Warner Basin Strategic Action Plan – Technical Report

WARNER BASIN AQUATIC HABITAT PARTNERSHIP

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Executive Summary

The Warner Basin Aquatic Habitat Partnership (WBAHP) was formally established in 2017 to complete fish passage, screen, and habitat restoration projects with the goal of recovering Warner Sucker and expanding Warner Lakes Redband Trout populations in the Warner Basin. To meet these goals, the Warner Basin Strategic Action Plan (Plan) was developed to identify the WBAHP members and their responsibilities, acknowledged the important relationships with local ranchers and water users who rely on surface water diversions for their economic livelihood, and identified the actions that will be necessary to improve stream corridor conditions for Warner Sucker and Warner Lakes Redband Trout. The Plan formed the basis for an Oregon Watershed Enhancement Board Focused Investment Partnership (FIP) application in 2018. WBAHP was awarded FIP funding intended to achieve the fish passage, screening, habitat enhancement, and water availability improvement goals outlined in the Plan.

WBAHP was also awarded a "Telling the Story" OWEB grant to prepare a technical document that will be used as a stand-along document and as an appendix to the Plan. This technical document includes a review of the Warner Basin, completed fish passage projects, monitoring results for fish passage projects, and other investigations that have improved understanding of Warner Sucker ecology and population demographics. Information gathered from project monitoring and fisheries investigations is used by WBAHP members to better understand limiting factors affecting Warner Sucker and to develop solutions to address limiting factors with the ultimate goal of recovering Warner Sucker populations in the basin.

Three completed fish passage projects have been monitored to assess Warner Sucker passage. Biological monitoring has documented passage at each of the fish passage structures located on Twentymile Creek (2 structures) and Honey Creek (1 structure). Similar fish passage projects that have not been monitored, have also be completed on upper Honey Creek. Additional projects are currently underway on Deep Creek and Honey Creek. Fish passage projects on Twentymile Creek have restored passage to approximately 33 miles of habitat. Projects to be completed on Deep Creek and Honey Creek will restore access to approximately 3 miles and 51 miles of habitat, respectively.

1 Introduction

The Warner Basin Aquatic Habitat Partnership (WBAHP) is a collaboration of local, state, and federal partners committed to the recovery of Warner Sucker (*Catostomus warnerensis*) and Warner Lakes Redband Trout (*Oncorhynchus mykiss newberrii*). The State of Oregon and federal government recognize the Warner Sucker as a threatened species, and Warner Lakes Redband Trout is a State of Oregon sensitive species and a federal species of concern. The WBAHP is comprised of seven organizations including the Lake County Umbrella Watershed Council (LCUWC), Lakeview Soil and Water Conservation District (LSWCD), Oregon Department of Fish and Wildlife (ODFW), U.S. Fish and Wildlife Service (USFWS), U.S. Bureau of Land Management (BLM), U.S. Forest Service (USFS), and River Design Group, Inc. (RDG). The WBAHP members have completed fish passage, screening, and habitat enhancement projects in the Warner Basin, and have a goal of expanding these efforts to address fish passage and habitat limiting factors across the three focal tributary watersheds that support Warner Sucker and Warner Lakes Redband Trout. Long-term population monitoring completed by ODFW, USFWS, and BLM, and more recent fish passage project monitoring completed by ODFW, provide informative data sets that WBAHP members use for Warner Sucker and Warner Lakes Redband Trout management.

The Warner Basin Strategic Action Plan – Technical Document is intended to be a companion document to the Warner Basin Strategic Action Plan (Plan) and provide more detailed information on the Warner Basin's geography, hydrology, and fish community. Additionally, the technical document summarizes completed fish passage projects and lessons learned from geomorphic and biological effectiveness monitoring completed for the fish passage projects. Monitoring results have been, and will continue to be used by WBAHP members to refine fish passage, screening, and habitat enhancement designs that will be implemented on the three focal tributaries in the Warner Basin. Finally, the technical document outlines partnership opportunities for stakeholder engagement, program funding, and project execution.

2 Warner Basin – Geographic Context

2.1 Physical Geography

The Warner Basin is located in south-central Oregon, northwestern Nevada, and extreme northeastern California. The basin is an endorheic (i.e., no outlet) basin approximately 60 miles long and 8 miles wide within the Basin and Range ecoregion (Figure 2-1). The valley has two regions commonly referred to as the South Warner Valley and the North Warner Valley with the area of separation between Crump Lake and Hart Lake, known as the Narrows.

Figure 2-1. The Warner Basin within the Basin and Range ecoregion.

Similar to adjacent endorheic basins, the Warner Valley was formed by horst and graben geology whereby a central downward-trending block of ground is bordered by two adjacent uplifted blocks of ground in a general north-south orientation (USFWS 1998). During the last two pluvial periods of the late Pleistocene, the Warner Basin was inundated by Pluvial Lake Warner. The first pluvial, synchronous with the Tahoe glaciation, was well advanced 46,000 years before present (BP) and lasted until 32,000 years BP (Flint and Gale 1958; Hansen 1961 *cited in* Taylor 1978). At its maximum extent, Pluvial Lake Warner reached an elevation of about 4,749 ft, whereas the lowest point in the basin boundary is 4,800 ft, located in Mule Springs Valley (Phillips and Van Denburgh 1971). If this pluvial lake ever did overflow, the water would have drained north through the Mule Springs Valley and eventually into the Malheur Basin (Van Winkle 1914 *cited in* Taylor 1978).

A second pluvial period, associated with the Tioga glaciation, commenced about 24,000 years BP and ended 10,000 or 12,000 years BP (Flint and Gale 1958; Hansen 1947 *cited in* Taylor 1978). Lakes again filled the basins of south-central Oregon, but not to the depths attained during the first pluvial period. Following the end of the last glaciation, the climate became progressively more arid. The warming increased to a maximum 4,000 to 8,000 years BP (Hansen 1947). Desiccation was widespread and the lakes of south-central Oregon dried completely. Cooler, moister conditions have prevailed for the last 4,000 years, although large fluctuations in lake levels have occurred (Phillips and Van Denburgh 1971 *cited in* Taylor 1978).

Pluvial periods resulted in biological exchange between basins, while drying periods were times of isolation. Over time, these periodic episodes of joining and isolation of habitats resulted in fish community differentiation, and in some instances, speciation of the native fishes of the region. Today (a period of isolation), the fish assemblage in the Warner Basin shows varying levels of differentiation relative to fish assemblages in adjacent endorheic basins.

Both sides of the South Warner Valley have steep cliffs rising from 1,000 to 2,000 ft above the valley floor (Figure 2-2). The eastern cliffs run the entire length of the valley, while the western wall turns into rolling hills at the north end of the valley. The Coyote Hills are the western boundary through the middle of the North Warner Valley, with the Rabbit Hills bounding the northwest corner of the valley. From the hills, the ground slopes west up to the crest of Abert Rim (Warner Ridge). The eastern boundary of the valley is Hart Mountain, a massive cliff face that rises 3,600 ft above the valley floor. Warner Peak with an elevation of 8,065 ft is the highest point on Hart Mountain.

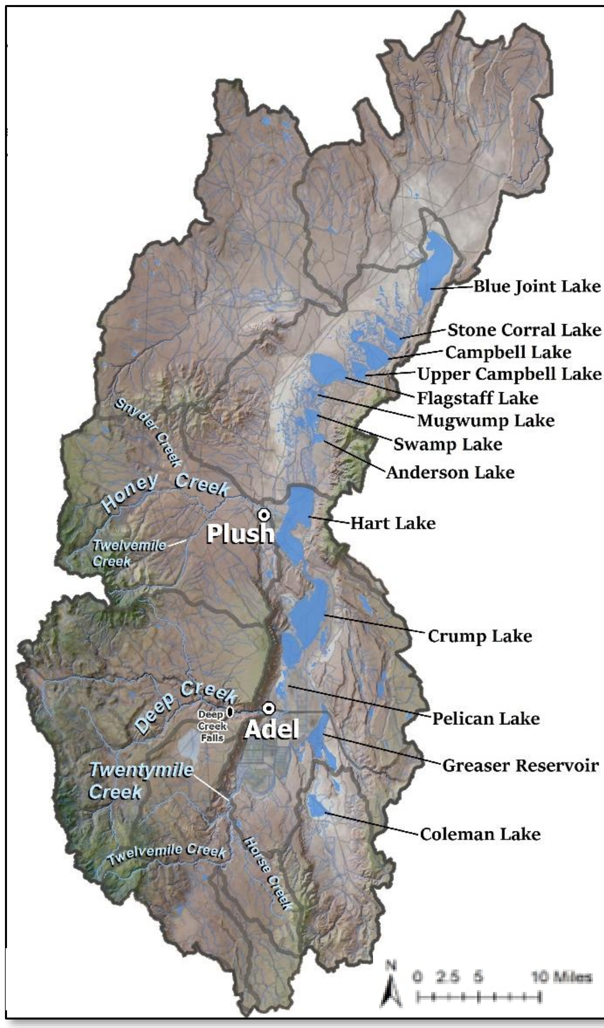

Figure 2-2. The Warner Basin including primary waterbodies.

The valley floor is occupied by a chain of lakes known collectively as the Warner Lakes (see **Figure 2-2**). Starting at the south end of the valley, the largest of the Warner Lakes are Pelican Lake, Crump Lake, Hart Lake, Anderson Lake, Swamp Lake, Mugwump Lake, Flagstaff Lake, Upper Campbell Lake, Lower Campbell Lake, Stone Corral Lake, Turpin Lake, and Bluejoint Lake. The three primary tributaries in the basin include, from north to south, Honey Creek, Deep Creek, and Twentymile Creek.

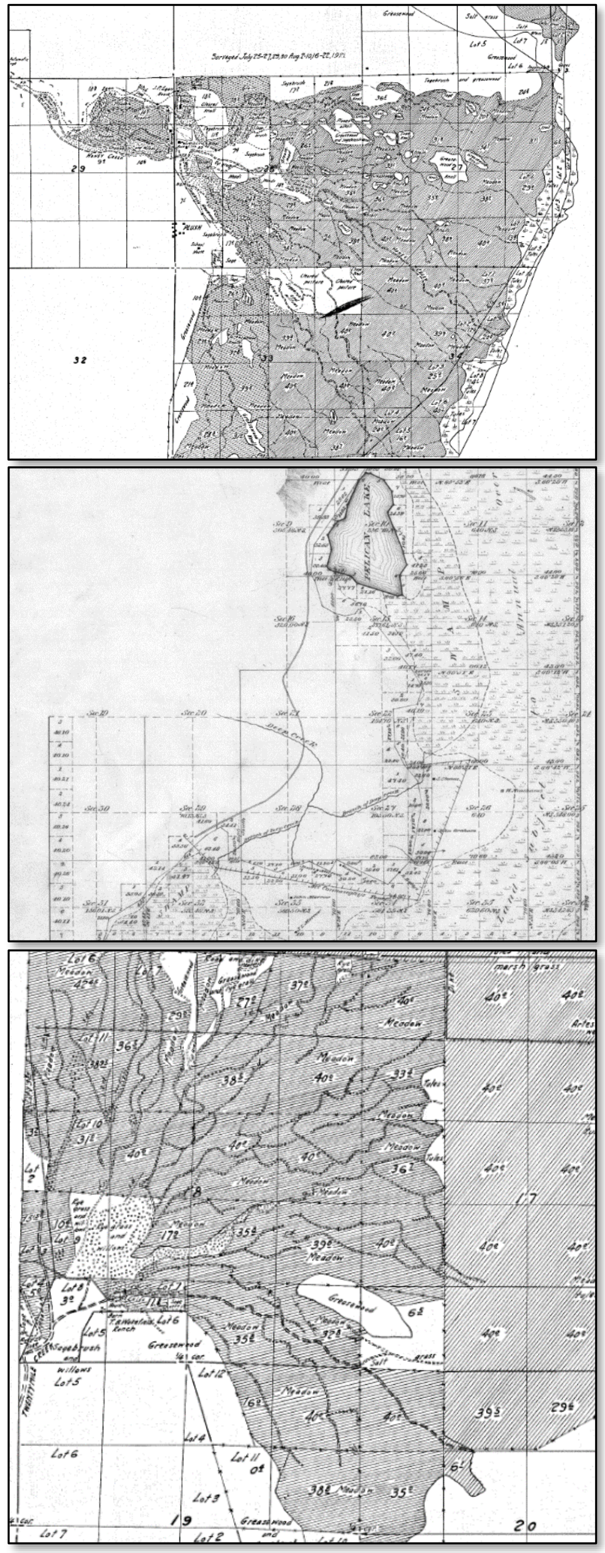

Figure 2-3. Relict alluvial fan channel patterns on Honey Creek (top; 1921), Deep Creek (middle; 1888) and Twentymile Creek (bottom; 1921).

Historical Stream Corridor Conditions

European-American sheep herders and cattlemen settled in the Warner Basin in the late 1800s, capitalizing on the lush valley bottoms for pasturing livestock. Agricultural activities focused on the lower reaches of the focal tributaries where the streams emerge from confined canyon reaches into the broad pluvial Warner Valley. The transition from confined canyon reaches to the broader valley, occurs over a relatively short distance in each tributary watershed, resulting in the formation of alluvial fans and distributary channel networks (Figure 2-3). Twentymile Creek and Deep Creek historically flowed through extensive wetlands that filtered runoff as tributary flow gradually progressed towards Pelican Lake and Crump Lake. Compared to the southern tributaries, Honey Creek has a more defined, higher gradient alluvial fan and likely smaller historical wetland complex. Flow from Twentymile Creek and Deep Creek likely intermingled in the expansive wetland that exceeded 20,000 acres.

