, B2) in 1996-1998 studies. Data based on "last contact" from Holmberg et al. (1996), Hensleigh et al. (Table 13, 1999), Hensleigh et al. (Table 8, 1998), and Hansel et al. (Table 4, 1998).

		Number				Proportion		
Species	Year	B1	Spillway	B2	Total	B1	Spillway	B2
CHIN 1	1996	48	152	47	247	0.19	0.62	0.19
	1997	37	158	15	210	0.18	0.75	0.07
	1998	139	194	137	470	0.30	0.41	0.29
	Combined	224	504	199	927	0.24	0.54	0.21
STEEL	1997	79	233	10	322	0.25	0.72	0.03
	1998	175	192	135	502	0.35	0.38	0.27
	Combined	254	425	145	824	0.31	0.52	0.18
CHIN 0	1996	34	51	43	128	0.27	0.40	0.34
	1997	52	53	101	206	0.25	0.26	0.49
	1998	108	218	102	428	0.25	0.51	0.24
	Combined	194	322	246	762	0.25	0.42	0.32
All	Combined	672	1251	590	2513	0.27	0.50	0.23

5.3.2 Forebay Residence Times

Smolts appear to migrate fairly quickly through the forebay and Bonneville Dam. In 1996, 1997, and 1998, mean forebay residence times of radio-tagged fish were short (< 1 h) (Table 7). Most fish did not delay at the dam. High flows in the three study-years may have influenced this behavior. Residence times varied between spring and summer migration seasons. There were shorter residence times in spring than summer 1997 because radio-tagged fish displayed less lateral movement in spring than summer (Hensleigh et al. 1999). Similar patterns were observed at B1 and B2.

Table 7. Mean residence times (h) of radio-tagged fish at Bonneville Dam in 1996, 1997, and 1998. Data are from Holmberg et al. (1996) and Hensleigh et al. (Table 14 hatchery steelhead 1997, Table 9, 1998), and Hansel et al. (Table 5, 1998).

Species	Year	B1	Spillway	B2	Overall
CHIN 1	1996	n/a	n/a	n/a	0.3
	1997	0.2	< 0.1	0.3	0.1
	1998	8.1	1.0	2.3	3.5
STEEL	1997	0.6	0.1	2.1	2.6
	1998	11.8	3.1	6.3	6.9
CHIN 0	1996	n/a	n/a	n/a	1.7
	1997	3.2	0.8	2.5	2.2
	1998	6.0	0.9	4.8	3.3

5.3.3 Vertical Distribution

In spring and summer 1996 and 1997 at B1 and B2, researchers used mobile hydroacoustics to study forebay vertical distributions. Vertical distribution varied between B1 and B2, day and night, spring and summer, and study-years (Ploskey et al. 1998b and BioSonics 1998). At B1, vertical distribution at B1 was generally 5-18 ft deeper than at B2 (Table 8). This might be due to the deeper bathymetry at B1 than B2. Fish were distributed deeper during day than night, except during spring 1996 (Table 8). This is contrary to typical behavior observed at mainstem dams, which is for fish to be deeper at night than day (e.g., Thorne and Johnson 1993). Spring migrants were generally distributed deeper than summer migrants, especially in 1997 (Table 8).

Table 8. Vertical distribution expressed as approximate depth (ft) of the uppermost 80th percentile. Data are from mobile hydroacoustic transects 30-60 ft from the dam in spring and summer 1996 by Ploskey et al. (1998b) and 1997 by BioSonics (1998).

Year	Season	Powerhouse	Day	Night
1996	Spring	B1	39	43
		B2	34	67
	Summer	B1	46	23
		B2	30	23
1997	Spring	B1	69	59
		B2	69	59
	Summer	B1	36	30
		B2	28	23

Vertical distribution can change as fish get closer to each powerhouse. Ploskey et al. (1998b) noted that the depth of the 80th percentile was 6-17 ft shallower at transects 30-60 ft from B1, than at transects 150-225 ft from the dam. On the other hand at B2, Ploskey et al. (1998b) noticed that vertical distribution in the forebay at night got deeper the closer one got to the dam (80th percentile had a 21 ft change). They surmised this was probably due to rapid increases in forebay depth near B2 and increasing downward currents. BioSonics (1998) observed that vertical distribution shifted downward in both B1 and B2 forebays as they got closer to the powerhouses in spring 1997, but the opposite was true in summer 1997. Thus, vertical distributions changed as smolts neared the powerhouses, but this change was variable seasonally and annually with no consistent trend.

5.3.4 Horizontal Distribution

In 1996, Ploskey et al. (1998b) studied horizontal distribution with mobile and fixed hydroacoustics surveys at both powerhouses. In 1997, BioSonics (1998) and Hensleigh et al. (1999) applied mobile hydroacoustic and radio telemetry techniques, respectively. The following horizontal distribution data reflect trends in where fish were actually located at the dam. They have not been adjusted for turbine operations. Most available units at Bonneville Dam, however, were on in spring 1996 and 1997.

In 1996 at B1, baseline data on fish distributions from mobile hydroacoustics in the B1 forebay indicated that highest average fish densities occurred upstream of Units 4-6 in spring and upstream of Units 4-6, 8, and 9 in summer (Ploskey et al. 1998b). These data supported the location of a prototype surface collector in the central part of B1.

In 1997 at B1, fish tended to concentrate in the forebay of the central and northern sections of the dam (BioSonics 1998), confirming the finding by Ploskey et al. (1998b).

Similarly, Hensleigh et al. (1999) reported a proportionately high number of contacts of radio-tagged fish in the same region of the B1 forebay, which may reflect a concentration of fish there since residence times were short (Table 7).

In 1996 at B2, smolt densities were highest at the south end of the forebay (Ploskey et al. 1998b). Fish passage rates were significantly higher at the sampled intakes at Units 11, 12, 13, and 18 than the others. These data indicated that the south end of the powerhouse where the sluice chute is currently located is, in general, an appropriate location for a surface bypass because of the horizontal concentration of fish there. Furthermore, they observed dense concentrations of smolts near the face of B2, suggesting that large numbers of smolts should encounter a corner collector entrance at its current location next to the powerhouse.

In 1997 at B2, fish density was high in the south eddy (BioSonics 1998), as observed by Ploskey et al. (1998b) in 1996. The distribution of radio-tagged subyearling chinook salmon in the B2 forebay in 1997 appeared to shift to the south toward the sluice chute when it was open (Hensleigh et al. 1999).

5.3.5 Diel Distribution

In 1996, for the run-at-large, hourly passage in-turbine at B1 and B2 was variable (Ploskey et al. 1998a). At Sluice Gate 5B, however, passage was predominately at night in spring and summer. As generally reported for radio telemetry data, hydroacoustic data showed highest passage rates during night hours.

In 1997 and 1998, Hensleigh et al. (1998 and 1999) observed the following diel passage peaks for radio-tagged fish released at Bonneville Dam: hatchery steelhead (1900-0100 h) and yearling chinook (1900-2300 h). Hensleigh et al. (1999) noted subyearling passage was primarily in the evening in 1997 (2000-2300 h). Hansel et al. (1998), however, noted that radio-tagged subyearling chinook passed the dam mostly in late afternoon and evening (1500-2400 h). We do not know if these data were affected by release time. For radio-tagged fish released at or above John Day Dam, diel passage at Bonneville Dam was uniform.

5.3.6 Fish Injury at the B1 and B2 Sluiceway Outfalls

Normandeau et al. (1996) used balloon tags at the sluiceways at B1 and B2 to study injury and mortality rates for hatchery yearling chinook salmon (n = 100 each). Control fish were not included in these preliminary investigations conducted in October 1995. B1 sluice discharge was about 200-300 cfs, while B2 sluice discharge was about 650 cfs. At the B1 sluice outfall, 7 of 100 fish were not recaptured, and 4 of the 7 were probably preyed upon based radio-tracking information. The authors noted that predation did not seem to be a problem during their October study at the B2 sluice outfall. Injury rates were low at both sluices (1 of 93 recaptured fish and 1 of 90 at B1 and B2, respectively).

5.3.7 Smolt Movement in the B1 and B2 Tailraces

Snelling and Mattson (1996) radio-tagged yearling and subyearling chinook salmon and released them below Bonneville Dam at existing and proposed outfall sites in 1996. These fish generally migrated directly downstream in the main channel. However, about 10% of the fish released from B2 tailrace and the proposed outfall site (2 miles downstream) used side channels. This nearly doubled their travel time. About 25% of the subyearlings released at existing outfall locations were apparently eaten by piscivores. Holding was infrequent; only 3% of the yearlings and 6% of the subyearlings held or otherwise delayed their migration. Travel times were relatively quick through the study area (6-13 km/h; Tables 9 and 10 in Snelling and Mattson 1996). The authors noted that smolt behavior downstream of Bonneville Dam may be different in a “normal” or low flow year than it was during their 1996 study, a high flow year.

5.3.8 Predation in Forebays and Tailraces of Bonneville Dam

Predation in the B1 and B2 forebays is a concern wherever smolts can become concentrated, such as at a surface bypass entrance. The B1 forebay is notorious for high concentrations of predators, especially the northern pikeminnow (*Ptychochelus oregonensis*). Uremovich et al. (1980) concluded that substantial numbers of juvenile salmonids were lost to predators in the B1 forebay, especially in August.

Knutsen and Reeves (1996) radio-tagged 60 northern pikeminnow and tracked them from April to August 1996. Frequency of contacts was highest at the northern end of B1. This is where smolts are known to congregate (e.g., Holmberg et al. 1996 and Ploskey et al. 1998b), the forebay is relatively shallow, and currents are variable due the Bradford Island shoreline and the wing wall between Units 6 and 7. Some radio-tagged pikeminnow moved downstream through the dam, while others moved upstream. Tagged-predators were contacted near areas where smolts were known to be present, e.g., bypass outfalls in the B1 and B2 tailraces. Knutsen and Reeves (1996) felt that predator distribution should be monitored in future surface bypass studies at Bonneville Dam because predators could influence the distribution of smolts, thereby affecting surface bypass performance.

In the B1 and B2 tailraces, smolt predation occurs in the powerhouse turbine boils and turbine screen bypass and sluiceway outfalls. Uremovich et al. (1980) found that frequency of salmonids in pikeminnow foreguts was similar for fish caught in forebay and tailrace of B1. Relative survival studies at Bonneville Dam in the early 1990s also indicated the presence of tailrace piscivores.

