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To: Sean Tackley, USACE Portland District

From: Matthew Keefer, University of Idaho

RE: Use of floating orifice gate fishway entrances by adult Chinook salmon, steelhead, sockeye salmon and Pacific lamprey at Bonneville Dam

Date: 5 July 2011

Introduction

A series of 16 floating orifice gates (FOGs) provide upstream-migrant fish access into the fishway collection channel at Powerhouse 2 at Bonneville Dam (Figure 1). The FOGs are relatively low-volume openings and the USACE and others have occasionally considered closing some or all FOGs to reduce fishway water requirements. The potential effects of FOG closures on fish behavior and fishway passage efficiency are not well understood. Possible negative effects include increased time to locate and enter fishway openings (i.e., passage delay) and failure to enter the fishway. A possible positive effect is reduced fishway fallout.

An experiment at Priest Rapids Dam in 1997 tested the effects of FOG closure on radio-tagged adult Chinook and sockeye salmon passage (Peery et al. 1998). That study found no significant biological effects on salmon passage with orifice gates closed, although minor passage delays (i.e., < 15 minutes for Chinook salmon and ~2 h for Chinook salmon, on median) were detected. Sockeye salmon were also somewhat less likely to exit the Priest Rapids fishway into the tailrace when the FOGs were closed, though this benefit did not appear to substantively affect either passage times or overall passage performance (Peery et al. 1998).

There has not been a similar experimental evaluation at Bonneville Dam. However, use of the Bonneville FOGs was evaluated using radio-tagged Chinook salmon, sockeye salmon, steelhead and Pacific lamprey in 1997-1998. For this report, we retrospectively summarized some basic fish behaviors at the Bonneville FOGs and in the adjacent collection channel and the larger fishway openings at the ends of Powerhouse 2. The data presented are intended to provide background information for possible future evaluations of the effects of seasonal closing of Bonneville FOGs to reduce fishway fallout by adult Pacific lamprey.