The historical stream network was modified as early as the late 1800s as settlers altered stream networks to facilitate land draining and flood irrigation. To improve agricultural efficiency, the mainstem channels in the lower valleys were straightened and cleared. Irrigation diversion structures were installed to divert water from the mainstem channels into diversion channel networks that used the distributary channel network and excavated ditches to route irrigation water. Rock, earthen, and log dams (later replaced by concrete structures) were built to create hydraulic head necessary for diversion operations especially during summertime low flows. Diverted streamflow continues to be used to flood irrigate pasture, hay, and other livestock feed, and provide stockwater.

2.2 Climate

In the rain shadow of the Cascades and Klamath mountains, the Warner Basin is in Oregon's driest ecoregion. Marked by extreme ranges of daily seasonal temperatures and precipitation patterns, precipitation and runoff events can also be highly variable on an interannual basis. Table 2-1 includes summary climate data for the weather stations in Plush and Adel, the two population centers located on the floor of the Warner Basin (WRCC 2019a).

Table 2-1. Average annual climate summary for weather stations at Plush and Adel, OR.

Average Annual	Plush	Adel
Max Temp (°F)	61.8	63.3
Min Temp (°F)	34.0	35.0
Total Precip (in)	7.4	8.9
Total Snowfall (in)	12.8	15.6
Period of Record	1910-1961	1956-2016

In contrast to the climate metrics for the valley floor weather stations, weather stations at higher elevations may receive considerable precipitation especially as snow in the winter. For example, the Warner Mountain Refuge weather stations, located 1,000 ft higher than the Adel and Plush weather stations, has an average annual total snowfall of 49.3 inches, over three times the total for the valley floor stations (WRCC 2019b).

Years with high elevation snowpack typically produce sustained streamflow into the summer irrigation season. Conversely, years with minimal snowpack or early snowmelt runoff may yield low streamflow and irrigation water demand exceeds supply by early summer. Warm storms between November and April can also result in high intensity rain-on-snow events which rapidly melt low and mid-elevation snowpack. Due to the basins' thin mineralized soils, snowmelt quickly raises streamflow periodically resulting in record floods in the basin.

2.3 Hydrology

Warner Basin tributaries experience similar hydrologic conditions characterized by low year-round precipitation, spring high flow, summer low flows, and periodic rain-on-snow events in late winter to early spring. Rain-on-snow events account for most of the largest floods on record. The Twentymile Creek subbasin is more susceptible to flooding during winter rain events due to its lower watershed elevation. Oregon Water Resources Department (OWRD) maintains real-time streamflow gages on Honey, Deep, and Twentymile creeks. These gages are located upstream of the primary irrigation diversions and each gage has a 100+ year period of record.

Honey Creek

OWRD maintains a real-time stream gage (Honey Creek near Plush, OR, gage #10378500) on Honey Creek located upstream of the JJ diversion, the most upstream diversion on lower Honey Creek. The gage has been in operation since 1910 and currently reports instantaneous, mean daily, and annual peak flows. The watershed area upstream of the gage is 168.0 square miles, the gage elevation is 4,550.0 ft (NAVD88). Peak flows and mean daily flows for the Honey Creek gage are presented in Figure 2-4. The December 1964 flood (11,000 cfs) is the flood of record on Honey Creek. The mean daily hydrograph is characterized by a late spring to early summer peak flow followed by low flows from August through October when fall rains increase streamflow. Table 2-2 includes the flood frequency analysis and Table 2-3 includes flow duration output including the 5% and 95% fish passage flows.

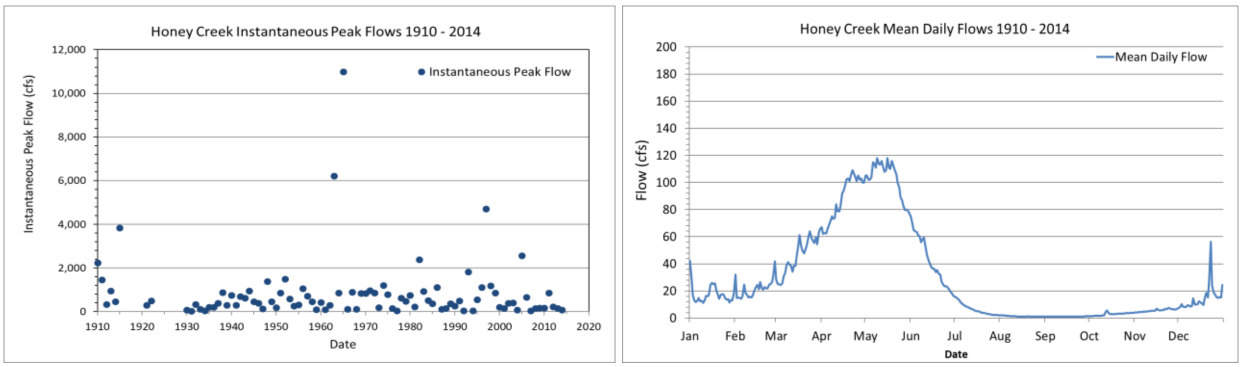

Figure 2-4. Instantaneous peak flows (left) and mean daily flows (right) for the period of record for the Honey Creek gage.

Table 2-2. Peak flows for the Honey Creek Near Plush, Oregon gage (#10378500) operated by OWRD.

Return Period (Years)	Station Calculation: Peak Flow (cfs)	95% Confidence: Lower (cfs)	95% Confidence: Upper (cfs)
2	453	362	566
5	1,210	951	1,600
10	2,020	1,530	2,810
20	3,060	2,250	4,480
25	3,460	2,510	5,130
50	4,890	3,440	7,570
100	6,650	4,550	10,700
500	12,400	7,960	21,800

Table 2-3. Annual flow exceedance for the Honey Creek Near Plush, Oregon gage (#10378500) operated by OWRD. Annual flow exceedance values associated with fish passage flows are highlighted.

Annual Flow Exceedance (%)	Flow (cfs)	Significance
95	0.24	Low Fish Passage Flow
90	0.46	
75	1.81	
50	6.26	Median Flow
25	26.2	
20	38.0	
10	85.3	
5	146.0	High Fish Passage Flow

Deep Creek

OWRD maintains a real-time stream gage (Deep Creek near Adel, OR, gage #10371500) on Deep Creek located downstream from Deep Creek falls and upstream from the first diversion on Deep Creek. The gage has been in operation since 1922 and currently reports instantaneous, mean daily, and annual peak flows. The watershed area upstream of the gage is 254.0 square miles and the gage elevation is 4,980.0 ft (NAVD88). Peak flows and mean daily flows for the Deep Creek gage are presented in Figure 2-5. The December 1964 flood (9,420 cfs) is the flood of record on Honey Creek. The mean daily hydrograph is characterized by a late spring to early summer peak flow followed by low flows from August through October when fall rains increase streamflow. Table 2-4 includes the flood frequency analysis and Table 2-3 includes flow duration output including the 5% and 95% fish passage flows.

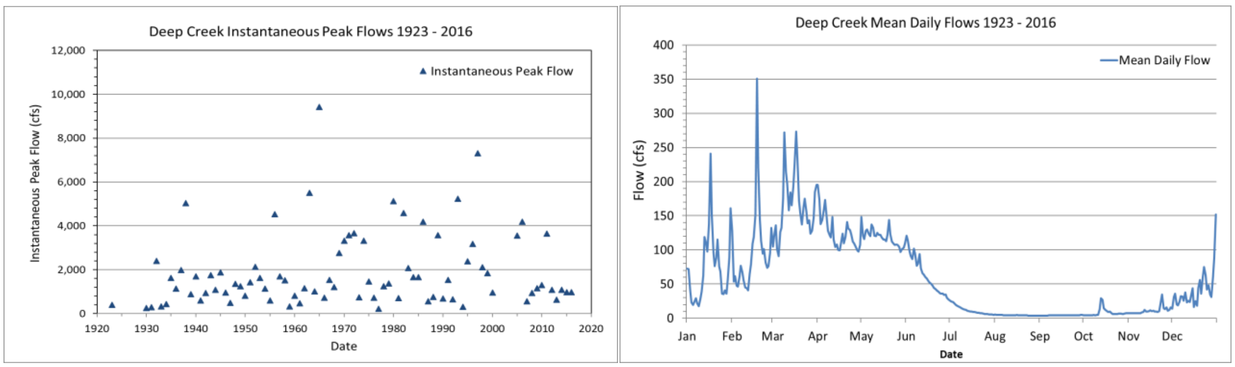

Figure 2-5. Instantaneous peak flows (left) and mean daily flows (right) for the period of record for the Deep Creek gage.

Table 2-4. Peak flows for the Deep Creek Near Adel, Oregon gage (#10371500) operated by OWRD.

	Station Calculation		
		95% Confidence	
Return Period (Years)	Peak Flow (cfs)	Lower (cfs)	Upper (cfs)
2	1,350	1,140	1,590
5	2,770	2,310	3,410
10	4,030	3,280	5,170
20	5,510	4,370	7,340
25	6,030	4,750	8,130
50	7,830	6,020	10,900
100	9,910	7,430	14,300
500	15,900	11,400	24,600

Table 2-5. Annual flow exceedance for the Deep Creek Near Adel, Oregon gage (#10371500) operated by OWRD. Annual flow exceedance values associated with fish passage flows are highlighted.

Annual Flow Exceedance (%)	Flow (cfs)	Significance
95	7.15	Low Fish Passage Flow
90	9.78	
75	17.4	
50	32.3	Median Flow
25	144	
20	202	
10	392	
5	576	High Fish Passage Flow

Twentymile Creek

OWRD maintains a real-time stream gage (Twentymile Creek near Adel, OR, gage #10366000) on Twentymile Creek located upstream of the Dyke diversion, the most upstream active diversion on Twentymile Creek. The gage has been in operation since 1911 and currently reports instantaneous, mean daily, and annual peak flows. The watershed area upstream of the gage is 189.0 square miles, the gage elevation is 4,580.0 ft (NAVD88). Peak flows and mean daily flows for the Twentymile Creek gage are presented in Figure 2-6. The February 1986 flood (10,400 cfs) is the flood of record on Twentymile Creek. The mean daily hydrograph is characterized by a late spring to early summer peak flow followed by low flows from August through October when fall rains increase streamflow. Table 2-6 includes the flood frequency analysis and Table 2-7 includes flow duration output including the 5% and 95% fish passage flows.

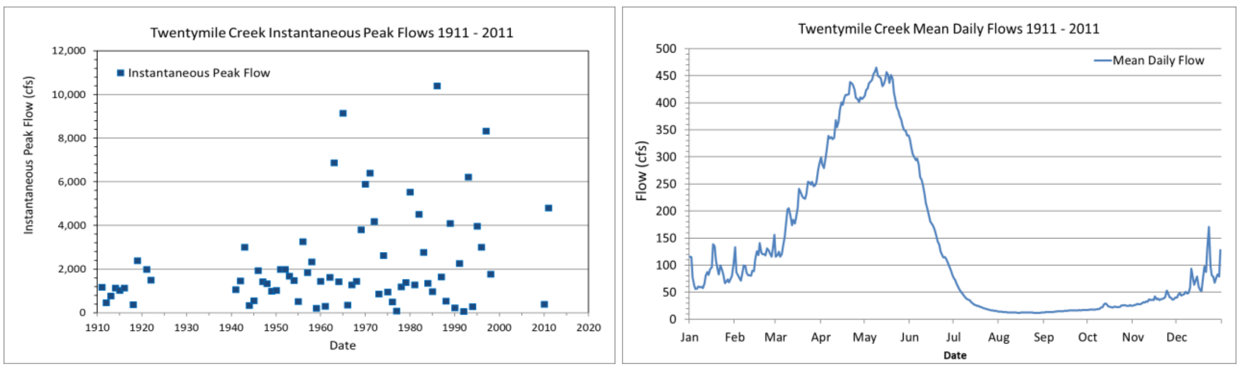

Figure 2-6. Instantaneous peak flows (left) and mean daily flows (right) for the period of record for the Twentymile Creek gage.

Table 2-6. Peak flows for the Twentymile Creek Near Adel, Oregon gage (#10366000) operated by OWRD.

	Station Calculation		
		95% Confidence	
Return Period (Years)	Peak Flow (cfs)	Lower (cfs)	Upper (cfs)
2	2,230	1,660	3,020
5	4,970	3,640	7,340
10	7,250	5,130	11,400
20	9,680	6,650	16,100
25	10,500	7,140	17,700
50	13,100	8,670	23,100
100	15,900	10,200	29,100
500	22,600	13,800	44,600

Table 2-7. Annual flow exceedance for the Twentymile Creek Near Adel, Oregon gage (#10366000) operated by OWRD. Annual flow exceedance values associated with fish passage flows are highlighted.

Annual Flow Exceedance (%)	Flow (cfs)	Significance
95	2.34	Low Fish Passage Flow
90	2.98	
75	4.41	
50	8.32	Median Flow
25	50.3	
20	70.4	
10	131	
5	228	High Fish Passage Flow

3 Fish Community

Native fish species found in the Warner Basin planning area include Warner Sucker, Warner Lakes Redband Trout, Tui Chub (*Siphateles bicolor thalassinus*), and Speckled Dace (*Rhinichthys osculus*). Non-native species including White Crappie (*Pomoxis anularis*), Black Crappie (*P. nigromaculatus*), and Largemouth Bass (*Micropterus salmoides*) were planted by ODFW into the Warner Lakes between 1971 and 1973 (White et al. 1990), and were well established by the late 1970s. Brown Bullhead (*Ameiurus nebulosus*) also inhabit the basin, although the year of introduction is unknown. The following sections include additional information on the native fish species.

3.1 Warner Sucker

The following information is largely adapted from Scheerer et al. (2016). A more extensive study of Warner Sucker life history is provided *Warner Sucker Life History: A Review* (Monzyk 2019).

The abundance and distribution of Warner Sucker has declined over the past century, and the species was listed as threatened under the U.S. Endangered Species Act in 1985 due to habitat fragmentation from impassable irrigation diversions and threats posed by the proliferation of piscivorous non-native game fishes (USFWS 1985).