5.3.9 Summary of Baseline Studies in 1995-1998

To summarize, the baseline studies in 1995-1998 provided pertinent data for surface bypass development at Bonneville Dam. The reports showed that:

- Smolt distribution in the channel upstream of Boat Rock influenced whether smolts migrated into B1, spillway, or B2 forebays.
- Residence time in the forebays was generally brief (< 1 h), which indicates smolts were actively migrating downstream and did not appreciably delay at the dam.
- Vertical distribution, while generally surface-oriented, was variable across seasons and years. There was no consistent pattern seen in the 1996 and 1997 mobile hydroacoustic survey data.
- Horizontal distribution data revealed concentrations of smolts upstream of Units 4-6 and Units 7-10 at various times at B1 and upstream of Units 11-13 in the south eddy at B2. Surface bypasses could be strategically spaced in these areas.
- Diel passage data were variable among species. Generally, there was a trend toward higher night than day passage.
- Preliminary smolt injury/mortality data from the B1 and B2 sluice outfalls were encouraging, but further injury/mortality research is necessary to develop high flow B1 and B2 surface bypasses.
- Smolt egress in the tailrace was relatively fast in 1996 (6-13 km/h), a high flow year. Egress, however, will have to be monitored in future surface bypasses at Bonneville Dam.
- The baseline data from the surface bypass program at Bonneville Dam in 1995-1998 provide a foundation for development of prototype structures. The baseline biological data are broad in scope, comprehensive, and relatively well reported.

5.4 Evaluation of the Trashrack Blockages below the B1 Sluiceway in 1996

In 1996, trashracks at Units 3 and 5 of B1 were blocked to El. 33 ft (about 42 ft deep) and sluiceway gates at 3B and 5B were opened. This produced a flow of approximately 750 cfs per gate (assuming forebay El. 75.0 ft). The purpose of the blockage or occlusion was to intensify and deepen the “zone of separation” between turbine flow and surface sluiceway flow in an attempt to increase sluiceway fish passage. The hypothesis was that smolts would avoid a region of rapidly changing flow characteristics, stay surface-oriented, and thereby pass into the sluiceway.

The primary results of the evaluation of trashrack blockages at B1 in 1996 come from fixed hydroacoustics. Too few radio-tagged fish were present in the area of interest during the experimental treatments to provide meaningful radio telemetry estimates of passage. Blocking in spring increased sluiceway passage at Gate 3B by 14.6% and at Gate 5B by 12.8%; however, neither increase was statistically significant because the tests lacked sufficient statistical power (Ploskey et al. 1998b). In summer 1996, blocking did not significantly increase sluice passage or sluice passage efficiency (Ploskey et al. 1998b).

Split-beam transducers aimed upward about 10-15 ft upstream of Gates 3B and 5B were used to monitor direction of fish movement. A ratio of upward-moving to downward-moving fish was used to characterize effects of the blockages. A ratio near 1 implies no effect, >>1 implies a positive effect, and <<1 implies a negative effect. In front of Gate 3B, the ratio of upward-moving the downward-moving fish was significantly greater with the blockages in (mean ratio 4.0) than with them out (mean ratio 1.9). No significant difference is the upward:downward ratio was found at Gate 5B.

In general, ratios of mean sluice passage rates with and without blockages were 4.8 for Gates 3B and 5B pooled, 6.8 for Gate 3B, and 2.2 for Gate 5B (Ploskey et al. 1998b). The same ratio for turbine passage at 3B and 5B pooled was 0.56 (Ploskey et al. 1998b). Daily passage was highly variable, which affected ability to statistically detect differences in passage with and without blockages.

In conclusion, the experiment with trashrack blockages at B1 in 1996 did not reveal negative impacts from the blockages. At Gates 3B and 5B, passage into the sluiceway increased and passage into the turbine decreased, or it was unchanged. Trashrack blockages should be investigated further at dams where enhancing sluiceway passage is a priority.

5.5 Evaluation of the Prototype Surface Collector at B1 in 1998

The PSC was designed to provide a structure to study entrance hydraulics and to test the efficacy of surface bypass at B1. Preliminary and final data were available from radio telemetry, fixed-location hydroacoustic, and multi-beam hydroacoustic studies of the PSC in 1998. The radio telemetry data indicated that 37% of steelhead, 32% of yearling chinook, and 48% of subyearling chinook were detected within 30 ft (detection range of underwater radio telemetry antennas on PSC) of the PSC entrances out of all radio-tagged fish that entered the forebay (Table 9). Fish within 30 ft, however, may not have discovered the PSC flownets because of the oblique flows. These percentages represented maximum possible discovery efficiencies (#discovering PSC flownets/total entering B1 forebay) if all fish within the 30-ft detection were in a PSC flownet.

Entrance efficiency (#entered/#within a PSC flownet or “available”) is a useful parameter to assess PSC performance. Although we do not have perfect data for the denominator (number of fish within PSC flownets) we can use number of fish detected within 30 ft of the entrances. This will provide a minimum estimate of entrance efficiency because it is likely that some of these fish did not enter a PSC flownet. Entrance efficiencies (within 30 ft) ranged from 26 to 46% (Table 9), which is not surprising given the oblique forebay currents. Entrance efficiency for the 20-ft width was about twice that for the 5-ft width (Table 9), although relatively few of the total population of radio-tagged fish were apportioned between 5-ft and 20-ft configurations at the time the data were reported.

Table 9. Passage metrics (see Section 2.4 for explanations) for radio-tagged steelhead, yearling chinook salmon, and subyearling chinook salmon at B1 in 1998. DE is discovery efficiency (# w/in 30 ft of PSC divided by total). EE is entrance efficiency (#into PSC divided by #within 30 ft). PSCE3+5 is PSC efficiency (#into PSC divided by PSC plus under PSC into Units 3 and 5). The two different PSC configurations are designated 5-ft and 20-ft. Data are from Hensleigh et al. (1998) and Hansel et al. (1998); updated by H. Hansel (pers. comm., February 25, 1999).

Species	STEEL			CHIN 1			CHIN 0			TOTAL
Entrance width	5-ft	20-ft	total	5-ft	20-ft	total	5-ft	20-ft	total	total
Entered forebay			182			158			108	448
Within 30 ft	33	35	68	23	28	51	28	24	52	171
Entered PSC	9	17	26	6	13	19	0	11	11	56
Under PSC into U3-5	0	2	2	6	1	7	1	0	1	10
Into U1-2			40			77			13	130
Into U7-10			106			35			71	212
Total into B1 and PSC			174			138			96	408
DE			0.37			0.32			0.48	0.38
EE	0.26	0.46	0.38	0.27	0.49	0.37	0.00	0.46	0.21	0.33
PSCE3+5	1.00	0.87	0.93	0.60	0.94	0.73	0.00	1.00	0.92	0.85

Collection efficiencies of the PSC at Units 3 and 5 (PSCE3+5) were estimated with hydroacoustics and radio telemetry by sampling smolts in turbine intakes at Units 3 and 5 downstream of the PSC in spring and summer 1998. Smolts in the turbine intakes at Units 3 and 5 probably either went through or under the PSC. In spring, the hydroacoustic data indicated that the PSC had collection efficiencies greater than 80%, relative to passage under the PSC into Turbines 3 and 5 (Ploskey et al. 1998a). The 20-ft wide slot passed significantly more fish than the 5-ft wide slot (Ploskey et al. 1998a) in spring; there was no significant difference between 5-ft and 20-ft in summer. PSC efficiency for all radio-tagged fish and slot-widths combined was 83% in spring (Hensleigh et al. 1998), similar to the hydroacoustic estimate for the run-at-large. In summer, 11 of 12 radio-tagged fish detected at the PSC and Units 3 and 5 went into the PSC (Table 9).

Besides being efficient (%fish), the PSC was also effective (%fish passage/%flow). Ploskey et al. (1998a) reported that PSC effectiveness was 6.0 for the 5-ft opening was and 3.1 for the 20-ft opening. Thus, while the 20-ft opening was more efficient, the 5-ft opening was more effective. If it is decided to design a permanent surface bypass at B1, both PSC efficiency and effectiveness data will be important to consider, along with the contribution of the PSC to improved fish condition, fish passage efficiency, and survival.

Some fish moved laterally and most exhibited complex behavior in front of the PSC. Radio telemetry data showed that about 67% of the fish detected within 100 ft of the PSC moved laterally across the forebay in front of the PSC, and ended up at Units 1 and 2 (Hensleigh et al. 1998). Forebay currents flowed obliquely across the forebay from northeast to southwest (Figures 17 and 19); these currents had a noticeable effect on fish movement. Multi-beam data demonstrated that fish movements 0-60 ft upstream of the PSC were complicated and nonlinear (Johnson et al. 1999b). Differences in fish movements between the 5-ft and 20-ft PSC configurations were not observed. Fish detected in front of the PSC exhibited a positive rheotactic response to the flow field as they got closer to the PSC. Their behavior became increasingly tortuous (variable) as they approached the PSC, suggesting milling or searching. This behavior was not prolonged, however, because forebay residence times were short (Table 7). Increased variability in movement generally occurred upstream of the PSC prior to the substantive acceleration in the flownet near the PSC entrances. This suggests that other stimuli, such as forebay macro-hydraulics, may have affected fish behavior.

For B1 as a whole, highest passage of radio-tagged steelhead and subyearling chinook occurred at Units 7-10, while highest passage for yearling chinook was at Units 1-2 (Figure 24). Lowest passage was at Units 3 and 5 beneath the PSC. (Recall, Units 4 and 6 were off-line during the 1998 PSC evaluation.) These trends held when the data were normalized to passage per unit. Yearling chinook were observed moving across the forebay in front of the PSC and then holding in front of Units 1-2. Most passed at Units 1-2, but a few of these radio-tagged fish retreated to pass elsewhere (e.g., Units 7-10). It is not known whether these fish avoided the PSC or simply were oblivious to it. This movement pattern should be investigated when Units 4 and 6 are on-line, as forebay hydraulics were undoubtedly affected by the lack of flow into these units beneath the PSC. The concentration of fish at Units 7-10 was similar to that observed during baseline studies (see Section 5.3.7). A complete surface bypass at B1 will obviously have to address fish passage at Units 7-10.

In conclusion, both radio telemetry and hydroacoustic data demonstrated that overall performance of the PSC relative to passage through Units 3 and 5 showed the efficacy of surface bypass at B1. PSC efficiency (%fish) was somewhat greater for the 20-ft than the 5-ft entrance in spring, but not summer when they were similar. PSC effectiveness (%fish/%water) was greater for the 5-ft than the 20-ft. There is concern about the fate of fish observed moving across the forebay 20-50 ft upstream of the PSC that apparently did not discover the PSC flownets. Many of these fish, especially the yearling chinook salmon, passed into Units 1-2. The PSC will be extended to Units 1-2 in 2000 to form a six-unit prototype (PSC 1-6). Other outstanding issues regarding surface bypass development at B1 will be explored in Section 6, and are also included in the 2000 M&E plan (Appendix B).

