DRAFT
FISHERIES TECHNICAL REPORT

WEBER HYDROELECTRIC PROJECT RELICENSING
FERC NO. 1744

Prepared for

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~~**December 22, 2016**~~

February 8, 2017

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1.0 INTRODUCTION

PacifiCorp, a subsidiary of Berkshire Hathaway Energy, plans to file a new application for relicense of a major project, the Weber Hydroelectric Project (Project), Federal Energy Regulatory Commission (FERC or Commission) Project No. 1744, on the Weber River in Weber, Morgan, and Davis counties,~~ in~~ Utah. The current license will expire~~ on~~ May 31, 2020. The Project has a generating capacity of 3.85 megawatts (MW) and is located partially on federal lands managed by the Wasatch-Cache National Forest (Intermountain Region 4, Utah), and partially on lands owned by the Union Pacific Railroad Company. PacifiCorp filed a Notice of Intent to File Application for New License (NOI) and a Pre-Application Document (PAD) to initiate the FERC Alternative Licensing Process (ALP) for the Project on May 29, 2015.

During preparation of the PAD, PacifiCorp evaluated existing information on general aquatic resources and aquatic threatened, endangered, and sensitive species within the Project Area to inform analysis of Project impacts on these resources.

The PAD and subsequent Weber Final Fisheries Study Plan (PacifiCorp 2016) identified two special status aquatic species: the Bonneville cutthroat trout (*Oncorhynchus clarki*) and the bluehead sucker (*Catostomus discobolus*). Both species are known to occur within the Project vicinity and were the focus of the Fisheries Study Plan to evaluate the potential for upstream movement, as well as any potential risk of downstream entrainment through the Project turbine. A Fisheries Working Group (FWG) was formed during Project scoping that consisted of any stakeholders interested in participating in development and implementation of the Fisheries Study Plan. This group is made up of members from FERC, Utah Division of Wildlife Resources (UDWR), U.S. Fish and Wildlife Service (USFWS), Trout Unlimited (TU), U.S. Forest Service (USFS), and Utah Department of Environmental Quality (UDEQ).

The Fisheries Study Plan called for PacifiCorp to provide the results of two studies: an upstream fish passage engineering feasibility study and a study of fish migration downstream of the P~~p~~roject. Results of the first study, titled “Study One - Upstream Fish Passage Conceptual Design Report,” provides a feasibility study of alternatives and a conceptual design with design criteria for an upstream passage facility at Weber dam. Study One is summarized in Section 5 of this report and appended in its entirety in Appendix 1. The second study, titled “Study Two - Fish Migration Downstream of the Project,” includes three phases, although only two were initially contemplated in the Fisheries Study Plan. Phase One~~I~~ of Study Two of the Fisheries Study Plan called for PacifiCorp to conduct a test to identify fish survival through the flowline and turbine using three sizes of hatchery trout. Phase Two~~II~~ of Study Two involved the use of a camera to determine how many and the approximate size range(s) of native~~endemic~~ fish that may actually be entrained at the Weber intake. When Phase Two~~II~~ could not be completed as planned, a Phase Three~~III~~ was agreed to by the FWG and added to the planned studies. Discussions of each of the Study Two phases can be found in Section 6 of this report.

2.0 BACKGROUND

The Weber Hydroelectric Project (FERC No. 1744; Project) is owned and operated by PacifiCorp. Constructed originally by Utah Light and Rail Company in 1910 and acquired by Utah Power and Light in 1944, the Project was issued its most recent license on June 28, 1990. That license expires on May 31, 2020. PacifiCorp (2015a) filed a PAD on May 29, 2015, indicating its intent to relicense.

The Weber hydroelectric facility includes the following components:

(1) a 27-foot-high, 79-foot-long concrete diversion dam, having two radial gates approximately 29 feet wide, and a 35-foot-wide intake structure, for a total width of 114 feet, on the Weber River;
(2) a 9,107-foot-long, 5-foot to 6.3-foot-diameter steel penstock pipeline partially encased in concrete, beginning at the intake and terminating at the powerhouse on the Weber River;
(3) a 3-foot by 18-foot non-operative fish passage structure (used however to pass the minimum flow through the calibrated slide gate opening);
(4) a powerhouse containing a double runner Francis turbine with 17 buckets per side (34 total), 3.7-foot diameter runner, runner speed of 360 rpm and peripheral runner velocity of 72.5 feet/sec;
(5) a rated capacity of 3,850 kilowatt (kW) operating under a head of 185 feet producing a 30-year average annual energy output of 16,932 megawatt-hours (MWh)

The diversion dam is located approximately 2.5 miles east of the mouth of Weber Canyon (Figure 1). The gatehouse structure containing the penstock intake leading to the powerhouse is located on the southern shoreline of the Project forebay.

During scoping consultations, one of the major fisheries issues that arose concerned potential impacts on upstream and downstream movement past the diversion structure. Passage implications for two sensitive species in the Project Area, bluehead sucker and Bonneville cutthroat trout, were of principal interest.

Concerns about entrainment and mortality of these two species in the Project's turbines led the working group, composed of PacifiCorp and interested federal, state and private stakeholders (the FWG, as detailed above in Section 1.0,) to recommend that two studies be undertaken to evaluate potential impacts. The first part of Study Two (Phase OneI) involved the release and recapture of different size groups of hatchery rainbow trout (*Oncorhynchus mykiss* and tiger trout (brown trout - brook trout hybrids *Salmo trutta x Salvelinus fontinalis*) through the penstock and turbines to estimate associated mortality. That study was conducted and documented by PacifiCorp in July 2016. The second portion (Phase TwoII of Study Two) utilized an underwater camera to identify and count fish as they passed through the penstock (PacifiCorp 2016). That study took place starting in early August of 2016 and was conducted by RedFISH Environmental. The physical characteristics of the Project infrastructure where the camera was placed limited the effectiveness of the monitoring system. Although multiple adjustments were made in the study design and camera placement over the next six weeks, the results were incomplete, inconclusive, and did not meet the study objectives. Thus, on September 14, 2016, the FWG agreed preliminarily to modify the study approach and conduct a qualitative desktop analysis to evaluate entrainment and mortality potential at the P~~p~~roject (Phase Three~~III~~). Phase Three~~III~~ of Study Two was also completed by RedFISH Environmental.

Section 6 of this report describes the results of the studies undertaken during Phases One~~I~~, Two~~II~~ and Three~~III~~ of Study Two.

3.0 PROJECT AREA

For the purposes of these studies, the FERC Project Boundary (or Project Boundary) is defined as all lands and waters within the existing FERC Project Boundary for the Weber Hydroelectric Project No. 1744, as denoted on the Project's Exhibit G map. The Project Area is the area that contains all Project features (encompassing the FERC Project Boundary as defined above), and that extends out for the purposes of characterization and analysis from the farthest edge of the Project Boundary, and across the river to the far riverbank (including the river regardless of which side of the river the Project features are found), as shown in Figure 1.

4.0 STUDY AREA

The Study Area includes the Project reservoir from just upstream of the Utah Department of Transportation (UDOT) rest area and extending downstream to the Project dam and the Project bypass reach from the dam to the powerhouse discharge. From the discharge point, the water immediately enters the Davis-Weber Canal Company diversion, and fish monitoring did not extend into that unrelated project area (Figure 1).

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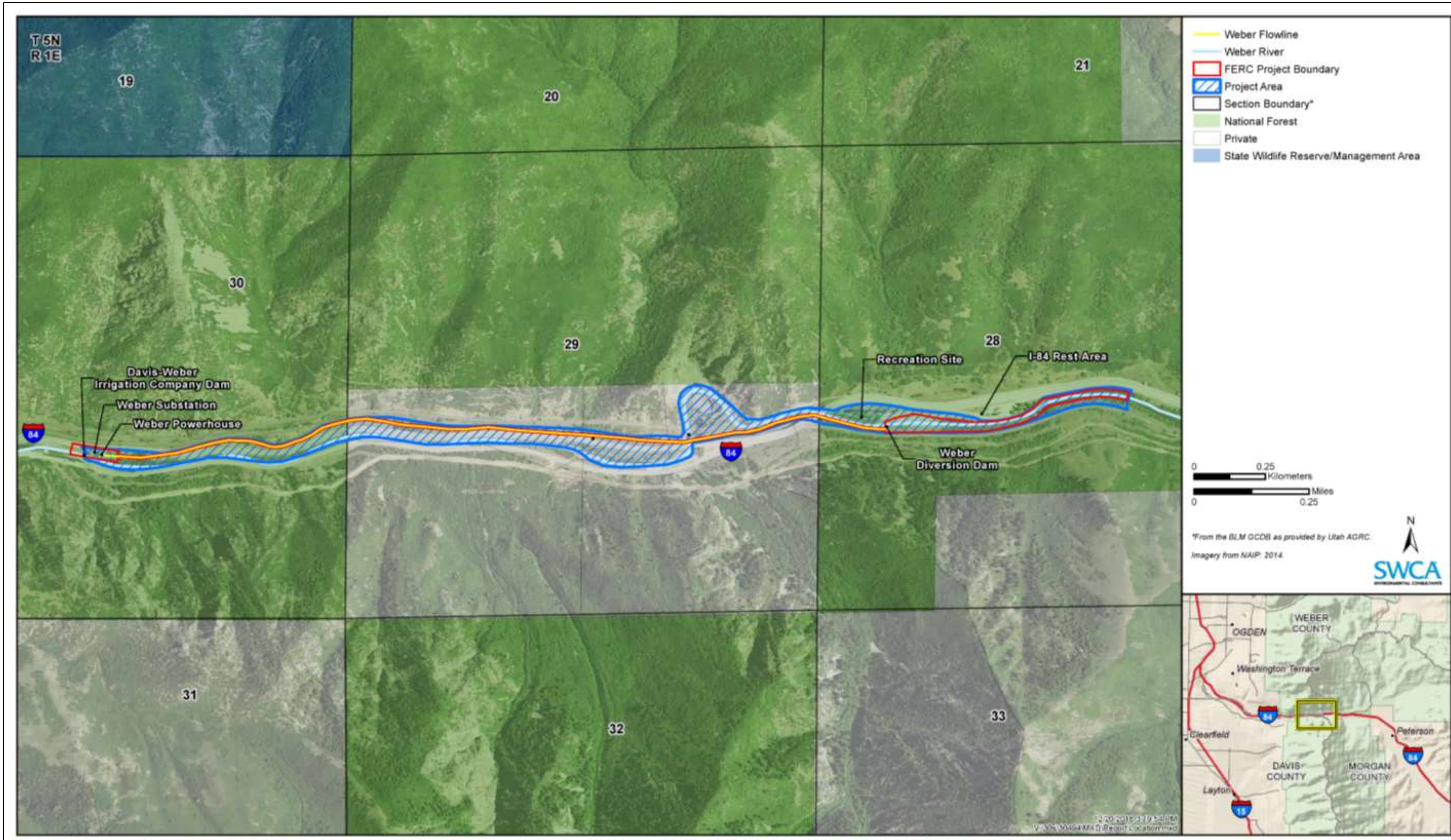

Figure 1. Weber Hydro Relicensing Project location and Project features.

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5.0 STUDY ONE: UPSTREAM FISH PASSAGE CONCEPTUAL DESIGN STUDY

In anticipation of a new FERC license, PacifiCorp is designing a new upstream fish passage facility to pass Bonneville cutthroat trout (*Oncorhynchus clarkii)* and bluehead sucker (*Catostomus discobolus*) at the Weber Hydroelectric Project diversion dam. Four distinct types of fishways were investigated as potential options. Variations on two of these types of fishways resulted in a total of six options that were considered in an alternatives analysis performed with input from PacifiCorp and the FWG (see Appendix 1).

One of the objectives of the FWG was to work together to come to consensus on a recommended fish passage design alternative for detailed consideration in the FERC relicensing process. The step-wise process used for the FWG to achieve this objective consisted of the following (dates refer to various meetings in person or via conference call of the FWG during the process):

1. Develop design criteria – Initiated on March 7, 2016 and finalized on July 13, 2016.
2. Develop and workshop draft alternatives for upstream fish passage and select a recommended upstream fish passage alternative (traditional vertical slow fishway) – May 4, 2016.
3. Amend the recommended upstream fish passage alternative to include supplemental attraction flow provided via the existing minimum flow gate and historic fish passage flume – June 2, 2016.
4. Finalize the conceptual design for the recommended upstream fish passage alternative (traditional vertical slot fishway with supplemental attraction flow provided via the existing minimum flow gate and historic fish passage flume) – July 13, 2016.

As a result of this collaborative process, the FWG selected a vertical slot fish ladder on the right bank adjacent to the existing ice sluice/fishway. The conceptual design drawings for the preferred alternative have been prepared and are included in Appendix C of the Conceptual Design Report (Appendix 1 of this report).

