HEMPHILL DIVERSION STRUCTURE AND FISH PASSAGE ASSESSMENT

FINAL REPORT

Prepared for:

Nevada Irrigation District
Grass Valley, California

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Sacramento, California

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EXECUTIVE SUMMARY

The Hemphill Diversion structure is located in the Auburn Ravine in Lincoln, CA. The diversion consists of a 64-foot channel-spanning flashboard dam that diverts up to 15 cfs into the diversion canal. The dam does not provide fish passage[1] and the diversion canal is unscreened. Nevada Irrigation District (NID), ECORP, and other key stakeholders have been working on a solution to provide fish passage for aquatic species at the dam. Specific species of interest include adult and juvenile fall-run Chinook salmon, steelhead, and Pacific Lamprey. The goal of this report is to offer solutions for providing fish passage past the existing Hemphill diversion dam. Northwest Hydraulic Consultants (NHC) is providing technical and engineering support to analyze the existing diversion structure and assess fish passage alternatives. This report summarizes NHC's analysis of previous reports and photographs, documents the findings from a site visit, presents fish passage and screening concepts that would be compatible with the existing dam.

Five alternatives for providing fish passage at the existing structure are presented. The existing Hemphill Dam would likely require significant structural improvements to support a structural fish ladder. Two alternatives entail removing the dam, replacing it with a new grade control structure, and installing channel-spanning nature-like fishways; two alternatives leave the existing dam in place without any structural modifications, and include bypass fishways; and the last alternative leaves the dam in place with some structural modifications with a concrete pool and chute fish ladder.

The report also includes a brief discussion on fish screen alternatives at the Hemphill Diversion Canal. Fish screens would reduce entrainment of juvenile fish in the diversion, and could be considered as an alternative to other diversion modifications such as infiltration galleries. Order of magnitude costs and considerations for these alternatives are provided.

[1] It is possible that the dam allows fish passage at higher flows; however, high velocities may be a barrier to migrating fish during high flows.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Purpose

Northwest Hydraulic Consultants (NHC) is assisting ECORP and Nevada Irrigation District (NID) with the development of fish passage alternatives at Hemphill Diversion Structure. According to NID, the Hemphill Diversion Structure is identified as a fish barrier to anadromous fish on the Auburn Ravine, east of the City of Lincoln in Placer County, California. The primary anadromous species of concern are fall-run Chinook salmon and Steelhead. Pacific Lamprey are present in Auburn Ravine and may also be a species of concern; however, that determination has to yet to be made. The purpose of this project is to improve fish passage in Auburn Ravine near the Hemphill Diversion Structure, minimize the potential environmental impacts of operating and maintaining the future project, and continuing to provide raw water service.

NHC originally assessed fish passage options that would not require removing the dam. However, after review of the existing dam structural design, history of maintenance, and downstream channel conditions, NHC noted the long-term viability of the existing structure may be limited and NID directed NHC to also evaluate passage alternatives which would replace the structure. NHC reviewed existing documents and as-built plans in addition to conducting a site visit. This report summarizes the finding of the analysis and provides an opinion on whether the Hemphill diversion dam structure will require replacement to implement the proposed fish passage structures, in addition to the benefits and costs of identified alternatives. Should NID select one of the alternatives presented below, this report serves as a precursor to an Environmental Impact Report of the eventual preferred fish passage alternative.

1.2 Background

1.2.1 Hemphill Diversion

The Hemphill diversion dam, constructed in 1981, is a 64-foot-wide channel-spanning concrete structure in Auburn Ravine. The dam's concrete crest has an elevation of 197.4 ft (NAVD88). Seasonal wooden flashboards raise the dam's crest three feet up to an elevation of 200.4 ft during the summer diversion season from about April 15th through October 15th. Given the depth of the original dam foundation (Figure 1-1), we presume the dam crest was constructed at the original channel bed elevation, prior to significant downstream incision. According to the 1981 as-built drawings, the dam was constructed with 6-foot-tall wing walls on both banks, and did not include any bank fortification upstream or downstream of the dam. Bank fortification was added later after three large flood events in 1997, 2006, and 2017 (see section 1.2.2) severely eroded the banks and dam foundation. Due to ongoing channel incision downstream, the concrete crest of the existing dam is approximately ten feet above the scoured channel bed immediately downstream of the dam, according to a topographic and bathymetric survey completed by NID in March 2020. In general, the wooden flashboards are in place from April 15th through October 15th during diversion season.

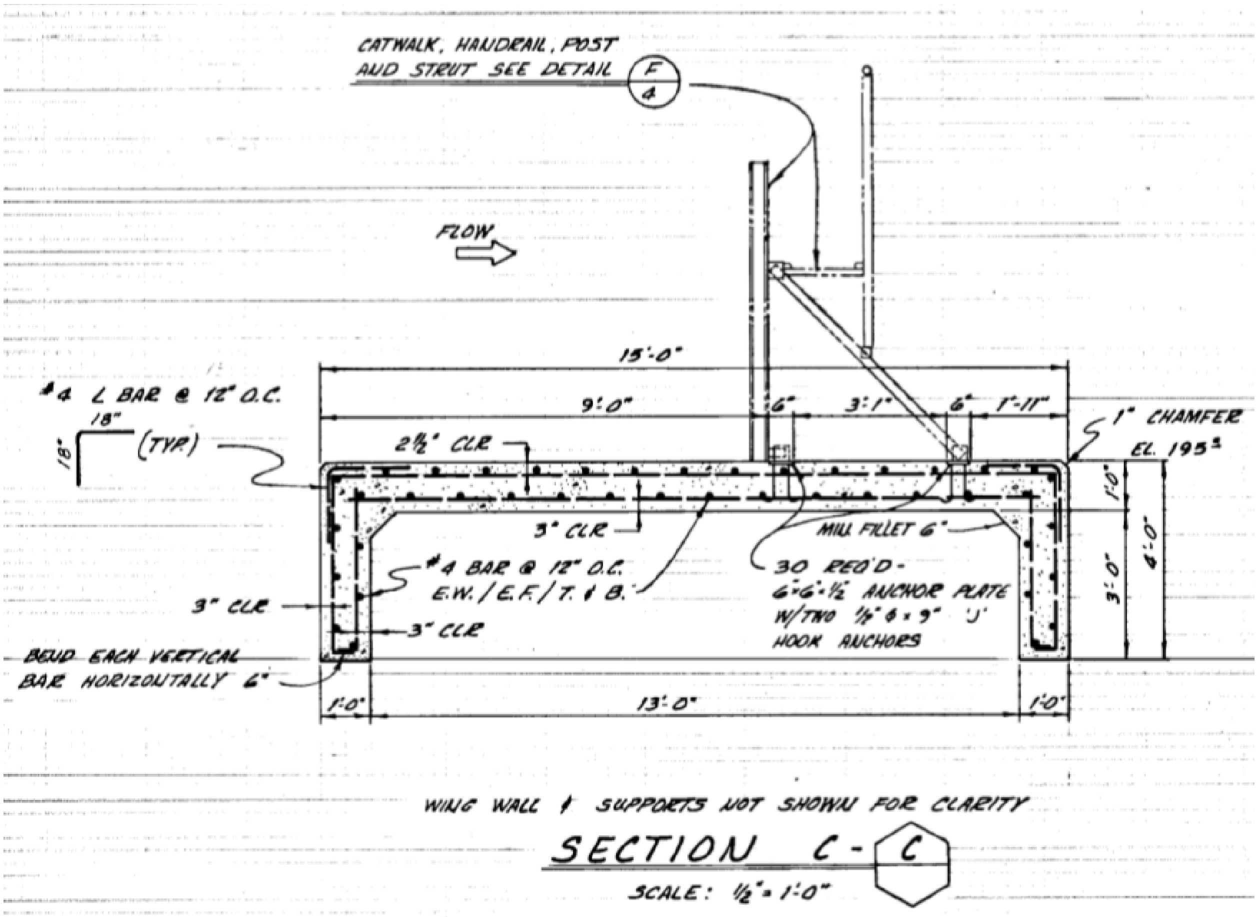

Figure 1-1. 1981 as-built cross section of existing dam. Figure source: NID's 1981 as-builts.