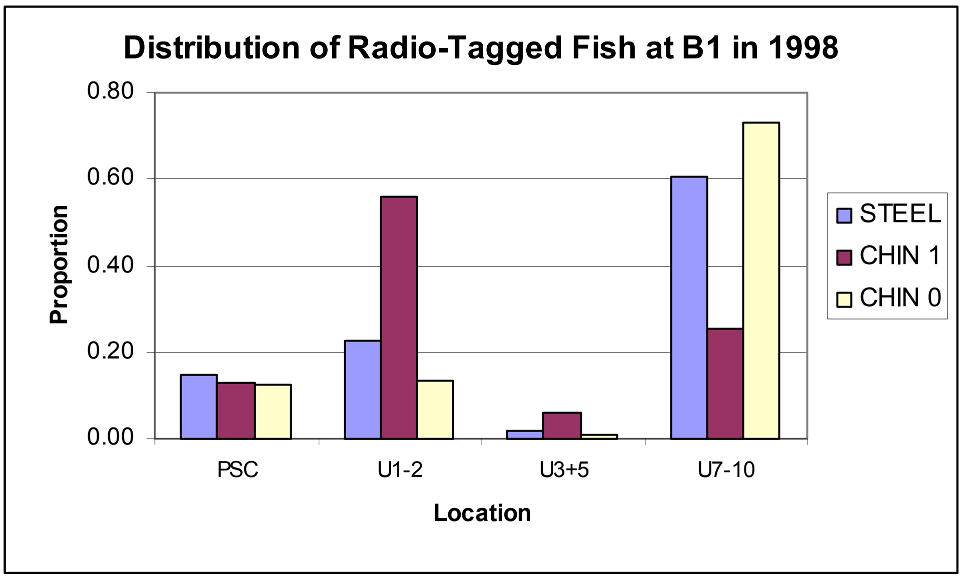

Figure 24. Passage distribution based on site of last detection of radio-tagged steelhead, yearling chinook salmon, and subyearling chinook salmon at B1 in 1998. Data from Hensleigh et al. (1998) and Hansel et al. (1998).

5.6 Evaluation of the Prototype Corner Collector at B2 in 1998

The B2 sluice chute was tested as a prototype corner collector in 1998, in addition to baseline studies in 1996 and 1997. In the baseline years, research regarding fish passage at the sluice chute was inconclusive. In 1996, 12 radio-tagged yearling and 25 subyearling chinook salmon were contacted in the vicinity of the sluice chute entrance, but none apparently entered it (Holmberg et al. 1996). That same year, fixed hydroacoustic estimates of fish passage at the sluice chute were problematic, because of excessive acoustic noise associated with turbulent surface currents created by the turbine intake extensions (TIEs) (Ploskey et al. 1998b). In 1997, BioSonics (1998) sampled fish passage at the sluice chute and Turbine Intake 11A to provide baseline data on chute efficiency. They also reported excessive acoustic noise from the TIEs with the weir gate at El. 61 (~3,300 cfs), but not at El. 68 (~1,100 cfs). INCA et al. (1997) recommended that the sluice chute be evaluated as a prototype corner collector in 1998, with the TIEs removed to allow for hydroacoustic monitoring of fish passage into the sluice chute with the gate at El. 61. The 1998 evaluation of the PCC, which was successful, is the basis for the following characterization of performance of the B2 sluice chute as a prototype corner collector.

In 1998, the PCC was opened and closed according to a randomized block experimental design. The objective was to determine if passage through non-turbine routes (PCC and intake screen system) was greater with the sluice chute on than with it off. Recall, the sluice gate was at El. 61 ft and the TIEs at Units 11-14 were removed. Sluice chute flow was about 3,000 cfs. The PCC and B2 intakes were monitored and evaluated using fixed radio telemetry and fixed hydroacoustics.

The radio telemetry study in 1998 provided useful information. About ¾ of the steelhead and ½ of the yearling chinook salmon that passed B2 were detected within 10 ft of the PCC entrance; this means discovery efficiency was high (overall DE = 61%; Table 10). The sluice chute was closed most of summer 1998, so few data on subyearlings could be collected.

Entrance efficiency (#entering/total # within 10 ft antenna detection range), according to radio telemetry data, was also high (Table 10). It was 71% for steelhead (42 of 59) and 76% for yearling chinook salmon (25 of 33). Since water velocity within 10 ft of the PCC entrance was relatively high (~12 fps at the weir gate), the radio telemetry detection zone was presumably this was within the PCC flownet. Thus, these data indicate that relatively few radio-tagged fish avoided the PCC entrance.

Overall, PCC efficiency (PCCE) for radio-tagged fish relative to passage at the entire B2 powerhouse was impressive; 52% for steelhead and 36% for yearling chinook salmon (Table 10). Given the relatively small proportion of flow entering the PCC (~2%), effectiveness (PCCE/%flow) of the PCC was about 26 for steelhead and 18 for yearling chinook salmon. Effectiveness this high has not been observed at any other surface bypass in the region (see Dauble et al. 1999 for a review).

Comparing combined bypass efficiency (CBE = (PCC+guided)/total at Units 11-13) with the PCC open and closed showed the positive effect of the PCC. CBE was higher for steelhead with the PCC open than with it closed (73% open vs. 50% closed; Table 10). The same trend held for yearling chinook salmon (50% open vs. 30% closed;

Table 10). Clearly, the operating the PCC resulted in more fish passing B2 through non-turbine routes than with it closed (23% more for steelhead and 20% more for yearling chinook salmon; Table 10). The PCC did not "rob" fish that would otherwise have been guided by the intake screens because CBE was so much higher with the PCC open than closed. In fact, the data indicated that the PCC passed many fish that would otherwise have gone through B2 turbines.

Table 10. Results from monitoring radio-tagged fish passage at the PCC and intake screen system at B2 in 1998. DE is discovery efficiency (# w/in 10 ft of PCC divided by total). EE is entrance efficiency (#into PCC divided by #within 10 ft). PCCE is PCC efficiency (#into PCC divided by total B2 passage). CBE is PCC plus guided fish passage divided by total B2 passage. n/a = not applicable. Data are from Hensleigh et al. (1998).

Species	STEEL		CHIN 1		TOTAL	
PCC entrance	open	closed	open	closed	open	closed
W/in 10 ft PCC	59	n/a	33	n/a	92	n/a
Into PCC	42	0	25	0	67	0
Guided	17	25	10	20	27	45
Unguided	22	25	35	46	57	71
Total into B2 and PCC	81	50	70	66	151	116
DE	0.73	n/a	0.47	n/a	0.61	n/a
EE	0.71	n/a	0.76	n/a	0.73	n/a
PCCE	0.52	n/a	0.36	n/a	0.44	n/a
CBE	0.73	0.50	0.50	0.30	0.62	0.39

Ploskey et al. (1998a) monitored fish passage into the PCC and Intakes 11B, 12B, and 13B. The trend in combined bypass efficiency for the PCC and Units 11-3 for the run-at-large was consistent with that observed for radio tagged fish; CBE was significantly higher with the PCC open than closed (Table 11). PCC efficiency relative to Units 11-13 was 83% in spring and 81% in summer. PCC effectiveness (%fish/%flow at Units 11-13) was 5.8 in spring and 4.6 in summer. When extrapolated to the entire powerhouse, effectiveness was about 12-16. These values are less than those estimated using radio telemetry data, but are still high relative to other regional surface bypasses.

Table 11. Combined bypass efficiency for the PCC and screens at Units 11-13 for when the PCC was open and closed in spring and summer 1998. Based on hydroacoustic data from Ploskey et al. (p. 49, 1998a).

	Spring	Summer
PCC Open	0.90	0.90
PCC Closed	0.55	0.30

The focus of PCC research in 1998 was on the entrance/collection component. Overall, the 1998 results from radio telemetry and fixed hydroacoustics comport well. The data indicate strong potential for the PCC to successfully collect smolts because of smolt distribution in the forebay. Distribution is hypothesized to be largely due to smolt behavior coupled with forebay macro-hydraulics. Smolts are concentrated in relatively shallow water (~45 ft deep) on approach over the forebay shelf. Many remain surface-oriented and are guided along the face of the dam toward the PCC in the large eddy in the southwest corner of the forebay. This eddy flow in conjunction with the 45o orientation of the PCC entrance relative to the face of the dam seems to cause high discovery efficiencies (~61%). Presumably gradual acceleration into the PCC entrance until smolts are entrained in the high velocity PCC flows probably causes the high entrance efficiencies (~73%). Smolts that do not enter initially can have multiple discovery and entry opportunities because of the large forebay eddy near the PCC. Thus, forebay collection efficiency (PCCE) is high (~44%) given the small amount of PCC flow (~3% of total B2). Conveyance and outfall issues, however, remain to be resolved and forebay discovery, entrance, and collection efficiencies should be verified for the PCC at B2.

6.0 Discussion, Recommendations, and Conclusions

In 1998, evaluations of prototype systems at B1 and B2 proved that the surface flow bypass concept is valid at these sites. Appreciable numbers and proportions of fish used the surface route at the B1 PSC and the B2 PCC (see Section 5). Furthermore, both prototypes were effective (%fish/%water) compared to other routes, such as turbines and spill. At the B1 PSC, biological data comport well with the hydraulic data in that fish and water both generally moved obliquely across the forebay. At the B2 PCC, removal of the TIEs at Units 11-14 allowed researchers to evaluate PCC passage and caused forebay flow conditions likely favorable to PCC passage. Data on efficiency and effectiveness of the PSC and PCC are consistent with other surface bypasses (Dauble et al. 1999). Results from PSC and PCC evaluations tend to support or at least not refute the surface bypass premises (see Section 2.3) where data are available (Table 12). But, while the initial results show the surface bypass concept appears to be valid, much work needs to be accomplished before permanent systems are installed, especially at B1.

Table 12. Qualitative evaluation of PSC and PCC results relative to premises for surface bypass. Symbols mean: ✪ = data support; **??** = data ambiguous; ❍ = data refute; **n/s** = not studied.

Premise	B1 PSC	B2 PCC
Approach – Smolts follow the bulk flow as they approach the dam.	✪	✪
Discovery -- Smolts can discover the surface bypass flownet.	**??**	✪
Decision: Surface bypass entrance conditions do not elicit an avoidance response.	**??**	✪
Conveyance: Smolts stay within the collector and pass through the conveyance structure safely.	**n/s**	**n/s**
Outfall: Smolts readily exit the outfall, safely enter the tailrace, and quickly migrate downstream with little risk from predation.	**n/s**	**n/s**

Numerous issues remain to be resolved concerning B1 PSC configurations and operations. Vertical slots seemed to work reasonably well in 1998, but it is not clear from the existing data which width (5-ft or 20-ft or other) is preferred. The 1999 evaluation should shed light on this issue. A surface orientation like a sluice weir may also be worth considering. Recall, the sluice chute at B2 appears to collect a relatively large proportion of fish. Optimum PSC discharge, flownet characteristics, and entrance velocities/accelerations are unknown. It seems important, however, to not have "null zone" of relatively slow water upstream of an entrance. Hydraulic design criteria will need to be determined to engineer the most efficient PSC configuration. The optimum number and location of PSC entrances have yet to be defined. Plus, Units 4 and 6 were off-line during the 1998 evaluation, so their effect on PSC efficiency is unknown. For example, should there be one entrance per turbine unit, per two turbine units, or other? Another way to ask this question is: Is PSC efficiency significantly different with one or two adjacent turbines operating? Turbine operations that allow for optimum PSC performance also are unknown. For example, should the units be operated at the low or high end of 1% peak efficiency? These and other questions will need to be answered for surface bypass development to progress at B1.