6.0 STUDY TWO: FISH MIGRATION DOWNSTREAM OF THE PROJECT

PacifiCorp proposed a phased approach to investigating downstream fish passage at the Weber P~~p~~roject. Phase One~~I~~ of Study Two was conducted on July 19, 2016 at a point where the Weber River hydrograph was at or near the tail end of spring run-off. Phase One~~I~~, which is the basis for this report section, was a pilot project where three size classes of test fish (3-inch, 6-inch, and 12-inch) consisting of sterile, triploid trout were adipose clipped and sent down the Weber penstock to determine the extent of injury and overall survival. If low levels of injury were observed (as determined by the FWG and further defined below), then Phase Two~~II~~ of Study Two would not be necessary. Depending on the outcome of Phase One~~I~~, Phase Two~~II~~ planned for the use of an acoustic or infrared camera to determine how many and which approximate size range(s) of native~~endemic~~ fish may actually be entrained at the Weber intake. That is, if Phase I determined that significant fish numbers could be injured by going through the turbine, then the next phase was to determine which, if any, fish were actually being entrained. Once it became clear that the Phase Two~~II~~ study could not be completed as anticipated, the FWG met, discussed, and approved a qualitative Phase Three~~III~~ study instead that would primarily analyze the existing Weber turbine, intake configuration, and pipeline specifications, as well as other literature and studies to help further refine all information possible to help address the issue of whether entrainment at the Weber Project is a significant risk for, especially, the two fish species of concern, Bonneville cutthroat trout and bluehead sucker.

6.1. Study Two Phase One~~I~~: Turbine Mortality Field Study

Methods

Investigators secured a group of triploid rainbow trout from two local (UDWR) hatchery facilities. A group of approximately 100 fish from each of the three size classes were used in this study. The 6-inch and 12-inch were rainbow trout (*Onchorynchus mykiss*) and the 3-inch fish were tiger trout (*Salmo trutta x Salvelinus fontinalis*). These fish were marked with an adipose fin clip since no other trout in the area are likely to have this mark and so that the study personnel could distinguish the test fish from trout already residing in the study area. Prior to implementation of Phase One~~I~~ of Study Two, members of the FWG agreed on several *a priori* directives regarding the study:

1) Only fish recaptured after going through the Weber turbine would be used to inform the study results; that is, unrecovered fish would not be used to draw inferences regarding the potential effects of the turbine on fish.
2) A minimum recovery of 30 percent of the fish placed in the Project flow line was desired to form inferences regarding the potential effects of the turbine on fish.
3) Of recovered fish, negative impacts (defined as a maximum of 10 percent descaling or more severe injury such as pop-eye or other wounds/trauma) to 30 percent or more of the fish would result in additional discussion with the FWG to determine next steps.

The Weber penstock is 9,107 feet long and the estimated velocity is approximately 11.7 feet per second (fps), so it was estimated to take about 13 minutes for water and fish to travel through the entire penstock and turbine. Each fish group released was preceded by an application of fluorescent green dye and followed by placement of 30 radishes. The radishes have the same buoyancy as fish so it was thought they could provide some indication of when all the fish had passed. A time-lapse video produced by TU documents the various fish releases, recovery efforts, and shows the effect of the green dye.

Prior to any releases, all fish were measured to the nearest fork length (mm)[1] and adipose fins were clipped. Test fish sizes are listed in~~ Table 2-1 in~~ Appendix 2. Beginning with the two larger-sized trout, 40 of each size class were introduced to the penstock intake behind the intake rack at the vent stack. Then 40 of the 3-inch tiger trout were released last followed by 30 radishes. A plunger device was used to force fish into the penstock flow thus preventing them

[1] Fork lengths are reported in millimeters (mm) in this report, in accordance with standard fisheries practice; most other measurements are reported in imperial units.

from holding in the vent stack. After a period of about 30 minutes, the second batch of 30 fish of each size class was released preceded by dye and followed with 30 radishes. Since there was a need to give collectors time to work in the tailrace, the last batch of fish, dye and radishes was released about 1.5 hours later with 30 fish of each size class and 30 radishes.

Results

During placement of the fish, the Weber Project turbine was operating at nearly full load (311 cubic feet per second [cfs]) through release of the last batch of fish. A group of about 15 field crew had set up block nets and fyke nets prior to the first release. In addition, a raft equipped for electrofishing and a second support raft were in position in the powerhouse tailrace area where they alternated between electrofishing and a two-person SCUBA team continually looking for and collecting test trout, also from the tailrace area. About one hour after the last fish release (and six hours after the initial fish release), the plant was shut down and commercial divers entered the discharge chamber of the turbine draft tube to look for fish while the rest of the biologists entered the tailrace/lower river with nets and electrofishing gear to collect as many test fish as possible. All fish captured were recorded as either alive or dead and examined for injury and descaling.

Table 1 lists the results of the fish capture, which ranged from 15 to 54 percent. The fewest recaptures were observed in the 3-inch size class with only 15 fish recovered. Of those, five were moribund resulting in 33 percent mortality. Forty-seven 6-inch trout were recaptured and 22 of those were mortalities resulting in 46 percent mortality. Finally, 54 12-inch fish were recaptured with 46 of those recorded as mortalities resulting in 85 percent mortality. All live fish were kept in a live pen until the test period was over to determine if there was any delayed mortality.

Table 1. Recapture Results from the Weber Project Tailrace

	3-Inch Size Group	6-Inch Size Group	12-Inch Size Group
Recaptured	15	47	54
Mortalities	5	22	46
Percent mortality	33%	46%	85%

Participants noted that it appeared that the study was biased towards recovery of injured or dead fish, especially in the larger size classes. That is, numerous individuals of the smallest size class were not recovered, although they were observed alive and swimming by divers in both the river and the powerhouse tailrace sections. In addition, the efficiency of recapture resulting from electrofishing the smallest fish was very low.

On July 29, 2016, and following dissemination of the Phase OneI preliminary results, members of the FWG who wanted to observe the intake gate area, flow configuration, and current velocity visited the dam to observe the inside of the intake gate house immediately prior to a meeting that same day to discuss next steps.

Given the higher-than-acceptable threshold results of the Phase One~~I~~ test, and following the FWG discussion on July 29, the group decided to proceed to Phase Two~~II~~ of the study plan, which was to install a camera at the flowline intake to observe native~~endemic~~ fish behavior upstream of the penstock and to observe whether or not native~~endemic~~ fish were actually being entrained by the Weber Project.

6.2. Study Two Phase Two~~II~~: Turbine Entrainment Visual Assessment

Methods

In this phase, investigators installed an underwater fish monitoring system to determine the number of fish that may be entrained, species composition, and their approximate size. Camera features and specifications are listed below:

Features

- Full waterproof enclosure
- Waterproof cable
- Stand-alone power with continuous maintenance-free operation for up to 2 weeks with one 12V deep-cycle battery
- H.264 HD DVR - time and date-stamped video recorded to SD card (32 GB)
- Variable frame capture rates (1-30 fps) and motion detection to remove periods of inactivity to reduce data processing time

Specifications

- True color image sensor: SONY 1/3" CMOS color
- Infrared lighting: 27 850 nm FEDs
- Effective pixels: 976 (H) x 582 (V)
- Resolution: 700 TVL lines
- Camera housing dimensions: 25.4(W) x 22.9(H) x 19.1(D) cm
- Operating temperature: -10 ~50 °C

The camera was mounted on a custom frame in the surge pipe (the same location where fish were put into the flowline for Phase One~~I~~ of Study Two) facing downward through the opening into the penstock. The mount was secured such that the camera could capture as much of the penstock pipe area as possible (Figure 2; also Photograph 1, Appendix 3).

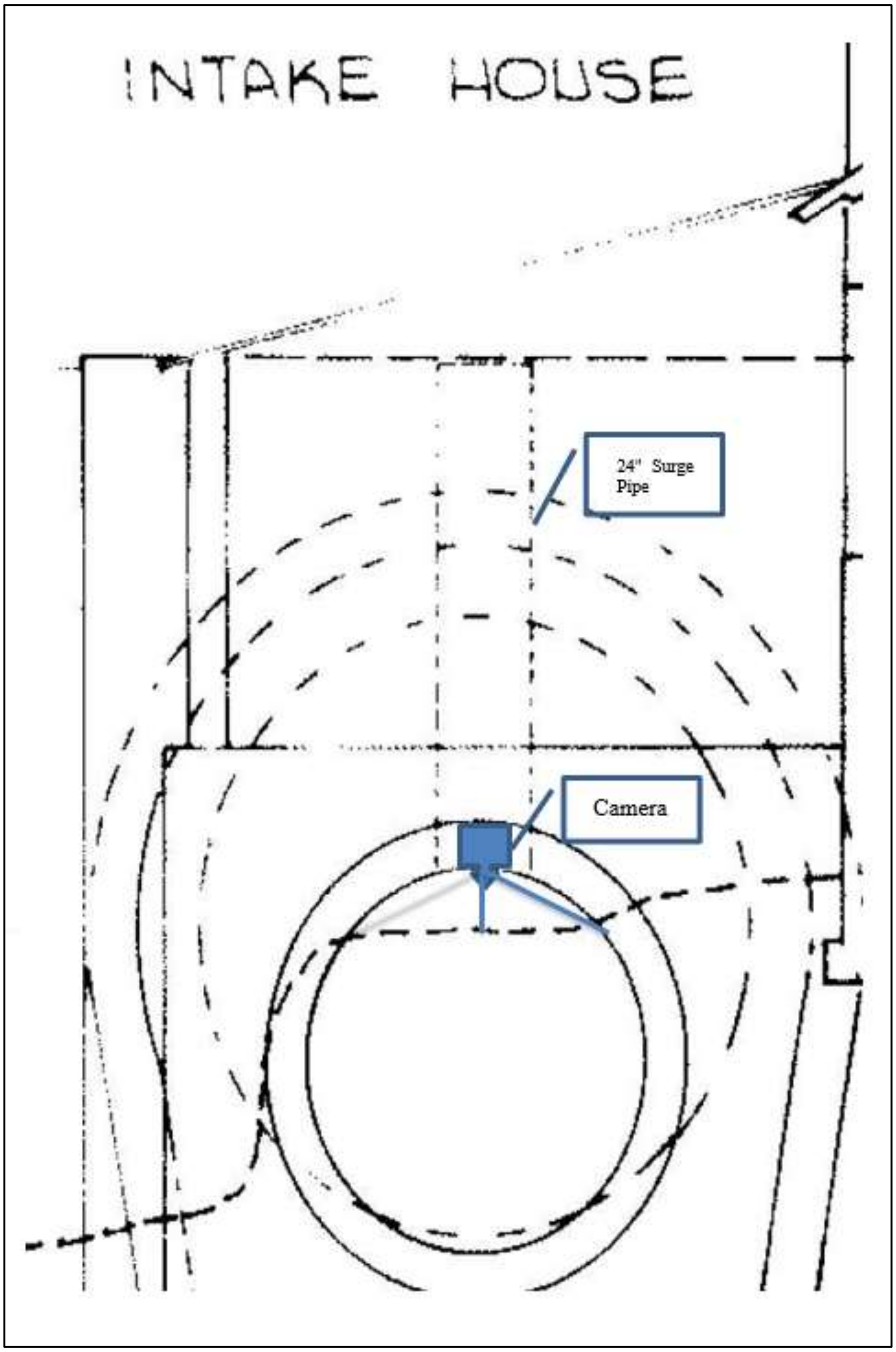

Figure 2. Diagram of the location where the underwater monitoring system camera was installed in the surge pipe of the penstock.

The camera was set to record fish entrained through the penstock intake using video capture regulated with motion detection sensors. When the sensors were triggered, the camera would record video for 10 seconds, giving processors adequate frames to positively identify fish species. The system was installed at the surge pipe on August 9, 2016. Due to the high degree of turbulence at this location, motion detection sensors were not effective and the video image was indistinct and limited. Dark conditions in the penstock also prompted the system to record using built-in infrared lights, which restricted the camera field of view. Consequently, on August 19, 2016, the camera was relocated to an opening between the trash rack and the penstock and mounted on a new custom frame (Photograph 2, Appendix 3). Although the camera field of view improved at this location, turbulence and debris continued to render the system ineffective. Alternate camera locations and positions were identified, discussed, and rejected (primarily for not meeting study objectives) during the period August 19 to September 2, 2016.

On September 2, 2016, PacifiCorp and RedFISH staff tested the underwater monitoring system by systematically placing 100 fish in front and behind the intake trash rack, as well as in close proximity and in line with the camera (Photograph 3, Appendix 3). Fish were rainbow trout hatchery mortalities (4-7 inches in total length) provided by the UDWR. The monitoring system was set to record continuously and video captured was downloaded weekly until October 19, 2016 when the system was removed from the Project after final consensus was reached with the FWG at a consultation meeting earlier that day.

Results

The underwater monitoring system recorded 7,288 files (62.8 GB file size) from August 9 - 19, 2016 at the first location and 59,105 files (91.4 GB file size) from August 16 - October 19, 2016 at the second location. Although this type of underwater monitoring system has been widely used on a variety of fisheries monitoring projects in low visibility situations, local conditions precluded the effective operation of the system. The camera field of view at the first location was limited to approximately 3 feet due to turbulent flow and light conditions. The camera field of view improved slightly at the second location (4–6 feet) but given the longer distance from the camera to the penstock intake (about 8 feet at the leading edge), it was not possible to effectively assess fish entrainment of the entire penstock. In addition, only four of the 100 fish used to test the system at the second location were captured by the camera. The identified fish were part of a batch of 20 fish that were individually placed directly in line with the camera (Photograph 3, Appendix 3). None of the other test fish placed in front or behind the intake trash rack were captured by the camera.