1.2.2 Hemphill Dam Repairs

Large floods in 1997, 2006, and 2017 caused significant erosion and scouring around and under the dam. In 1997, the flow flanked the dam and eroded the north and south banks. As such, both banks and the dam's apron are heavily armored with grouted riprap. Photos of the damage, provided by NID, confirmed that the erosion was extensive (Figure 1-2). NID rectified the issue by fortifying the northern bank and dam apron with grouted riprap (Figure 1-3). An aerial view of the Hemphill Dam shows that the dam is located on a mild meander bend in the Auburn Ravine, with the northern side of the dam on the outside of the bend. Because of this, NHC recognizes that the north side of the dam remains more susceptible to flanking and erosion than the south bank of the dam.

Another large flood in 2006 caused significant scouring underneath the dam. According to discussions with NID, the 2006 flood also flanked the dam on both sides, but not nearly as extensively as the 1997 flood; instead, the erosive force was directed downward under the dam. After the 2006 flood, NID placed a concrete slurry under the dam to fill the scour hole. During our field visit on September 22, 2020, Doug Andrews, with NID maintenance, mentioned that working conditions were less than ideal when placing the concrete slurry under the dam. Doug recalled that there was a gap between the top of the concrete plug and the bottom of the original dam foundation, indicating that the dam's foundation is compromised. Finally, NID had to complete an emergency repair due to water going around and under the dam near the right bank, likely following high winter flows. The 2017 repair consisted of placing erosion resistant fabric and rip rap upstream of the dam (Figure 1-4).

Figure 1-2. Extensive erosion on the north bank caused by high flows in 1997. Photo provided by NID.

Figure 1-3. Fortifying the banks and dam apron with grouted riprap following the 1997 flood. Photo provided by NID.

Figure 1-4. Placing riprap in scour hole upstream of dam following winter 2017 floods. Photo provided by NID

1.2.3 Previous Alternative Analyses

NID and ECORP are considering the following options to improve fish passage at Hemphill Dam. Several alternatives have been previously proposed to aid fish passage while leaving the existing dam in place. In 2009, Michael Love & Associates, in partnership with and Winzler & Kelly, proposed four fish passage alternatives for the Hemphill Diversion Structure, each of which would keep the existing dam in place. Two of their alternatives included a bypass fishway around the dam, and the other two entailed notching into the existing dam and installing a pool and chute fish ladder past the dam. Of the four alternatives proposed, NID identified a two stage fish ladder, installed in the main stem of the river, as the most desirable alternative. However, based on internal conversations, NID expressed concern that the structural integrity of the existing diversion would become compromised and would not support the pool-and-chute ladder, eventually requiring the entire dam to be replaced. We expand upon the feasible fish passage alternatives, including new alternatives that leave the existing dam in place, as well as new alternatives that replace the existing dam with a new grade control structure in section 3.

2 FIELD INVESTIGATION

On September 22, 2020 Amiana McEwen (Project Engineer with NHC) and Mitch Swanson (Senior Geomorphologist with NHC) met with Tonia Tabucchi Herrera (Senior Engineer with NID) and Doug Andrews (NID maintenance manager) at the Hemphill Dam Diversion. They reviewed the existing dam, banks, first few hundred feet of the irrigation canal, and geomorphic conditions upstream and downstream of the diversion structure.

2.1 Existing conditions

Existing Dam

During the September 22, 2020 site visit, we observed that the downstream edge of the dam's concrete apron constructed as part of the 1997 repair (Figure 1-3) was perched approximately 1.5 feet above the downstream channel, and the scour hole extended approximately 11 feet under the concrete apron(Figure 2-1 and Figure 2-2). Some of the wire mesh had become exposed within the shotcrete on top of the apron. It was also evident that there was seepage flow under the dam. Based on field observations, and Doug's recounting of the attempts to plug the dam with concrete, it is likely that another large flood event may further compromise the dam or cause it to fail entirely, given that its foundation is already compromised. Large woody debris had also accumulated on the dam's apron (Figure 2-3). NID noted that woody debris was common at this site, which may limit the feasibility of some in-channel fish passage designs.[2]

[2] For example, a traditional fish ladder (e.g. pool and chute or vertical slot) installed within the main stem of the river may become clogged and impassible with wood jams. On the other hand, a series of channel-spanning concrete weirs within the main stem of the river may be better suited for passing woody debris. Similarly, a bypass fishway, inset within the bank and around the existing dam, would be less susceptible to woody debris entrainment.

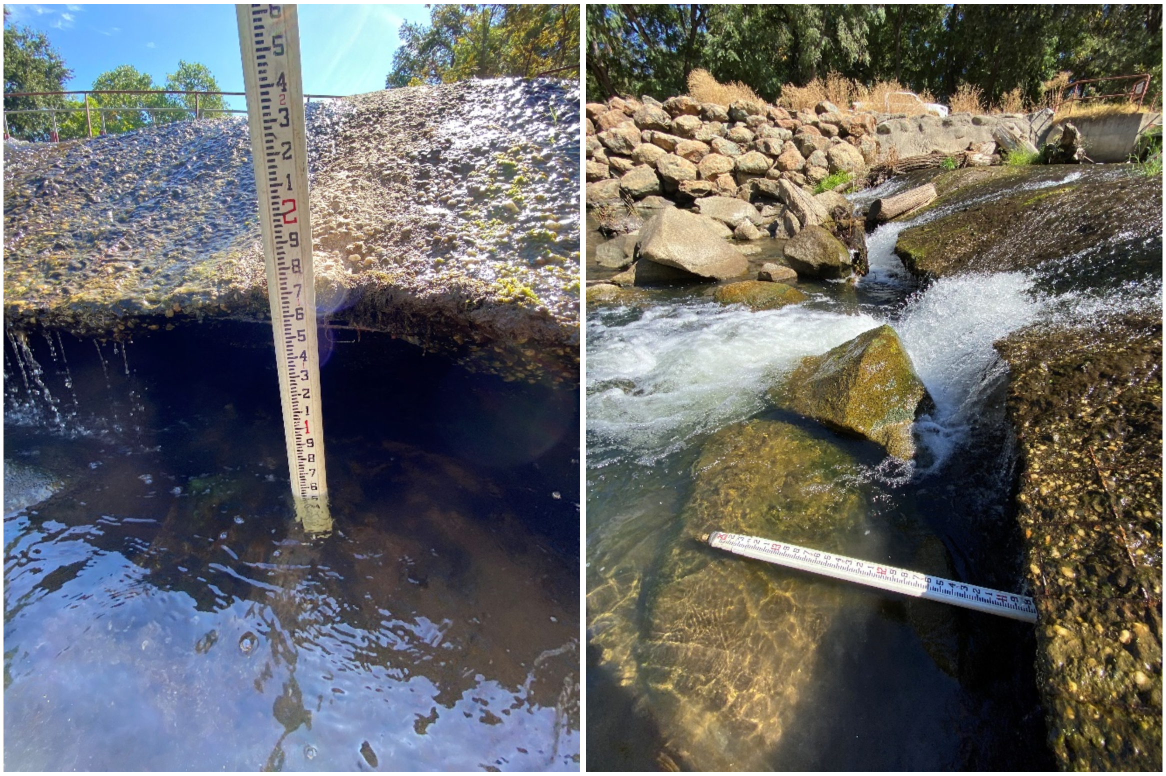

Figure 2-1. Erosion under the dam apron as of September 22, 2020. The apron was constructed after the 1997 flood, as shown in Figure 1-3. The photo on the left shows the apron perched approximately 1.5 feet above the downstream channel bed. The photo on the right shows that the scour hole extends approximately 11 feet under the dam; the wire mesh, that was originally encased in the shotcrete is becoming exposed on the apron's surface.