The Warner Sucker inhabits the lakes and low gradient stream reaches of the Warner Valley. The species exhibits two life-history forms: lake and stream morphs (Figure 3-1). The lake-residing Warner Sucker has a lacustrine-adfluvial life history, spending most of the year in a lake environment but migrating into tributary streams in large aggregations to spawn (USFWS 1998). The adfluvial form generally matures later, lives longer, and is much larger and more fecund than the stream form. When upstream migration of lake-residing suckers is hindered by low stream flows during drought years or by irrigation diversion weirs, lake-residing suckers may spawn in nearshore areas of the lakes (White et al. 1991).

Large lake-residing populations of introduced fishes may reduce Warner Sucker recruitment by preying upon young suckers (USFWS 1998). Periodic lake drying also threatens the lake-residing suckers, and suckers from the tributaries have recolonized the lakes after past drying events (mid-1930s and early 1990s; Allen et al. 1994). The stream-residing suckers have a fluvial life-history pattern and rear-spawn in the three major tributary drainages (Twentymile, Deep, and Honey Creeks). Threats specific to the stream form include water withdrawals for irrigation and habitat degradation associated with grazing and agricultural practices. Both the lake- and stream-residing Warner Sucker spawn in the spring (April–June) (Coombs et al. 1979) in response to temperature and flow cues (Scheerer et al. 2016). Warner Sucker in the lakes are long-lived (17 years; White et al. 1991) and mature at 3 to 4 years of age (Coombs et al. 1979).

Figure 3-1. Stream form (top) and lake form (bottom) male Warner Suckers in spawning condition. Photos courtesy ODFW.

Warner Sucker Distribution

The following Warner Sucker distribution information is adapted from USFWS (1998).

Historical - The probable historical range of the Warner Sucker includes the main Warner Lakes (Pelican, Crump, and Hart), and other accessible standing or flowing water in the Warner Valley, as well as the low to moderate gradient reaches of the tributaries which drain into the Warner Valley. The tributaries include Deep Creek, up to the Deep Creek falls 3.1 miles west of Adel, the Honey Creek drainage, and the Twentymile Creek drainage. In Twelvemile Creek, a tributary to Twentymile Creek, the historical range of Warner Suckers extended through Nevada and back into Oregon, but the sucker occupied habitat probably did not extend into the California portion of Twelvemile Creek.

Early collection records document the occurrence of the Warner Sucker from Deep Creek up to the falls west of Adel, the sloughs south of Deep Creek, and Honey Creek (Snyder 1908). Andreasen (1975) reported that long-time residents of the Warner Valley described large runs of suckers in the Honey Creek drainage, even far up into the canyon reach.

Current – Figure 3-2 includes the current Warner Sucker distribution and designated critical habitat in the basin. Eight studies between 1977 and 1991, and more recent investigations since 2010, have examined the range and distribution of the Warner Sucker throughout the Warner Valley. These surveys showed that when adequate water is present, Warner Sucker may inhabit all the lakes, sloughs, and potholes in the Warner Valley. The documented range of the sucker extended as far north into the ephemeral lakes as Flagstaff Lake during high water in the early 1980s, and again in the 1990s. The northern-most lake where suckers have been found was Stone Corral Lake in the early 2000s.

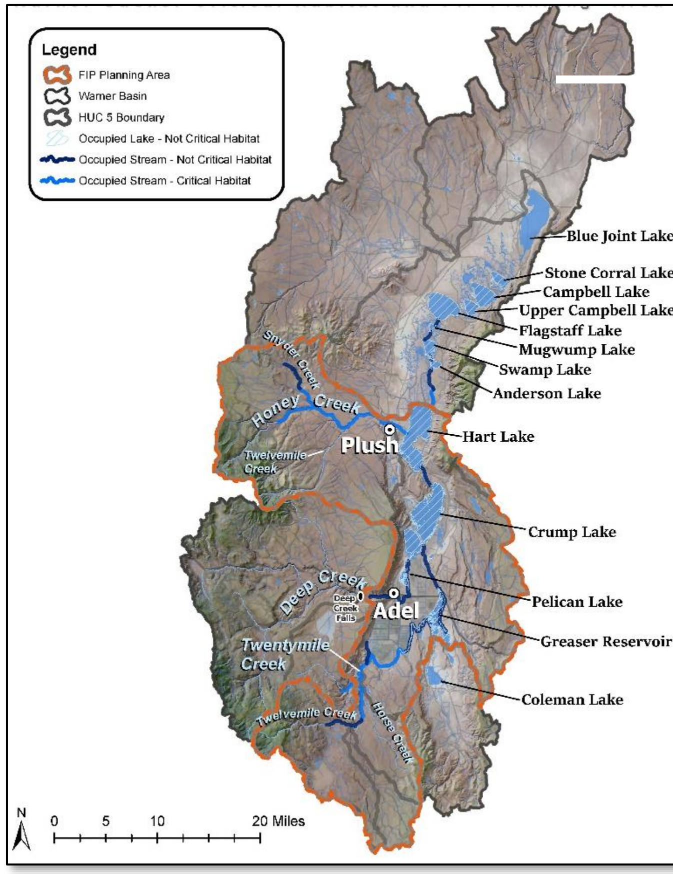

Figure 3-2. Warner Sucker occupied and designated critical habitat, and the Focused Investment Partnership planning area.

Stream resident populations are found in Honey Creek, Snyder Creek, Twentymile Creek and Twelvemile Creek. Intermittent streams in the drainages may support small numbers of migratory suckers in high water years. No stream resident suckers have been found in Deep Creek since 1983 (Smith et al. 1984, Allen et al. 1994), although a lake resident female apparently trying to migrate to stream spawning habitats was captured and released in 1990 (White et al. 1990). The known upstream limit of the Warner Sucker in Twelvemile Creek is through the Nevada reach and back into Oregon (Allen et al. 1994). However, the distribution appears to be discontinuous and centered around low gradient areas that form deep pools with protective cover. In the lower Twentymile Slough (i.e., flood ditch) on the east side of the Warner Valley, White et al. (1990) collected adult and young suckers throughout the slough and Greaser Reservoir. This area dried up in 1991, but because of its marshy character, may be important sucker habitat during high flows. Larval, young-of-year, juvenile and adult suckers captured immediately below Greaser Dam suggest either a slough resident population, or lake resident suckers migrating up the Twentymile Slough channel from Crump Lake to spawn (White et al. 1990, Allen et al. 1996).

Life Stages

The following Warner Sucker life stages information is adapted from Monzyk (2019).

Egg and Larval Stage – Eggs are partially buried in gravel substrate during stream spawning. After approximately one month of incubation, larval suckers hatch at 7-8 mm and emerge from the gravel at approximately 10 mm in late spring and early summer (White et al. 1991; Kennedy and Vinyard 1997). In streams, larvae occupy vegetated areas with low to moderate flow and relatively shallow depths along stream margins or backwater areas during the first few months after hatching (~10-17 mm TL) (Coombs et al. 1979; Kennedy and Vinyard 2006). As the larvae grow in size, they move into mid-water habitats with moderate flows (Coombs et al. 1979; Kennedy and Vinyard 2006). Larvae select microhabitats with focal point velocities (FPV) between 3-6 cm/s and avoided areas with FPV >15 cm/s (Kennedy and Vinyard 2006). They feed on invertebrates in the upper half of the water column with planktonic cladocerans dominating the diet (Coombs et al. 1979; Tait and Mulkey 1993a). They also appear to segregate from larval Speckled Dace (*Rhinichthys osculus*) by feeding higher in the water column (Coombs et al. 1979). At night larvae move closer to shore, presumably to avoid entrainment into swift currents when visual orientation in the stream is lost (Kennedy and North 1993; Kennedy and Vinyard 1997).

Larval suckers are rarely collected in drift samples (Coombs et al. 1979; Kennedy and Vinyard 1997; Kennedy and North 1993; Bosse et al. 1997; Richardson 2009) and express a distinct drift avoidance behavior. Kennedy and Vinyard (1997) measured the response of larval suckers to artificial entrainment in mid-channel current and found larvae of all sizes (16-30 mm TL) resisted downstream displacement. Once released into the current, fish would immediately seek current refugia behind rocks and vegetation. Warner Suckers are unique from other western suckers in that larvae do not drift downstream after hatching in streams (Cooperman and Markle 2011; Kennedy and Vinyard 1997).

Juvenile Stage – As larvae develop into juveniles they become more bottom orientated. During the day juveniles associate with macrophyte beds, while at night they move into riffles and open areas to feed (Tait and Mulkey 1993a). Several other studies have noted that movements of both juvenile and adult Warner Suckers are primarily nocturnal (Richardson et al. 2009; Scheerer et al. 2015; Scheerer et al. 2016). Most juvenile foraging time (75%) occurs over large gravel or boulders, where they likely feed on diatoms, filamentous algae, and detritus (Tait and Mulkey 1993a).

Adult Stage – Warner Sucker adults reside in both tributaries and the lakes. Suckers born in tributaries, may migrate to the lakes when they are 3-4 years old. The more productive lake environments support faster growth and lake resident suckers reach larger sizes compared to stream type suckers. Spawning takes place in both stream and lake environments. Monzyk (2019) provides extensive information on adult spawning habitat, timing, and behavior.

Population Abundance

ODFW periodically estimates Warner Sucker population abundance in the Warner Basin. Stream populations are sampled using backpack electrofishing (Scheerer et al. 2011; and multiple gear types are used to estimate lake populations (Scheerer et al. 2016). Scheerer et al. (2011) provides a summary of population abundance estimates completed in Honey, Deep, and Twentymile Creeks from the mid-1990s through 2011. Table 3-1 includes summary Warner Sucker abundance estimates for the three Warner Basin tributaries.

Table 3-1. Warner Sucker abundance estimates completed for Honey, Twentymile, and Deep Creeks.

Stream	Reach	Year	Distance Surveyed (km)	Fish per km	Abundance Estimate (95% CI)
Honey Creek		2007[1]	2.9	59	2,202 (418 - 3,986)
		2011[2]	25.6	176	4,495 (3,668 - 5,448)
		2011[2]	25.6	148	2,105 (1,372 - 3,201
Twentymile Creek		2007[1]	2.0	237	4,746 (0 - 12,529)
		2009[3]	21.3	219	4,612 (3,820 - 5,567)
	Lower	2014[4]	3.15	153	482 (368 - 638)
	Lower	2015	1.7	478	813 (761 - 861)
Deep Creek		2007[1]	0.7	19	150 (0 - 438)

[1] Scheerer et al. 2007; [2] Scheerer et al. 2011; [3] Richardson et al. 2009; [4] Scheerer et al. 2014

Habitat Use

In addition to completing population abundance estimates, ODFW has also surveyed and documented habitat conditions in the sampling reaches. Pools and aquatic vegetation are primary habitat variables, water temperature and undercut banks are secondary habitat variables (Scheerer et al. 2011). Deep pools provide an important refuge habitat during low flow periods especially during drought. Scheerer et al. (2014) sampled lower Twentymile Creek from the Dyke diversion to the Cahill Wing Deflector located in the Twentymile Creek bypass. Warner Sucker were only captured in pools with the majority (65%) captured in a single deep pool (>2 m).

Genetic Diversity

DeHaan and VonBargen (2012) completed a genetic analysis of Warner Suckers in Honey Creek, Deep Creek, Twentymile Creek and a translocated population that occupies a naturalized irrigation ditch on the Summer Lake Wildlife Management Area managed by ODFW. The investigators found no differences in the levels of genetic variation between tributary populations, suggesting that no population currently faces an increased risk of threats from reduced genetic diversity. DeHaan and VonBargen also found that Warner Sucker exhibited a relatively high level of genetic variation among the different tributaries (Twelvemile, Deep, Honey, and Snyder Creeks) and tests of allele frequency heterogeneity suggested that each tributary contained a genetically independent spawning population. Warner Sucker in Deep Creek had the highest levels of genetic diversity, suckers in Twentymile Creek had the lowest genetic diversity. These results suggest the higher degree of population connectivity between lower Deep Creek and Crump Lake, and the isolation of the Twentymile Creek stream population from Deep Creek and Honey Creek populations potentially caused by the modification of lower Twentymile Creek.

Conservation History

Conservation actions in the Warner Basin are relatively recent. Fish passage projects have been completed on upper and lower Honey Creek (2008 and 2010, and 2013 and 2017, respectively, Twentymile Creek (2014 and 2017), and as of 2019, the Town diversion fish passage project is underway on Deep Creek. WBAHP is currently working with landowners, individual irrigators, and irrigation districts on fish passage projects on the three focal tributaries.

ODFW completed biological monitoring on fish passage projects on Twentymile Creek (Dike diversion) and Honey Creek (Rookery diversion) and confirmed passage of Warner Sucker in the completed fish passage structures using Warner Suckers implanted with passive integrated transponder (PIT) tags. A fish passage project completed at the MC diversion on Twentymile Creek is currently being studied (2019). A second fish passage project on lower Honey Creek (Flood Ditch) was completed in 2017 and has not been studied by ODFW.

The continued pursuit of fish passage, screening, and habitat enhancement work on the three focal tributaries in the Warner Valley, is anticipated to result in the future recovery of Warner Sucker and improved conditions for Warner Lakes Redband Trout. Lessons learned on each project are discussed among the WBAHP members and applied during the development of future projects.

3.2 Warner Lakes Redband Trout

Warner Lakes Redband Trout are endemic to the Warner Basin and the species management unit (SMU) includes four populations. Although Warner Lakes Redband Trout are widely distributed among perennial streams, lakes, and reservoirs in the basin, irrigation diversions and stream dewatering affect Warner Lakes Redband Trout population connectivity and resilience. These limiting factors are most pronounced in the lower reaches of Honey, Deep, and Twentymile Creeks which are influenced by agricultural production. Non-native warm water predatory fish species inhabiting the Warner Lakes, may also impact Warner Lakes Redband Trout through predation and competition for food resources.