Highly turbulent flow and light conditions at both locations also triggered the motion detection feature of the monitoring system. As a result, the system recorded a very large volume of files. Given the results of the test run at the second location, it was determined that processing the recorded video files was not practical, cost-effective, and most importantly, unlikely to yield accurate fish entrainment data.

Given these incomplete and inconclusive results, and after assessing all identified potential alternative camera locations and alignments, the FWG agreed to modify the study approach and instead conduct a qualitative desktop analysis to evaluate entrainment and mortality potential at the Project (Phase Three~~III~~ of Study Two). This study phase was not originally anticipated by the FWG, and was not included in the approved Final Fisheries Study Plan (PacifiCorp 2016).

6.3. Study Two Phase Three~~III~~: Turbine Entrainment and Survival Literature Analysis

Methods

The primary objective of Phase Three~~III~~ was to qualitatively evaluate entrainment and mortality potential of Bonneville cutthroat trout and bluehead sucker at the Weber Hydroelectric Project. This analysis was not intended to determine quantitative estimates of Weber-specific project entrainment and mortality as the information required to complete that task could not be collected as planned in Phase Two~~II~~. Rather, the intent was to provide a qualitative assessment of relative risk to target species using information from Project Area studies and published literature on other hydroelectric systems and entrainment studies. A number of physical and biological factors may affect fish entrainment and mortality. Much of the Phase Three~~III~~ analysis accounts for those factors, how they could affect fish in the Weber River, and how they relate to measured entrainment and mortality at other hydroelectric projects.

Results

Fish Community

Fish species known to occur in the P~~p~~roject A~~a~~rea include Bonneville cutthroat trout (*Oncorhynchus clarkii utah*), rainbow trout (*O. mykiss*), brown trout (*Salmo trutta*), bluehead sucker (*Catostomus discobolus*), mountain sucker (*C. platyrhynchus*), Utah sucker (*C. ardens*), mottled sculpin (*Cottus bairdii*), speckled dace (*Rhinichthys osculus*), longnose dace (*R. cataractae*), mountain whitefish (*Prosopium williamsoni*), redside shiner (*Richardsonius balteatus*) and common carp (*Cyprinus carpio*) (PacifiCorp 2015a). Other species that have been collected in the Weber River and may occur in the P~~p~~roject A~~a~~rea include Paiute sculpin (*C. beldingii*), Utah chub (*Gila atraria*), green sunfish (*Lepomis cyanellus*) and yellow perch (*Perca flavescens*) (Budy et al. 2014). Most of the species are native except for rainbow trout, brown trout, green sunfish, yellow perch and common carp. Hybridization of Bonneville cutthroat with rainbow trout has occurred in the past. Although there appear to be few specimens in the Project Area, hybrids are typically removed by biologists when they are encountered (PacifiCorp 2015a). While any resident species may become entrained by the Project, Bonneville cutthroat trout and bluehead sucker are a concern at this time due to their affinity to the Weber River upstream and downstream of the Weber Project dam, their reduced population numbers throughout their range, and their Utah State sensitive status.

Previous surveys by UDWR found that brown trout, cutthroat trout and mountain whitefish comprise more than 95 percent of all game fishes in the reach bypassed by the Project. Stocking of brown trout was discontinued several years ago. The Weber River and its tributaries in the Project Area are classified by the State of Utah as Class IIIB, meaning it is a quality fishery that includes species of special concern. Management is directed toward improvement of these species in particular (PacifiCorp 2015a).

Bonneville Cutthroat Trout

Biology and Life History: Bonneville Cutthroat Trout

Bonneville cutthroat (Photograph 4, Appendix 3) is one of 14 subspecies of cutthroat trout recognized as native to interior portions of western North America (Behnke 1992). Fish may be found in a variety of different environments ranging from small headwater streams to rivers and streams at lower elevations to lakes or reservoirs. Individuals feed primarily on aquatic invertebrates and terrestrial insects during their lives (May et al. 1978), but may consume small fish once they attain sufficient size (Lentsch et al. 2000). Growth is largely a function of temperature and productivity.

Maturity is reached generally by Age 2 for males and Age 3 for females. Bonneville cutthroat in Birch Creek, a small tributary in southcentral Utah, became mature in their second year upon reaching about 134 mm as males and 147 mm as females (May et al. 1978); however, maturity typically occurs at a larger size in adfluvial and fluvial populations where resources are more plentiful and growth rates are higher, such as in the Weber River. Spawning occurs in late spring when temperatures range from about 4-10^{o}C (May et al. 1978) and chiefly during May and June, although elevation, temperature and life history strategy can influence the exact timing (USFWS 2001). This species can achieve considerable size in the Weber River. Biologists working on the area consider BCTs in the Weber to exhibit a fluvial life history when they exceed 300 mm in total length (Thompson, personal communication, 2017)~~This species can achieve considerable size in the Weber River – in excess of 600mm – though the average is about 300 mm (Budy et al. 2014)~~.

Larval emergence occurs typically during mid to late summer. Precise timing depends largely on when spawning occurs and stream temperatures. Larvae are poor swimmers and migrate or drift downstream, settling into lower velocity habitats along the stream margins. As the fish grow, they soon occupy more mid-channel habitats (Nielson and Lentsch 1988).

Bonneville cutthroat exhibit four distinct life history adaptations: lacustrine (spawning/rearing occurs in lakes); adfluvial (adults live in lakes, spawn in lake tributaries); fluvial (live in mainstem rivers and spawn in tributaries); and resident (entire life history remains in smaller stream). Past studies indicate a population can exhibit more than one life history strategy, such as a stream population including both fluvial and resident components (Colyer et al. 2005; Randall 2012).

Habitat fragmentation from the construction of diversions and other human activities has caused many populations of fluvial Bonneville and other native cutthroat to decline or disappear. As a result, there are relatively few remaining fluvial Bonneville cutthroat populations for study. One such study examined movement of radio-tagged adults in the Thomas Fork of the Bear River in Idaho and Wyoming in relation to a diversion structure. Home ranges were more extensive above the structure than below it; however, the researchers noted attempts to ascend the structure in the spring. Substantial portions (>50%) of both groups were mobile (>1 kilometer [km] movement) with median home ranges of about 2 km even during the fall and winter periods, contrary to the relatively sedentary behavior that was expected initially. During spring, some fish had moved as far as 86 km into tributaries of the Thomas Fork, presumably for spawning (Colyer et al. 2005). Related work documented post-spawning movements of similar magnitude in the spring of up to 82 km, but fish remained relatively sedentary in the summer when movements did not exceed 0.5 km. They also reported that 23 percent of the radio-tagged fish eventually became entrained in an irrigation diversion (Schrank and Rahel 2004). Stream resident populations appear to move far less than fluvial populations, particularly during fall and winter (Hilderbrand and Kershner 2000). Budy et al. (2007) observed site fidelity in the majority of cutthroat tagged during their study in the Logan River, Utah~~T~~, but also noted substantial movements of some individuals up to 34 km.

Conservation Status: Bonneville Cutthroat Trout

Bonneville cutthroat were present historically throughout the Bonneville Basin, which was covered by Lake Bonneville during the Pleistocene Epoch up to about 30,000 years ago. The lake encompassed parts of Idaho, Wyoming, Nevada and Utah. After the lake retreated, cutthroat populations became restricted to headwater streams and lakes. Numbers have dwindled in recent years due to various human activities, raising concerns among resource agencies regarding the species' future prospects (Lentsch et al. 1997).

Because of declining populations, Bonneville cutthroat trout were listed as a Tier I Sensitive Species by UDWR. They have also been afforded Sensitive Species status by the USFS Intermountain Region and the U.S. Bureau of Land Management (BLM). In 1992 and 1998, they were unsuccessfully petitioned for listing under the Endangered Species Act (ESA) (Lentsch et al. 2000). Most recently, on September 9, 2008, the USFWS again concluded there was insufficient cause to list it as either threatened or endangered under the ESA (Federal Register 2008).

Continuing threats include: 1) water development projects resulting in changes in the timing, magnitude, and duration of stream flows; 2) degraded aquatic habitat and water quality; 3) riparian habitat loss; 4) interruption of migratory corridors by man-made barriers; and 5) competition with, predation by, and hybridization with nonnative fishes (Lentsch et al. 2000). Potential impacts on upstream and downstream movement of Bonneville cutthroat is a principal concern of agencies regarding PacifiCorp's Project, but other issues exist in the basin that may affect these species. For example, brown trout have been found to hinder performance (McHugh and Budy 2005) and movement (McHugh and Budy 2006) and affect distribution of Bonneville cutthroat (De la Hoz and Budy 2005).

In addition, natural factors such as drought and fires have also been shown to impact Bonneville cutthroat through vegetation community change, water quality impacts, and other mechanisms (Hepworth et al. 1997; White and Rahel 2008). Frequency and severity of these events may be exacerbated by ongoing, human-induced climate change, which could further threaten coldwater species like Bonneville cutthroat well into the future (Williams et al. 2007; Haak et al. 2010).

To protect Bonneville cutthroat from further decline and foster recovery, the State of Utah implemented a Conservation Agreement and Strategy in 1997 (Lentsch et al. 1997). A Range-wide Conservation Agreement and Strategy was later drafted in 2000 (Lentsch et al. 2000). To facilitate management efforts in Utah, its known range was separated into five Geographic Management Units (GMUs) extending from Bear Lake in its northern distribution to the Virgin River Basin in the south. Within the Project Area, they have been placed into the Northern Bonneville GMU which includes the following drainages: Weber River, Ogden River, Jordan River and Provo River/Utah Lake. PacifiCorp's Project occurs in the Lower Weber reach, which also includes a number of tributaries such as Strawberry, Jacob's, Peterson and Gordon creeks. In total, 39 conservation populations were identified in Utah in 1997, only a few of which were known to be genetically pure at that time (Lentsch et al. 1997).

Conservation actions recommended to guide recovery efforts in Utah included: 1) surveys to document population status and life history; 2) genetic analysis to determine purity; 3) reconnecting and enhancing important habitats; 4) nonnative fish control; 5) reintroduction via broodstock stocking or transplants; and 6) continued monitoring (Lentsch et al. 1997). Of these, the first three activities have been undertaken in the Northern Bonneville GMU at present.

Project Area Studies: Bonneville Cutthroat Trout

UDWR, USFWS, Utah State University (USU), TU and various other partners have collaborated on research and improvement projects in recent years to better understand and expand Bonneville cutthroat trout populations in the Weber River. A collaborative investigation initiated by UDWR, USU and TU in 2011 began documenting population structure, genetics, survival probability and adult migratory movements because of its relevance to population viability and persistence.

Using multiple-pass electrofishing, a population estimate of 405 (95% CI, 310-584) Bonneville cutthroat occurring from the Project powerhouse diversion downstream to the Lower Weber Diversion was obtained in 2011 (Budy et al. 2014). Generally, there appears to be a trend toward increasing densities of BCT moving upstream from the canyon mouth into the tributaries above the powerhouse diversion (Table 2). Length-frequency histograms for fish in the Weber River indicated the smallest individual collected from 2011-2013 was about 100 mm TL and the largest 550 mm (Figure 3). The average was about 300mm.

Table 2. Population Estimates with 95% Confidence Intervals of Bonneville Cutthroat Trout in Three Mainstem Sections of the Weber River, Utah, in 2011 and 2012

Year and Weber River Section	Sampled Distance	Electrofishing Passes	Sampling Dates	Population Est. (N hat)	95% Confidence Intervals
2011 Section 03 Lower Weber Diversion upstream to Powerhouse Diversion	Combined 1.8 of 4.4 km	2 and 3 (combined)	15 Nov, 17 Nov, 29 Nov, 14 Dec	405	310–584
2011 Section 04 Powerhouse Diversion upstream to Peterson Creek confluence in Weber River, plus portions of multiple upstream tributaries	11.7 km	4	20 July, 21 July, 26 Jul, 12 Aug	877	684–1,124
2012 Section 02 Canyon mouth upstream to Lower Weber Diversion	Lower 19 km of 20 km reach	2	19 June, 21 June	139	66–672
2012 Section 04 Powerhouse Diversion upstream to Peterson Creek confluence in Weber River, plus portions of multiple upstream tributaries	9.5 km	2	8 Aug, 16 Oct	1,296	911–2,069

Note: Modified from Budy et al. 2014.

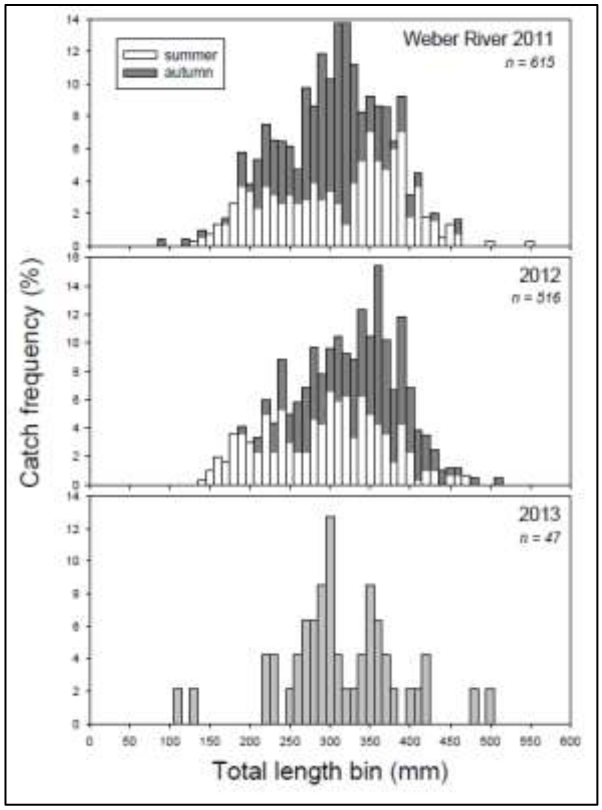

Figure 3. Bonneville cutthroat trout length-frequency histograms in the Weber River within the Project vicinity (from Budy et al. 2014).