Figure 2-2. Looking under the dam apron – the foundation has eroded under the concrete encased boulders.

Figure 2-3. Large woody debris accumulated on the banks and the dam's apron

Existing Diversion

The existing Hemphill diversion canal is an open-channel, earthen-lined canal located on the south (left) bank approximately 40 feet upstream of the existing dam. The maximum diversion rate is 15 cfs; however, typical diversions are 8 cfs or less (NID, 2020). The canal's existing intake elevation is at 197.0', nearly a half foot below the existing dam's crest. According to NID, the canal is approximately 3,600 ft long before reaching the first point of use (i.e. service box) at an elevation of 189.0 ft. Over this 3,600 feet, the canal drops eight feet and has an average slope of 0.22%. Flow in the canal is provided during irrigation season when NID installs wooden flashboards along the crest of the dam, providing three feet of head to drive the diversion flow. Flow within the canal is then regulated with a slide gate at its intake; however, the canal is unscreened and does not exclude fish from entering the canal. There are several structures within the canal such as a culvert at the canal's entrance, a gaging station (Figure 2-4), several culverts that flow underneath the Turkey Creek Golf Club, and at least one check station before the first point of use. During a brief field visit in September 2020, we noticed that there was a significant hydraulic drop downstream of the Parshall flume gaging station, which can be seen in Figure 2-4, indicating that there is room to improve the canal's hydraulic efficiency, such as regrading a portion of the canal, lining the canal with smooth concrete, or piping a portion of the canal (discussed in Alternative 2).

Figure 2-4. Gaging station and Parshall flume within the Hemphill Diversion. Photo source: NHC

2.2 Geomorphic Conditions

NHC conducted a reconnaissance level analysis of geomorphic conditions at Hemphill Diversion Dam site and the immediate areas upstream and downstream. NHC reviewed current and historical information and reports directly related to Hemphill Diversion Dam and Auburn Ravine Creek. Current and historical aerials and maps were also examined. A field inspection was conducted with NID personnel knowledgeable in the history of the Hemphill Diversion Dam and watershed area. The following key findings were made to assist and support this fish passage engineering study.

1) The Hemphill Diversion Dam is acting as a channel bed grade control structure holding the channel bed artificially high for perhaps hundreds of feet of channel upstream. Completely removing the dam without countermeasures would likely cause head cutting erosion up to several feet deep at Hemphill Diversion Dam then dissipating upstream until channel longitudinal profile is smoothed. This incision would propagate upstream and lower the channel bed at least several feet over hundreds of feet upstream, unless there are shallow bedrock exposures or other grade controls; however these too could be undermined and have dramatic erosional effects. Downcutting the channel bed would increase already unstable bank heights and accelerate ongoing lateral bank erosion and channel expansion. It is also possible that lowered bed could cause undercutting of root zones in stable vegetated banks and cause new instabilities and erosion. Bank erosion is already very active in upstream areas. Up to 100 feet of lateral erosion has occurred between 2011 and 2019 on the north (right bank) upstream of Hemphill Diversion Dam. Similar and independent conclusions were reported by Balance Hydrologic's 2020 sediment transport report (discussed further in section 3.1).
2) Completely removing the Hemphill Diversion Dam and lowering of the channel bed upstream would also lower the water surface in the channel during the irrigation season, possibly affecting pumps and shallow groundwater wells. Lowering the channel bed and shallow groundwater table could also negatively affect natural bank vegetation by abruptly lowering groundwater levels below established root zones and reducing soil moisture during hot summer seasons.
3) The bed and bank materials at Hemphill Diversion Dam and upstream and downstream consist of highly erodible materials, mostly silty sand mining spoils from historic placer gold dredger mining from the mid 1800s to early 1900s. Mining was reportedly carried out by dredger from upstream to downstream. This dredger could reach through the depths of gold placer deposits and as a result the original natural valley fill sediments, which were likely a wide variety of sediments and sizes from boulders and cobbles to gravels, sand silt and clay were completely replaced with fine grained spoils left over from sluicing out gold. These spoils are highly erodible, fine grained materials with little to no clay content to bind soil particles. These spoils erode rapidly as evidenced by the eroding banks in the Hemphill Diversion Dam impoundment area and other areas upstream and downstream. The erosion around and under the Hemphill Diversion Dam in 1997, 2006, and 2017, as well as the extensive and repeated repair and installation of rip rap and cement armoring is further evidence of the high erodibility of materials and the low level of resistance to hydraulic forces in floods that can occur once every ten years (or less) on average.
4) The channel at and upstream of Hemphill Diversion Dam is unstable as a result of an ongoing, decadal response of the stream channel to historical modifications near the Hemphill Diversion Dam site and in the Auburn Ravine watershed. These cumulative direct and indirect changes are associated with mining, land reclamation / agricultural practices and urbanization. Auburn Ravine was likely placed in a straight ditch after placer mining in order to accommodate property lines, irrigation, and drainage works for agricultural uses. The straight channel became somewhat naturalized with dense bank vegetation and fairly abundant water during the growing season. Auburn Ravine just upstream of Hemphill Diversion Dam was reportedly a narrow, straight, well vegetated and stable channel until upset by the record 1997 flood and its

overwhelming hydraulic force and sediment load. Now the channel is still seeking a stable morphology along many reaches as evidenced by actively growing bars, bank erosion and the beginning of channel meandering at many locations upstream and downstream of Hemphill Diversion Dam.

5) The hydraulic and sediment transport discontinuity caused by the hard Hemphill Diversion Dam structure adds additional factors of systemwide instability. Of local importance to and the result of the Hemphill Diversion Dam, a large bar of flood deposited sediments formed in the January 1997 flood in the backwater /impoundment area just upstream of Hemphill Diversion Dam. The bar consists of sediments that could not be transported downstream likely due to reduced sediment transport capacity in the backwater and impoundment of Hemphill Diversion Dam. The bar has continued to grow laterally and vertically and is a significant obstruction to flood flows. With the middle of the channel blocked by the bar, the channel boundaries must be expanded to accommodate flood flows. The paths of least resistance are the eroding channel banks on north and south sides. As the bar is stabilized by vegetation, it continues to attract more sediment deposition and stability. The process of bar growth and channel widening through bank erosion continues as a self reinforcing process. As discussed above, completely removing Hemphill Diversion Dam would involve additional risks without countermeasures; however, partially lowering the dam (i.e. a new grade control structure) could improve sediment continuity and reduce the lateral forces on the banks upstream (see Alternative 2 in section 3.4.2).
6) In any scenario of removal, modification or replacement of Hemphill Diversion Dam, consideration of geomorphic and channel stability factors is essential to address the imbalances of bank resistance and the force of flood flows and sediment transport. Any protective measures must work with natural forces imposed on Hemphill Diversion Dam and the local channel reaches upstream and downstream.