Distribution of Warner Lakes Redband Trout varies according to annual fluctuation of instream flows. During drought years, fish distribution constricts as streams and lakes dry and become uninhabitable. Warner Lakes Redband Trout recolonize these streams during wet cycles, restoring their basin-wide distribution. Many of the large lakes in Warner Valley dried in 1992 and redband trout were found in the lakes before and after the dry period (USFWS 1998).

Redband trout in Honey, Lower Deep, and Twentymile Creek populations have access to the Warner Lakes and express multiple life histories. However, irrigation diversions and irrigation canal networks hinder upstream and downstream passage of migrating Warner Lakes Redband Trout. Water availability and climatic conditions determine stream flow and irrigation needs, which in turn, influence the migratory success of redband trout between the lakes and upper stream reaches.

Inter-population connection is possible between the Honey Creek and Lower Deep Creek via Hart, Crump, and Pelican Lakes. These populations may interact when hydrologic connectivity is sufficient for Warner Lakes Redband Trout to access stream spawning habitats. Twentymile Creek is more isolated from the other populations due to agricultural modification of the stream network and Twentymile Creek fish are unlikely to mix with the Honey Creek and Lower Deep Creek populations. Deep Creek Falls is a natural fish passage barrier that isolates the Upper Deep Creek population. Both the Twentymile Creek and Upper Deep Creek populations lack the opportunity for genetic mixing which creates a greater risk of extinction due to the effects of inbreeding if the populations become very small.

4 Warner Basin Limiting Factors

Warner Basin fish populations are subjected to factors that limit the historical expression of physical and ecological conditions. Limiting factors are defined as the impacted physical, biological, or chemical conditions and associated processes and interactions experienced by fish that may limit population parameters including abundance, productivity, spatial structure, and genetic diversity.

The following limiting factors have been identified for the Warner Basin (USFWS 1988).

- Habitat connectivity
- Habitat quality
- Water quantity (decreased instream flows)
- Water quality (water temperature)
- Introduced fish species

Primary threats to Warner Basin fish populations directly addressed by this document include fish passage barriers, unscreened diversion infrastructure, and improving water efficiency. Migration timing for Warner Basin species is tied to the hydrograph, fish migrate and spawn during the spring when there is sufficient flow in most tributaries for fish to navigate migration corridors to reach spawning grounds. Warner Sucker and Warner Lakes Redband Trout typically ascend tributary streams from April to late June to locate mates and spawning habitat. Historically, fish were able to migrate throughout the Warner Basin during years with sufficient flow in the spring. Adult fish residing in the Warner Lakes and tributary streams spawned in desirable locations.

The construction of irrigation diversions on Honey, Deep, and Twentymile Creeks from the late 1800s to the early 1900s, severed watershed connectivity. Eight diversion weirs on the lower 3.5 miles of Honey Creek create partial or complete fish passage barriers, restricting fish access to 24 miles of upstream habitat. The lower six weirs may be passable during high flows and before diversion stoplogs are installed in the weirs. However, no large lake form suckers have been reported passing the seventh diversion (Town diversion at Hogback Road), approximately 2.2 miles upstream from the mouth of Honey Creek (Coombs et al. 1979; Scheerer et al. 2006). The lowermost diversion (Rookery diversion) was rebuilt in 2015 and the Flood diversion was rebuilt in 2018, both with fish passage-friendly structures. The remaining diversions continue to affect upstream adult passage and may route adult and juvenile suckers into diversion networks.

Deep Creek has six diversions along its 9 miles of Warner Sucker habitat from the mouth of Deep Creek at Crump Lake to Deep Creek Falls. Upstream movement of lake-dwelling suckers is blocked at Starveout diversion based on results of radio-telemetry studies (Scheerer et al. 2006). Warner Suckers appear to have been extirpated above this diversion located 7.6 km upstream from the mouth based on the lack of observations during past surveys (White et al. 1990; Allen et al. 1994).

In the Twentymile Creek subbasin, Warner Suckers occupy 15 miles of stream habitat from the Cahill diversion up to the headwaters of Twelvemile Creek. Recently added fish passage at the Dyke diversion (2016) and the MC diversion (2018) allows free movement of suckers in this reach. Providing connectivity to the lake system through the irrigation canals in the valley remains a challenge.

diversion weirs create vertical blockages in most years. Combined with the physical obstructions, diversions also reduce instream flows during the irrigation season. Improving diversion network efficiency may provide an opportunity to increase instream flows especially during low flow periods when water temperature and water quality are important for aquatic resources.

Improving fish passage at irrigation diversions, screening diversion canals, and increasing instream flows through water efficiency, are goals for Warner Sucker recovery and improving conditions for other Warner Basin fish species.

5 Fish Passage and Screening Design

5.1 Fish Passage

Fish Passage Goals

The USFWS (1998) recovery plan for Warner Sucker outlines steps designed to recover the Warner Basin and Alkali Subbasin aquatic ecosystems with specific goals for Warner Sucker and other listed species (Hutton Tui Chub and Foskett Speckled Dace) which are located outside of the Plan area. USFWS delisted Foskett Speckled Dace in 2019 (USFWS 2018). The primary recovery objective for the Warner Sucker is the eventual delisting of the species. Species delisting is an administrative process overseen by USFWS. While WBAHP can execute projects that achieve recovery criteria, WBAHP does not have the authority to delist the species.

USFWS is currently (2019) reviewing threats and recovery criteria for Warner Sucker, however, based on the 1998 recovery plan, USFWS may consider delisting the Warner Sucker when the following recovery criteria are met:

1. A self-sustaining metapopulation (a group of populations of one species coexisting in time, but not in space) is distributed throughout the Twentymile Creek, Honey Creek, and Deep Creek (below the falls) drainages, and in Pelican, Crump, and Hart Lakes. Self-sustaining populations will be determined based on parameters such as:
   - Multiple age-classes, including adults, juveniles, and young of the year, which approximate normal frequency distributions,
   - A stable or increasing population size,
   - Documented reproduction and recruitment, and
   - Self-sustaining populations form a viable metapopulation, large enough to maintain sufficient genetic variation to enable it to evolve and respond to natural habitat changes.
2. Passage is restored within and among the Twentymile Creek, Honey Creek, and Deep Creek (below the falls) drainages so that the individual populations of Warner Sucker can function as a metapopulation.
3. No threats exist that would likely threaten the survival of the species over a significant portion of its range.

Actions needed for Warner Sucker recovery include:

- Protect and rehabilitate Warner Sucker populations and habitat.
- Conserve genetic diversity of Warner Sucker populations.
- Ensure adequate water supplies are available for Warner Sucker recovery.
- Monitor Warner Sucker populations and habitat conditions.
- Evaluate long-term effects of climatic trends on the recovery of Warner Sucker.

Fish Passage Criteria

Oregon Administrative Rules 412 administered by ODFW, outlines fish passage criteria for Oregon's native fish that migrate to meet their lifecycle needs. Fish passage criteria are available for Warner Sucker and Warner Lakes Redband Trout (Table 5-1). Since Warner Sucker passage criteria are more limiting than passage criteria for trout, sucker criteria are used as the basis for Warner Basin fish passage project designs.

Table 5-1. ODFW fish passage criteria (Oregon Administrative Rules 2006) for trout and sucker. Since sucker criteria are more conservative, sucker criteria are used for fish passage designs in the Warner Basin.

Parameter	Trout	Sucker	Limiting Value
Fishway Slope (%)	-	<4%	<4%
Velocity (feet per second [ft/s])	1-2 ft/s in transport channels <8 ft/s in discrete fishway transitions	4 ft/s max	1-2 ft/s for juveniles
Minimum Water Depth (inches)	6 inches juvenile 12 inches adult	12 inches	12 inches
Jump Height (inches)	6 inches	No jump	No jump
Jump Pool Depth (inches)	6 inches juvenile 12 inches adult	No jump	No jump

Fish Passage Concepts

The following section outlines fish passage considerations and fish passage structures that may apply to Warner Basin diversions. Fish passage considerations are reviewed during the fish passage alternatives review and address water user management goals and biological criteria.

Fish Passage Alternatives Considerations

The following considerations have been encountered during planning for Warner Basin fish passage projects.

- Maintain existing point of diversion and diversion management.
- Improve diversion operational safety and efficiency.
- Meet fish passage criteria for Warner Sucker and Warner Lakes Redband Trout and provide volitional fish passage for the four native fish species in the Warner Basin.

- Execute cost-effective and robust designs that minimize annual operational demands and future maintenance needs.

Fishways are differentiated into two categories, technical fishways and nature-like fishways. Technical fishways include structural solutions like concrete fish ladders, while nature-like fishways may include roughened channels and bypass channels that are analogous to higher gradient stream reaches in the vicinity of the project site. The following sections provide an overview of technical and nature-like fishways that may be considered for improving passage in Warner Basin tributaries.

Technical Fishways

Technical fishways include a concrete fish ladder framework with varied interior structural orientations designed to meet fish passage criteria within the constraints of flow limitations. The following information is adapted from *Fish Passes: Design, Dimensions, and Monitoring* (FAO 2002).

Pool and Weir with Orifice Fishway

Pool and weir fishways are fish ladders with cross-walls that create a series of stepped pools. Stream flow enters the upstream entrance of the ladder and passes downstream through orifices and over cross-walls. The potential energy of the water is dissipated in each pool and fish migrate from one pool to the next. Migrating fish encounter higher water velocities while passing through orifices or over the weir notch at the top of the cross-wall, but experience lower velocities in the intervening pools. A rough channel bottom is added to the fish ladder and orifices are placed near the bottom of each cross-wall to enhance passage conditions for Warner Sucker.

Conventional pool and weir fishways are characterized by vertical cross-walls located at right angles to the pool axis (Figure 5-1). Cross-walls may be constructed from concrete or wood, wood cross-walls may be modified in response to fish passage monitoring data. Wooden cross-walls may need to be replaced periodically as the wood degrades. Incorporating orifices in the cross-wall provides submerged openings that facilitate passage of benthic species like the Warner Sucker. Alternating orifice locations on subsequent cross-walls reduces velocities through the cross-walls. Grouting cobble to the bottom of the fishway creates a stable, continuous nature-like channel bottom through the fishway. The rougher fishway bottom creates a lower velocity zone that is used by benthic species to navigate the fishway.

Pool and weir fishways have low water requirements and may be a preferred fish passage solution in streams like the Warner Basin tributaries where low flows are an annual occurrence. The fishways also address passage needs for both surface-oriented and bottom-oriented, as well as small fish species. In contrast to these benefits, pool and weir fishways may also require more maintenance than other fishway types. Fishways need to be monitored during and following high flow periods to ensure sediment and debris do not block orifices. Fishway entrances can be blocked and the fishway drained in order to provide a comprehensive review of fishway conditions. Wooden cross-walls may need to be replaced over time as wood degrades. At replacement, managers should determine if cross-wall design should be modified in accordance with fish passage and hydraulic monitoring results.

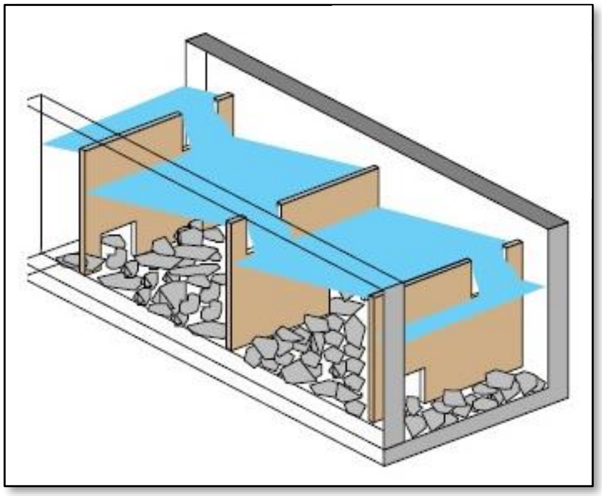

Figure 5-1. A pool and weir with orifice and streambed simulation material (DVWK 2002, left). The downstream extent of the Dike diversion fishway on Twentymile Creek.

Vertical Slot Fishway

The vertical slot fishway (Figure 5-2) is a variation of the pool and weir fishway whereby the cross-walls are notched by vertical slots extending over the entire height of the cross-wall. In comparison to the alternating orifice positions in a pool and weir fishway, vertical slots are placed on the same side of the fishway. Vertical slot fishways allow energy dissipation as a function of the pool, longitudinal slope, baffle and vertical slot design.

In particular, slot width and the number of slots (one or two), and the resulting discharge, determine the pool dimensions required. As with pool and weir fishways, velocities and turbulence are highest through the slot and lowest in intervening pools. The shape of the cross-walls must be such that no short-circuit current, that would pass through the pools in a straight line from slot to slot, is formed but rather a main current is created that curls back on itself such that the entire pool volume is used for energy dissipation. Such current regimes are encouraged by incorporating a hook-shaped projection into the cross-walls that deflects the flow in front of the slot entrance.

Like the pool and weir fishway, cross-walls may be constructed from concrete or wood. Wooden cross-walls require the installation of steel channel in the concrete formwork of the fishway. The cross-walls should be sufficiently high so that at mean discharge the water does not flow over the cross-walls.

Like the pool and weir bottom orifices, the vertical slot fishway includes a vertical slot pass that allows the creation of a continuous bottom substrate through the whole fish ladder. Grouting cobble to the fishway bottom provides additional roughness and velocity breaks within the fishway.