During this study, from 2011 to 2013, researchers also implanted a total of 1,671 Bonneville cutthroat with passive integrated transponder (PIT) tags and documented movements in the Weber River from the canyon mouth and among tributaries located just upstream of the Project using passive instream arrays (PIAs) installed in a number of the tributaries. There was frequent use of tributaries by the mainstem population for spawning and movement between the tributaries, suggesting a sizable fluvial life history component still exists in the Weber River and may play an important role in the population's long term viability. Manmade barriers exist in all of the major tributaries, although some appear passable under certain conditions. Those on Strawberry and Gordon creeks are impassable (Budy et al. 2014), but efforts are underway to restore connectivity (Thompson 2015). Genetic mixing between mainstem and tributary populations was evident based on mitochondrial and otolith analysis, however, both appear largely pure (Budy et al. 2014).

Recent UDWR tagging studies demonstrated that 28 Bonneville cutthroat moved upstream past the Weber powerhouse diversion during spawning migrations in 2013 and 2014 (PacifiCorp 2015a). Only three pathways are available to accomplish this: 1) an old historic fishway on the north side of the river; 2) the spillway; and 3) a low-flow gate on the south side of the diversion. At lower flows, the first two pathways do not appear to be feasible due to a large terminal drop at the fishway with very high velocities throughout and insufficient depths across the spillway

(Photograph 5, Appendix 3). Trout are commonly observed by PacifiCorp personnel attempting unsuccessfully to ascend the fishway outflow. It is also likely that at higher river flow/stage conditions both would remain impassable. The low-level gate is the most likely possibility when open, and the timing of movements from past studies suggest it could have been utilized, though there has been no field verification of the exact pathway (PacifiCorp 2015a). These questions may be less relevant now because PacifiCorp is coordinating with resource agencies and other stakeholders to design and build a new fish ladder as part of relicensing mitigation (PacifiCorp 2015a, 2016). However, it is important to note that the low-level gate will remain a component of the overall fish passage plan at Weber dam, by functioning as the passage route during periods when the forebay is down and the fish ladder is therefore inoperable (see also details in Study One, Appendix 1).

<u>Bluehead Sucker</u>

Biology and Life History: Bluehead Sucker

Bluehead suckers have a bluish head and bluish-gray to olivaceous dorsum (Photograph 6, Appendix 3). They are basically facultative herbivores, using their disc-shaped mouths to scrape algae from rocks; although as larvae they consume small invertebrates, diatoms and zooplankton. Benthic invertebrates, detritus and other organic matter are consumed opportunistically later in life, comprising a substantial portion of their diet. They may be found in a variety of cool to warm lotic systems from small streams to large rivers (Sigler and Sigler 1987; UDWR 2006a).

Depending on their size, adults spawn over gravel or cobble substrate during the spring and early summer. Maturity is reached typically by their second to fourth year in populations occupying larger rivers, where individuals may live up to 20 years. In smaller rivers including some headwater streams, fish sometimes mature earlier and longevity may be reduced (Douglas et al. 2009), although other studies have found maturation occurs by about the same time and fish may live as long as those in larger rivers (Sweet 2007).

Spawning usually takes place when stream temperature reaches about 16^{o}C (UDWR 2006a) and has been estimated as occurring in the Upper Colorado River Basin between about 18^{o} and 24^{o}C (Ptacek et al 2005). However, studies in the Big Sandy River, Wyoming, indicated spawning from mid-May to early June when mean daily temperatures ranged from about 8.5^{o} to 11^{o}C. Spawning time was estimated using back-calculations from larval growth rates (Zelasko et al. 2011). An early study suggested bluehead suckers in the Weber River have a rather protracted spawning period based on gonadal index, extending from early May to late July (Andreasen and Barnes 1975). During that time period, average daily temperatures in the Weber River between 1995 and 2006 ranged from about 12^{o} to 20^{o}C (PacifiCorp 2015a).

Habitat use differs according to life stage, with larvae and young-of-year fish occupying low velocity habitats along stream margins after drifting some distance from spawning areas. Seasonal timing of larval emergence and drift is contingent on when spawning occurs and temperature-dependent egg development. As bluehead suckers grow, they often relocate to higher velocity habitats with greater cover (UDWR 2006a), though some research indicates use of pools with rocky substrate year-round (Sweet and Hubert 2010). Bluehead suckers do not thrive in impounded waters, tending to utilize habitats more swift than many other suckers (UDWR 2006a). An intensive fish habitat and habitat selection study in the San Juan River indicated bluehead sucker selected towards slackwater habitat. This was characterized as low velocity habitat usually along inside margin of river bends, shoreline invaginations, or immediately downstream of debris piles, bars or other in-stream features, but deeper than shoals (>25 cm) (Bliesner et al. 2010). The same study indicated this species selected against backwater, shoal, run, and riffle habitat. Generally, adult bluehead sucker occurrence is correlated with habitats where cobble substrate is dominant; most likely due to their feeding habits. Juvenile occurrence can be negatively affected by partially desiccated sections of river (Bower et al. 2008).

Bluehead sucker movements can vary by season. During spring, adult bluehead suckers generally shifted downstream in a Colorado River tributary with distances ranging from about 16 to over 64 km. Such movements coincided with high runoff flows. Fall and winter were typified by little movement (<2 km). Summer was also a relatively sedentary period, though some fish moved some distance back upstream (Sweet and Hubert 2010). PIT-tagged bluehead suckers have been observed moving downstream over low-head, boulder irrigation diversions (Compton 2007). Overall, the literature regarding adult bluehead sucker movements is limited, but generally indicates they may be quite sedentary or undergo substantial migrations depending on the system (Ptacek et al. 2005). They have also been documented utilizing their suction-like mouth to maintain position in response to increasing current (Aedo et al. 2009).

Conservation Status: Bluehead Sucker

Bluehead suckers have been listed as a Species of Concern in Utah. Historically, they occurred in Utah in mainstem rivers and tributaries of the Colorado River Basin (Colorado, San Juan and Green Rivers), the Snake River Basin and the Bonneville Basin. Abundance and distribution have been reduced substantially throughout its range in recent history for a variety of reasons. Habitat alterations, habitat fragmentation, dams and diversions, regulated river flows, land use activities, water quality changes and nonnative fish introductions have been factors in their decline (Ptacek et al. 2005; UDWR 2006a). Within the Colorado Basin, it is estimated that they have experienced at least a 50 percent decline in their distribution from historical levels (Bezzerides and Bestgen 2002) and that level of decline has likely occurred throughout its entire range (UDWR 2006a).

To avoid further decline and potential federal listing, a Range-wide Conservation Agreement and Strategy was implemented in 2006. Among the recommended conservation actions were to: 1) conduct population surveys; 2) examine life history and habitat needs; 3) genetically characterize populations; 4) maintain and enhance important habitats; 5) control nonnative fishes where feasible; 6) expand populations; and 7) continue monitoring populations in the longer term (UDWR 2006a).

Project Area Studies: Bluehead Sucker

Genetic studies have confirmed that bluehead sucker populations in the Upper Snake, Bear and Weber Rivers are distinct from those in the Colorado River Basin, and as such, are deserving of protection (Douglas et al. 2009). Concomitantly, various efforts have been undertaken recently by UDWR, USU and others to better understand demographics, life history and habitat requirements of Weber River bluehead suckers.

Webber et al. (2012) assessed bluehead sucker population size, survival rates and movements in two Weber River reaches from 2006 to 2009. Reach 1 was between Rockport Reservoir and Echo Reservoir. Echo Dam is about 46 km upstream of the project diversion. Reach 2 was located between the irrigation diversion just downstream from the Project powerhouse and another irrigation diversion near the city of Ogden. Each reach was about 20 km. Brown trout population size was also estimated in each section due to its predatory habits. Populations were surveyed via raft electrofishing using multiple passes.

The bluehead sucker population >150 mm long in Reach 2 (357; 95% CI 191-984) during 2008 was not statistically different from that in Reach 1 (225; 95% CI 141-416) in 2007 based on confidence intervals. However, increasing the number of electrofishing passes from two to four in Reach 2 in 2008 increased the population estimate to 546 (CI 95% 423-772) and improved variance around the estimate. From that perspective, the researchers posited that the population size was significantly greater in Reach 2 than in Reach 1, although densities were similar at about 0.7 to 0.9 per 1,000 m^2. Brown trout >200 mm were far more numerous than suckers with estimates of 9,995 in Reach 1 and 2,125 in Reach 2 (Webber et al. 2012).

Size distributions were markedly different between reaches. Reach 1 was dominated by larger fish averaging about 450mm (Figure 4). Few fish <400mm were captured and none were <200 mm long, suggesting poor recruitment. In contrast, multiple age classes were found in Reach 2. The smallest sexually mature suckers were about 400 mm in length (Webber et al. 2012). Earlier surveys by UDWR in 2006 had also indicated few juvenile bluehead sucker in Reach 2. A group of about 20 adults discovered near Coalville had prompted UDWR (2006b) to recommend future surveys be conducted.

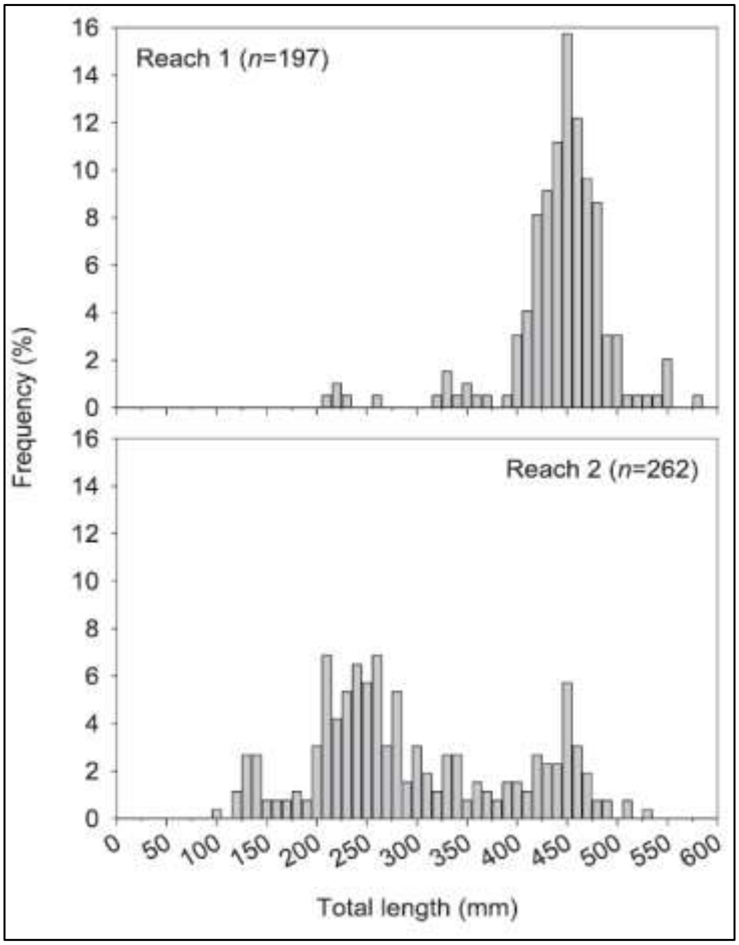

Figure 4. Bluehead sucker size structure in the Weber River, 2006–2009 (from Budy et al. 2014).

Movements of PIT-tagged suckers (all >150mm) were evaluated using a passive antenna in Reach 1 only from September to March. The greatest movement recorded was 2.6 km upstream. Nearly all movements were <1 km (62%) and during September. Most detections (88%) occurred at night (Webber et al. 2012). To our knowledge, there have not yet been any studies directed towards movements of adult bluehead sucker during the spawning season (i.e., late spring and early summer) in the Weber River.

Annual mean survival in Reach 1 was estimated at 77 percent (95% CI 39-95%) using a combination of the PIT-tag sightings and population survey data. That rate was considered relatively high by the researchers and was stable over the three years of the study (Webber et al. 2012).

More recent estimates conducted by UDWR and TU in 2012 (Burnett et al. 2013) indicated a somewhat lower number of bluehead suckers in Reach 2 of about 150 than obtained by Budy et al. (2014). However, generally the research conducted to date indicates that the population below the Project, from the canyon mouth to the Ogden River confluence, is somewhere in the hundreds and is experiencing some limited recruitment. Bluehead suckers are known to occur upstream from the hydroelectric diversion, but population estimates have only been conducted between Echo and Rockport reservoirs. To what extent spawning and recruitment occur upstream from the project to Echo Dam is not understood at this time.