3 NHC ANALYSIS AND RECOMMENDATIONS

3.1 Dam and Geomorphic Stability

Based on our review of existing documents, photographs, bathymetric survey data, and from the site visit on September 22, 2020, it is evident that the existing dam's foundation has become significantly compromised due to three major flood events, and through ongoing erosion processes. Only the concrete sill (Figure 1-1) is composed of structural concrete, and this structural concrete is relatively thin and sitting on a foundation of unreinforced concrete grout with likely voids (Section 2.1). Much of the downstream apron is composed of grouted riprap which has been undercut by downstream erosion and the 2006 and 2017 damage. Due to the previous performance, lack of structural concrete, and changes in site conditions since implementation of the original design, it is assumed cutting into any of the dam structure may have adverse impacts to its overall structural stability.

Downstream channel incision has gradually increased the height of the Hemphill Dam as the downstream channel deepened. As the height of the dam increases, the depth of local scour downstream caused by flow plunging over the dam also increases. Under existing conditions, the dam crest is 10.1 feet above the channel invert immediately downstream of the dam. The channel invert rises about 4.2 feet from the low point of the scour hole to the downstream channel (Figure 3-1). They hydraulic drop over the dam appears to be about 6 feet. Incorporating the hydraulic control point into a nature-like fishway (discussed in Alternatives 1 and 2) can significantly decrease the amount of elevation fish will have to overcome to navigate past Hemphill diversion.

As noted in Section 2.2, the dam also acts as a grade control structure, preventing incision upstream of the dam. A sediment transport report prepared by Balance Hydrologics in 2020 (Balance Hydrologics, 2020) evaluated several dam removal scenarios including partial removal and full removal at 2-year, 10-year, and 25-year flow events. Their findings indicate that completely removing the dam may induce one to seven feet of erosion up to about 1,300 feet upstream.

Balance Hydrologics (2020) showed lowering the dam crest by only two feet will promote sediment continuity over the dam limiting upstream deposition. The model results suggested about 1 foot of incision could occur along the left bank up to 500 feet upstream in select locations, while sediment deposition may occur up to approximately 1,000 feet downstream of the existing Hemphill dam. Improving sediment continuity over the dam would limit ongoing bar deposition and the resultant bank erosion upstream of the dam. The potential for limited incision upstream is unlikely to inhibit bank stability, while the deposition downstream may offset recent channel incision effects and possibly provide additional spawning habitat. As such, we recognize that lowering the dam crest by two feet may be an ideal solution for upstream channel stability if retrofitting the Hemphill diversion site.

3.2 Hydrology and Hydraulics

For the purpose of this report, NHC has not conducted an independent hydrologic or hydraulic analysis of the Auburn Ravine Watershed or the Hemphill site. An alternatives analysis by Michael Love and Associates & Winzler and Kelly completed in 2009 (MLA, 2009) included a preliminary hydrologic assessment of Auburn Ravine. The MLA (2009) study primarily relied on three reference reaches to build a flow duration curve of the Hemphill site since there was limited flow data on Auburn Ravine during non-diversion seasons. A high level review of the methods suggest the hydrologic flows are reasonable, although an additional 12 years of data is now available to improve estimates. For the purpose of this report, we have used the MLA (2009) data and have assumed that their hydrologic analysis is still reasonably accurate; however, it would be important to revisit and update the hydrologic analysis with more recent data before moving forward with more nuanced design calcuations. Updated flow data will be important for developing hydraulic models of the selected alternative; it will better inform the range of low and high fish passage flow rates; and it will ensure that the selected alternative is designed to withstand large flood events.

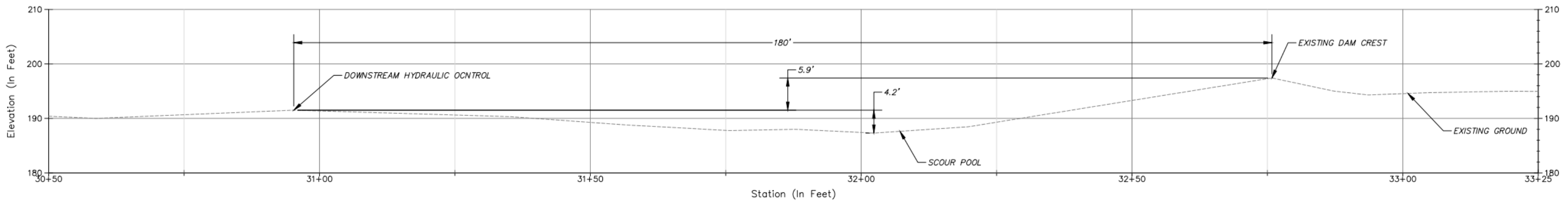

Figure 3-1. Channel profile downstream of the Hemphill Dam showing a scour pool and a hydraulic control point. There is a 5.9 ft elevation difference between the existing dam crest and the hydraulic control 180 ft downstream. There is a 10.1 ft elevation difference between the dam crest and the scour pool immediately downstream of the dam.

3.3 Design Species

In order to design an appropriate fish passage structure, it is imperative to identify the species and life stages for which the structure will be designed. Previous reports have identified adult and juvenile fall-run Chinook salmon and steelhead as the two primary species migrating at the Hemphill site. However, other species may also rely on passage past the dam, that should be considered in the design process. The dam has been identified as a total upstream passage barrier for adult resident trout, and a downstream passage barrier for kelts (adult steelhead that have spawned in the river and are returning to the ocean). NID mentioned that at a public meeting on September 21, 2020, members of the public raised concern about Pacific Lamprey passage at the dam. Friends of Auburn Ravine have confirmed that Pacific Lamprey are present in Auburn Ravine based on their monitoring camera at the Lincoln gaging station. Pacific Lamprey are migratory fish, and while they have similar habitat preferences to salmon, they are much weaker swimmers and have a difficult time navigating traditional fish ladders that are designed for salmon and steelhead (Foulds & Lucas, 2013). Lamprey are generally unable to overcome swift velocities (greater than 1-3 ft/sec), and cannot navigate the sharp angles and corners found in traditional fish ladders (Pacific Lamprey Technical Workgroup, 2017). Since lamprey are channel-bottom-oriented and attach to channel bed substrate using their oral discs, they need continuous, smooth, and rounded surfaces when navigating through a fishway. If Pacific Lamprey are identified as one of the design species, the fishway design will need to account for their weaker swimming abilities and preference for rounded surfaces (e.g. any concrete corners within the fishway must be rounded with a radius greater than or equal to 3-4 inches). In general, nature-like fishways such as chutes and pools (Alternative 1) and roughened rock ramps (Alternative 2) are better suited for a wider range of fish species and life stages.