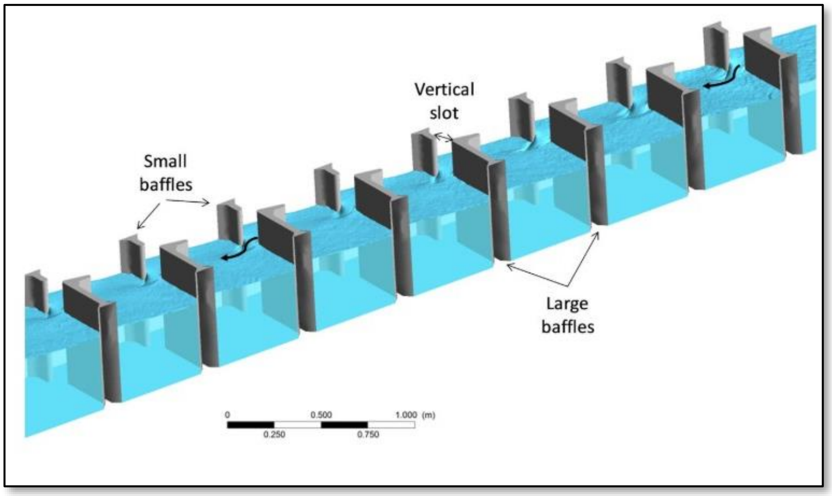

Figure 5-2. A vertical slot fishway schematic (Sanagiotto et al. 2019; left) and the vertical slot fishway on the Link River Dam in the Klamath Basin (right). The Link River Dam fishway has two slots and chevron-shaped baffles to reduce water velocities for Klamath Lake sucker passage.

In addition to facilitating upstream passage of Warner Sucker, the bottom substrate considerably reduces flow velocities near the fishway bottom and through the vertical slots. The roughness created by the grouted bed materials makes it possible for species with low swimming performance to migrate through the fishway. It is important to ensure that the bottom substrate in the fishway is connected to the bottom substrate of the stream at the upstream and downstream extents of the fishway. Adding rock fill to the channel at the inlet and outlet of the fishway may be necessary.

Vertical slot fishways have many advantages including:

- Providing passage opportunities for water column and bottom-oriented fish species,
- Fishways allow for the installation of natural channel materials to emulate streambed hydraulic and habitat conditions,
- Vertical slots are less sensitive to headwater and tailwater levels,
- Vertical slots are less susceptible to sediment or debris build-up compared to pool and weir with orifice fishways.

Vertical slot fishways may require more water to operate compared to pool and weir fishways. Operational flow requirements are affected by the vertical slot opening width which in turn is determined by the target fish species to be passed.

Table 5-2 includes advantages and disadvantages of technical fishways.

Table 5-2. Advantages and disadvantages associated with technical fishways.

Advantage	Disadvantage
• Accepted fish passage technology • Long-term persistence • Design certainty • Maintains existing point of diversion and can be retrofitted to diversion weir • Designed to pass range of fish species with varied swimming abilities • No effect on irrigation water delivery • May be easier to monitor fish passage and hydraulic conditions	• Often the most expensive alternative • Technical construction • Aesthetics • Potentially frequent maintenance following high flows

Nature-like Fishways

Nature-like fishways include roughened channels and bypass channels. These fishways incorporate natural materials and apply geomorphic and hydraulic conditions similar to nearby steeper channel reaches as design analogues. Nature-like fishways are designed to be site-specific as the structures are more sensitive to site conditions than technical fishways. The construction approach and building materials are similar for the three types of nature-like fishways that will be reviewed. For example, roughened channels and bypass channels are constructed using boulder sills or ribs, and single or clusters of boulders to increase channel bed roughness for energy dissipation and habitat complexity.

Roughened Channel

A roughened channel is a mechanism to disperse the hydraulic head (i.e. the vertical difference in water level between the upstream and downstream water surfaces) over a certain distance by keeping the hydraulic gradient of the slope as gradual as possible. Roughened channels provide a range of velocity and water depth conditions as influenced by flow, stage, and channel bed roughness (Figure 5-3). Roughened channel gradients may be between 2% and 10%, with the steeper the channel, the larger the bed material that is needed to resist bed material erosion.

The roughened channel should be constructed as a multi-layered rockfill comprised of a rock matrix and larger boulders. The rock matrix should be comprised of angular and subangular materials that are more resistant to erosion. Larger boulders that are incorporated to increase roughness, should be rounded for aesthetics.

The downstream transition from the roughened channel to the natural channel bed may require additional attention to avoid scour in this transitional area. A transition to a coarse bed or a channel bed that has been armored as a result of pre-project conditions, may require minimal treatment. Conversely, a channel bed characterized by finer materials may necessitate extending a coarse channel bed downstream of the roughened channel slope transition. Transitioning the roughened channel into a pool is another option for dissipating stream energy downstream of the steeper roughened channel. Planting the banks of the roughened channel with appropriate vegetation enhances streambank resistance to erosion and promotes the main flow axis in the center of the roughened channel during floods.

Rock matrix and boulder placement should accommodate fish passage routes at all stages. Openings between surface boulders and placing boulders in clusters, create fish passage routes and variable hydraulic conditions that fish use to pass steeper channel features. Clustered boulders are also more resistant to scour as joined boulders are more resistant to hydraulic forces.

From the ecological point of view, low to moderate slope roughened channels offer the best means for restoring fish passage in streams where diversion weir cannot be removed. Maintenance is relatively low and can be limited to the occasional replacement of scoured rockfill, additional streambank plantings, and removal of debris. Maintenance may follow large floods or ice floes that damage the roughened channel surface. When constructed correctly, the Warner Basin's native fish species will be able to freely pass the roughened channel and irrigation diversion infrastructure.

Figure 5-3. An irrigation diversion weir on Whychus Creek near Sisters, Oregon before (left) and after (right) the construction of a roughened channel.

The most important advantages of roughened channels are as follows:

- Roughened channels provide diverse flow pathways and habitat conditions.
- The diverse flow pathways can be negotiated by bottom-oriented fish species, small fish species, and juvenile fish since they have a nature-like morphology.
- In some systems like the Warner Basin where adjacent stream reaches are backwatered by the diversion weir or are otherwise low gradient, the roughened channel may provide a higher gradient habitat.
- Relative to technical fishways, roughened channels may require less maintenance with maintenance mainly related to replacing scoured bed material and maintaining riparian vegetation.

Potential roughened channel disadvantages include:

- Potential large volume of imported materials for the rock matrix and boulders.
- Attention to construction techniques and ensuring the rock matrix is sufficiently compacted and void spaces are filled to avoid roughened channel dewatering.
- The potential for periodic maintenance to address roughened channel bed scour.
- Poor passage conditions during low flows if flow volumes and roughened channel surface roughness do not maintain minimum water depths for passage.

- Potential excavation requirements to locate the bypass channel in the adjacent land surface.

Bypass Channels

Bypass channels provide passage around a diversion weir and may be used singularly or in combination with other fishways. The bypass channel is typically constructed to resemble a natural channel within the constraints of the project site. Bypass channels are particularly suitable for sites where in-line fishways integrated into the diversion weir is not possible. Additionally, a bypass channel may provide fish passage during the diversion season when an adjustable weir is an impassable structure, but passage over the weir is possible during the non-irrigation season when fish can migrate over the structure.

Bypass channels are designed to pass a portion of the streamflow, and therefore the channel design is tailored to the design flow range. Only a proportion of the discharge is diverted through the bypass channel, and in Oregon, a minimum of 10% of the stream flow is targeted for bypass channel operation. The main disadvantage of a bypass channel is the relatively large surface area required for the construction. Therefore, the application of a bypass channel is in part predicated on available surface area and the landowner's agreement to remove that land area from production.

The slope of the bypass channel should be as gentle as possible, and a channel slope of less than 5% is preferable (Figure 5-4). A steeper slope can be broken up by incorporating steeper riffles and lower gradient pools, or a step pool morphology for the steepest channels. Proposed bypass channel designs should be hydraulically modeled to assess water velocities and depths. The headwater condition at the upstream end of the bypass channel must also be known for appropriate function of the bypass channel. The downstream extent of the bypass channel may be a slightly steeper slope to accentuate attraction flow at the transition from the bypass channel to the stream. Similarly, the downstream end of the bypass channel should enter the stream near the diversion weir so that the bypass channel entrance is easy for upstream-migrating fish to find.

Like the roughened channel, natural substrate should be used to build the channel bed. A range of substrate sizes forms the channel bed matrix, larger boulders are used for energy dissipation and to create a channel framework similarly to the approach described for the roughened channel. Channel bed material should be sized according to the modeled hydraulic conditions. Streambank treatments should likewise be tailored to the hydraulic conditions. Streambank treatments should include roughness elements and live vegetation so that over time, vegetation will colonize the bypass channel banks and provide habitat, shading, and material inputs to the channel.

Figure 5-4. A moderate gradient bypass channel (left) on Sevenmile Creek and a steeper riffle and pool bypass channel (right) on Brownsprings Creek, Upper Klamath Basin.

Large boulders and boulder sills provide stability for the constructed nature-like fishway and create hydraulic shadows used by migrating fish. Placing large boulders in an offset, irregular arrangement increases channel roughness that influences water depth and velocity. During medium and low stream flows, the water flows around or only slightly over such boulders. The boulders also increase the water depth and reduce flow velocity, providing flow shadows fish use during upstream migration. Local alternations in the flow regime may occur in the narrowed cross-section.

Boulders should be embedded into the channel bed matrix by up to one third or one half of the boulder's height. The boulders must be big enough to resist hydraulic and ice floe displacement and should be irregularly spaced and vertically positioned for fish passage and aesthetics (if a concern). Boulder sills can also be used to create habitat features while ensuring grade stability. Boulder sills should include boulders set at variable depths and incorporate notches over the length of the sill to ensure fish passage at low flows.

The most important advantages of bypass channels are as follows:

- Bypass channels can be located to complement the existing landscape.
- They can be negotiated by small fish species and juvenile fish since they have a nature-like morphology and bypass flows can be selected to meet swimming abilities of target species.
- In some systems like the Warner Basin where adjacent stream reaches are backwatered by the diversion weir or are otherwise low gradient, the bypass channel may provide a higher gradient habitat.
- Bypass channels may require less maintenance compared to with maintenance mainly related to replacing scoured bed material and maintaining riparian vegetation.
- Bypass channels may be used singularly or in combination with other fish passage techniques. Inclusion of a bypass channel may also allow fish to avoid passing over the irrigation diversion.

Potential bypass channel disadvantages include:

- Dedication of land surface area for bypass channel placement.
- The potential for periodic maintenance if bypass flows exceed the intended operational flow range.
- Sensitivity of bypass channel operation relative to headwater elevations and diversion operation.
- Potential excavation requirements to locate the bypass channel in the adjacent land surface.

Table 5-3 includes advantages and disadvantages of nature-like fishways.

Table 5-3. Advantages and disadvantages associated with nature-like fishways.

Advantage	Disadvantage
• Creates more natural channel conditions for passage • Potentially lower implementation cost than technical fishway, requires less technical construction • Maintains existing point of diversion and weir	• May require additional land area • Attention to construction detail to avoid channel dewatering • Attention to boulder placement for stability and fish passage pathways

Table 5-3. Advantages and disadvantages associated with nature-like fishways.	
Advantage	Disadvantage
• Designed to pass range of fish species with varied swimming abilities • No effect on irrigation water delivery	• Periodic maintenance to replace channel bed material • Periodic removal of debris • Low flow conditions may not meet fish passage criteria

Fishway Constructability and Costs

Project site location and site conditions influence fishway constructability and implementation costs. In the Warner Basin, project sites may be influenced by topography and geology. Site access and project construction may require unique techniques due to restrictive landforms and bedrock exposures. Additionally, the remote nature of the Warner Basin project locations may elevate project costs relative to projects in other more accessible locations. For example, basalt quarries may be up to 10 miles away and concrete providers may be up to 50 miles away from some project sites. Project construction costs should be developed during the alternatives analysis to provide stakeholders with an understanding of anticipated project costs for each alternative. Costs should be updated as designs are progressively refined through the multi-step design process.

Fishway Operation and Maintenance

Optimal fishways minimize operational and maintenance effort and require minimal change from existing diversion operations. Operation and maintenance needs vary between technical and nature-like fishways. Technical fishways require regular monitoring to ensure passage is maintained through submerged orifices. Sediment and debris may obstruct submerged orifices, leading to poor hydraulic function and physical blockage of fish passage routes. Depending on the blockage source and flows in the ladder, the blockage may be removed by working from above or outside of the ladder, or the manager may need to enter the fishway to remove more persistent blockages. Since blockages are most likely to form during or following high flow events, the manager may not be able to remove the blockage until after flows have receded, potentially impacting the fish passage period. Technical fishway designs should incorporate debris exclusion devices such as trash racks, access structures like ladders, and means for blocking flow from entering the fishway in order to access the fishway interior.

Compared to technical fishways, nature-like fishways are less affected by debris, but may be influenced by flood flows and ice floes that destabilize fishway materials. Appropriate rock sizing and adhering to construction methods during fishway construction is important for nature-like fishway persistence. Sediment supply and transport are typically disrupted by surface water diversions as the diversion weir creates a backwater. Sediment transported in the reach may deposit upstream from the weir, necessitating periodic removal of the deposited material. The roughened channel located downstream from the weir is typically steeper than adjacent channel gradients, increasing the stream's sediment transport efficiency in the project reach. Roughened channel bed erosion may result if the size of placed rock is not sufficient to resist hydraulic forces. As smaller diameter materials are mobilized, large boulders may then move and eventually form boulder clusters. Periodic maintenance of the roughened channel surface may be necessary to ensure fish passage conditions and roughened channel stability persist.

In summary, flood and ice floe events have the potential to impact both technical and nature-like fishways. Technical fishways are likely to require more regular monitoring and low-cost maintenance to remove debris from submerged orifices. Nature-like fishways require less frequent monitoring, but erosion of the roughened channel requires more costly repairs. Incorporating potential operation and maintenance costs during the project alternatives analysis is recommended to ensure stakeholder understanding of future maintenance responsibilities.