Current efforts by USU researchers have been directed at identifying spawning areas in the lower section of the Weber River (i.e., below the canyon mouth) during late spring and quantifying habitat in these spawning reaches to assess what factors may limit recruitment. Researchers have also determined numbers of young-of-year suckers in low velocity habitats in that portion of the river. Abundance was positively associated with maximum backwater depth (Bryan Maloney, USU Fish Ecology Lab, pers. comm.). Low velocity habitats along the river margins are relatively rare in the river upstream from the Project due to much channelization, higher gradient and altered hydrology. However, the impoundment upstream from the Project diversion may provide suitable rearing habitat for bluehead suckers.

Fish Entrainment Literature Review

Entrainment into hydroelectric turbines has long been acknowledged as a potentially significant source of mortality for fishes migrating downstream. Entrainment may be defined as "the unintended diversion of fish into an unsafe passage route" (NMFS 2008). Many studies have attempted to quantify numbers of fishes passing through turbines (FERC 1995; Franke et al. 1997). These studies commonly involve the use of netting to capture fish as they exit the powerhouse. In recent years, most evaluations of entrainment involved desktop analysis where the results of prior studies were used to estimate these rates (Alden 2001; AIC 2005; Geosyntec Consultants 2005; Progress Energy 2005). In synthesizing the results of prior field studies, a key emphasis has been to try to identify which factors may be correlated with fish entrainment.

FERC (1995) undertook probably the most comprehensive effort to compile and evaluate fish entrainment at hydroelectric projects. They reviewed dozens of studies and, based on their independent assessment and interviews with entities that conducted the studies, selected 45 sites with suitable information upon which to base their analysis of factors that affected entrainment.

Factors that may influence fish entrainment include (EPRI 1992; FERC 1995; Franke et al. 1997):

- intake screen bar spacing
- intake screen approach velocity
- intake location
- impoundment characteristics
- plant flow
- fish species
- fish size

Intake Screen Bar Spacing

Intake screens at hydroelectric facilities are essentially angled trash racks used to restrict the intrusion of coarse floating debris into the penstock, thereby reducing potential damage to the turbines. Such screens can vary considerably in bar spacing from one to as much as 10 inches, though smaller intervals of about 1-3 inches are more common at small- to medium-sized projects (EPRI 1992; Winchell et al. 2000). The intake bar spacing at Weber is ≤1.5 inches across the entire intake area.

Screen spacing appeared to have no significant effect on either absolute or flow-adjusted entrainment rate according to linear regression analyses conducted by FERC (1995). That held true even when only full flow tailrace netting studies were used (hydroacoustic and partial tailrace netting studies were excluded due to unreliability of results) and when analyses were binned by basin. The researchers postulated that the preponderance of small fish in the catch at all sites might account for their findings because they could easily fit through the entire range of screen openings.

FERC (1995) also performed more intensive statistical tests using Pearson correlations, principal components analysis and multiple regression. Average entrainment rate was highly correlated ($r=0.956$) with screen spacing, but multiple regression showed no significant effect of screen spacing ($P>0.05$).

Winchell et al. (2000) summarized results of 39 field studies and found interesting relationships between bar opening and size of fish entrained. Most entrained fish (~80%) occurred in the smallest size group (≤4 inches) where screen openings were ≥3 inches (Figure 5). Lower percentages (60-70%) of this size group were entrained where bar spacing was one to about three inches, even though fish of this size should easily pass through the screen. Where bars were further apart, about 35 percent of fish were ≤4 inches compared to about 20 percent that were >4 inches in length. On average, about 70 percent of entrained fish were ≤4 inches and about 90 percent were ≤8 inches regardless of screen size. About 99.5 percent were ≤15 inches. Entrainment of fish >15 inches was rare even where screen openings were wide enough to accommodate fish of that size. Occasionally, fish are captured during entrainment studies that appear too large to have fit through the intake screen. Some speculated reasons for this may be that partial-flow netting was used which can allow infiltration by these fish from below the net, or that there may be gaps or certain areas of the screen more widely spaced than those near the surface (EPRI 1992).

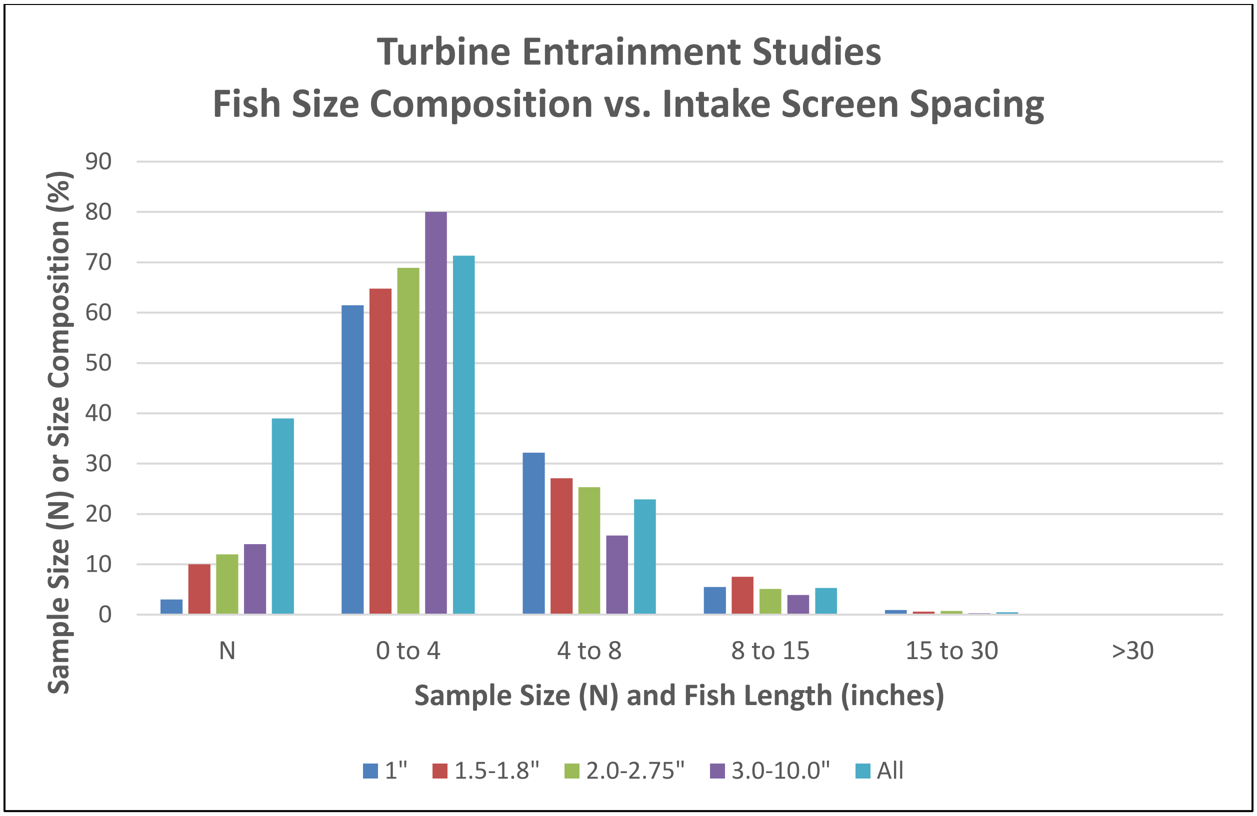

Figure 5. Size composition of all entrained fishes from 39 studies in relation to intake screen opening (shown as the legend on the bottom of the graph – e.g., blue is a 1” bar opening) (figure derived from tabular data by Winchell et al. 2000).

Why considerably fewer larger (4–8 inches) than smaller (0–4 inches) fish were entrained in wider screens where both size groups would easily pass may have some relation to engineering considerations. Determination of bar spacing during screen design is often dependent on what the theoretical approach velocity will be. At sites where relatively high velocities are anticipated, larger openings are often prescribed so there will be less force imposed and less debris accumulation on the screen. Under those conditions larger fish may have a greater ability to avoid entrainment due to superior swimming ability (FERC 1995). This explanation is speculative, however, and other factors such as life history may also be important (EPRI 1992).

<u>Intake Screen Approach Velocity</u>

Approach velocity is usually measured about 3 inches in front of the screen. To minimize potential fish impingement, velocities should be kept within cruising speeds of target fish (OTA 1995). FERC (1995) analyzed entrainment catch at dozens of hydroelectric sites and found no significant effect of approach velocity on fish entrainment rates using exploratory regression analysis. However, correlation analysis indicated a high positive association between average entrainment rate and approach velocity (r=0.996). Approach velocity and screen spacing were positively cross-correlated. The researchers did emphasize that correlations are meant to depict associations and do not infer predictive capabilities. Furthermore, highly leveraged sites (i.e., those where most of the entrainment occurred) were not parsed from the dataset and therefore could have had disproportionate influence on the results. Velocity immediately in front of the intake rack at Weber was measured at 1.0-1.5 fps; still photos and video footage of fish in front of the Weber intake rack were taken in 2016.

Intake Location

Various configurations for powerhouse intake location may include forebay versus power canal, shoreline versus center dam, and shallow versus deep. FERC (1995) found very mixed, site-specific results during its analysis of the aforementioned entrainment database. However, it appeared that projects with forebay intakes located in shallow water along the shoreline had relatively high entrainment overall. Several sites with vegetation in shallow water located in close proximity to the intake had relatively high entrainment rates of sunfishes and juveniles of larger sized species using the forebay as rearing habitat. At Weber the intake is located at the deepest part of the relatively shallow forebay (approximately 14 feet maximum), and extends from near the south edge of the impoundment approximately 20 feet to the north (but still south of the centerline of the Project diversion dam).

Impoundment Characteristics

The results of exploratory regression analysis of the extensive fish entrainment database showed no effect of reservoir area, reservoir volume or reservoir length on entrainment (FERC 1995). More intensive analysis showed significant effects of reservoir size and volume, but none for reservoir length. These results were obtained after binning the sites into multiple categories by dominant fish assemblage and applying flow-adjusted entrainment rates. Despite these approaches, there was still high variability in the data between sites and it was apparent that a few high-leveraged sites highly influenced the results. The researchers concluded that their analysis was unable to produce reliably, statistically significant trends between entrainment and the physical variables they evaluated. Weber's forebay consists of a relatively shallow, linear, 8-surface-acre impoundment.

Plant Flow

FERC (1995) found no significant relationships between plant flow and either raw or flow-adjusted rates of entrainment. That being said, entrainment is often estimated at proposed or existing hydroelectric sites using flow-based entrainment rates from prior studies (Geosyntec 2005; Normandeau Associates 2009; Duke Energy 2008), something which is both generally discouraged (FERC 1995) yet often still accepted by the FERC during project licensing and relicensing. The Weber plant flow under full load is 320 cfs.

Fish Species

Pelagic fishes like trout and whitefish are typically more predisposed to entrainment than benthic fishes like suckers, dace and sculpin. Migratory species are usually more at risk than non-migratory species. Generally, many of the species found upstream are found in the entrainment catch, but often in different percentages than in the upstream population. FERC (1995) found no consistent relationship between the upstream reservoir fish assemblage and the species composition of the entrainment catch. However, both FERC (1995) and EPRI (1992) pointed out that biases inherent in different, inconsistent gear types used to survey the upstream populations likely played a major role in the findings. As noted previously, the primary fish species of concern at the Weber Project are Bonneville cutthroat trout and bluehead sucker.

Fish Size

The majority of entrained fishes tend to be relatively small. Over the broad range of sites that have been studied about 70 percent were <4 inches in length and nearly 95 percent were <8 inches (EPRI 1992; FERC 1995). Of the 40 sites evaluated for size composition, FERC (1995) reported that 23 were dominated (≥75%) by fish ≤6 inches. The remaining 17 sites were dominated by fish >6 inches; however, 10 of these may have been compromised by the use of partial-flow netting to quantify entrainment, which can allow intrusion of larger fish into the net from the tailrace. ERPI (1992) summarized some of these same entrainment studies and reported that in some cases more than 90 percent of the fish were <4 inches and at most sites the majority were <8 inches (Table 3). Results of the Phase ~~I~~ One study indicated the least mortality or injury to the smallest size class (3-inch) of fish tested.

Table 3. Size Distribution of Entrained Fish from Nine Comprehensive Studies

Project and Location	**Size Distribution**	**Trash Rack Spacing**
Kleber Michigan	46% <100 mm 96% <200 mm	3 inches
Prickett Michigan	84% <4 inches 99% <8 inches	Not provided
Tower Michigan	50% <100 mm 82% <200 mm	1 inch
Centralia Wisconsin	95% <100 mm	3.5 inches
Pine Wisconsin	49% <100 mm 94% <200 mm	None upstream of netting site
Wisconsin River Division Wisconsin	96% <100 mm	2 3/16 inches
Thornapple Wisconsin	58% <4 inches 85% <8 inches	1 11/16 inches
Escanaba Dam #1 Michigan	59% <5 inches 93% <7.5 inches	1 ¾ inches
Escanaba Dam #3 Michigan	75% <5 inches 96% <7.5 inches	1 ¾ inches

Note: From EPRI 1992.