3.4 Fish Passage Recommendations

In the following section, we present five fish passage alternatives. The fish passage options in alternatives 1 and 2 assume the existing dam is replaced with a new grade control structure. NID has indicated that replacing the dam with a new grade control structure may be prudent given the dam's continued issues with erosion, scour, and costly repair. Alternatives 3 through 5 assume the existing dam is left in place, thus the fish passage options in these alternatives are compatible with the existing dam. We do not recommend fully removing the dam unless NID is prepared to address significant upstream erosion and bank instability. As such, all of our fish passage alternatives assume some level of grade control structure is present at Hemphill site. Additionally, all of the following fish passage recommendations are working under the assumption that the fishway will be operational year-round.

3.4.1 Alternative 1: Nature-like Chutes and Pools

Alternative 1 consists of a nature-like roughened channel with chutes and pools, similar to the passage structure at the Lincoln Gaging Station farther downstream. This alternative entails removing the existing Hemphill Dam and replacing it with the nature-like chute and pool structure. The chute and pool structure would provide adequate fish passage while also maintaining the existing grade of Auburn

Ravine upstream of the dam. The crest of the chute and pool structure would be at the same elevation as the existing dam crest (without flashboards). This alternative is designed primarily to maintain the grade upstream of the dam, which is showing evidence of bank instability. However, it is important to note that a 2020 sediment transport report by Balance Hydrologics indicates that lowering the dam crest by two feet likely will not adversely affect the bank stability upstream (lowering the grade control structure crest will be presented in Alternative 2).

During our September 22, 2020 field visit with NID, Tonia Tabucchi Herrera mentioned that members of the public were interested in pursuing a fish passage structure similar to the Lincoln gaging station, located downstream from the Hemphill Diversion. The fish passage structure at the Lincoln gaging station is a nature-like fishway where fish passage provided by a series of channel-spanning concrete weirs and rock chutes constructed at a 4% slope.

Figure 3-2 shows a similar chute and pool structure as the Lincoln gaging station laid out at the Hemphill site. The widths and extents shown in the concept will require refinement at further levels of design. The chute and pool structure for the Hemphill diversion would have an overall slope of 4% over approximately 180 feet, providing 5.9 feet of elevation gain past the structure. The downstream end of the chute and pool structure would tie into a naturally-occurring hydraulic control approximately 180 feet downstream of the existing dam[3]. The chutes would have a slope of 8%, with drops ranging from 1 to 2 feet, while the drops across the pools will be 0 feet. Chute and pool structures are recommended when the passage structure needs to overcome elevation differences greater than five feet. Each pool dissipates energy and slows the velocity from the chute immediately upstream of it, while also providing resting zones for migrating fish. The bed of the chutes and pools will be comprised of engineered streambed material with a similar composition as the native streambed material. Due to its nature-like design, the chute and pool would meet the longitudinal connectivity needs of the target species and likely the seasonal distribution needs of other endemic fishes.

To maintain a stable grade throughout the structure, several channel-spanning sheetpile or concrete weirs, fortified with large boulders, are recommended. The weirs will keep the structure stable during high flow events to minimize detrimental erosion and scour within the structure. In order to determine the depth of weir embeddedness, we recommend conducting a geotechnical investigation beneath the surface of the proposed structure to determine the depth to bedrock and/or sediment composition of subsurface layers. The structure will be sized to remain stable up to the 100-year flood event.

To provide year-round fish passage, the crest of chute and pool structure will not require flashboards during irrigation season. Because of this, the entrance of the Hemphill diversion canal will need to be lowered by up to three feet. As such, a portion of the diversion canal will need to be regraded, starting at the entrance, which may affect certain structures within the canal (i.e. gaging station and culverts). Lowering the canal intake by three feet will still allow for an average diversion canal slope of 0.14%

[3] The elevation difference between the downstream hydraulic control and the crest of the existing dam is approximately 6.5 feet.

between the entrance and point of first use, which is reasonable and typical for an irrigation canal of this size. As shown in Figure 2-4, taking advantage of hydraulic inefficiencies, such as the drop downstream of the Parshall Flume, can partially make up for the effects of reprofiling a portion of the canal. Additionally, a portion of the canal can be piped with smooth-walled HDPE pipe or lined with smooth concrete to further improve hydraulic efficiency. We recommend completing a detailed topographic survey of the canal and performing a subsequent hydraulic analysis of its flow characteristics in order to determine the extents and parameters for regrading the canal.

To be compliant with CDFW fish passage and screening guidelines, we also recommend installing a fish screening structure at or near the entrance of the irrigation canal. Fish screening options are discussed in more detail in section 3.5.

There are a few shortfalls of this alternative that are worth considering. First, it is important to recognize that a meander has been steadily forming immediately upstream of the dam for the past several years (discussed in section 2.2, and independently verified by Balance Hydrologics' 2020 sediment transport report). Should the meander continue its current course, it is likely that the Hemphill Diversion may eventually be flanked if the meander is left untreated[4]. Matching the new grade control structure's elevation to the existing dam crest will likely cause this meander to continue forming due to sediment discontinuity. Lowering the structure's crest (as will be presented in Alternative 2), may promote better sediment continuity and relieve some of the upstream forces that are promoting the upstream meander, and dam erosion. A second shortfall is that lowering the elevation of the irrigation canal may cause additional sediment accumulation in the canal entrance. This could increase the operation and maintenance activity for the canal.

3.4.2 Alternative 2: Lower Grade Control Structure with Roughened Rock Ramp

Alternative 2 entails removing the existing Hemphill Dam and replacing it with a nature-like roughened rock ramp with the upstream crest elevation two feet lower than the existing dam crest. Figure 3-3 provides a conceptual planview and profile of this alternative. The extents of the concept are approximate, and will require refinement in further levels of design. The rock ramp structure would provide fish passage while also improving sediment continuity over the dam and likely improving bank stability upstream of the dam. Due to its nature-like characteristics, the rock ramp would aesthetically "blend in" with the natural riverine environment and resemble a typical riffle.

[4] Similarly, if the existing dam is left in place, the meander may eventually flank the Hemphill Diversion if left untreated.