Diversion Operation

Fishways should either complement or neutrally affect diversion operations. Fishway locations, hydraulic control elevations, and operation should be planned with an understanding of diversion operations. It is imperative that the fishway design team meets with water users throughout the design development process to ensure the fish passage design accounts for water users' concerns and management. An operational manual should be prepared so that water users and other stakeholders understand the purpose of the fishway, fishway operation and maintenance directions, and contingency plans for correcting fishway deficiencies.

Completed Warner Basin Fishways

Both technical and nature-like fishways have been constructed in the Warner Basin. Technical pool and weir with submerged orifice fish ladders have been constructed on Honey Creek (Rookery diversion) and Twentymile Creek (Dyke diversion). Nature-like fishways have been built on Twentymile Creek (MC diversion bypass channel) and Honey Creek (Middle Taylor diversion roughened channel, Flood diversion roughened channel). Table 5-4 provides a summary of completed Warner Basin fishways. Monitoring information is presented in Section 6 - Effectiveness Monitoring.

Table 5-4. Completed fishways in the Warner Basin.

Location	Fishway Type	Construction Cost	Year Completed	Fish Passage Monitored
Honey Creek – Rookery diversion	Technical – Pool and Weir	$306,000	2013	Yes*
Honey Creek – Lower Taylor diversion	Nature-like – Roughened Channel	$20,000	2008	No
Honey Creek – Middle Taylor diversion	Nature-like – Roughened Channel	$20,000	2010	No
Honey Creek – Flood Ditch diversion	Nature-like – Roughened Channel	$270,000	2018	No
Twentymile Creek – Dyke diversion	Technical – Pool and Weir	$355,000	2015	Yes
Twentymile Creek – MC diversion and two culverts	Nature-like – Bypass Channel	$332,000	2018	Yes

5.2 Irrigation Diversion Screening

Screening Goals

Irrigation diversion screens are intended to exclude fish from entering the diversion canal network as fish entering the diversion network may be lost from the population through predation, canal dewatering, or declining water quality over time. The variable hydrology of Warner Basin streams is noted by periodic extreme high flows and more regular extreme low flows. Additionally, Warner Basin irrigators hold water rights that exceed streamflow during the summer in most years, allowing for the diversion of all streamflow. Diversion headworks and screening systems should be designed to account for the extreme flow variability, and innovative screen designs are encouraged to maximize screen performance and minimize the effort necessary to operate and maintain screens.

The screen design team should coordinate screening projects with project stakeholders and regulatory agencies to ensure fish screens meet design criteria or are screens are given variances to deviate from criteria. Two conditions that may require innovate approaches include first, how to address fish bypass when all streamflow is diverted and the stream channel immediately downstream from the diversion dewaters, and secondly, how to size screens to exclude fish during common irrigation flows rather than extreme flows which may only occur during short periods of the year.

Screen Criteria

Fish screen criteria developed by ODFW (2016) and NOAA-Fisheries (2011) are used to develop and evaluate fish screens. Although there are no anadromous species in the Warner Basin, the U.S. Fish and Wildlife Service defers to NOAA-Fisheries screening criteria for evaluating screen designs. NOAA-Fisheries' screening criteria are also the industry standard for screen design in the Pacific Northwest. A summary of pertinent guidelines fish screen design is included in Table 5-5.

Table 5-5. Fish screen criteria based on ODFW (2016) and NOAA-Fisheries (2011) guidance.

Consideration	Standard / Guidance / Note	Site Specific Criteria (if applicable)
Screen Placement	Canal Installation with bypass system	Placement to accommodate sediment, debris, access, and fish bypass
Design Flow	All installation types to consider 5% to 95% hydraulic conditions	Account for extreme flow range, typical diversion flows, and screen cost
Screen Area	Sized for approach velocity and diversion rate	Account for typical diversion flows
Screen Hydraulics	Approach velocity: 0.4 ft/s for active screen	0.8 ft/s acceptable for fingerling size and larger salmonids
Sweeping Velocity	Greater than approach velocity (Optimally: 0.8-3 ft/s)	-
Submergence	Consideration for roll drum	65% to 85% of roll drum diameter submerged in water
Screen material	3/32" perforations or 1.75 mm slots Minimum 27% open area Corrosion resistant	FCA screen: <3/32" perforations Pitman screen: 3/16" perforations
		50% open area assumed for preliminary design

Table 5-5. Fish screen criteria based on ODFW (2016) and NOAA-Fisheries (2011) guidance.

Consideration	Standard / Guidance / Note	Site Specific Criteria (if applicable)
Bypass Flow	For diverted flows of 0 - 25 cfs, minimum 5% of diverted flow	Estimate 10% - 15% of diverted flow
Bypass Location	For screens > 6 ft, end of screen terminates at bypass entrance	-
Bypass Pipe Diameter / Geometry	The bypass pipe should be designed to maintain velocity of 6 - 12 ft/s with a minimum depth of 40% of the bypass pipe diameter	For diverted flows of 0 - 25 cfs, this equates to a 10 inch diameter with slope of 1.3%. Other designs should meet depth and velocity criteria. Bypass operation should reflect diversion flow vs. instream flows

Fish Screen Alternatives

The following fish screen alternatives discussion provides example active and passive fish screens that maybe used to meet screening needs in the Warner Basin. Active screens rely on mechanical cleaning while passive screens rely on flow seeping along the screen surface to limit debris impingement. Active screen mechanical cleaning systems may be driven by water, solar, or electrical power. While most screens would be placed downstream from the irrigation headworks to protect the screen from debris and sediment, screens may also be placed either in front of headworks or on the channel margin. The following sections contain a general description of each screen type.

Rotary Drum Screen

Rotary drum screens are a common screen design used in the Warner Basin. Diverted flow enters the screening bay and passes through the drum screen (Figure 5-5). The drum screen, which may be water, solar, or electrically powered, rotates and passes debris into the diversion canal on the other side of the screen forebay. Fish, sediment, and debris may also be returned to the stream via the bypass pipe. The screen rotates continuously when operational.

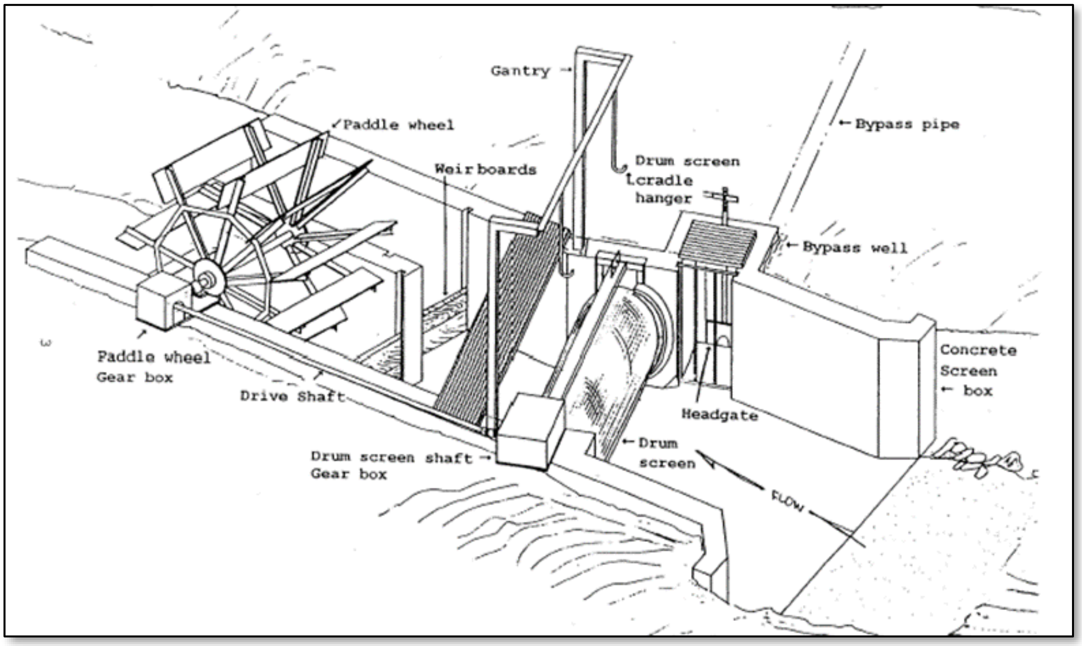

Figure 5-5. Rotary drum screen schematic for a screen typically fabricated by ODFW. Flow enters the screen structure from the right. A portion of flow passes through the rotary drum fish screens and down the irrigation canal, and a portion of flow passes down the fish return bypass pipe and is returned to the stream.

Screens can be designed to pass up to 15 cfs and multiple drum screens may be included to accommodate variable flows similar to those experienced in the Warner Basin (Figure 5-6). Operation and maintenance is comparable to other screen types, although streams with high fine sediment and debris loads may result in more maintenance effort to ensure proper screen function.

Figure 5-6. Example paddle wheel-driven rotary drum screens at the O'Keeffe diversion on Deep Creek (left) and the Taylor diversion on Honey Creek (right).

Vertical Flat Plate Screen

Like the rotary drum screen, vertical flat panel screens are active screens placed in a concrete vault downstream of a headworks. A powered brush arm continuously sweeps across the screen face to dislodge debris. Multiple brush arms may be installed depending on the screen length. Screen orientations include both single and double “vee” style vertical screens (Figure 5-7). Water flows through the screen while fish, return flow, sediment, and debris are returned to the stream via a bypass pipe. Screen maintenance often focuses on replacing the moving parts of the brush trolley including the cable and pullies that run the trolley and the brushes themselves. Deposited sediment may also be periodically removed to ensure proper screen function and water delivery.

Figure 5-7. Example vertical flat plate screens in single (left) and double or “vee” orientation (right). Screens are actively cleaned by powered brush systems.

FCA Horizontal Plate Screen

The FCA horizontal flat plate screen was invented by the Farmers Conservation Alliance (FCA) of Hood River, Oregon. FCA screens have no moving parts and require relatively little maintenance. The FCA screen is installed in the existing ditch and consists of a screen box constructed from plate steel and a fish screen constructed from perforated stainless steel plate (Figure 5-8). Water flows over the screen and most of the water is screened and delivered downstream to the irrigation ditch. A portion of the diverted flow returns fish, sediment, and debris from the screen face, back to the stream via the bypass pipe. The FCA screen is considered a passive screen since there are no moving parts and screen cleaning is accomplished by flow over the screen. A minimum ditch or screen slope is necessary to ensure proper screen function. Minimal screen maintenance may be required to remove sediment and debris from the screen forebay and conveyance flume.

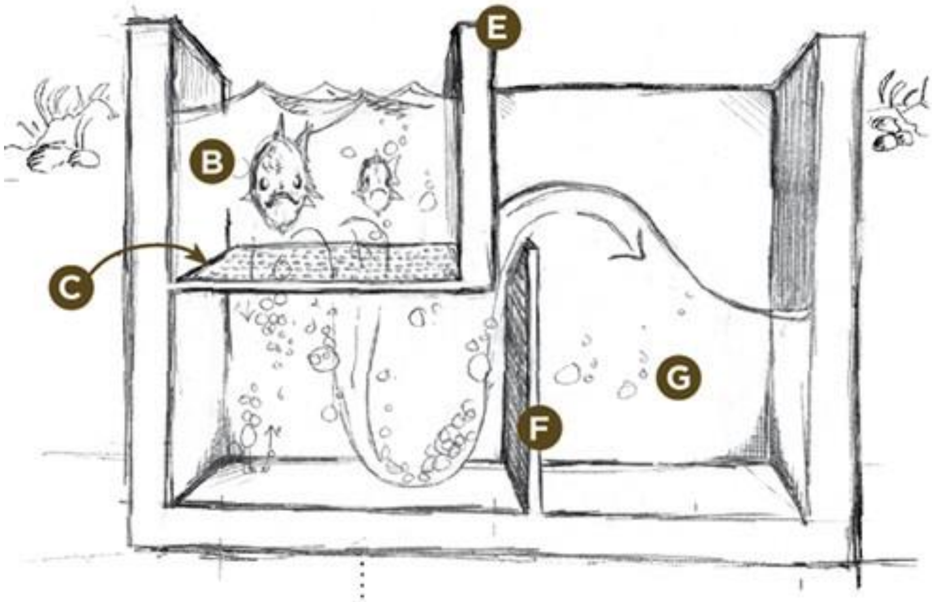

Figure 5-8. Schematic of a Farmers Screen, courtesy of FCA. View of schematic is facing upstream. Water flows over the screen (C) approximately 16 times faster than it flows through the screen, which passes fish and debris downstream. Screened water passes over a weir wall (F) and is conveyed to the irrigation ditch (G). Fish and debris are returned to the channel.

Modular screens may be used for smaller diversions while larger diversions may require site-specific designs (Figure 5-9). Depending on diversion volume, the screen size may require a land surface area larger than the diversion ditch. Larger screens can be adapted with sediment drains to reduce screen maintenance.