The development process began in 1995 when Harza and ENSR (1996a and 1996b), under direction of the Portland District, considered various surface bypass options for B1 and B2. For B1, the option called "Alternative A" has received the most attention. Given the state of knowledge on B1 surface bypass, Alternative A still appears to be viable. Many other uncertainties (see Table 13) remain to be resolved before the next surface bypass development phase at B1 is attempted. The next steps for B1 are to evaluate the PSC1-6 in 2000 and start to consider ways to deal with conveyance and outfall issues, at least on a prototype basis. For example, a "partial" Alternative A structure may be developed with surface bypass flow routed into the existing sluiceway or perhaps through the old navigation lock.

The development issues for surface bypass at B1 are much more complex than those at B2. B1 surface bypass is being considered as a stand-alone smolt bypass, i.e., it may replace intake screens at B1. Plus, there are no obvious ways to convey the high flows from a B1 surface bypass through the dam. On the other hand, B2 surface bypass using the sluice chute as a corner collector is intended to supplement the intake screen system. And, the route through the dam and outfall exist, although they need modifications to become fish-friendly. Thus, the forebay component of the B2 corner collector could be largely completed, although 1998 performance should be verified. Given favorable forebay hydraulics for the B2 corner collector, B2 PCC performance should not be compromised by efforts to improve FGE of the STSs at B2. Future surface bypass work at B2 will be focused on the gate structure, conveyance channel, and outfall. All future surface bypass development at Bonneville Dam will require quantitatively integrated biological and hydraulic data.

Biological and hydraulic data sets on surface bypass at Bonneville Dam have not been quantitatively well integrated, with one exception. To date, the one approach to quantitatively integrate fish and water data at Bonneville Dam has been the vector analysis technique (e.g., Johnson et al. 1999b). Generally, data are not well integrated for several reasons. First, hydraulic data are not often collected in conjunction with biological studies. This makes merging of any available data after-the-fact problematic. Second, hydraulic data generally are not readily available. Data from the physical models is not always formally reported or available informally because model studies often were undertaken for specific design issues where the intent was to get the "answer" and move on. CFDs have yet to be developed for the Bonneville surface bypass program, although a CFD for the B1 forebay is scheduled to be ready by December 1999. Field measurements of hydraulic conditions are rare. Third, it is difficult to "match" model and field conditions. Models only represent average conditions, while actual field conditions are quite variable. And, fourth, adequate software capable of quantitative integration of biological and hydraulic data are just now being applied in surface bypass research.

Despite this, the current body of biological research is generally providing information that is useful to surface bypass development at Bonneville Dam. Efficiencies for the run-at-large and for particular species have been estimated. Fish behavior at a broad-scale is fairly well understood. Fine-scale fish behavior and fundamental behavioral responses of smolts to hydraulic features near entrances at surface bypasses, however, are not well understood. Results from various studies generally comport; contradictory findings are usually explained by annual variability in limited data sets. For example, annual variability may explain contradictory observations of the trend in vertical distribution moving toward the dam between 1996 and 1997 mobile hydroacoustic surveys (see Section 5). Thus, given results to date, surface bypass development at Bonneville Dam seems to be on the right track. There are, nevertheless, critical information gaps that will require additional research.

Research will be necessary at both the B1 PSC and the B2 PCC. For the B1 PSC, the information gaps are fundamental to development of the PSC surface bypass. For the B2 PCC, the information gaps relate mostly to performance of individual surface bypass components. In Table 13, we present questions, assessments, recommended actions, and schedule regarding uncertainties in surface bypass development at B1 and B2. These issues should be addressed during M&E activities in 2000 and beyond.

Table 13. Plan for SFB development at B1 and B2. The plan is based on questions, assessments, recommended actions, and schedules to address uncertainties in surface bypass development at B1 and B2.

No.	Uncertainty question	Assessment	Recommended Actions	Years
1	Do we have research tools that will yield instructive information? This refers to tools needed for both hydraulic and biological investigations at both powerhouses.	Hydroacoustics, radio telemetry, and physical hydraulic models are well developed. Multi-beam, acoustic telemetry, and CFD are new but can be initiated now. Quantitative integration is missing.	Continue to refine existing techniques and apply the new ones. Develop and emphasize techniques that "integrate" data.	2000-2002
2	What are the optimum entrance conditions, e.g., dimensions, configuration, velocity, etc., which maximize entrance efficiency at the B1 PSC?	Of the two configuration studied to date (5-ft and 20-ft vertical slots), higher flow and approach velocity (20-ft) was slightly more efficient (%fish) in spring, but the	Continue to test entrance configurations (e.g., 5-ft vs 20-ft). Evaluate the flow/velocity/acceleration factor by controlling turbine loading.	2000-2001

	What features are fish responding to at the entrances?	same in summer. Other factors have not been tested. It is not clear what environmental features fish are responding to.	Perform laboratory, field, and numerical model research to understand fish responses and what causes "attraction" or "avoidance." Use a CFD to investigate differences in hydraulic conditions for various entrances.	

Table 13 continued

No.	Uncertainty question	Assessment	Recommended Actions	Years
3	Is PSC efficiency significantly different with one or two adjacent PSC entrances operating? For example, is another PSC entrance necessary with an adjacent turbine operating, or will one entrance per two turbine units suffice?	This has not been evaluated. Results have fairly important implications to a Phase 2 (after the PSC) partial or full powerhouse prototype.	Evaluate the "adjacency" factor.	2000
4	What will be the fate of smolts moving laterally across in front of the PSC if a complete structure spans the powerhouse? Will they ultimately use a surface bypass route, or is the horizontal movement observed in 1998 an indication that fish are avoiding the PSC entrance conditions?	In 1998 some fish upstream of PSC3-6 in 1998 moved laterally across the forebay toward Units 1-2. Many of these fish passed there, but others retreated elsewhere (e.g., Units 7-10). The fate of these fish is a concern.	Evaluate PSC1-6 for fate of fish moving laterally across the forebay toward Units 1-2 (assuming this behavior is repeated). In general, determine the movements and passage fate of individual fish.	2000
5	Will entrance conditions that appeared effective in 1998 remain so when the surface bypass flow is passed through a collection channel, instead of back through the trashracks into the turbine?	This uncertainty is key, but can be assessed only when we have a Phase 2 prototype or suitable physical and numeric hydraulic and fish models.	Develop physical and CFD models for a Phase 2 PSC and numeric fish surrogate to "predict" fish response to the new conditions. Communicate this information w/ regional decision-makers.	2001
6	Many smolts were observed to pass at B1 Units 7-10. How does this observation impact surface bypass development?	We do not completely understand what is causing this so that alternatives for PSC at Units 7-10 can be identified.	Examine a CFD and fish movement data for the B1 forebay. Formulate PSC alternatives for Units 7-10.	2000-2003
7	PSC entrances have trashracks and the PCC entrance does not. What difference might this make? What sounds and hydraulics are associated with PSC trashracks?	We do not know whether trashracks at surface bypass entrances affect passage. However, FGE appears to be sensitive to trashrack presence and configuration.	Remove the trashracks at the PSC entrances if project maintenance allows. If not, take field measurements of acoustic and hydraulic features near PSC trashracks.	2000
8	What are the options for routing PSC flow (perhaps 10-15 kcfs) through the dam?	ENSR et al. (1998) completed a high flow routing and outfall alternatives study. Several reasonable option to route PSC flow through B1 exist.	Perform the engineering necessary to take the ENSR study to the next level (i.e., a routing and outfall letter report).	2000-2001
9	Where will the B1 surface bypass outfall be situated and	See point immediately above. Also, work is underway on a 0-	Complete 0-30% outfall options report and consider moving	2000-2004

	how will it be configured?	30% assessment of high flow outfall options for B1.	forward after 2000 test results are available.	

Table 13 continued

No.	Uncertainty question	Assessment	Recommended Actions	Years
10	What are the benefits of surface bypass relative to extended screens at B1?	This important question can only be answered when we can project the guidance efficiency and injury/survival of each system.	Collect the efficiency and injury/survival data necessary to compare extended screens and surface bypass at B1.	2000-2001
11	What is forebay collection efficiency of the PCC (PCCE) relative to the entire B2 powerhouse? How does it compare between spring and summer migrations?	These data are not available, except for a limited number of radio-tagged fish in spring 1998. PCCE was 36% for yearling chinook and 52% for steelhead.	Estimate total B2 forebay collection efficiency for the run-at-large and by species. These data are necessary to understand performance of all B2 bypass systems combined.	2000-2001
12	What is combined bypass efficiency (PCC + screens) for B2?	See point immediately above. In 1998, CBE was 50% for yearling chinook and 73% for steelhead (Table 10).	Estimate combined bypass efficiency for the run-at-large and by species. As above, these data are necessary to understand performance of all B2 bypass systems combined.	2000-2001
13	Does the PCC have an effect on forebay residence time?	Residence times are already so low that survival benefits from further reductions are not apparent.	Continue to monitor residence times for radio-tagged fish released for other objectives.	2000
14	What are fish injury/mortality rates through a new B2 PCC conveyance channel? New outfall?	This will be part of the post-construction evaluation.	Perform these studies during the post-construction evaluation in spring 2003.	2003
15	What is overall survival (direct and indirect) through the PCC and outfall plumes?	Ibid.	Ibid.	2003
16	What are the effects of the PCC outfall on adult passage at B2?	Ibid.	Ibid.	2003
17	How does the high level of smoltification and passage "experience" at Bonneville Dam relative to upstream dams affect surface bypass performance at Bonneville?	Little is known about the relationship between smoltification or passage experience and surface bypass performance.	Keep these factors in mind when interpreting results and consider research.	2000-2003

At B1 (Figure 25), plans for surface bypass development at B1 depend on the 2001 "decision". Thus, the evaluation in 2000 will be critical as its results will feed into the 2001 decision on whether to proceed to the next developmental phase for deep slot surface bypasses. If deep slots do not go forward, other surface bypass development is not precluded. For example, horizontal, surface sluice-type configurations might be a viable option. In 2001, the goal and objectives for field tests are unclear at this time and depend on 2000 results. If Phase 2 is started, a key issue will be whether to develop a partial powerhouse prototype or a full production structure. If a partial prototype is chosen, the conveyance and outfall components should be designed so that they can be used with a full production structure in the event it gets approval. Preliminary engineering for Phase 2 is underway. These engineering plans do not include dewatering for B1 surface bypass. No dewatering means high flow (> 1,000 cfs) conveyance channels and outfalls. B1 high flow outfall is currently being studied further at a reconnaissance level of engineering. Out-year planning for a B1 Phase 2 surface bypass is ongoing; at this time the schedule is for evaluation in 2004-2006. After 2000, development of surface bypass at B1 has many possibilities.