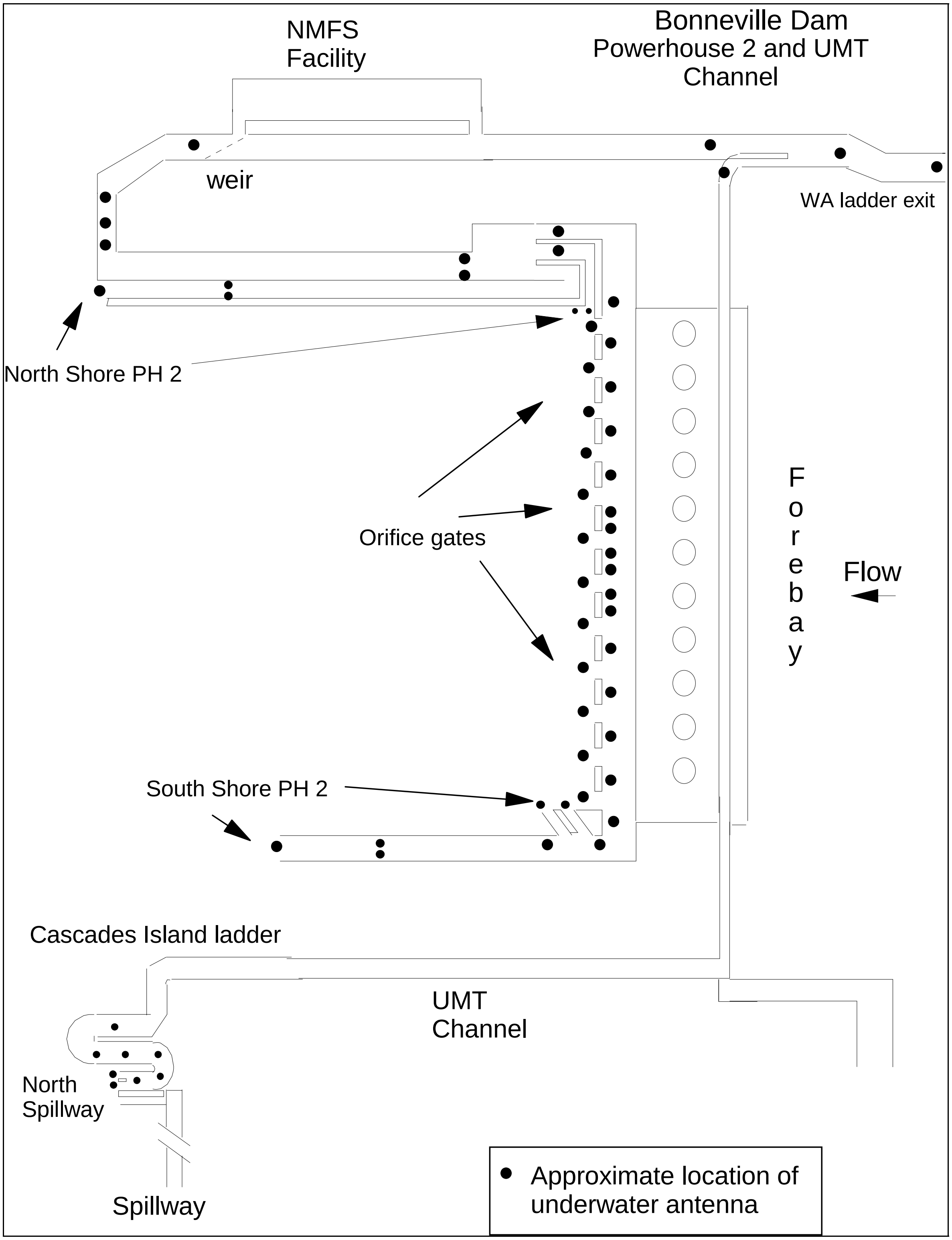

Figure 1. Schematic of the Powerhouse 2 and Cascades Island fishways at Bonneville Dam, showing radiotelemetry antennas (●) used to monitor fish movements in 1997-1998. Not to scale: 12 of 16 floating orifice gates (FOGs) shown.

Methods

All Bonneville fishway openings, including Powerhouse 2 FOGs, were monitored in 1997-1998. FOGs were not monitored in subsequent (1999-2010) adult salmon or adult lamprey radiotelemetry studies. In 1997-1998, radio-tagged adult spring–summer Chinook (2 years), fall Chinook (1 year), sockeye salmon (1 year), steelhead (1 year), and Pacific lamprey (2 years) were released downstream from Bonneville and monitored as they approached, entered, and passed through Bonneville fishways. Collection, tagging, and monitoring details are described in Ocker et al. (2001), Vella et al. (2001), Burke et al. (2005), and Keefer et al. (2008).

Underwater antennas were located outside each FOG as well as inside the collection channel at sites near each FOG. Each receiver typically had four antennas inside and outside a pair of FOGs. These antennas were often in relatively close proximity and it was therefore challenging to interpret some behaviors and to confidently assign fish locations when there were near-simultaneous detections on adjacent antennas. In these instances, the data coding protocols were designed to assign 'unknown' codes to the telemetry records and consequently there are a relatively high proportion of unknown fishway entry and fishway exit records at the FOGs. Generally, the uncertainty was related more to which of two adjacent openings were used rather than to whether or not fish moved in and out of the fishway. However, the latter challenge was also an issue. Because of these limitations, we assigned FOG approach, entry, and exit behaviors to the most likely pair of FOGs, grouped by receiver site. The presented results are based on coded telemetry data, but should be considered relatively qualitative.

The summaries below are based primarily on simple queries from the radiotelemetry databases. To describe basic FOG use patterns, the numbers and/or locations of approaches, entries, and exits were summarized. Overall FOG entrance efficiencies were calculated for unique fish (number that entered / number that approached) and for all movements (total entries / total approaches). These two metrics give a basic picture of how effective the FOGs were for getting fish into the fishway. FOG exit ratios were also calculated for unique fish and total movements. These metrics give a sense of whether FOGs were net positive or net negative in terms of fishway entry. Importantly, the exit ratios include fish that exited FOGs after entering at either south- or north- shore openings as well as fish that entered via FOGs.