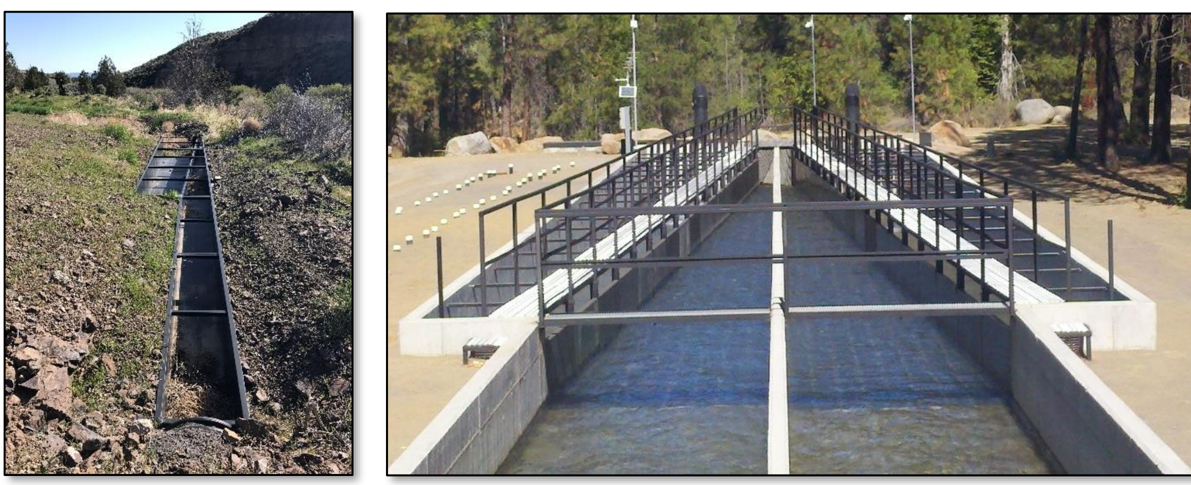

Figure 5-9. The 6.25 cfs modular FCA screen at the Dyke diversion on Twentymile Creek (left) and the 150 cfs custom fabricated FCA screen at the Three Sisters Irrigation District diversion on Whychus Creek near Sisters, Oregon (right).

Fish Screen Concepts Discussion

The fish screen concepts provide a range of screen types that have been successfully applied on other projects in the Warner Basin and in adjacent high desert watersheds. While there are other available screen types that stakeholders may choose to investigate, the three reviewed screens presented in the previous section, have a history of success in meeting irrigator water needs and excluding fish from diversion networks. Table 5-6 includes a relative comparison of the three screen types.

Screens would be designed to meet ODFW and NOAA-Fisheries criteria or a variance on screening criteria would be pursued if necessary. Screen design and construction could be completed by ODFW where appropriate. Other screen fabricators could also be contracted to design and construct screens.

Screen maintenance considerations for all screens involve periodic (daily to weekly) observations of the screen during the irrigation season to adjust flow rates, examine the screen for debris and to remove any accumulated debris. Management of fine sediment will likely be required for all designs. Fine sediments tend to accumulate in the forebay of the rotary drum and vertical plate screens, and on and below the screen surface in the FCA screen. Fines can be removed with a shovel or agitated and washed down the bypass pipe or the diversion canal. Closing the ditch headgate once the irrigation season is over is recommended as it will reduce sediment accumulation for any of the screen alternatives. Rotary drum screens are typically raised above the screen bay to reduce wear when the screen is not in use. The FCA screen has no moving parts and therefore the mechanical maintenance requirement on this screen is lower than on the rotary drum and vertical plate screens that have mechanical parts as part of the cleaning systems.

Diversion structures, headgates and sluice gates also require periodic inspection and maintenance. Fine sediment may accumulate near the entrance to the headworks due to expansion of the channel area and the flatter slope that often leads to the diversion canal. Sediment may also accumulate at the headworks inlet during the non-irrigation season when the headworks are closed. A sluice gate set lower than the headgate invert (i.e., bottom) elevation and connected to a sluice pipe is recommended to provide a means to flush the accumulated fine sediments out of the headworks inlet during high flows. Headgates and sluice gates require annual inspection and maintenance of moving parts.

Table 5-6. Relative comparison of fish screen alternatives for diversions less than 15 cfs.

Metric	Rotary Drum Screen	Vertical Flat Panel Screen	FCA Screen
Fish Screening Performance	Good	Excellent	Excellent
Approach Velocity	< 0.4 ft/s	< 0.4 ft/s	< 0.2 ft/s
Debris Maintenance	Medium (weekly check)	Low (scrub 1-2x per month to remove algae if present)	Medium (weekly check)

Table 5-6. Relative comparison of fish screen alternatives for diversions less than 15 cfs.

Metric	Rotary Drum Screen	Vertical Flat Panel Screen	FCA Screen
Screen Maintenance	Medium (periodically remove drum to flush sediment, annual mechanical, periodically replace bushings)	Medium (periodically flush sediment, annual mechanical, replace brushes every ~6 yrs)	Low (annual sediment flush)
Constructability	Moderate ~2 - 3 weeks	Simple ~2 weeks	Simple ~2 weeks

Fish screen construction costs vary by screen size, type and location. However, construction unit costs typically range from $10,000 to $15,000 per cfs of diverted flow.

Completed Warner Basin Fish Screens

Fish screens have been completed on each of the three focus tributaries in the Warner Basin (Table 5-7). Rotary drum screens have been constructed on Honey Creek (3) and Deep Creek (2), an FCA screen was installed on Twentymile Creek, and a vertical plate screen was built on Honey Creek. These screen types were selected based on site conditions, water user input, and funding support. These screens have generally been sized for less than 20 cfs. Primary maintenance obligations have included sediment and debris removal (e.g., counteract beaver activity) on the rotary screens. The FCA screen has required seasonal maintenance to remove sediment and brush. The vertical plate screen is in its first season of use.

Table 5-7. Completed screens in the Warner Basin.

Location	Screen Type	Construction Cost	Year Completed	Typical Maintenance
Honey Creek – Lower Taylor diversion	Rotary Drum	$70,000	2008	Debris
Honey Creek – Middle Taylor diversion	Rotary Drum (2)	$70,000	2010	Debris
Honey Creek – Flood Ditch diversion	Vertical Plate	$45,000	2018	New
Deep Creek – O’Keeffe Ditch diversion	Rotary Drum	$138,000	2007	Fine Sediment
Twentymile Creek – Dyke diversion	FCA Horizontal Plate	$45,000	2015	Fine Sediment, Debris

Planned Warner Basin Fish Passage and Screening Locations

Figure 5-10 includes the locations of planned fish passage and screening projects in the Warner Basin. Planned projects are located in the Honey Creek and Deep Creek drainages. Once the planned fish passage projects are completed, Warner Basin fish will have restored connectivity and access to over 50 miles in Honey Creek, 3 miles in Deep Creek, and 33 miles in Twentymile Creek (Table 5-8).

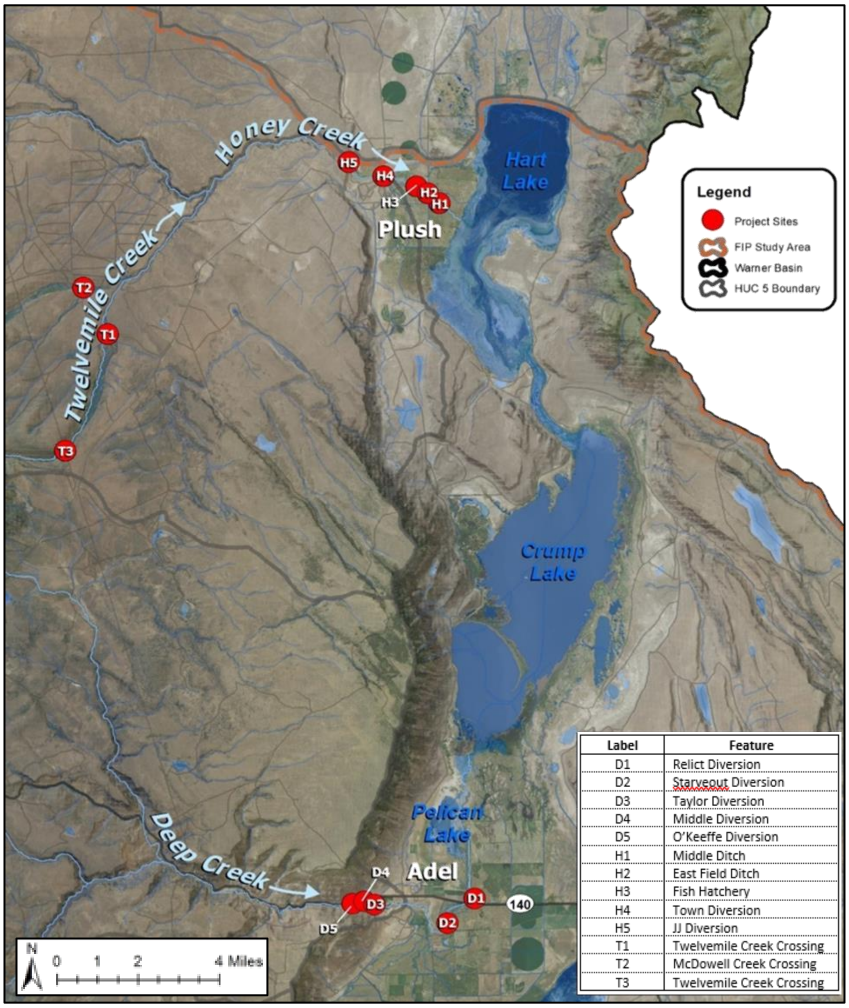

Figure 5-10. Planned fish passage projects in the Deep Creek and Honey Creek drainages.

Table 5-8. Addresing fish passage barriers will restore habitat connectivity in the three tributaries.

Stream	Stream Length from Mouth (mi)	First Diversion	Diversion Location (river mile)	Restored Access (mi)
Honey Creek	53.2	Rookery Diversion	0.25	53.0
Deep Creek (lower)	7.1	Relict Diversion	3.9	3.2
Twentymile Creek	35.1	MC Diversion	1.3	33.8

6 Effectiveness Monitoring

The following section provides an overview of the biological and hydraulic effectiveness monitoring that has been conducted on technical and nature-like fishways completed in the Warner Basin.

6.1 Methods

The criterion to determine the effectiveness of passage structures is the demonstration of successful upstream passage by Warner Suckers. The monitoring approach is based on tagging suckers with Passive Integrated Transponder (PIT) tags, releasing them downstream of the passage structure, and the detection of suckers by antennas mounted at the downstream and upstream ends of the structure. For some evaluations, additional antennas are located farther downstream or upstream of the structure, depending on the design of the structure. Beacons are installed on at least one antenna on the structure to monitor the functional continuity of the antenna system. Passage metrics assessed include the number of successful passage events and travel time through the structure. We also evaluate the effect of fish size on passage metrics.

Water velocity at points within passage structures have been measured with a portable flow meter and compared to predicted design velocities. Velocities through orifices of fish ladders are measured at three heights along the vertical centerline corresponding to 20%, 50%, and 80% of the orifice height from the fishway floor. Water velocities and water depths in nature-like fish passage structures have also been measured and compared to criteria.

A limitation of the biological effectiveness monitoring approach is the assumption that tagged adult suckers will want to migrate upstream when they are released below the fish passage structure. Fish that do not enter the passage structure, or enter but fall back, may not reflect a limitation of the structure's effectiveness, but rather variability in fish behavior. To increase the likelihood that fish will attempt to pass through the structure, the general approach has been to tag adult suckers (>130 mm fork length) in early spring with the assumption that they would be more likely to migrate upstream to spawn (F. Monzyk, ODFW, personal communication). When possible, suckers are sampled from upstream of the fish passage structure and translocated to downstream of the structure. To further increase the likelihood of upstream movement, suckers are released as a subgroup of tagged fish downstream of the fish passage structure (F. Monzyk, ODFW, personal communication).

Passage information is occasionally supplemented with detections of fish residing downstream of the structure that were previously tagged as part of other PIT-tag studies occurring in the basin. These fish can provide an unbiased estimate of travel time through the structure since they do not experience the same tagging and translocation effects that fish released specifically for effectiveness monitoring may exhibit.

To date, three structures have been evaluated for passage including the Dyke and MC diversions on Twentymile Creek, and the Rookery diversion on Honey Creek. Below, is a brief description of the structures and the specific approaches used to monitor passage at each structure, and a summary of the monitoring results.

6.2 Site Descriptions and Results

Dyke Diversion

The Dyke diversion is a concrete diversion weir located near the downstream end of a bedrock canyon on Twentymile Creek. The weir was recast in 1991 and a steel Denil fish ladder was installed on the downstream river-right side of the weir. ODFW monitored the Denil fish ladder for fish passage and determined that Warner Sucker were unlikely to pass the ladder due to the steep gradient and turbulence. The Lake County Umbrella Watershed Council, U.S. Bureau of Land Management, and River Design Group, Inc. coordinated a fish passage and screening alternatives analysis with the landowner. The preferred alternative included a technical fishway and FCA horizontal fish screen.

The technical fishway is a concrete fish ladder consisting of 10 pools created by wooden stoplog cross-walls. Each weir wall has a 12-inch square orifice set at the bottom of the weir wall. Cobble was added to the fish ladder floor to simulate a natural channel bed with the expectation the cobble floor would improve passage conditions for the benthically-oriented Warner Sucker. Cobble was grouted in the vicinity of each orifice, but was loosely placed elsewhere in each pool (Figure 6-1).

Figure 6-1. The existing Dyke diversion weir showing the weir, Denil fish ladder, and headwall with irrigation canal (left). The fish ladder completed in 2015, includes wooden weir walls with a 12-inch square orifice and streambed simulation material (right, photo during construction).

The ladder was designed to meet fish passage criteria (e.g., water velocity and depth) between 35 cfs and 148 cfs which are the 95% and 5% fish passage flows during the April 1 to July 1 Warner Sucker spawning period, respectively. Warner Sucker passage criteria included a maximum water velocity of 4 ft/s, minimum depth of 12 inches, a ladder floor slope of less than 4%, and no jumps.

The following information is largely adapted from Scheerer et al. (2015; 2017). Passage at the Dyke diversion was evaluated in 2015 and 2016. PIT-tag antennas were positioned at the downstream-most and upstream-most orifices of the ladder, and near the OWRD gage approximately 800 ft upstream from the ladder (Figure 6-1). A flat-plate antenna was also positioned along the stream bottom approximately 10 ft downstream from the ladder entrance. Suckers were captured from reaches upstream of the fish ladder, measured, tagged, and either released in a pool approximately 140 ft downstream of the ladder (n=20) or in the downstream-most pool of the ladder (n=8, 2015 only) in April and May.