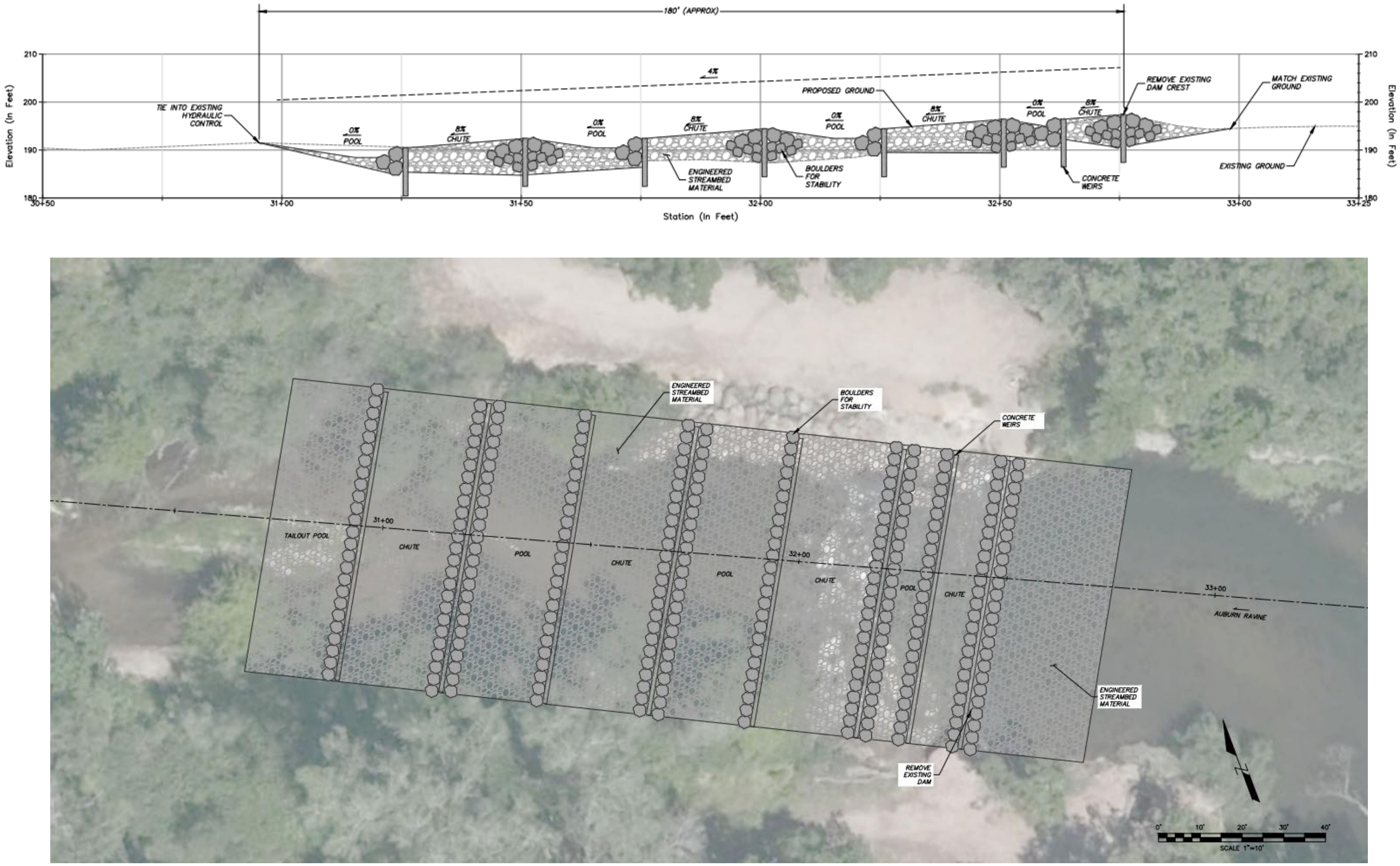

Figure 3-2. Profile and plan view of proposed chute and pool nature-like fishway (Alternative 1)

The roughened rock ramp would have an overall slope of 2.2% over approximately 180 feet, providing 3.9 feet of elevation gain past the structure. The downstream end of the ramp would tie into a naturally-occurring hydraulic control approximately 180 feet downstream of the existing dam[5]. The ramp would have a continuous slope, with no major pools, chutes, or jumps constructed within the ramp. Rock ramps are often limited to slopes less than 4% and are best for overcoming elevation differences of five feet or less. They rely on the swimming abilities of the fish, rather than the leaping abilities, making them better suited for passing a wider range of fish species and life stages, including those that have poor or no leaping abilities (e.g. Pacific Lamprey), and other non-anadromous, endemic fishes.

To maintain a stable grade throughout the structure, several channel-spanning boulder weirs are recommended. The weirs will keep the structure stable during high flow events to minimize detrimental erosion and scour within the structure. The boulders will be sized to remain stable up to the 100-year flood event. The bed material of the ramp would be comprised of engineered streambed material, such as gravels, sands, and cobbles, with similar sediment sizes characteristically found in Auburn Ravine. Roughness elements, such as large boulders protruding above the bed, could be constructed to provide slower wake zones downstream of the boulders. Commonly called “emergent boulders,” they provide low-velocity resting zones for fish migrating up the ramp.

To provide year-round fish passage, the crest of rock ramp will not require flashboards during irrigation season. Because of this, the entrance of the Hemphill diversion canal will need to be lowered by up to five feet. As such, a portion of the diversion canal will need to be regraded, starting at the entrance, which may affect certain structures within the canal (i.e. gaging station and culverts). Lowering the canal intake by five feet will still allow for an average diversion canal slope of 0.08% between the entrance and point of first use, which is at the low end for a typical gravity diversion, but not unreasonable for an irrigation canal of this size. As shown in Figure 2-4, taking advantage of hydraulic inefficiencies, such as the drop downstream of the Parshall Flume, can partially make up for the effects of reprofiling a portion of the canal. Additionally, a portion of the canal can be piped with smooth-walled HDPE pipe or lined with smooth concrete to further improve hydraulic efficiency. We recommend completing a detailed topographic survey of the canal and performing a subsequent hydraulic analysis of its flow characteristics in order to determine the extents and parameters for regrading the canal.

To be compliant with CDFW fish passage and screening guidelines, we also recommend installing a fish screening structure at or near the entrance of the irrigation canal. Fish screening options are discussed in more detail in section 3.5.

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[5] The elevation difference between the downstream hydraulic control and the crest of the existing dam is approximately 5.9 feet. If the new grade control structure’s crest is lowered by two feet, the elevation difference will be 3.9 feet.