Francis Turbine Mortality Literature Review

Francis turbines are typically installed at sites where head is relatively high and runners are situated high above the tailwater, operating at high speeds (Eicher et al. 1987). Many hydroelectric projects utilize high head to generate power, and therefore, are typically fitted with Francis units. Accordingly, many of the sites that have been evaluated for turbine passage survival utilize this type of turbine. Generally, survival tends to be lower in Francis turbines than Kaplan turbines. Kaplan turbines have fewer blades, operate at slower speeds and are used at lower head sites than Francis turbines.

Two basic types of mortality transpire from turbine passage: direct and indirect mortality. Direct mortality is the immediate killing of fish typically due to contact with one of the turbine components, shear forces, turbulence, grinding, cavitation, or pressure effects (Coutant and Whitney 2000). Indirect mortality is delayed death occurring as a result of injury suffered during passage, usually measured over about a 48-hour period (Cada 2001; Bickford and Skalski 2000).

Indirect mortality can further decrease survival beyond direct mortality, but is frequently not measured. Winchell et al. (2000) analyzed the EPRI (1997) database to evaluate indirect mortality over a 48-hour period following turbine passage. They eliminated all studies where control group survival did not exceed 90 percent and immediate survival was relatively low. Indirect mortality increased by about 3-4 percent over direct mortality. Geosyntec (2005) assessed indirect mortality at 10 sites from the same database. Indirect mortality decreased immediate survival from 95 to 92 percent for a 3 percent reduction over 48 hours. Bickford and Skalski (2000) analyzed smolt survival data from turbine passage in the Snake-Columbia River Basin and likewise estimated a 3 percent additional indirect mortality.

Fish survival through Francis turbines has been evaluated (Amaral 2001; Normandeau Associates 2012) and summarized (Eicher et al. 1987; EPRI 1992; FERC 1995; Franke et al. 1997) in a number of studies. Subsequently, various factors have been analyzed for their potential effect on survival. Among these are:

- turbine type
- turbine discharge
- number of blades or buckets
- runner blade angle
- peripheral runner speed
- operating efficiency
- intake depth
- fish species
- fish length
- fish trajectory

We restricted our analysis to the following more commonly implicated and relevant parameters.

<u>Peripheral Runner Speed</u>

Eicher et al. (1987) found that mortality increased significantly as runner speed increased (Figure 6). His results were based on 14 sites. Runner speed is generally accepted to be a major contributing factor in fish mortality for Francis turbines (EPRI 1992; Franke et al. 1997), which are intended to be operated at relatively high speeds. We compiled data from Franke et al. (1997) comprising 33 sites including 12 of 14 indicated above. Our analysis likewise showed a negative trend for runner speed on survival (Figure 7). Dispersion in the data is due to the range in mortality rates at each site arising from a number of factors including fish species, size and operating conditions. It is important to note that although absolute runner speed is significantly correlated with mortality, relative speed (i.e., rpm) is not (Eicher et al. 1987).

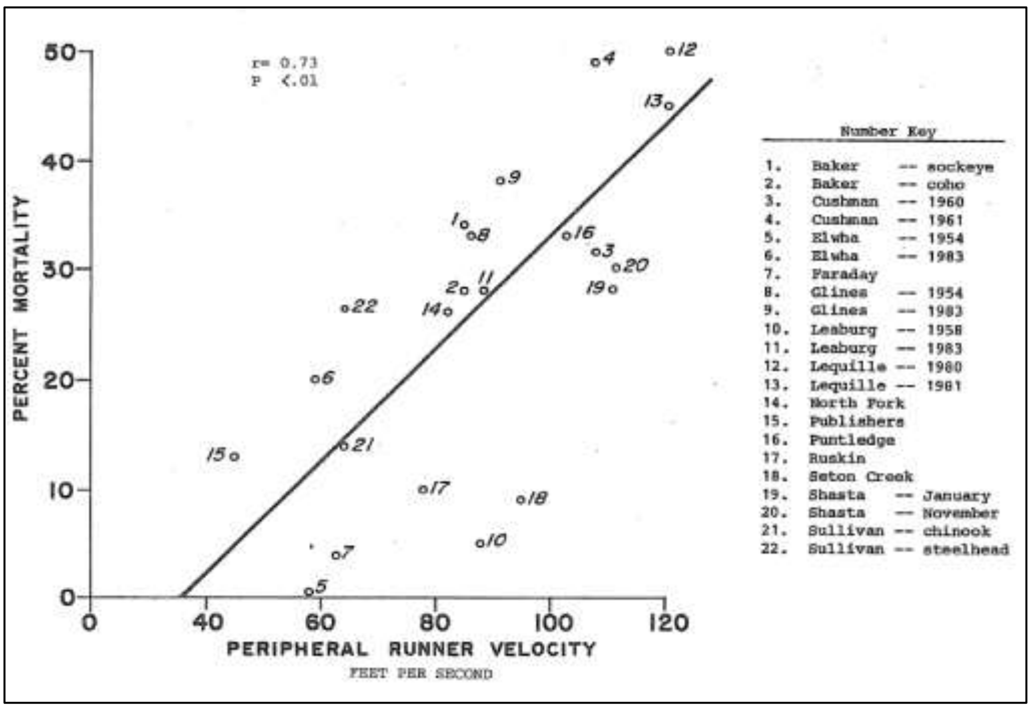

Figure 6. Relationship between runner speed and mortality for Francis turbines (from Eicher et al. 1987).

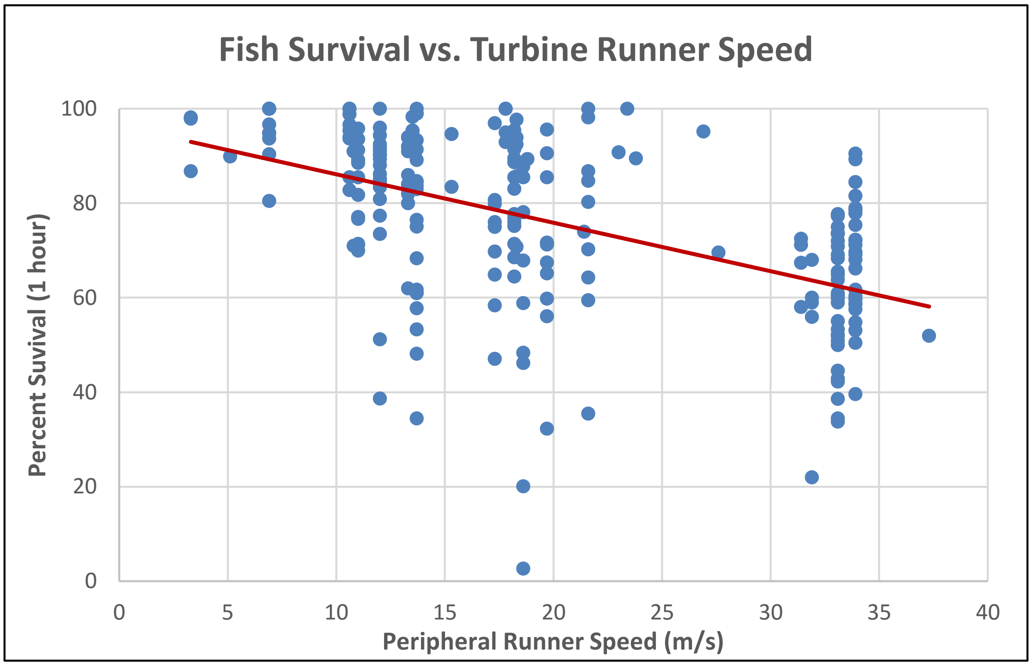

Figure 7. Relationship between runner speed and fish survival (figure derived from tabular data in Franke et al. 1997).

Head

Head by itself does not impact fish survival (Eicher et al. 1987; Franke et al. 1997), although head does appear to be positively correlated with mortality (Figure 8). However, the principal effect of head is on runner speed, with higher net heads resulting in increased peripheral speed of the runner (Figure 9); and runner speed is correlated with survival in Francis turbines. This is a critical although somewhat confusing distinction. Greater mortality with increasing head may also be an artifact of pressure-related effects, as noted below, though this an issue only with deep water intakes (Coutant and Whitney 2000).

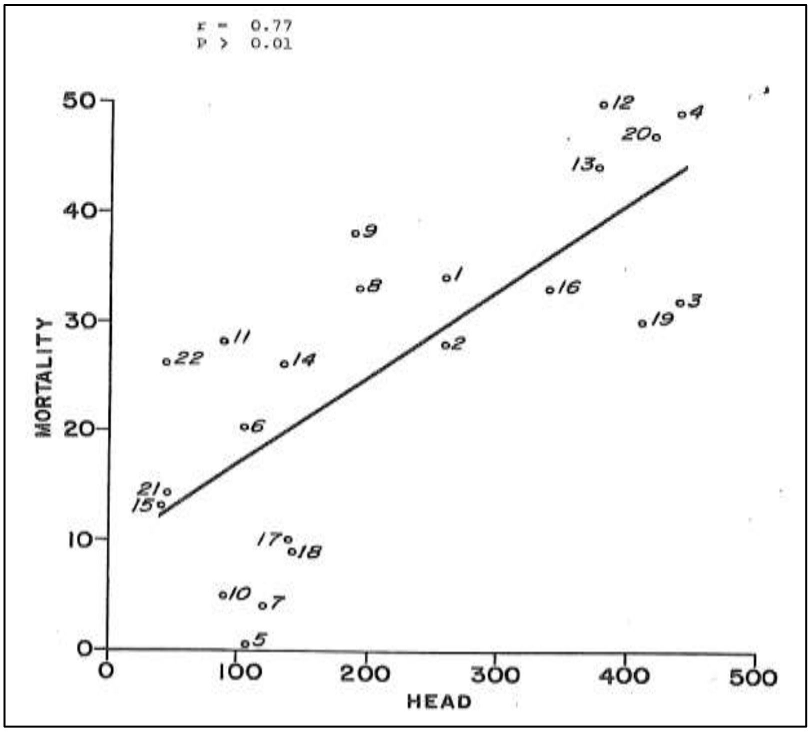

Figure 8. Relationship between head and mortality for Francis turbines (from Eicher et al. 1987).

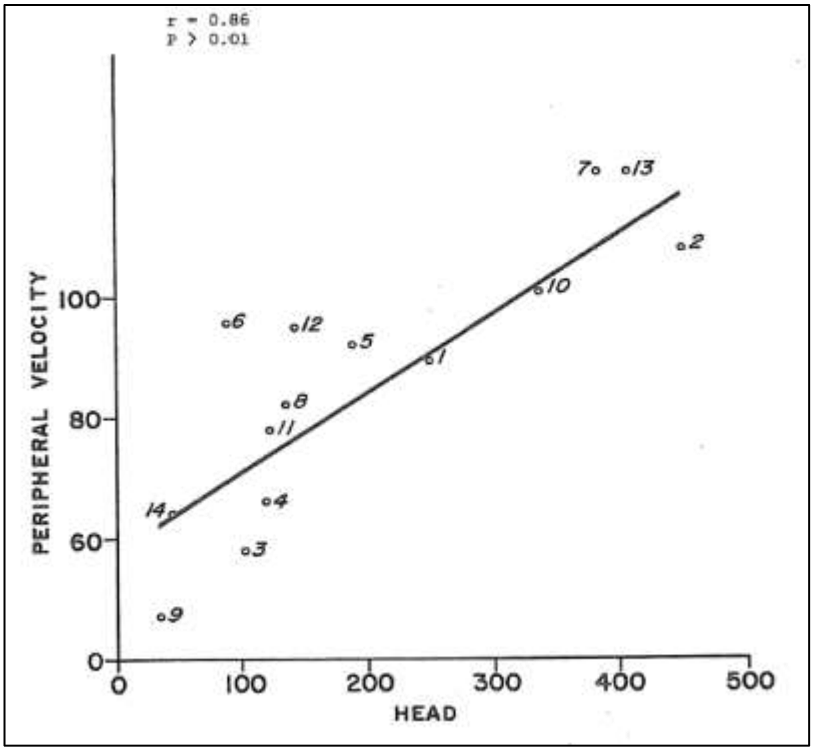

Figure 9. Relationship between head and runner speed for Francis turbines (from Eicher et al. 1987).

Intake Depth

Intakes located at greater depths may cause higher mortality if fish are subjected to rapid decompression during passage through the powerhouse. That effect is related not just to the intake depth and net head, but also to negative pressures that may exist posterior to the turbine buckets. Fishes lacking a connection from the swim bladder to the gut (termed physoclistous) are more vulnerable to such effects because they are unable to vent excess bladder air via the mouth. These are typically bottom dwellers. Physostomous fishes possess this connection and are typically surface oriented, but may still be harmed by pressure effects (Eicher et al. 1987). Burst or extruded swim bladders, internal hemorrhaging and bulging eyes are common signs of pressure-related effects. Magnitude and rapidness of the pressure change are critical factors in the degree of injury that may occur. One study concerning yellow perch suggested the pressure differential must exceed 10m, or one atmosphere of pressure, before deleterious effects are observed (Cada 1990). Longer penstocks such as the one at Weber with greater travel times may facilitate pressure acclimation so harmful effects are avoided (Franke et al. 1997).