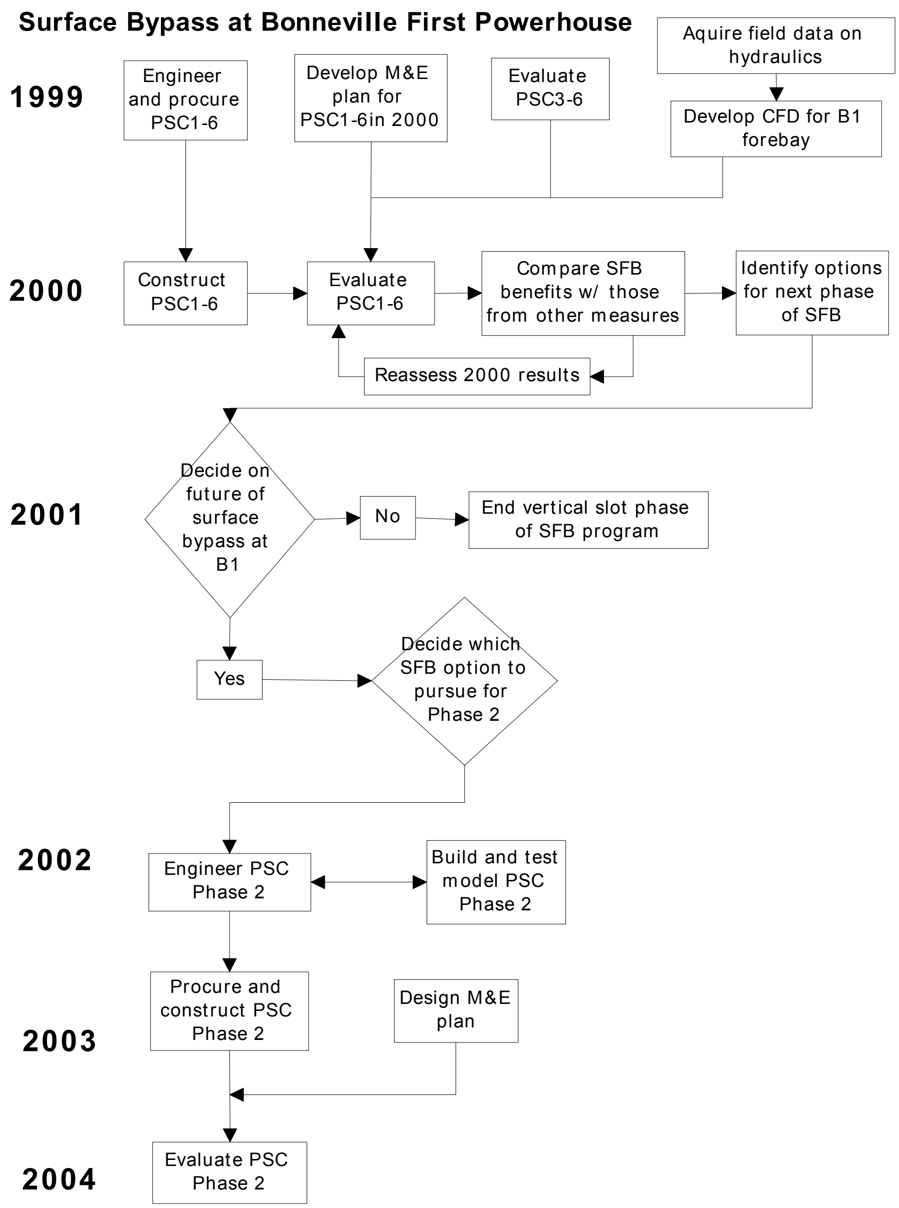

Figure 25. Flow chart for potential surface bypass development at B1. Tentative, optimistic calendar years are shown.

At B2 (Figure 26), surface bypass development at the PCC is moving forward. Improvements to make the PCC surface bypass permanent have been approved. These include gate modifications to El. 52 to get approximately 5,000 cfs, an ogee after the entrance gate, sloped channel, and a new high flow outfall location and design. The permanent corner collector is scheduled to be completed by spring 2003.

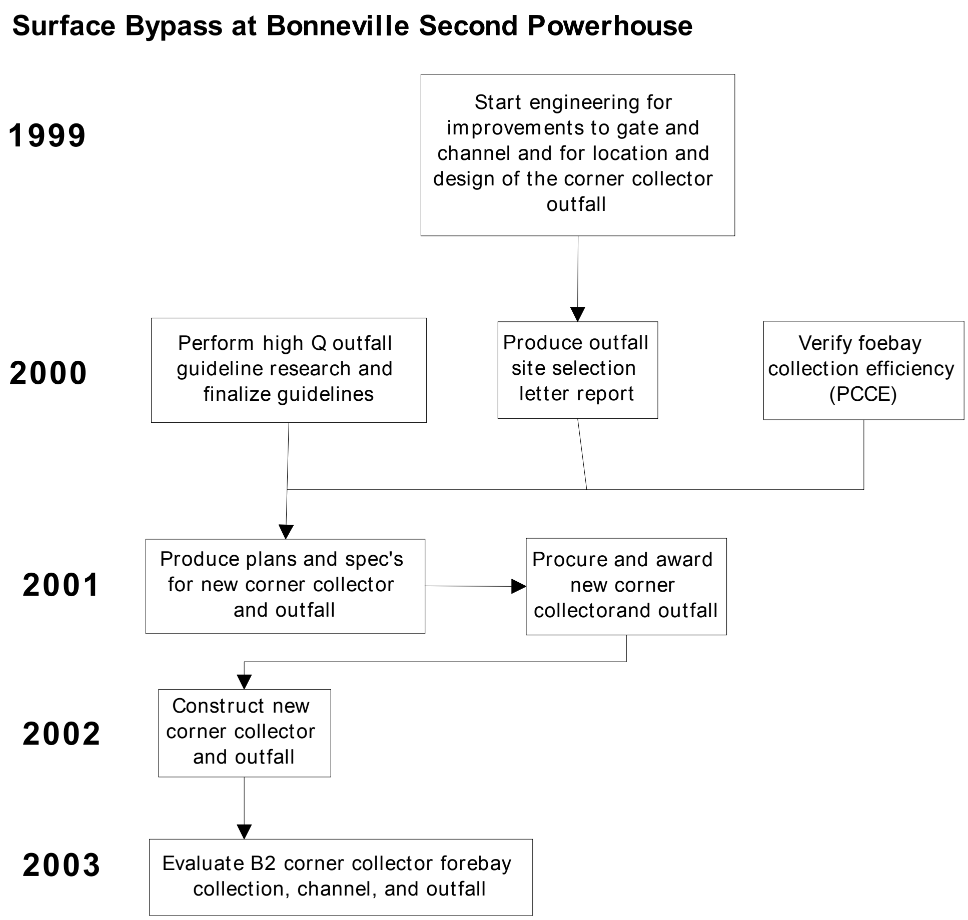

Figure 26. Flow chart for surface bypass development at B2. Tentative, optimistic calendar years are shown.

In general, we make the following recommendations for surface bypass development at Bonneville Dam.

- Collect synoptic environmental and biological data, e.g., water velocity, temperature, etc. during M&E studies.
- Disseminate hydraulic data from physical models of surface bypasses as available and appropriate, e.g., trip reports, letter reports, full hydraulic reports, etc.

- Create a formal archive and retrieval system for surface bypass hydraulic data from physical and CFD models.
- Develop CFDs for B1 and B2 forebays and tailraces to aid in surface bypass development, including forebay, conveyance, and outfall components.
- Develop tools to quantitatively integrate biological and hydraulic data.
- Study fine-scale fish behavior and fundamental behavioral responses of smolts to hydraulic features near the entrances at surface bypasses.
- Estimate the contribution of surface bypass at B1 and B2 to project-wide FPE.
- Incorporate planning for hydraulic investigations related to surface bypass development into the AFEP process for planning for biological research.
- Perform the research recommended by Johnson et al. (1999a) to finalize the guidelines for high flow outfalls.
- Have routine dialogue between engineers and biologists throughout the surface bypass development process to ensure that all parties are working together in the same direction.

We have the following recommendations specifically for surface bypass development at B1:

- Implement the 2000 M&E plan (see Appendix B) to continue to resolve uncertainties in surface bypass development at B1.
- Start engineering planning for the next phase of prototype surface collector, i.e., a "partial" prototype.
- Develop ways to convey and deposit PSC flow.
- Develop physical and CFD models of any Phase 2 surface bypass for B1.

Finally, we have the following recommendations specifically for surface bypass development at B2:

- Collect forebay hydraulic data near the PCC entrance because, although the PCC appears to be efficient at collecting smolts, we do not explicitly know the mechanisms.
- When the PCC is operated, leave the TIEs at Units 11-14 out.
- Do not do anything to disrupt the favorable forebay hydraulics for the PCC.
- Verify forebay collection efficiency of the PCC. (This could be done in 2000 in conjunction with the large radio telemetry study for B1 PSC.)

- Implement the 2000 M&E plan to continue to resolve uncertainties in surface bypass development at B2.
- Continue with development of the new conveyance and outfall structures.

In conclusion, the collective information to date supports continued development of surface bypasses at Bonneville Dam. At B1, the 1998 results from the PSC at Units 3-6 were encouraging. This encouragement, coupled with the uncertainty in fate of fish moving laterally across the PSC, justified the decision to extend the PSC to Units 1 and 2. Results from the 2000 evaluation at the B1 PSC1-6 will be instrumental in deciding the future course of surface bypass development at B1. At B2, existing data justify development of the sluice chute as a corner collector surface bypass, although verification would be useful. The conveyance channel and outfall, however, must be made more fish-friendly. Surface flow bypass seems to have the potential to increase smolt survival over that of existing systems at Bonneville Dam.

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Appendix A:
Hydraulic Modeling and Field Work Related To Surface Bypass at Bonneville Dam

Appendix A Hydraulic Modeling and Field Work Related To Surface Bypass at Bonneville Dam

Table A.1. Hydraulic studies related to surface bypass 1995-1998. Data compiled by K. Kuhn (NWP).