Potential future changes to FOG operations are being considered to improve lamprey passage. Therefore, we additionally examined individual lamprey passage histories to provide a sense of where they entered and exited FOGs and the outcomes of all FOG entries (e.g., did a FOG entry result in dam passage or exit to the tailrace). Similarly, we examined lamprey routes prior to all FOG exits to see where these fish entered the fishway.

Results

General use of FOGs – A relatively cursory review of the telemetry data indicated that fish from all species moved north and south along the face of the Powerhouse 2 fishway collection channel, often multiple times per fish. This resulted in many coded fishway approaches at the FOG openings: 28-42% of the radio-tagged samples in each species-year were recorded approaching one or more FOGs (Table 1). Much smaller proportions used FOGs to enter the fishway, with only 2-5% of steelhead and sockeye salmon and 9-10% of Chinook salmon recorded entering. Lamprey were the most likely to enter FOGs (11-18% of the tagged samples). Fish of all species were recorded exiting FOGs, and proportionately more lamprey exited (9-17% of the tagged samples) than salmonids (2-6%). The exit estimates include fish that entered the fishway at all locations (i.e., FOGs and larger fishway entrances at the north and south ends of the Powerhouse).

Table 1. General use of floating orifice gates (% of radio-tagged sample detected) plus floating orifice gate entrance efficiencies (FOG entries / FOG approaches) and exit ratios (FOG exits / FOG entries) for radio-tagged adult salmonids and adult Pacific lamprey at at Bonneville Dam, 1997-1998. 'Total' includes multiple movements (i.e., FOG approaches, entries, or exits) by individual fish.

	Spring-summer Chinook		Fall Chinook	Steelhead	Sockeye	Pacific lamprey	
	1997	1998	1998	1997	1997	1997	1998
Approached FOG	32%	28%	41%	42%	39%	40%	39%
Entered FOG	10%	9%	10%	2%	5%	18%	11%
Exited FOG	4%	3%	6%	2%	3%	17%	9%
Unique entrance efficiency	0.40	0.30	0.37	0.11	0.32	0.39	0.34
Unique exit ratio	0.40	0.22	0.52	1.32	0.59	0.89	0.67
Total entrance efficiency	0.05	0.03	0.03	0.01	0.05	0.05	0.04
Total exit ratio	0.31	0.17	0.42	1.25	0.45	0.78	0.73

FOG entrance efficiencies at the individual fish scale were relatively consistent across species. Unique fish entrance efficiency (number that entered a FOG / number that approached a FOG) ranged from 0.30-0.40 for all species except steelhead (0.11) (Table 1). Unique fish exit ratios (number that exited a FOG / number than entered a FOG) were considerably more variable. The lowest exit ratios were for spring–summer and fall Chinook salmon (0.22-0.52), the highest was for steelhead (1.32), and estimates were intermediate to high for sockeye salmon and lamprey (0.59-0.89). Note that exit ratios < 1.0 suggest a positive net entry rate while ratios > 1.0 suggest a negative net entry rate; the latter was possible because fish could enter at sites other than FOGs and then exit via FOGs.

FOG entrance efficiencies calculated using all movements of all fish indicated that FOGs were relatively inefficient, with estimates of 0.01-0.05 for all species (Table 1). The low total efficiency estimates were potentially the result of 'swim-by' behavior as fish moved along the face of the collection channel. It is likely that some of these approach records were not associated with fishway entry attempts. Patterns for total exit ratios were similar to the unique fish exit ratios, as this metric was not affected by swim-by behavior (Table 1).

Spatial distribution – The close proximity of the many underwater antennas used to monitor FOGs made it difficult to conclusively differentiate among which sites radio-tagged fish used. Nonetheless, inferred fishway entries for all species were least frequent at FOGs located near the middle of the collection channel and were more frequent at the northern-most and southern-most

FOGs (Figure 2). FOG exits were also relatively more common from those near the ends of the collection channel, particularly for salmonids. However, proportionately more lamprey exited from FOGs near the middle of the collection channel (Figure 2).