Operating Efficiency

Operating efficiency is widely identified as a key factor in fish survival (Eicher et al. 1987; Coutant and Whitney 2000; Cada and Rinehart 2000). Some parameters related to efficiency include operating at the optimal turbine setting, wicket gate opening, runner speed, and gaps between the blades and other turbine components (Eicher et al. 1987). When operated under more optimal settings usually closer to the design settings, potentially harmful turbulence, cavitation and shear forces are minimized. The magnitude of these forces appears to be correlated with efficiency, which in turn can impact survival. However, these interrelated forces generally come into play only at the extreme ends of operating conditions, which are typically realized on only rare occasions at most sites. Plant operators generally avoid such circumstances because cavitation can damage turbine components (Cada and Rinehart 2000).

Fish Species

Generally, salmonids (trout, salmon) are among the hardier groups with respect to turbine survival and clupeids (shad, herring) are among the most sensitive. Very limited information is available regarding catostomids (suckers). White suckers are among the most studied of catostomids and typically experience somewhat intermediate survival compared to these other two families, although among all groups there is tremendous influence of other variables such as operating conditions and fish size (Eicher et al. 1987).

Fish Size

Generally, larger fish experience higher mortality from turbine passage than smaller fish. This is true for both Francis and Kaplan turbines (EPRI 1992; Eicher et al. 1987; Franke et al. 1997). Equations used to estimate fish mortality for both turbine types use fish size as a direct multiplier, illustrating that it is highly influential. Such equations commonly incorporate the size-based potential for strike as fish pass through the runner as a criterion for determining mortality (Eicher et al. 1987). However, cavitation, shear forces and pressure changes are other parameters that can harm fish. Figure 10 illustrates the hypothetical relationship between various turbine-related causes of mortality in relation to size (up to the largest marine mammals) based on extrapolated research involving tidal power projects. Potential for mechanical strike increases with size exponentially while pressure effects disproportionately harm smaller fish (Coutant and Whitney 2000). Within the range of sizes common to most river systems (i.e., 2-40 cm), the relationship is closer to linear. That is consistent with research on river-based turbine studies (Eicher et al. 1987; Franke et al. 1997). Cavitation affects all sizes fairly uniformly across most sizes of fish that would occur in most river systems. Shear forces appear to be most problematic for juveniles of larger sized species. Little is known about effects on larvae (Coutant and Whitney 2000).

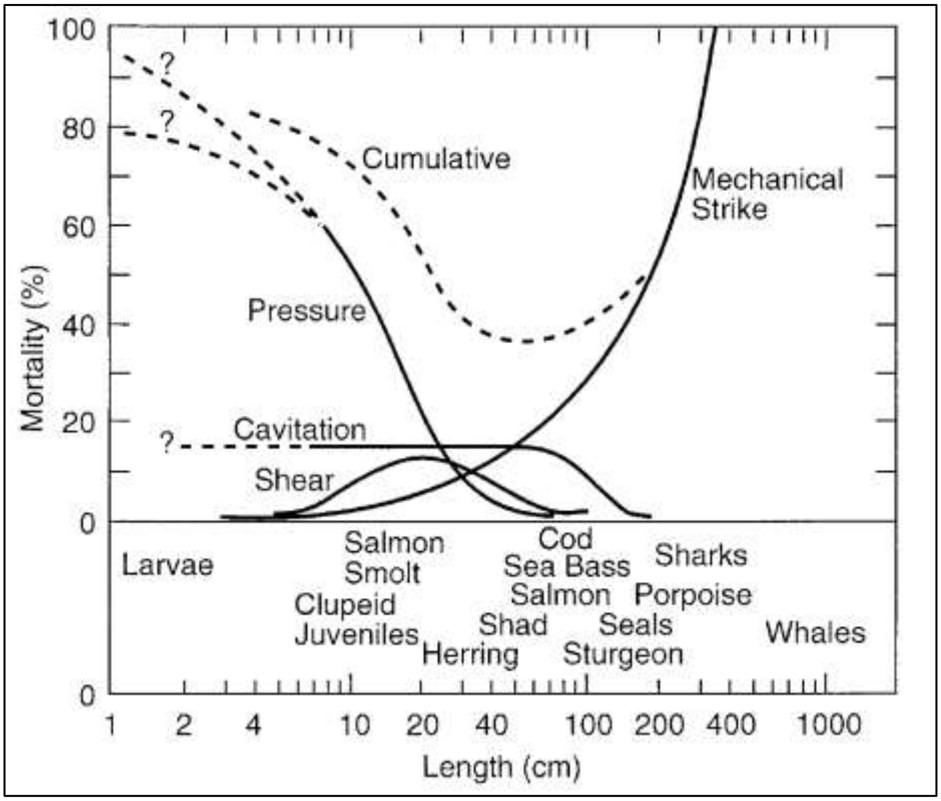

Figure 10. Hypothetical distribution of mortality and its causes from passage through hydraulic, low-head turbines in relation to body length of aquatic organisms (from Coutant and Whitney 2000).

Mortality of larval fish from turbine passage is very difficult to measure, but has been estimated at <5% in bulb-type turbines based on equations relating sized-based probability of contact (Cada 2011). Still, the innate fragility of larval fish may raise the potential for injury from other effects (Figure 10).

6.4. Study Two: Discussion of Potential Entrainment at the Weber Project Specifically

Turbine Mortality

The recommended operating flows for the Weber Project turbines minimize hydraulic impacts from shear, turbulence and cavitation. Correspondingly, potential fish mortality due to such effects should be minimized for the size of fishes with the highest entrainment potential (fish ≤8 inches). According to PacifiCorp, there are areas of turbulence within the penstock at junctures where sections are joined together. Such areas could conceivably cause minor injuries as fish travel toward the powerhouse at an estimated 11.7 fps.

Net head is relatively high at 185 feet; however, intake depth is shallow and the pipeline length at 9,107 feet is almost two miles long, thus reducing the effect of head. These conditions are not conducive to pressure change effects and no pressure-associated injuries were observed during the Phase OneI turbine mortality study. We conclude that potential cavitation, turbulence, shear and pressure effects should be relatively low, or in some cases nonexistent. Under these conditions, entrainment mortality should be due primarily to blade strike. Although head pressure should have no direct relationship to mortality, it does have a positive effect on runner speed.

Runner speed is positively and significantly correlated with fish mortality. The Weber Project has a runner speed of about 73 fps (22 m/s) and is roughly in the midrange of velocities tested for fish survival (10–120 fps, or 3–36.5 m/s) at 33 other sites with Francis turbines. Based on runner speed alone, survival at the Weber Project is estimated at about 70 percent (Figure 7). Survival is likely influenced by species and sizes of fish as well as the unique physical characteristics of each site. Fish size may be the single most important of these. Entrained fish at the Weber Project are expected to be smaller fish that would likely experience better survival.

Turbine passage studies performed during Phase One~~I~~ suggested that survival for larger-sized trout (average length 285 mm) was relatively low at 15 percent compared to an average rate of 70 percent for comparably sized fish (range 290-420 mm) from studies at other sites using Francis turbines (Franke et al. 1997). One factor that may influence survival is the relatively high number of buckets (34) at the Weber Project compared to those from other studies (13-17). The Weber Project turbine is a double-runner design, with 17 buckets per side. Double-runner Francis turbines may be used to generate additional speed at sites where head is too low for one runner (Gordon 2003). No test results for double-runner Francis turbines were identified in the literature. Based on field tests, Franke et al. (1997) considered the number of buckets to effect survival of intermediate sized fish (150 mm), with an increase in buckets from 13 to 25 potentially reducing survival from about 95 to 90 percent. Survival of intermediate sized fish (average length 166 mm) at the Weber River during the Phase One~~I~~ study was estimated at 54 percent. Survival of small fish (<100mm) could not be assessed during the Phase One~~I~~ study due to the inability to recover surviving fish swimming in the tailrace, although it is noteworthy that both dive teams observed numerous, small (3-inch test class tiger trout) fish swimming in the tailrace and the river below, apparently unharmed; these fish are also known to be less affected by electrofishing recovery tactics. Minimal survival rate was estimated at 67 percent, but was based on recapture of only 15 of 100 fish released. It is possible that small fish survival at the Weber Project is similar to rates observed at other Francis turbine sites.

Another factor that may influence mortality of larger fish at the Weber Project is runner diameter (3.7 feet or 1.1 m). Runner diameter in the reviewed literature was between 1.4–4.7 m (Franke et al. 1997). A smaller runner diameter may leave limited space between the buckets for fish to pass through. Finally, Francis turbines are somewhat more susceptible to cavitation (and potentially increased fish mortality) than other turbine designs. Running below a 50 percent load for long periods may increase cavitation risk (RIVERS 2014).

Entrainment

Like most riverine fishes, Bonneville cutthroat and bluehead sucker exhibit life history characteristics that render certain life stages vulnerable to entrainment at hydropower or irrigation diversions on the Weber River. Bonneville cutthroat in the Weber River exhibit both resident and fluvial strategies, moving from the river to various tributaries and even between tributaries during spawning. UDWR has documented adult fish moving upstream past the Project diversion. In the event these or other adult fish attempt to move downstream past the diversion, through the intake (rather than through the historic fishway, the spill gates, or the low-level gate when open, all of which potentially allow safe downstream passage) there is a potential risk of entrainment into the Project turbines. Larvae, young-of-year and other juvenile cutthroat may also travel downstream during certain times of the year and likely do so, although this has not been studied in the Weber River. Adult suckers may undergo spawning and other migrations of varying distances and have been documented in the Weber River below the Project. Downstream movement of larvae or juvenile fish appears likely based on studies in other basins which renders these fish potentially susceptible to entrainment at the Weber Project, if one of the three safer routes is not utilized.

Fish entrainment at hydroelectric projects has not been measured at many sites due to a variety of factors, one of which is the potential difficulty of meeting study objectives and high costs to conduct an in-depth study. While there is no overriding concern by the agencies about entrainment and mortality at this time, there is still interest by the FWG to have some understanding of what might occur based on the existing body of knowledge.

Studies that have attempted to evaluate entrainment encompass sites with a wide range of physical factors (i.e., intake locations, intake screen design, operating conditions, reservoir features, etc.) and fish communities. These factors have hindered past efforts to isolate individual variable effects. Indeed, agencies often require operators to evaluate entrainment over several years to incorporate a range of operating and hydrologic conditions due to the high variability inherent at each site.

With these caveats in mind, it is still worthwhile to consider how the Weber Project compares to other sites regarding entrainment-related parameters. As noted, the intake screen spacing at diversion projects can vary between one and 10 inches, but appears to have little effect on smaller-sized fish (<8 inches) which are entrained in the greatest numbers at most sites. Bar spacing at the Weber Project varies between 1.25 and 1.5 inches (Photograph 7, Appendix 3). Fish <8 inches can easily pass through the intake rack. This was confirmed during Phase Two~~II~~ when rainbow trout ranging between 4.5 and 7 inches were released above the rack to evaluate the effectiveness of the camera system to detect fish. At some larger size, girth should prevent fish from passing through the rack. Although we do not know precisely what that size would be for the two species of interest, it is apparent that many if not most adult Bonneville cutthroat (ranging from about 300 mm to more than 600 mm [12 to more than 23.5 inches] in the Weber River project vicinity) and bluehead sucker (ranging from about 350 to 600 mm [13.75 to 23.5 inches]) would be excluded from passing through the Weber intake rack. The Project's rack is close to the 1-inch spacing often recommended as mitigation to prevent entrainment of larger fish (FERC 1995). Additionally, as noted, multiple potential 'safe' paths exist for fish of all sizes migrating downstream at the Weber Project.

Approach velocity to the intake screen is often not measured or reported at sites where entrainment has been studied. While no significant relationship has been found with entrainment rates, approach velocities measured just above the Weber Project trash rack in mid-summer ranged from 1–1.5 fps. This is within the range typically prescribed to reduce head loss, vibration, and debris accumulation and provide better safety margins for errant recreationists (Wahl 1992). Ideally, velocities should be kept within the cruising speeds of the species of concern to reduce impingement potential (OTA 1995), and it follows logically that this should also apply to entrainment. Prolonged swimming speeds in the range of 1–1.5 fps have been documented for Bonneville cutthroat that varied in standard length between 40–70 mm (1.5-2.75 inches) (Aedo et al. 2009) (Figure 11). Most young-of-year cutthroat should be able to swim against currents in front of the Weber intake rack and potentially escape via burst swimming. Indeed, fish of a wide range in sizes have been observed swimming in front of the Weber intake rack. It is highly likely that, with the exception of larval fish, actual involuntary entrainment is rare at Weber. Juvenile bluehead suckers have been found to have relatively good swimming ability as well. Ward et al. (2003) tested fishes native to the southwestern U.S. to determine the velocity at which failure occurred. Bluehead suckers ranged from 61–82 mm (2.4-3.2 inches) total length. Mean failure velocity was about 90 cm (3 feet) per second (Figure 12) and was among the highest for all species tested. This suggests that even young-of-year bluehead suckers should be capable of resisting entrainment based solely upon swimming ability. Yet, both young-of-year cutthroat and suckers may still be vulnerable to entrainment from behavioral downstream movement.