A total of 19 of the 28 suckers successfully migrated upstream through the ladder, including all 8 released into the ladder (Table 6-1). In addition, 13 previously tagged suckers residing downstream of the Dyke diversion were detected successfully passing upstream through the ladder.

Table 6-1. Summary of PIT-tagged Warner Suckers detected successfully passing upstream through the Dyke diversion fish ladder by release location and year. The extant downstream fish were previously tagged suckers that were residing downstream of the structure and detected passing through the ladder.

Year	Release location	Number Released	Number Passing	% Passed
2015	Pool downstream of ladder	12	6	50
	In ladder	8	8	100
	Extant downstream	n/a	6	--
2016	Pool downstream of ladder	8	5	62.5
	Extant downstream	n/a	7	--

Passage times through the ladder were more variable for smaller suckers than for larger suckers (Figure 6-2), requiring a log transformation of passage time to normalize the residuals before performing regression statistics. A significant negative relationship was found between the passage timing and fish size, but no relationship was found between passage time and stream discharge. The mean passage time for suckers >160 mm fork length (FL) was 6.4 hours (range: 0.62-36.4 hours). Passage time for previously tagged fish were not significantly different from those tagged and released during the study year.

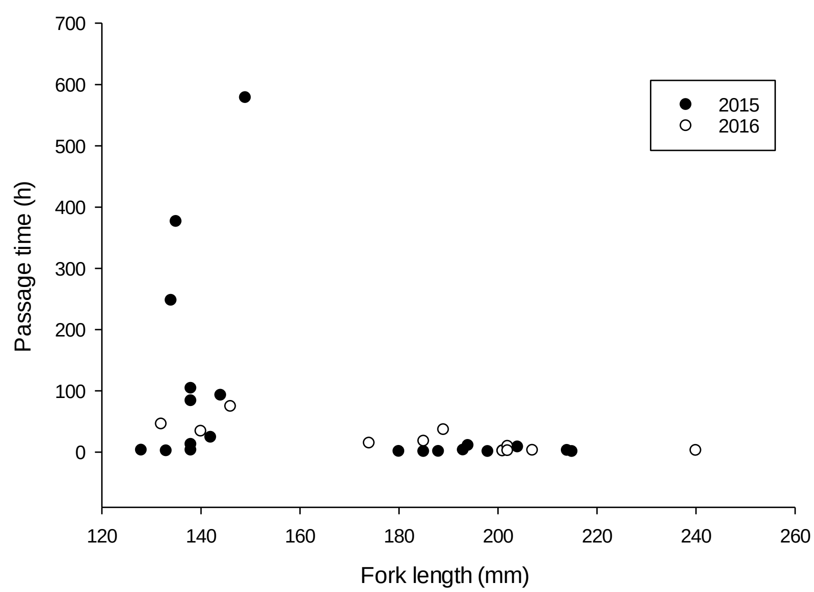

Figure 6-2. Relationship between passage time and size of Warner Suckers ascending the Dyke diversion fish ladder in 2015 and 2016. Passage time was measured as the duration between the first detection at the antenna 10 ft downstream of the ladder to the first detection at the antenna positioned at the upstream-most orifice of the ladder. Data and graphic from Scheerer et al. (2017).

Average stream discharge in Twentymile Creek was lower in 2015 compared to 2016. In 2015, passage events occurred at discharge ranging from 5 cfs to 62 cfs, whereas discharge during passage events in 2016 ranged from 33 cfs to 93 cfs. Water velocities through the ladder orifices were measured on two occasions under different stream discharge conditions: in 2015 with stream discharge approximately 4 cfs and in 2016 with discharge approximately 57 cfs. Measured water velocities through the orifices were generally higher than the designed maximum velocity of 4 ft/s. However, velocities measured near the bottom of the orifice were close to or less than the design criterion (Table 6-2).

Table 6-2. Measured orifice water velocities at the Dyke diversion fishway. Velocity measurements were taken on 16 June 2015 and 04 May 2016 with a Marsh-McBirney meter at the centerline of each orifice.

Water Column Measurement Location Relative to Orifice Bottom	2015 (4 cfs)		2016 (57 cfs)	
	Mean (ft/s)	Range (ft/s)	Mean (ft/s)	Range (ft/s)
20%	2.89	0.89 - 3.71	4.30	1.41 - 5.18
50%	4.79	4.00 - 5.51	6.10	2.10 - 7.90
80%	4.79	4.20 - 5.18	5.67	3.51 - 7.51

Additional information on fish passage effectiveness monitoring for the Dyke diversion is included in Scheerer et al. 2015, Scheerer et al. 2016, and Scheerer et al. 2017.

The former irrigation canal headgate was replaced with a new headgate that sufficiently seals to exclude leakage when the diversion is not in use. The first approximately 95 ft of the irrigation canal was piped and an FCA screen was installed at the end of the piped section of the canal (Figure 6-3). The screen has delivered sufficient flow to the landowner and maintenance has been relatively minimal (e.g., periodic fine sediment and debris removal). Other project elements including the removal and filling of the former Denil fish ladder, and the installation of a headgate in the diversion weir sluiceway, are operating as intended.


Figure 6-3. The FCA fish screen on the Dyke diversion irrigation canal (left) and the open canal downstream of the screen (right).

MC Diversion

The MC diversion is located on Twentymile Creek approximately 1 mile downstream from the Dyke diversion. The existing diversion infrastructure includes a 5 ft high concrete weir that creates sufficient head to divert water through a headworks located in the Twentymile Creek dike. Three 36-inch culverts with headgates located in the headworks allow water users to manage water diverted from Twentymile Creek into the MC canal. The MC canal includes both natural and excavated segments, but only conveys flow bypassed by the headworks. Twentymile Creek flow that exceeds water users' needs, flows over the MC weir and into the Twentymile Flood Ditch. Figure 6-4 includes a panoramic schematic of the MC diversion infrastructure.

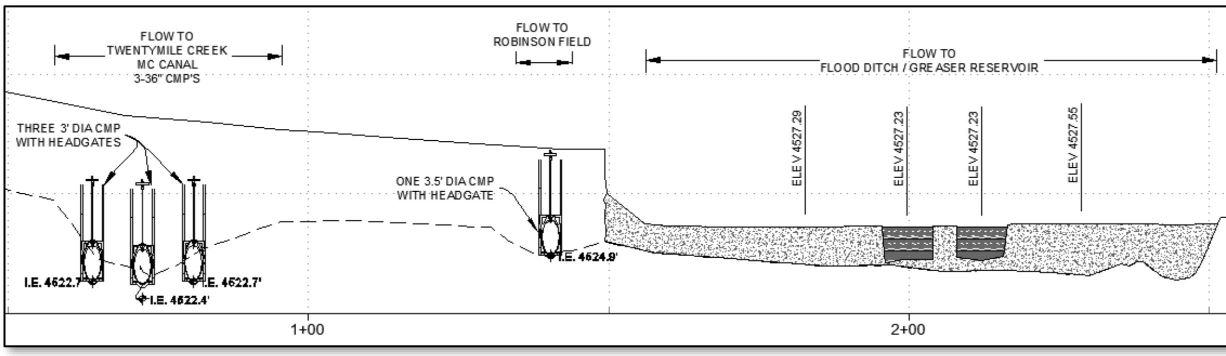

Figure 6-4. A panoramic schematic of the MC diversion weir, three headgates in the MC diversion headworks and a single headgate that delivers water to the Robinson field. Flow exceeding water users' needs flows over the MC weir and into the Twentymile Flood Ditch.

The fish passage project was designed to pass fish between the MC canal and Twentymile Creek upstream of the MC diversion weir. The nature-like fishway included a new headgate and box culvert, and bypass channel (Figure 6-5**)**. Streambed simulation material was placed in the box culvert and a bypass channel was constructed downstream of the box culvert. The bypass channel was connected with a remnant low gradient channel segment with dense willows and woody debris (Figure 6-6). The bypass channel was designed to meet fish passage criteria between 6 cfs and 150 cfs. Water users are able to use the bypass channel to meet most of their water needs although the original headgates can also be managed to supplement water delivered by the bypass channel.

Figure 6-5. Upstream (left) and downstream (right) views of the MC bypass channel in March 2019.

Figure 6-6. Low elevation aerial photo showing the MC diversion area features.

ODFW evaluated fish passage in 2018 and 2019 using methods similar to those described for the Dyke diversion. The bypass channel did not convey sufficient flow in 2018 and fish passage monitoring only document one 1 of 21 tagged Warner Suckers passing through the bypass channel (Monzyk and

Meeuwig 2018). The bypass channel box culvert was modified in early 2019 by removing a weir wall that was originally cast at the downstream end of the box culvert. The weir wall was intended to regulate the amount of flow entering the box culvert and the weir was determined to be overly restrictive. Removal of the weir increased flow conveyance and improved fish passage conditions.

ODFW monitoring in 2019 documented passage of Warner Suckers through the bypass pass channel and box culvert (F. Monzyk, ODFW, personal communication). Half of the Warner Suckers (15 of 30) tagged and released downstream of the bypass channel in 2019, migrated up through the bypass channel and culvert to Twentymile Creek. The remaining 15 suckers appear to have remained downstream of the bypass channel and did not attempt to enter the box culvert. Warner Suckers that migrated upstream through the bypass channel tended to be larger (mean = 170 mm FL, range 95-248 mm) than the fish that had not attempted to pass (mean = 123 mm FL, range 98-162 mm) (Monzyk and Harrison 2019). Passage may have also been influenced by periodic closure of the box culvert that prohibited flows from entering the box culvert and the bypass channel. Future coordination with the water users will focus on maintaining surface flows through the bypass channel during the Warner Sucker spawning migration period.

Rookery Diversion

Sucker passage at the Rookery diversion was evaluated in 2017 (Scheerer and Meeuwig 2017). The Rookery diversion is the farthest downstream diversion of eight diversions on lower Honey Creek, the diversion is located 0.2 mi upstream from Hart Lake. The new fishway is ~130 ft long with 12 pools (cells) that are divided by cross-walls that each have 9 inch square orifices on the fishway floor for Warner Sucker passage, 12 inch weir drops, and a simulated streambed floor (artificial boulders) in the downstream half of the fishway (Figure 6-7). The fishway was designed for a passage period of April to June with fishway discharges ranging from 0.35 - 167 cfs, maximum orifice velocities of 3.81 ft/sec, cross-wall v-slot velocities ranging from 0.95 - 4.43 ft/s, a minimum pool depth of 6 inches, and no vertical jump.

Figure 6-7. The reconstructed Rookery diversion weir on lower Honey Creek (left), includes wooden cross-walls, a 9-inch square orifice in each cross-wall, and artificial boulders on the ladder floor to reduce velocities (right).

Antennas were installed around the upstream-most and downstream-most orifices of the ladder to assess sucker passage. Because of concerns about blocking upstream movement through the multiple diversions on lower Honey Creek, adult suckers from upstream of the diversions were not sampled for the evaluation of the Rookery diversion fishway. Instead, adult suckers from an auxiliary population at the ODFW Summer Lake Wildlife Management Area were tagged and translocated to the Rookery diversion on 30 May (n=12). Additionally, four adult suckers were caught and tagged from Hart Lake from 12-20 June. Six of the suckers from the SLMWA were released in the downstream-most pool of the fish ladder. All other suckers (n=10) were released in a pool immediately downstream of the ladder.

Four of the six SLWMA suckers released in the downstream-most pool of the ladder successfully passed upstream with the remaining two passing downstream. Additionally, a SLWMA sucker released in the pool below the ladder successfully passed upstream through the ladder. Overall, the mean fork length of the five fish that successfully passed upstream was 178 mm (range: 155 - 215 mm), whereas the mean fork length of the 11 fish that did not pass through the structure was 143 mm (range: 110 -160 mm). Passage duration through the fishway varied from 1.1 hours to 46.2 days, with a mean of 21.1 days. None of the Hart Lake suckers released in June passed the ladder. However, the propensity of these fish to move upstream may have been lessened by the fact that they were tagged and released relatively late in the spawning season.

Stream discharge during the passage events ranged from 25 - 93 cfs as measured at the Honey Creek gage near Plush (gage #10378500). Because of the seven diversions upstream of the Rookery diversion, discharge through the fishway was likely less than recorded at the gage. Water velocities measured at the upstream-most orifice on 01 June when the stream discharge at the Plush gage was 102 cfs were close to or below the designed maximum velocity of 3.81 ft/s. Velocities measured at the 20%, 50%, and 80% centerline height were 2.89 ft/s, 3.81 ft/s, and 3.90 ft/s, respectively.

7 Summary

The Warner Basin in southcentral Oregon is a large endorheic basin influenced by the geologic forces that formed the basin. Three tributaries and numerous lakes in the basin provide habitat for the four native fish species that inhabit the watershed. Warner Sucker and Warner Lakes Redband Trout are the two focal fish species that have spurred a program to restore fish passage in the basin. The fish passage program is a collaborative effort among organizations comprising the Warner Basin Aquatic Habitat Partnership, and the three water user associations that oversee water distribution for agricultural production. The WBAHP has completed fish passage and screening projects on each of the three tributaries, and the Partnership will oversee the development and implementation of at least 10 more passage and screening projects as part of an Oregon Watershed Enhancement Board Focused Investment Partnership grant. Proposed projects will include restoring fish passage, screening diversion canals, enhancing habitat, and improving water use efficiency. Biological, hydraulic, and structural performance monitoring data will be collected, analyzed, and used to refine future project designs. Restoring system connectivity is anticipated to improve population dynamics for both Warner Sucker and Warner Lakes Redband Trout, leading to the ultimate goal of Warner Sucker recovery and Warner Lakes Redband Trout population resiliency.

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APPENDIX A

WARNER SUCKER LIFE HISTORY: A REVIEW