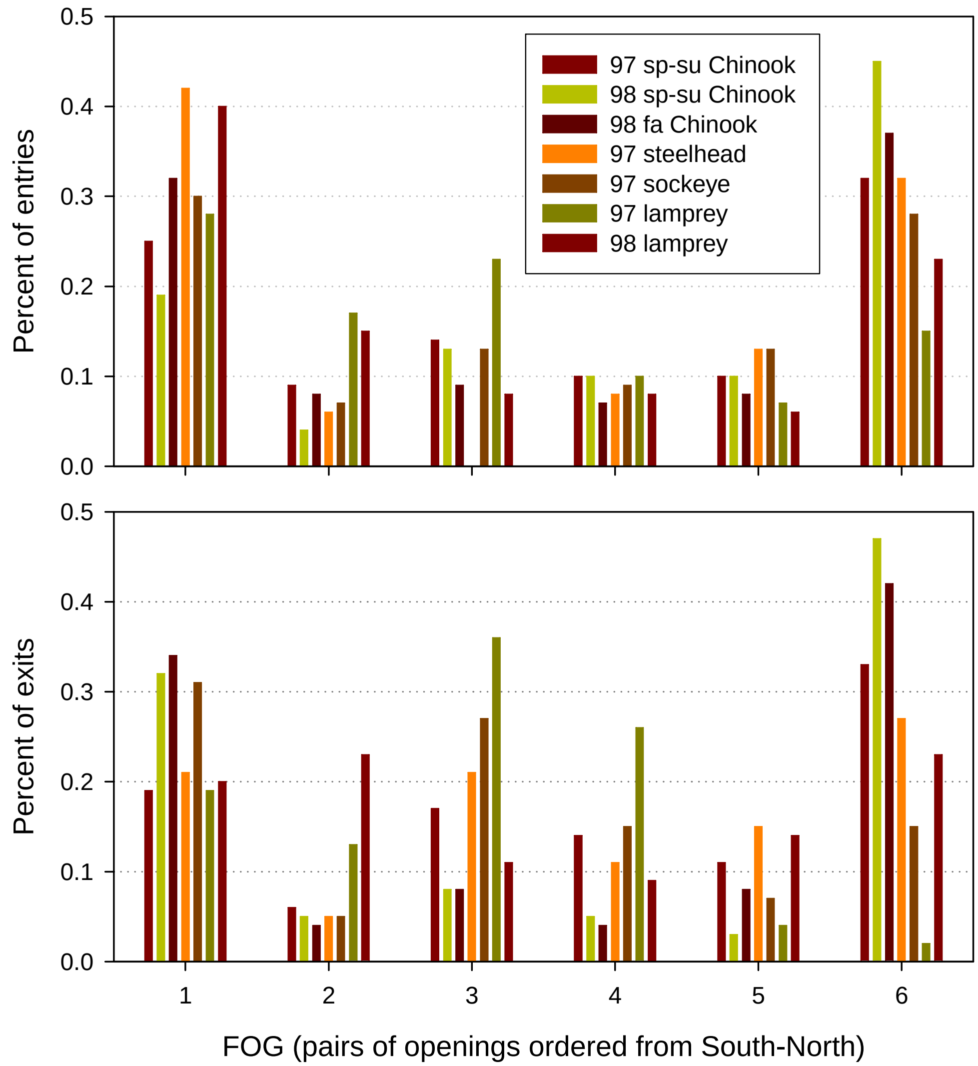

Figure 2. Estimated distribution of FOG entries (top) and exits (bottom) by radio-tagged fish in 1997-1998. Note that resolution among sites was challenging and these distributions are approximate only.