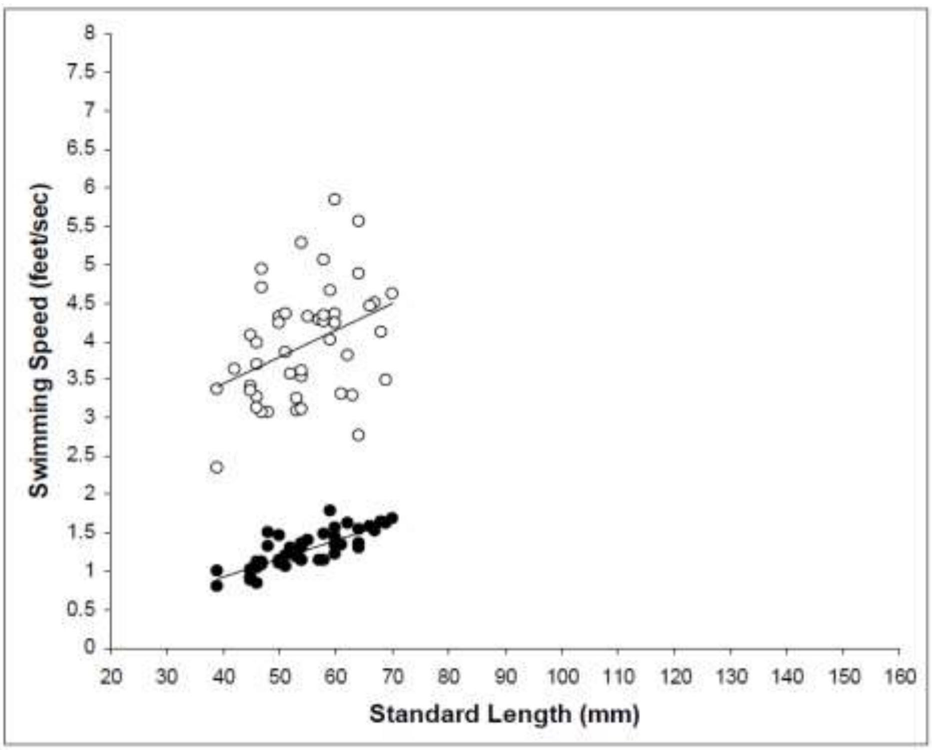

Figure 11. Results of laboratory swimming performance tests for Bonneville cutthroat trout for burst (○) and prolonged (●) swimming (from Aedo et al. 2009).

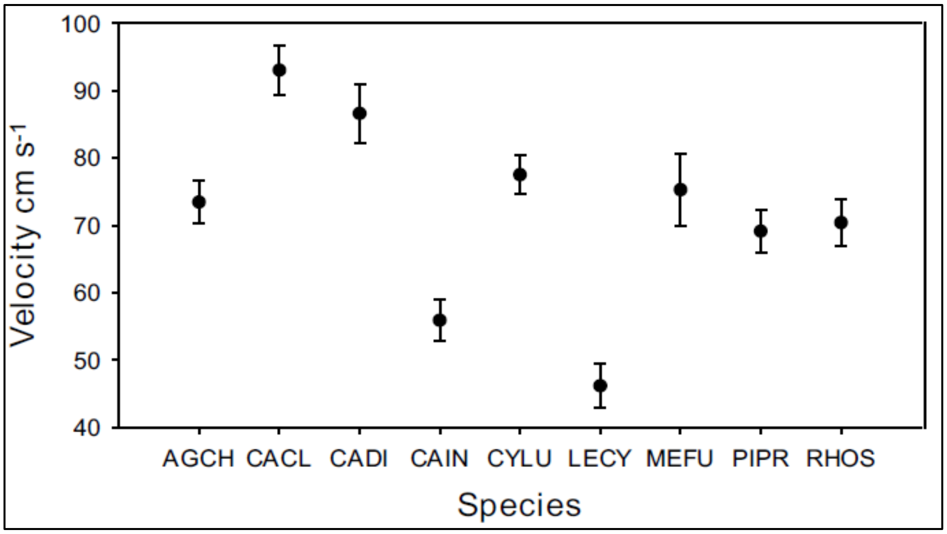

Figure 12. Relative swimming ability of six native and three nonnative fish species of similar size found in Arizona streams. Each point is the mean velocity for which that species failed to maintain position in laboratory swimming tests. Bars indicate 95% confidence intervals. AGCH = Agosia chrysogaster, CACL = Catostomus clarki, CADI = bluehead sucker (size range 61-82mm), CAIN = Catostomus insignis, CYLU = Cyprinella lutrensis, LECY = Lepomis cyanellus, MEFU = Meda fulgida, PIPR = Pimephales promelas, RHOS = Rhinichthys osculus (from Ward et al. 2003).

The Weber Project's basic configuration with an intake just downstream of a shallow, narrow reservoir with a high flush rate and shallow intake located along the shoreline may predispose certain fish to relatively higher entrainment rates compared to an intake in a large, deep reservoir at greater depth (Photograph 8, Appendix 3). Many juvenile fish move along the shoreline, which may render them more vulnerable to entrainment at the Weber Project if they tend to migrate down the south shore. However, the impoundment above the diversion also contains abundant macrophytes which could serve as rearing habitat and foraging areas for these fish, potentially discouraging further downstream movement.

Research has shown that for many riverine fish species spring and summer are generally the time periods when peak movements of adult and juvenile fishes occur. The two species of concern in the Weber River appear to be no exception based on ongoing studies. Adults move primarily during spring in association with spawning. Juveniles, particularly young-of-year, may be displaced by higher flows during the spring or disperse downstream from potentially more crowded areas in the spring and summer. During those times, entrainment potential is probably greatest. However, with construction of the new ladder and modification of the existing ice sluice as attraction flow coupled with spill, which can occur more often during the higher flow periods, there are several avenues for fish to move downstream without having to go through the turbines.

On average, Weber plant flows are at their highest levels from April through September when peak movements are taking place (Table 4). Although no consistent relationships between hydropower plant flow and entrainment have been found (FERC 1995), there has been some attention devoted to the potential association between diversion flow as a percent of river flow and entrainment for irrigation uses. Entrainment rate increases with flow at certain irrigation diversions (Kennedy 2009; Vogel 2012). The presumption that there is a relationship between these two variables has been used recently to rank the potential of diversions to entrain bluehead suckers and other native fishes in the San Juan and Animas River Basins (Lyons et al. 2016). It seems logical this may also apply to hydroelectric uses.

Table 4. Monthly average Weber River Discharge Relative to Plant Flow from 1966 through 2014

Month	River Discharge (cfs)*	Turbine Discharge (cfs)	Turbine/River (%)
January	231	130	56.3%
February	291	150	51.5%
March	562	219	39.0%
April	949	273	28.8%
May	1,310	296	22.6%
June	1,110	303	27.3%
July	515	296	57.5%
August	423	292	69.0%
September	371	271	73.0%
October	232	167	72.0%
November	150	98	65.3%
December	185	108	58.4%

*Weber River discharge from USGS gage 10136500 at Gateway, UT, located about 1.1 miles upstream from Pproject diversion.

From that perspective, mean Weber Pproject flow as a percent of river flow has ranged from 22.6 percent in May to 73.0 percent in September during the 1966–2014 period of record (see Table 4). During April–June when adult movements associated with spawning are expected to be at their highest levels, Pproject flows range from about 23–29 percent of river flows including the three lowest percentages for the entire year. After June, these percentages increase rapidly and substantially as river discharge decreases and plant flows remain fairly constant. This corresponds roughly to the period when fry emergence and downstream movement of larvae and young-of-year may be most likely and raises entrainment risk for these stages of both species of concern.

6.5. Study Two Potential Entrainment Conclusions

Based on our analysis of the biology of species of concern, Pproject features and the existing entrainment literature we draw the following conclusions:

1) Juveniles of Bonneville cutthroat and bluehead sucker (about 150 mm [8 inches] or less) are most likely to be entrained. However, fish of this size should suffer relatively lower

levels of mortality than larger fish, as observed during the Weber Project Phase One~~I~~ study.

2) Young-of-year of both species may have highest entrainment risk during the late spring and early summer when Weber Project flows, as a percentage of river flow, increase rapidly. This coincides with the period when newly emerged fish are most likely to move downstream either behaviorally or in response to relatively high river flows. Other pathways exist for downstream movement, such as the diversion spillway, the historic fishway and the low-level gate, that may be used under certain conditions.

3) Young-of-year and juvenile bluehead sucker appear to be rare in collections well upstream of the Project. Abundance in the Project Area is not well understood at this time. Low numbers of juveniles should reduce the potential numbers of these species that may be entrained.

~~1)~~4) Bonneville cutthroat are known to traverse the Project diversion and spawn in tributaries above the diversion. Potential downstream migration of juvenile trout produced in these areas is not well understood. These numbers may not be substantial if sufficient resources and suitable habitat exist upstream of the Project, including the impoundment.

5) Entrainment risk should be reduced during the fall and winter when movements of all life stages are lower. This coincides with the period when Project flow (as a percentage of river flow) is at its highest annual levels.

6) Approach velocities to the intake rack (1-1.5 fps) are within the documented prolonged swimming speeds of young-of-year of both species, which may reduce entrainment risk; further, fish of all sizes have been observed swimming freely immediately in front of and along the intake rack.

7) Larger sized fish (mostly adults) of both species (>300 mm [12 inches]) should suffer substantially higher mortality than smaller individuals (about 150 mm [8 inches] or less). However, these are much less likely to be entrained according to previous studies, and by observation at the Project, due to intake bar spacing and downstream-swimming fish orientation.

8) The largest fish (>350 mm [13.75 inches]) are likely precluded from entrainment due to the size of the intake opening (1.5 inches). Individuals of this size are common among adult populations of both species.

~~2)~~9) Overall, entrainment and mortality potential of Bonneville cutthroat and bluehead sucker appears to be relatively low for the Weber Project. Entrainment and mortality risk at unscreened irrigation diversions, such as the Davis-Weber Irrigation District diversion just below the power plant, may be greater for these populations. This is due to the high percentage of river flow removed and the presumably high mortality levels of entrained fish.

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APPENDIX 1

Upstream Fish Passage Conceptual Design Report

APPENDIX 2

Recorded Lengths and Numbers of Each Size Class of Trout Used in the Turbine Mortality Field Study

Recorded Lengths and Numbers of Each Size Class of Trout Used in the Turbine Mortality Field Study

3-Inch Size Group Length (mm)	6-Inch Size Group Length (mm)	12-Inch Size Group Length (mm)
78	170	260
109	185	310
95	185	210
95	160	270
97	180	200
110	165	290
105	178	270
100	165	290
115	170	270
115	182	300
105	150	310
109	170	290
105	185	260
110	162	270
95	185	275
78	175	275
98	155	305
93	180	320
110	175	230
92	155	285
88	170	300
90	195	265
115	160	285
102	160	278
80	175	310
95	180	285
78	185	260
100	165	300
105	180	205

Recorded Lengths and Numbers of Each Size Class of Trout Used in the Turbine Mortality Field Study

3-Inch Size Group Length (mm)	6-Inch Size Group Length (mm)	12-Inch Size Group Length (mm)
100	160	210
95	145	300
95	168	300
105	150	295
97	160	275
87	152	200
84	172	265
96	160	292
98	165	255
100	175	258
85	170	300
109	148	315
100	163	270
98	193	385
101	190	310
113	176	292
85	179	288
90	191	277
94	155	290
107	185	250
115	185	285
101	145	285
113	175	300
105	160	275
103	165	265
94	168	273
114	153	310
89	155	305
109	155	285

Recorded Lengths and Numbers of Each Size Class of Trout Used in the Turbine Mortality Field Study

3-Inch Size Group Length (mm)	6-Inch Size Group Length (mm)	12-Inch Size Group Length (mm)
105	196	288
119	155	300
103	164	315
110	148	330
92	171	300
93	160	290
112	160	255
100	145	290
100	180	295
116	155	310
90	135	275
120	155	255
96	185	300
98	180	290
94	160	295
107	165	288
100	150	294
105	184	295
110	160	310
100	154	303
95	155	280
106	185	250
92	150	285
100	160	398
105	175	280
100	175	305
112	185	300
88	155	305
90	199	285

Recorded Lengths and Numbers of Each Size Class of Trout Used in the Turbine Mortality Field Study

3-Inch Size Group Length (mm)	6-Inch Size Group Length (mm)	12-Inch Size Group Length (mm)
96	158	310
105	170	285
100	150	335
95	155	310
85	100	295
105	125	288
90	165	275
110	150	243
96	165	290
99	120	304
95	165	265
97	175	270
110		225
100		285
103		
85		
96		
102		
Average length: 99.8 mm	Average length: 165.8 mm	Average length: 284.5 mm

APPENDIX 3

Photographs

Photograph 1. Location where the underwater monitoring system camera was initially installed.

Photograph 2. Relocation of the camera between intake rack and penstock gates.

Photograph 3. Testing the underwater monitoring system with dead fish. RedFISH staff placing fish in close proximity of the camera.

Photograph 4. An adult Bonneville cutthroat trout from the Weber River (photo by Western Native Trout Initiative, Sage Lion Media)

Photograph 5. Weber powerhouse diversion with old fishway visible at rear retaining wall (photo taken on August 9, 2016). River flow was approximately 336 cfs at USGS 10136500, located at Gateway, UT.

Photograph 6. An adult bluehead sucker from the Weber River (Photo by UDWR).

Photograph 7. Project intake trash rack. Bar spacing is 1.25 to 1.5 inches.

Photograph 8. Project impoundment area.

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