Model	Year	Data Type	Format	Purpose	General Flow Conditions	NOTES:
1:100	1997	Vel dir/mag-Floats depth averaged to 25 ft.	Plan plots	Prototype corner collector	100k, 110k	TR only
1:100	1995/96	Vel dir/mag-Floats depth averaged to 25 ft.	Plan plots	Calibration of 1:40 scale models.	269k, 341k, 386k, 179k, 101k, 141k, 217k, 262k	FB Only
1:100	1995/96	Vel dir/mag-Floats depth averaged to 25 ft.	Plan plots	Comparison with field data.	275k, 128.3k	FB/TR
1:100	1995	Vel dir/mag-Floats depth averaged to 25 ft.	Plan plots	Low flow outfall study.	110k, 250k, 70k, 180k, 375k	TR Only
1:100			Photos			
1:100	1994	Vel dir/mag-Floats depth averaged to 25 ft.	Plan plots	Spill pattern study.	118k, 190k, 335k	TR Only(1)
1:100	1993/94	Vel dir/mag-Floats depth averaged to 25 ft.	Plan plots	Spill pattern study.	190k, 335k	TR Only(2)
1:100	?	Vel dir/mag-Floats depth averaged to 10 ft.	Plan plots		200k, 335k, 300k	TR Only(3)
1:100	1980's	Vel dir/mag-Floats depth averaged to 14 ft.	Plan plots	Navigation lock study.	70.4k, 142.4k, 162.4k, 118.4k, 200.4k, 335k, 485k, 660k	FB/TR(4)
1:100	1980's	Vel dir/mag-Floats depth averaged to 14 ft.	Plan plots	Navigation lock study.	335k	FB(5)
1:100	1980's	Vel dir/mag-Directional Vel Meter-Top,Mid, Bottom Vel.	Plan plots	Navigation lock study.	B1: 56k, 98k, 140k	FB(6)
1:100	1980's?	Vel dir/mag-Directional Vel Meter-Top,Mid, Bottom Vel.	Plan plots	Navigation lock study.	70.4k, 118.4k, 200.4k, 335k, 485k, 660k	FB/TR(7)
Field	1995	Vel dir/mag-ADCP at various depths and averages	Plan plots/ArcInfo/ArcView		128.3k, 283k	FB/TR

		Cross sections and echo intensity contours	Composite and Vertical-Only			
Model	**Date**	**Data Type**	**Format**	**Purpose**	**General Flow Conditions**	**NOTES:**
B1 1:40	1996	Dye tracing-5 ft.,Mid, Bottom-40ft grid up to 220 ft u/s x-sect show 70% dye intercept up to 135 ft u/s	Plan/Pro file Plots	PSC testing	PSC @ EL25 ft.; Slot W=20 ft.; 11.3kcfs/turbine; FB=75.3 ft. (1) PSC-1,2,3 (units 4&6 off); (2) PSC-1,2,3 (all units on) (3) PSC-4,5,6 (all units on); (4) PSC-3,4,5 (all units on) (5) PSC-3,4,5 (Unit 4 off); (6) PSC-3,4,5,6 (Unit 4 off) (7) PSC-3,4,5,6 (Units 4&6 off)	
B1 1:40	1997	Upward facing ADV-PSC to 50 ft. u/s, 20 ft. ea. side centerline, down to 60 ft. depth.	Plan/Pro file Plots	PSC testing	PSC @ EL 25 ft.; FB EL 74.5 ft. (1) PSC-3,4,5,6 (units 4&6 off) U3:W=20 ft.; U5:W=5 ft. (2) PSC-3,4,5,6 (units4&6 off) U3:W=5 ft.; U5:W=20ft. (3) PSC-3,4,5,6 (unit 4 off) U3:W=20 ft.; U5:W=5 ft. (4) PSC-3,4,5,6 (unit 4 off) U3:W=5 ft.; U5:W=20 ft.	
B1 Field	1996	Gurley Meter (1D) Units 3 & 5 for Blocked/Unblocked Trashracks and Ice & Trash Sluiceways Open/Closed1D velocity magnitude range at 3 ft. intervals of depth to 57 ft. depending on scenario. Data taken along CL at 22 ft. upstream of sluice gate.	Tables	Blocked Trashrack Field Test	Blocked Trashracks @ EL 33 ft. Q varies somewhat with scenario but operations: Units 1,3,5,7,9,10 on. FB 74.6-74.9 ft.	(8)
B1 1:40	1997	ADV 3D probe & 1D probe-for Blocked/Unblocked Trashracks and Ice & Trash Sluiceways Open/Closed3D and 1D velocities taken at 3 ft. intervals of depth to 57 ft, depending on scenario. Data taken along CL at 12.5, 22, and 30 ft. upstream of sluice gate.	Plan/Pro file Plots	Blocked Trashrack Field Test Modeling of field conditions	Blocked Trashracks @ EL 33 ft. Q varies somewhat with scenario operations: Units 1,3,5,7,9,10 on. FB 74.6-74.9 ft.	

Model	Date	Data Type	Format	Purpose	General Flow Conditions	NOTES:
B1 1:25	1996	LDV 2D throughout depth just upstream of STS slot in turbine intake, 3 locations in ea. bay. Limited tests at CL of PSC just upstream of slot & just inside throughout depth. Some tests with additional Vel between trashracks and STS slots. Used to determine limited PSC slot Q & Vave. Some tabular and graphic investigation of relative turbulence.	Profile Plots	PSC testing for determination of floor elevation based on turbine intake environment.	Various combinations of STS in/out; Turbine Q=14.7, 11.2, and 8kcfs; PSC @ EL 25, 33, 59 ft. or removed; Trashracks blocked to EL 25 & 33 ft. or no blockage; Slot width of 10, 5, or 20 ft. ; FB EL 75.3 ft.; Sluiceway open/closed; Venturi blockage; Blocked trashrack with center slot open;	
B1 1:25	1998	LDV 2D throughout depth at 4 locations upstream &1 location just inside PSC at CL. Slot Q/Vave; sluice Q; headloss to PSC and gate slot		1998 PSC ratings.	PSC @ EL 30.5 ft., FB EL 75.3 ft., Sluice B open EL 68 ft. Slot W=20 & 5 ft.; Turbine Q=11.2 & 8kcfs.	(9)
B1 1:40	1998	ADV 3D probe for 1998 PSC field conditions. Area=50 ft. parallel to powerhouse centered on Unit 3 PSC, 50 ft. perpendicular to ph from PSC upstream, 76.5 ft. vertically from water surface to floor.	Plan/Profile Plots; Ascii		PSC @ EL 30.5 ft.; FB EL 74.5 ft.; Sluice 10C EL 71.5 ft., 5B EL 71.8 ft., 3B EL 72.0 ft., 7A EL 73.9 ft.; Slot W=20 & 5 ft.; Units 1,2,7,8,9,10 @ 11.3kcfs; Units 3 & 5 @9.8kcfs	
B2 1:40	1997	Dye injections along grid to test sensitivity of Corner Collector dye capture to: TIE removal; Ph operations; intake extensions, gate elevations.	Plan Plots	Development of Corner Collector (CC) concept	Ph @ approximately 59kcfs and 130kcfs CC @ EL's: 68, 52, 42 ft. CC @ approximately 0.9, 5.4, 10 kcfs	
	1997	1D spot velocities along CL of chute EL 71.25' and1D spot velocities u/s Unit 11 EL 71.25' in zone of estimated Max. velocity. CC configurations same as for dye injections listed above.	Plan Plots	CC concept development	Ph @ approximately 59kcfs and 130kcfs CC @ EL's: 68, 52, 42 ft. CC @ approximately 0.9, 5.4, 10 kcfs	
	1997	Rating curves for gate EL 52' and EL 42'	Curves	CC concept development		
	1997	1D spot velocities at EL's: 73,70,67,64,61,58 ft. at entrance to CC for gate EL 61 ft.	Plan Plots	CC concept development		

Notes

(1) Data from spillway tailrace to approximately 1000 ft. downstream of navigation lock entrance. Data does not represent existing conditions (1995) in main river channel immediately opposite the downstream entrance of the lock canal. Spill pattern not current to 1996 FPP. No near TR of B1 or B2.

(2) Data from spillway tailrace only to approx. 2000 ft. downstream of spillway. Spill pattern not necessarily current to 1996 FPP. No near TR of B1 or B2.

(3) Data from spillway tailrace only to approx. 1000 ft. downstream of spillway. Spill pattern not necessarily current to 1996 FPP.

(4) Data in tailrace does not include near TR of B1 or B2. Spill pattern not available. Data does not represent existing conditions (1995) in main river channel immediately opposite the downstream entrance of the lock canal, in the upstream navigation channel starting at a point about 500 ft. upstream of the guidewall and extending downstream to B1, along the right descending bank immediately upstream of B1.

(5) Data for upstream entrance to navigation lock and S side of B1 only. Area along right descending bank immediately upstream of B1 does not represent existing conditions (1995).

(6) Data for upstream entrance to navigation lock and S side of B1 only. Area along right descending bank immediately upstream of B1 does not represent exidting conditions (1995).

(7) Data for S side of spillway FB, B1 FB and upstream from tip of Bradford Island approx. 3000 ft. Tailrace data at downstream entrance of navigation lock and approximately2000 ft. downstream. Data does not represent existing conditions (1995) in main river channel immediately opposite the downstream entrance of the lock canal, in the upstream navigation channel starting at a point about 500 ft. upstream of the guardwall and extending downstream to B1, along the right descending bank immediately upstream of B1.

(8) Direction of vectors are suspect. Gurley meter suspended from crane. As depth increased, gurley meter moved closer to powerhouse at an undetermined rate. Data useful for generalized trends only.

(9) Velocities will likely overestimate vel magnitude at surface since flow through sluiceway would have been less during field testing.

Appendix B:

Draft M&E Plan for Surface Bypass Research at Bonneville Dam in 2000

Appendix B Draft M&E Plan for Surface Bypass Research at Bonneville Dam in 2000

B.1 Introduction

A monitoring and evaluation (M&E) plan provides a blueprint to direct research activities. This plan for 2000 focuses on research of the B1 PSC and the B2 PCC. The plan will be a working document within the Anadromous Fish Evaluation Program. The intent is to coordinate M&E activities and provide a means to regularly review the objectives, studies, results and performance standards of the surface bypass program at Bonneville Dam. The M&E plan should be revisited as new information arises, e.g., 1999 results.

Surface bypass prototypes were evaluated at B1 in 1998 and 1999 and at B2 in 1998 (e.g., Hensleigh et al. 1998; Ploskey et al. 1998). These results were summarized by Johnson and Giorgi (1999). B1 results led to the decision to add PSC entrances at Units 1 and 2 in 2000. B2 results led to the decision to begin engineering steps to locate and design a high flow outfall for the PSC in 2000. Thus, the main goals for the surface bypass program at Bonneville Dam in 2000 are to:

- Evaluate the six-unit PSC;
- Begin development of the permanent collector surface bypass at B2.

B.2 PSC at B1

In this section, we describe the M&E plan for the B1 PSC in 2000. Included are goals, structural modifications and operations, technical approach, AFEP projects and schedule, and expected outcomes. This M&E plan covers biological and hydraulic work. The PSC test in 2000 is critical because the results will be pivotal for the decision regarding the future direction of surface bypass at B1, which will be made in 2001.

B.2.1 Goals and Objectives

The goals for surface bypass research and development at B1 in 2000 are (1) to verify proof-of-concept established in 1998, and (2) provide decision-makers useful data on PSC performance and the underlying mechanisms.

The general objectives for research at the PSC in 2000 are to assess PSC performance and fish behavior. Specific objectives pertain to entrance conditions, the second uncertainty in Table 13 of the Bonneville surface bypass synthesis report (Johnson and Giorgi 1999). Other uncertainties regarding B1 surface bypass may also be addressed. Optimum PSC entrance conditions are not well-described. Data on entrance conditions will be useful to the 2001 decision and any future surface bypass designs at B1. The general and specific objectives will be revised when the experimental factors are further defined. As of now, the objectives are:

1) PSC Performance – Estimate PSC passage efficiency and effectiveness for the experimental treatments (exact treatment yet to be determined).
    a) Determine which entrance conditions at B1 PSC (e.g., flows, area, velocity, acceleration) maximize performance.
2) Fish Behavior – Assess fish behavior on approach and encounter with the PSC.
    a) Determine hydraulic conditions for the experimental treatments.
    b) Estimate fine-scale (±1 m) and micro-scale (± 0.1m) movements of tagged and untagged smolts within 50 m of the PSC.
    c) Assess responses of smolts to a PSC flownet by integrating fish movement and hydraulic data.