I examined the telemetry data fish-by-fish to determine the outcomes of all FOG entries by lamprey. A majority (52%) of the FOG entries were eventually followed by FOG exits (Figure 3). Another 30% of FOG entries were followed by fishway exits from the south-shore fishway openings, indicating that lampreys moved downstream after entering FOGs. This behavior often occurred after some upstream movement in the collection channel and some fish moved into the transition pool area before retreating downstream. About 9% of FOG entries resulted in lamprey passage up the collection channel and fishway and eventual exit into the Bonneville forebay. A few others moved upstream through the collection channel and exited to the tailrace via north-shore fishway openings or moved up the ladder and then downstream through the UMT channel and exited into the tailrace via the Cascades Island fishway (Figure 3).

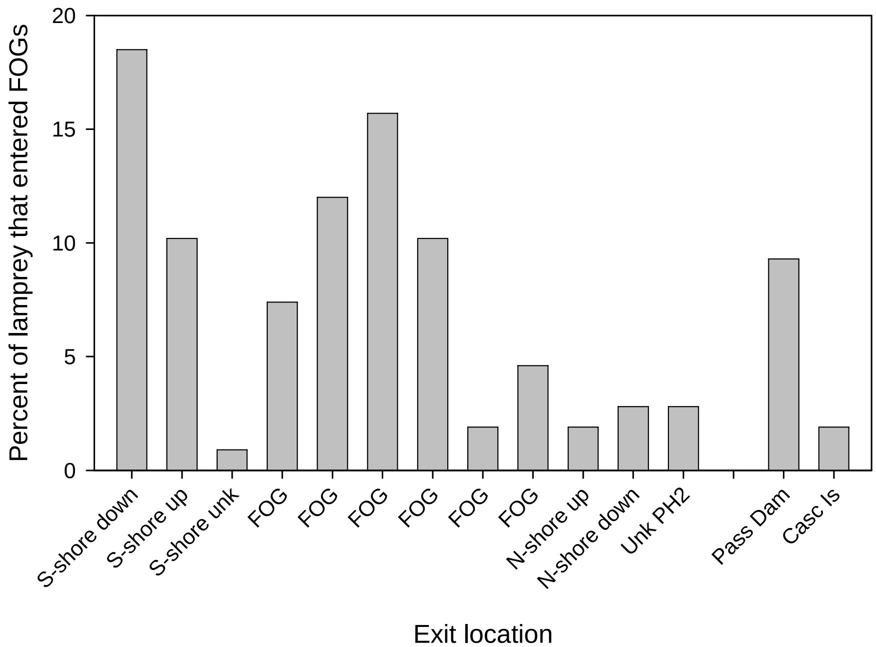

Figure 3. Fishway exit locations that were recorded or inferred following 108 FOG entries by radio-tagged Pacific lamprey in 1997-1998. Sites are ordered from South to North and each FOG in the bar chart is associated with a pair of FOG openings monitored with a single receiver.