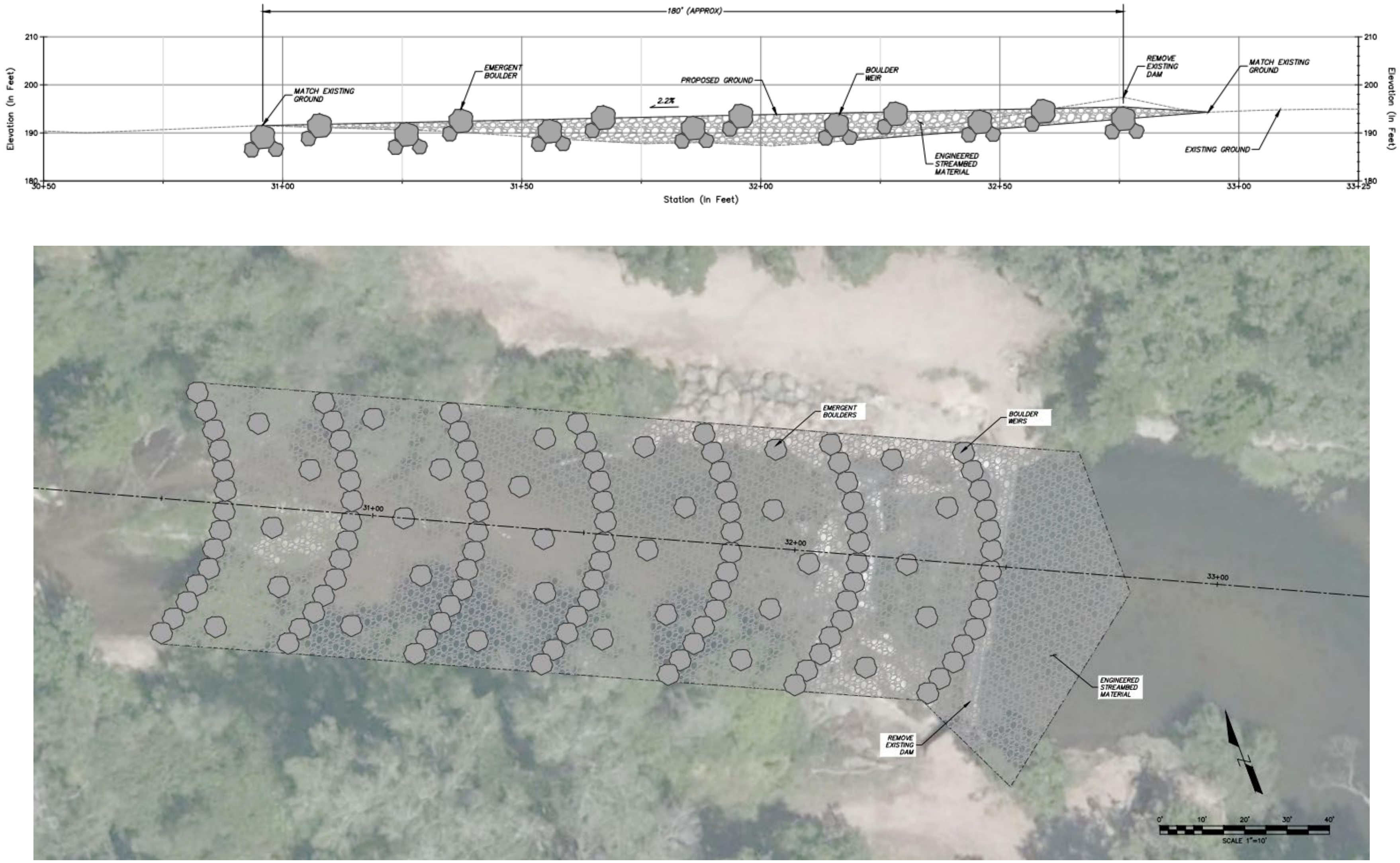

Figure 3-3. Profile and plan view of proposed roughened rock ramp (Alternative 2)

Based on the fish passage alternatives presented in this report, and other previous reports, we believe this alternative best meets all of the current needs at the Hemphill site. Alternative 2 would replace the existing dam with a more stable grade control structure. Lowering its crest by two feet would provide better sediment continuity, allowing impounded sediments upstream to deposit downstream, thus reversing some of the effects of channel incision and possibly providing suitable instream fish spawning habitat. Lowering the crest height by two feet would also have minimal erosion effects upstream while also relieving the lateral stress that is promoting the meander bend upstream. An elevation gain of 3.9 feet would be the least exhausting option for migrating fish compared to all of the other alternatives presented in this report.

3.4.3 Alternative 3: Vertical Slot Bypass Fishway

A vertical slot fishway is a traditional, technical fishway (Figure 3-4). It is constructed in a rectangular concrete channel with a downstream sloping floor, and is divided into a number of pools. Each pool is separated by concrete partition with a vertical slot extending to the floor. As water passes downstream through the fishway, fish are able to migrate upstream through the vertical slots. In vertical slot fishways, the water level is self-adjusting based on the flow rate through the structure allowing it to function both with and without flashboards installed on top of the existing dam.

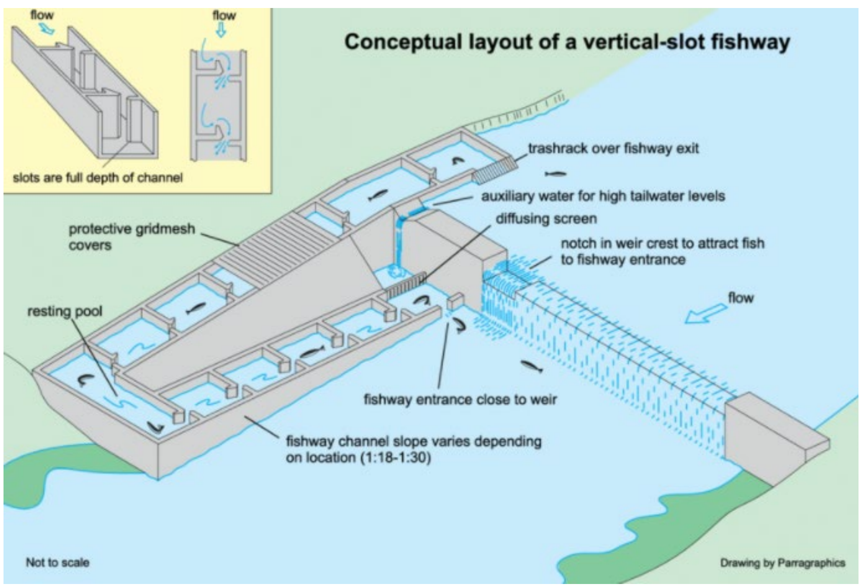

Figure 3-4. Schematic diagram of a vertical slot fishway bypassing a dam. Note that the fishway entrance is as far upstream as possible, which is preferable for migrating salmonids. Figure credit: Thorncraft & Harris, 2000

This alternative assumes the existing dam is left in place. The vertical slot fishway could be installed to bypass around the existing dam, and would be inset within the bank. This type of structure would not alter the existing dam structure, which would avoid further compromising it. Off-channel bypass fishways are generally less-susceptible to becoming clogged with debris since they are not in the main course of the river. This option could work on either the north or the south bank; however, NID expressed preference for the north bank for ease of access and maintenance. The vertical slot fishway would be constructed close to the dam within the scour pool immediately downstream, which is approximately 13 feet lower than the top of the flashboards during diversion season. This structure would not be able to tie into the existing hydraulic control approximately 170 feet downstream. For a slot width of one-foot (typical for salmonids), and an elevation gain of 13 feet, the overall migration pathway length would be approximately 130 feet long (Rajaratnam, Katopodis, & Solanki, 1992); however, as Figure 3-4 shows, a turning/resting pool would allow for the fishway footprint to be much shorter, instead of having a continuous linear 130-foot long structure. Vertical slot fishways are typically suitable for fish species with strong swimming abilities, such as salmonids. Weaker fish, such as lamprey, often have a harder time overcoming the fast through each of the vertical slots. However, some modifications, such as rounded corners, can be made to make the vertical slots more suitable for Pacific Lamprey to provide a continuous attachment point (Figure 3-5).

Figure 3-5. An example of a vertical slot fishway with rounded corners for Pacific Lamprey passage. Lamprey passage is improved in fishways when concrete corners are rounded with a 3-4 inch radius. Photo credit: Eugene Water and Electric Board

This alternative also assumes that flashboards will be installed across the dam crest during diversion season, thereby raising the upstream water surface elevation by three feet for portions of the year. Because the bypass fishway would be inset within the bank, maintenance would be less frequent compared to if it was installed within the main channel. However, with the narrow slots, debris entrainment will likely still occur which will reduce the fishway's functionality until the debris is removed. To minimize this, we recommend installing a trash rack on the upstream end (exit) of the fishway and frequently checking the fishway for blockages and sediment accumulation.

Since the existing structure will be left in place in this alternative, the addition of the vertical slot fishway should not put additional pressure on the dam. The dam will be operated as it currently is, flashboards and all. The dam and the fishway will act as two separate structures, not structurally tied to one another. Since the fishway would cut into the bank, the bank may be more susceptible to erosion (particularly, given the flood/erosion history of the dam site). This would be addressed using suitable bank armoring around the fishway. If the existing dam were to fail, it would likely be independent of whether or not an off-channel fishway is installed. Aside from adding a fish screen on the diversion, the diversion will mostly be left untouched; it will not have to be regraded like Alternatives 1 and 2.

A limitation of this alternative is the amount of elevation the fish will have to overcome when swimming past the dam. Even in a well-designed fish ladder, overcoming 13 feet of elevation can be physically taxing on a fish, which may lead to premature exhaustion. Additionally, this alternative does not address the failing structural stability of the existing dam, nor does it address the meander bend upstream that may eventually flank the Hemphill Diversion.