B.2.2 Structural Modifications and Operations

Except for extending the PSC to Units 1-2, the following proposed structural modifications and operations (highlighted in bold Italics) are subject to change as these topics are deliberated.

PSC Extension -- By spring 2000, the Corps plans to extend the B1 PSC to Units 1 and 2 so that the entire PSC will cover Units 1-6 (PSC1-6) (Figure B.1). Basic operation of the PSC will remain the same with PSC flow exiting the PSC into the turbine intakes behind (Figure B.2 and Table B.1). The intent of this extension is to improve PSC collection efficiency by providing a surface bypass entrance for fish that were observed in 1998 moving laterally from NE to SW across the B1 forebay 50-150 ft upstream of PSC3-6 (Johnson et al. 1999; Hensleigh et al. 1998).

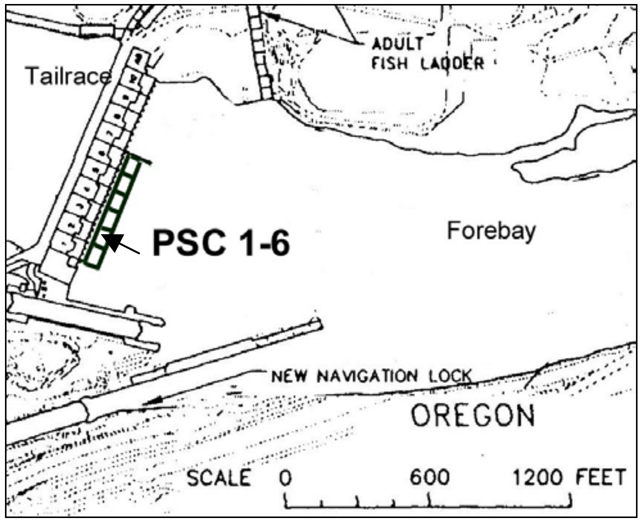

Figure B.1. Plan view of Bonneville First Powerhouse showing location of PSC1-6.

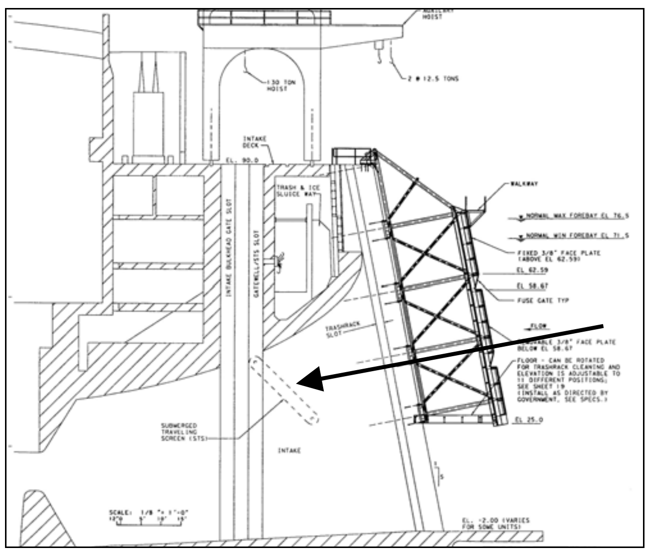

Figure B.2. Side view of PSC1-6 at Bonneville Dam First Powerhouse. Arrow depicts flow into and through the PSC into turbine. PSC floor is at El. 30.5, not El. 25.

Table B.1. Anticipated flows, areas, and velocities for the 5 and 20-ft entrance widths and floor El. 25.0 and 30.5 ft at the PSC in 2000. Data are for forebay at El. 74.5 and for turbine unit discharge at ~10,000 cfs.

Entrance Conditions	Floor El. 25.0 ft		Floor El. 30.5 ft	
Width	5 ft	20 ft	5 ft	20 ft
PSC flow (cfs)	1,700	3,900	980	2,750
Area (ft^2)	253	1,010	225	900
Velocity (fps)	7.8	4.6	5.0	3.6

PSC Floor – In 1998 the PSC floor was at El. 30.5 ft, instead of the planned El. 25.0 ft, because of concerns about the impact of a relatively large occlusion (the PSC structure) on the turbine machinery. Since 1998, this issue has been investigated further, but some questions still remain. If these concerns are alleviated, the floor should be placed at *El. 25.0 ft* for purposes of the 2000 test. This will increase flows and velocities into and under the PSC (Table B.1), more likely resembling a Phase 2 situation.

PSC Trashracks – The PSC trashracks were in place during 1998 tests. However, project maintenance does not require them because there are still trashracks at the turbine intakes. The PSC trashracks should be *removed* for the 2000 test because it is possible they could cause some smolts to avoid the PSC entrances, although we do not have direct evidence this would be the case.

PSC Entrance Widths – The 1998 test compared PSC performance and fish behavior for 5-ft vs. 20-ft wide vertical entrances at PSC3 and PSC5. At this time, the results are somewhat inconclusive. Recall, the 20-ft entrance was more efficient (%fish) than the 5-ft entrance in spring, but not summer when they were similar. The 5-ft entrance was most effective (%fish/%water). Results from the 1999 test will shed light on this issue. Until they are available, plans for PSC entrances should include 5-ft and 20-ft widths. An intermediate width does not appear to be useful because of the desire to make the conditions as different as possible to detect performance and behavior differences. Thus, PSC entrance width will probably be *5-ft and/or 20-ft* in 2000.

PSC Entrance Locations – The PSC1-6 will have capability for six entrances, one in front of the B-intake of each unit. Depending on the selected experimental design (see below), either *all six, or a subset* will be opened.

Turbine Operations – For purposes of the PSC evaluation, Turbine Units 1-6 should be priority units at B1 in 2000 with block loading if at all possible to reduce hydraulic variability. Units 1-6 may be block-loaded at the low end within 1% of peak efficiency, the high end, some other level, or not at all. Specific discharges are *yet to be determined*. Also, turbine load could be an experimental factor (see below). At this time, we anticipate that all Units 1-6 will be operational for PSC tests in spring and summer 2000.

Sluiceway Operations – Based on general observation, open sluice gates behind the PSC entrances appear to improve hydraulics in the PSC. For example, without a sluice gate open, surface flow is sometimes upstream inside that particular compartment. Upstream flow inside the PSC is undesirable because smolt passage through the PSC may decrease. Thus, *lowered sluice gates* behind each PSC entrance is needed to obtain the maximum sluiceway discharge possible. It may be necessary to open an additional sluice gate at Units 7-10 to get acceptable smolt egress in the sluiceway.

Forebay Elevation – The PSC is fixed in place, so forebay elevation affects PSC flows. To minimize this effect on the PSC test in 2000, forebay elevation should have a "soft" constraint at *± 1 ft around El. 74.5 ft*.

Intake Screens – Deployment of the intake screens at Units 1-6 has *yet to be determined*.

B.2.3 Technical Approach

The technical approach for M&E at the B1 PSC in 2000 includes experimental design, evaluation parameters, and general methods. Specific methods and objectives are not included here, however they may be found in the respective AFEP research proposals and engineering scopes of work. Recall, the general objectives may be to refine research tools, study effects of PSC entrance conditions, and assess effects of adjacent PSC entrance operations. The technical approach is depicted in Figure B.3.

B.2.3.1 Experimental Design

The experimental factors and treatments for the 2000 PSC test have not been identified as yet. As mentioned previously, in 1998 and 1999 two slot widths were tested (5-ft and 20-ft). Experimental factors that may be considered in 2000 are (a) entrance width, (b) turbine loading, which affects PSC entrance flow and velocity/acceleration, and (c) adjacency, the effect of operating two adjacent PSC entrances on PSC efficiency at a particular pair of turbine units. (Note that the individual variables are confounded, i.e., PSC flow, entrance area, and entrance velocity.)

As a strawman, assume the experimental factors are entrance width (5-ft vs. 20-ft) and adjacency (single vs. double). Thus, there could be two levels for each factor. This produces four experimental treatments: 5-ft/single, 5-ft/double, 20-ft/single, and 20-ft/double (Table B.2). Refer to the treatment codes in Table B.2. The following comparisons would address the general objectives: entrance effects – 5S vs. 20S and 5D vs. 20D; adjacency effects – 5S vs. 5D and 20S vs. 20D.

Table B.2. Possible PSC treatments for experimental factors of entrance width and adjacency. Floor at El. 25.0. Flows (cfs) from Table B.1. *This is just an example; actual factors may differ.*

Treatment	Code	PSC 1	PSC 2	PSC 3	PSC 4	PSC 5	PSC 6	Total PSC Q
5-ft/single	5S	5-ft	Closed	5-ft	closed	5-ft	closed	5,100
5-ft/double	5D	5-ft	5-ft	5-ft	5-ft	5-ft	5-ft	10,200
20-ft/single	20S	20-ft	Closed	20-ft	closed	20-ft	closed	11,700
20-ft/double	20D	20-ft	20-ft	20-ft	20-ft	20-ft	20-ft	23,400

In 2000, the Corps proposes to conduct spring and summer evaluations (exact dates yet to be determined) at the B1 PSC. Data will be obtained for about 48 days in each seasonal period. Treatments will be changed according to a randomized block design. There could be 12 blocks in each study period, spring and summer, if blocks are 4 days long and each treatment is in place for 1 day at a time. Under this scenario, each treatment would be in place 12 times. A power analysis will be performed and the statistical analysis model determined once the experimental factors and treatments are finalized or sooner.

B.2.3.2 M&E Data

The Corps proposes to collect the following M&E data at the PSC1-6 in 2000. These are details about the example data referred to in Figure B.3.

- PSC efficiency relative to Units 1-6 (PSCE1-6) and relative to individual areas (e.g., Units 1 and 2, PSCE1-2).

  PSCE = PSC passage divided by PSC plus passage under the PSC

- PSC effectiveness relative to Units 1-6 (PSCF1-6) and relative to individual areas (e.g., Units 1 and 2, PSCF1-2).

  PSCF = PSCE divided by the proportion of turbine unit flow that went through the PSC

- PSC entrance efficiency (EE) for the PSC as a whole relative to fish within 10 ft (EE_{10}), 30 ft (EE_{30}), and 150 ft (EE_{150}) and for individual entrances, e.g., PSC 5 relative to available fish within 10 ft ($EE5_{10}$).

  EE = PSC passage divided by the total number of fish available within the prescribed area

- Residence time (RES) in the forebay for each route of passage (into PSC, under PSC, and into Units 7-10) by species.

  RES = time between first and last detections

- Trajectory (TRAJ) of fish passing into a PSC by entrance.

  TRAJ = depth and direction between first and last detections

- Three-dimensional swimming effort vectors (VSWIM) by distance along the PSC, distance upstream from the PSC, and depth of water in micro-scale (± 0.2-2 ft).