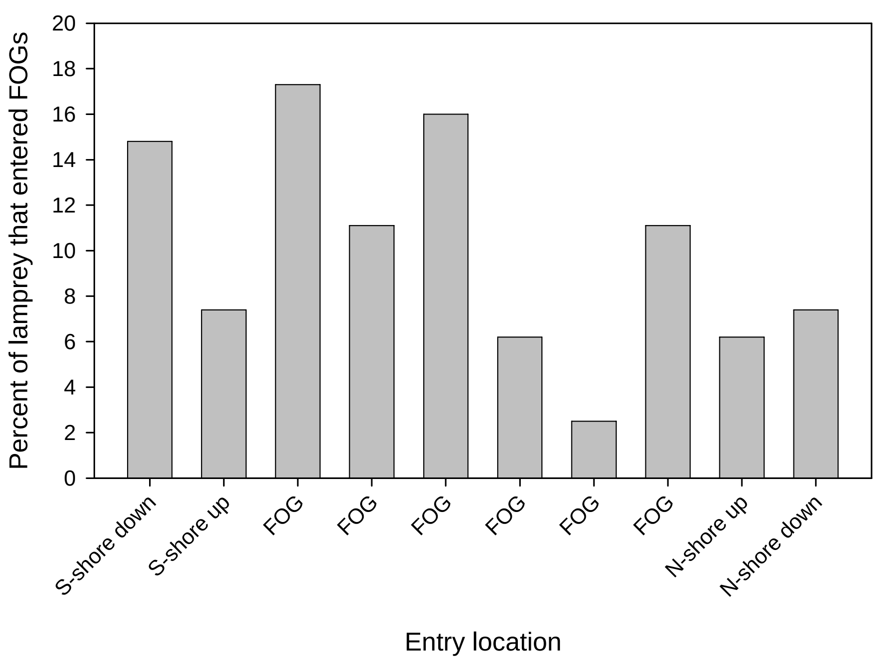

Figure 4. Fishway entry locations that were recorded or inferred prior to 81 FOG exits by radio-tagged Pacific lamprey in 1997-1998. Sites are ordered from South to North and each FOG in the bar chart is associated with a pair of FOG openings monitored with a single receiver.

An examination of lamprey behavior prior to each FOG exit to the tailrace indicated that the majority (64%) entered the fishway via FOGs, 22% entered via the large south-shore openings, and 14% entered via the large north-shore openings (Figure 4). Some lamprey moved upstream and downstream inside the collection channel prior to FOG exit, while others moved relatively quickly from entry to exit without much movement inside the fishway.

Conclusions

● Fish of all species used the Powerhouse 2 FOGs at Bonneville Dam to enter and exit the fishway.

● Unique fish entrance efficiencies at FOGs were relatively high for all species, but total FOG entrance efficiencies were quite low, presumably because many fish swam past the openings and entered at the larger openings at the ends of the Powerhouse.

● FOG exit ratios were > 1.0 for steelhead, indicating likely negative net entry rates. FOG exit ratios were also relatively high for Pacific lamprey, but were < 1.0.

● Fish of all species were more likely to enter FOGs closer to the ends of the collection channel than those in the middle of the collection channel. Relatively larger percentages of lamprey than salmonids exited from the mid-channel FOGs.

● Most lamprey that exited FOGs subsequently exited to the tailrace, primarily via FOGs but also via the south-shore fishway openings. Less than 10% of FOG entries resulted in Bonneville Dam passages.

● About a third of the FOG exits by lamprey were preceded by fishway entries at the larger south- and north-shore fishway openings, indicating that FOGs may reduce overall fishway passage efficiency for this species.

While the data presented above give a general sense of fish activity at the FOGs, it is difficult to move from these summaries to making conclusions about what effect FOG closure may have on fish passage. Lamprey conversion from the south to the north end of this fishway has often been among the lowest recorded inside any fishway monitored in the radiotelemetry studies, but the mechanisms that affect this poor performance are not understood. It is possible that hydraulic conditions (i.e., turbulence, attraction flow, water velocity), the presence of white sturgeon, floor diffuser grating, or some combination of features make this fishway segment unattractive to lamprey. Based on radiotelemetry results for lamprey over multiple years and at multiple fishways, I think it is unlikely that the FOGs are causing the poor performance, although fallout from the Powerhouse 2 collection channel via FOGs may be a contributing factor.

I expect that FOG closure would have limited effects on adult salmonids, although some minor passage delay is possible. The latter would most likely accrue in the tailrace, and would primarily be a concern in the spring when California and Steller sea lions are present and feeding on adult spring Chinook salmon, steelhead, and Pacific lamprey (Stansell et al. 2010). It is also possible that FOG closure could provide some benefit to adult steelhead, the only run that had more FOG exits than FOG entries. Reducing exits from FOGs would be beneficial given the relatively large effect that fishway exit has on total dam passage times (e.g., Keefer et al. 2008).

To test whether FOG closure benefits lamprey passage, a randomized block design could be applied, perhaps similar to the study at Priest Rapids Dam (Peery et al. 1998) or to the Bonneville Dam night-time fishway flow experiment (Johnson et al. 2010). Such a test could be conducted in summer, during the peak of lamprey passage and after sea lions have left the Bonneville tailrace. Alternately, an evaluation of the hydraulic environment inside the collection channel, or passive monitoring of lamprey inside the channel (i.e., using underwater video or DIDSON) could identify lamprey passage problems that may or may not include FOGs.

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