  VSWIM = observed fish movement vector minus water velocity vector

- Three-dimensional fish movement characteristics (CHAR) by distance along the PSC, distance upstream from the PSC, and depth of water in micro-scale (± 0.2-2 ft).

  CHAR includes parameters such as tortuosity, displacement distance fraction, and loopyness

- Three-dim. tracks (TRAK) for long distances (5-100 ft) in the B1 forebay by species.

  TRAK = fish traces through the forebay

- Biological/hydraulic statistical associations between fish movement data and hydraulic characteristics (BIOHYD).

  BIOHYD is a multiple regression analysis that integrates fish and environmental data sets.

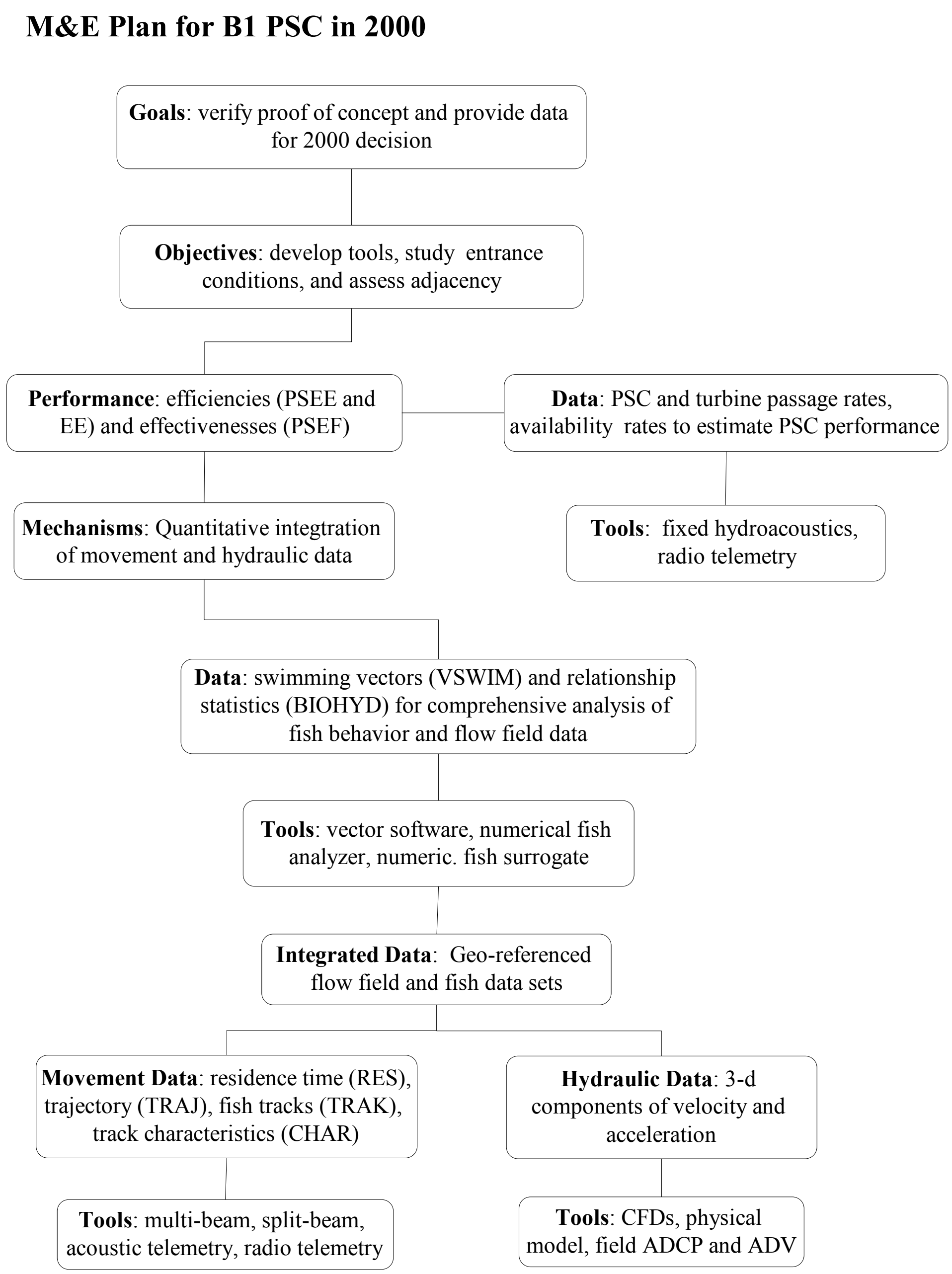

Figure B.3. M&E plan for B1 PSC in 2000 showing relationship between goals, objectives, performance, mechanisms, M&E data, and tools. Refer to section B2.3.2 for an explanation of the "data."

B.2.3.3 M&E Tools

M&E at the B1 PSC in 2000 will involve hydraulic data, biological data, and their integration. Hydraulic data will be obtained from physical models (1:25, 1:40, 1:100 of B1 at WES), computational fluid dynamics models (B1 forebay initially), and field-work. The specific scope of work for hydraulic modeling is currently being formulated. It is clear, however, that appropriate field data (ADCP and/or ADV) will need to be collected to calibrate the physical and CFD models.

Biological M&E methods at the B1 PSC will probably entail a combination of fish tag and non-tag studies. Tag studies may include radio or acoustic devices. Radio tags are monitored from mobile and fixed stations. Acoustic tags are monitoring with hydrophones or other acoustic receiving systems. Several acoustic telemetry approaches are being developed. Non-tag studies usually employ hydroacoustics, because direct capture techniques using nets or electrofishing can kill or injure endangered salmon. Hydroacoustic studies include single-beam for fish passage, split-beam for passage and/or behavior, multi-beam for behavior, and mobile surveys for mapping fish distributions.

Hydraulic and biological data will be integrated using software for fish swimming vectors, numerical fish analysis, and numerical fish surrogates. Quantitative integration is critical. This is the step that brings fish and environmental data together to examine and formulate hypotheses about mechanisms underlying observed PSC performance. Data integration can lead to biological specifications for surface bypass design at B1.

To provide the necessary data, previous research at Bonneville Dam has shown that a suite of techniques is required. In July 1999, the Corps proposed six biological studies to address M&E for the B1 PSC in 2000 (Table B.3).

B.2.4 Conclusion

The B1 PSC test is expected to verify or refute the proof-of-concept for surface bypass, as expressed in performance and behavior data, and provide data useful to decision-makers in 2001, when the utility of deep vertical slot surface bypass at B1 is debated. M&E data could include PSC efficiencies and effectiveness, residence times, trajectories, swimming effort vectors, fish tracks, and biological/hydraulic data integration. M&E tools might involve fixed single, split, and multi-beam hydroacoustics, radio and acoustic telemetry, and vector and numerical analysis software. The 2000 M&E plan is designed to thoroughly assess PSC performance and investigate causal mechanisms underlying that performance.

Table B.3. M&E studies proposed in the AFEP process and hydraulic model work planned for the B1 PSC in 2000.

Study Code	Title	M&E Data	M&E Tools
SBE-P-95-6	Movement, distribution, and passage behavior of radio-tagged juvenile salmonids at Bonneville Dam associated with the surface bypass program, 2000	PSCE, PSCEF, EE, RES	Radio telemetry
SBE-P-98-8a	Hydroacoustic evaluation of the Bonneville Dam First Powerhouse 2000 prototype surface flow bypass: passage	PSCE, PSCEF, EE, TRAJ	Fixed single and split-beam hydroacoustics
SBE-P-98-8b	Hydroacoustic evaluation of the Bonneville Dam First Powerhouse 2000 prototype surface flow bypass: behavior	VSWIM, CHAR	Multi-beam hydroacoustics
SBE-P-95-9	Development of fish sampling capability for evaluation of surface flow bypass	PSCE, PSCEF	PIT tags
SBE-P-00-13	Biological and hydraulic data integration in support of the Bonneville surface bypass program	BIOHYD, STAT, TRAK	Num. fish analyzer and surrogate, telemetry, acoustics
SBE-P-00-14	Evaluations of three-dimensional fish behavior associated with fish passage through, around, and under prototype surface flow bypass structures	TRAK	Acoustic telemetry
SBE-P-00-7	Hydroacoustic evaluations and studies of fish passage at Bonneville Dam	Fish passage and spill efficiencies	Fixed single-beam hydroacoustics
----	Computational fluid dynamics model for B1 forebay including the PSC	3-d velocity, acceleration	CFD
----	Physical model assessment of water velocity in the forebay of B1 PSC, WES 1:40 and 1:25	3-d velocity	Physical model
----	Physical model assessment of water velocity and high flow outfall plume characteristics of B1 tailrace, WES 1:100	3-d velocity, dye plumes	Physical model
----	Field measurements of water velocity	3-d velocity	ADCP and ADV

B.3 PCC at B2

In 2000, surface bypass development at the PCC will emphasize the conveyance structure and high flow outfall. A new conveyance structure and outfall specifically located and designed to provide safe fish passage are scheduled to be completed by spring 2003. At which time M&E of these structures will occur. In the meantime, more baseline biological and hydraulic data on the PCC would be desirable to justify and support engineering for the permanent structure.

B.3.1 M&E Objectives

The M&E objectives for B2 corner collector in 2000 are:

1. Verify PCC forebay collection efficiency.
2. Investigate causal mechanisms for the apparently high efficiency.
3. Assess predator distribution and abundance in the tailrace.
4. Finalize preliminary guidelines for high flow outfalls, i.e., research entry and receiving water characteristics.

B.3.2 M&E Studies

In July 1999, the Corps proposed five biological studies to address M&E for the B2 PCC in 2000 (Table B.4). Three of these are related to high flow outfalls. One deals with verification of 1998 PCC efficiency data. And the last one relates to baseline biological conditions in the B2 tailrace. Hydraulic data will be obtained from physical models at 1:100 and 1:30 scales.

Table B.3. M&E studies proposed in the AFEP process and hydraulic model work planned for the B2 PCC in 2000.

Study Code	Title
SBE-P-00-10	Research on the high flow outfall guideline for receiving water characteristics
SBE-P-00-11	Research on the high flow outfall guideline for entry characteristics
SBE-P-00-12	Characterization of fish exposure to high intensity energy dissipation environments
SBE-P-00-15	Evaluation of forebay collection at the PCC at B2
SBE-P-00-16	Evaluation of conveyance and tailrace conditions at the existing PCC outfall at B2
----	Physical model assessment of outfall jet characteristics to design high flow outfall for B2 corner collector, ENSR 1:30
----	Physical model assessment of water velocity and high flow outfall plume characteristics of B1 tailrace, WES 1:100

B.4 Conclusion on M&E in 2000

Surface bypass M&E activities in 2000 at Bonneville Dam will emphasize performance of the PSC1-6 at B1 and development of the high flow outfall at the PCC at B2. The results from these studies will be used to make fisheries management, environmental planning, and engineering design decisions on surface bypass initiatives at Bonneville Dam. These decisions will rely heavily on data from the 2000 M&E activities.

B.5 Literature Cited

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