3.4.4 Alternative 4: Larinier Fishway

Alternative 4 entails installing a Larinier fishway. Larinier fishways are modified Denil fishways (Larinier, Travade, & Porcher, 2002; Armstrong, et al., 2010), and are typically designed for passing salmonids and sea trout in the United Kingdom. They are constructed with vertical walls – generally from concrete – and have steel herringbone baffles on the bottom. They also tend to have strong attraction flows. Given similar species characteristics with Chinook salmon and steelhead, this structure may be compatible with NID's project objectives while also meeting fish passage requirements for salmonids. Larinier fishways can be constructed at a steep slope, up to approximately 15%, which reduces its overall footprint. We propose two Larinier fishway alternatives: 1) installing a Larinier fishway as a bypass around the dam, and 2) installing a seasonal, modular Larinier fishway over the existing dam.

Figure 3-6. Larinier fishway looking downstream. Note the vertical, smooth side walls, and the wide, baffled base. Photo credit: Aquatic Control Engineering

For the bypass Larinier fishway, we recommend a two-stage Larinier designed to bypass around the dam. Like the vertical slot fishway alternative, this alternative also assumes that flashboards will be installed across the dam crest during diversion season, thereby raising the upstream water surface elevation by three feet for portions of the year. As such, we recommend designed a two-stage fishway. A two-stage fishway allows the structure to be operational year-round. During non-diversion season (when flashboards are not installed along the dam crest), the lower stage of the fishway exit would be open. During diversion season (when flashboards are installed), the upper stage of the fishway exit would be open. A bypass Larinier fishway would be approximately 90 feet long at a 15% slope to account for 13 feet head drop during irrigation season (assuming three feet of flashboards are installed across the dam crest). The fishway could be installed on the north or south bank; however, based on comments from NID, the north (right) bank would be easier to access for maintenance. Because Larinier fishways can be designed as rather wide channels (their overall width can be highly variable), they are also generally less susceptible to debris entrainment, which would lower maintenance frequency. Additionally, insetting the Larinier structure within the bank would increase the susceptibility of flanking the dam during large flood events. To minimize flanking, we recommend heavily fortifying the banks surrounding the structure with grouted boulders or gabion baskets.

A removable, modular, in-stream Larinier fishway could potentially be installed on the existing dam. This would be a relatively low-cost option (compared to other alternatives in this report); however, not without possible complications. Given that the existing dam's foundation is highly compromised, we recommend a thorough structural analysis of the dam before pursuing this option. We do not recommend this option if the added weight of the Larinier structure will further compromise the dam. This temporary Larinier structure would be approximately 75-90 feet long at a variable 11-15% slope. The structure would be modular (to install and remove in pieces, rather than as an entire structure). During non-irrigation season, the Larinier structure would be flush with the existing dam crest. During irrigation season, the upstream side of the structure would be raised to account for the addition of flashboards across the dam. The downstream pivot point would remain the same. This option could provide year-round fish passage provided that the upstream portion of the fishway is raised and lowered depending on whether the flashboards are installed. Figure 3-7 shows an example of a temporary, removable fishway, installed during diversion season.

Figure 3-7. Example of a removable fishway structure on a diversion dam installed during diversion season (while flashboards are currently installed). Photo credit: NHC

While Larinier fishways are suitable for strong swimmers, such as adult salmon and steelhead, they are not as compatible for weaker swimmers such as lamprey. If Pacific Lamprey are identified as a target species, we recommend installing a studded tile fishway adjacent to the Larnier fishway (Figure 3-8). Similar to Larinier fishways, studded tile fishways have smooth, vertical walls; however, instead of metal herringbone plates, they have studded plastic plates along the bottom of the fishway. The studded plates are designed to be compatible with lamprey morphology by providing the lamprey with a continuous smooth attachment surface, while the studs provide energy dissipation (Lothian, Tummers, A, O'Brien, & Lucas, 2020; Tummers, et al., 2016).

Similar to Alternative 3, a limitation of this alternative is the amount of elevation the fish will have to overcome when swimming past the dam. Overcoming 13 feet of elevation can be physically taxing on a fish, which may lead to premature exhaustion. Additionally, this alternative does not address the failing structural stability of the existing dam, nor does it address the meander bend upstream that may eventually flank the Hemphill Diversion.

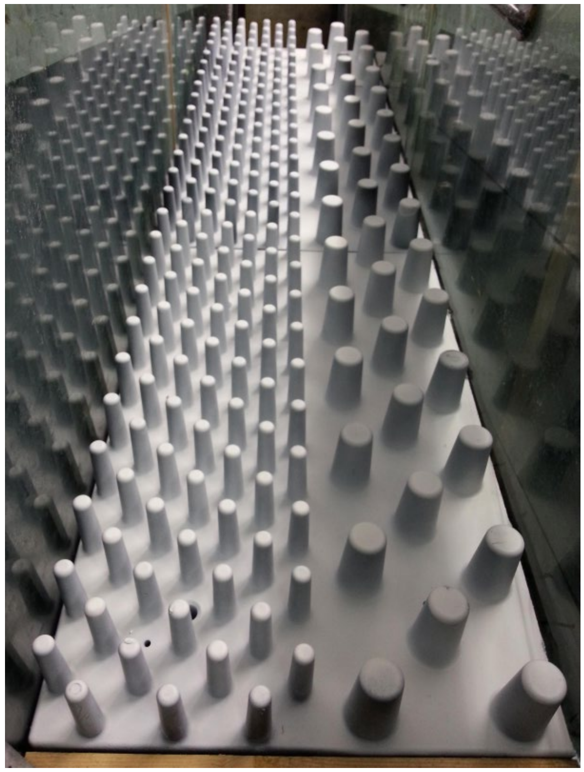

Figure 3-8. An example of studded tiles designed for lamprey passage. Photo credit: University of Southampton

3.4.5 Alternative 5: Pool and Chute

NID previously identified a possible fish passage solution presented by Michael Love and Associates (2009). This alternative entailed installing a concrete pool and chute ladder notched into the existing dam. We do not recommend installing a pool and chute fish ladder as they presented. The pool and chute ladder would require notching into the existing dam, which would further compromise its structural integrity, or rebuilding a channel wide structure. Additionally, given that the pool and chute ladder alternative is within the main course of the river, it would more susceptible to sediment and woody debris entrainment, increasing the frequency of maintenance relative to Alternatives 1 and 2.

3.4.6 Summary of Alternatives

Table 3-1 presents a summary of the proposed alternatives listed above. This table it intended to briefly summarize what each alternative entails as a broad overview. The opinion of probable cost is a rough order-of-magnitude approximation and is variable depending on inflation, current construction and supply rates, and final design. The cost does not include fish screening options; fish screening options are proposed in section 3.5.

Table 3-1. Summary of alternatives

Alternative	Maintenance Requirements	Require Dam Removal/Replacement	Require Regrading Irrigation Canal?	Instream Impacts	Permanent/ Seasonal	Opinion of Probable Cost*
Alt 1: Nature-like chute and pool	Inspect for scour and repair streambed material and boulders as necessary. Accessible from north bank.	Remove dam and construct a new grade control structure	Yes	Place chute and pool structure within main channel. Minimal upstream or downstream impacts	Permanent	$3.2 million
Alt 2: Roughened rock ramp	Inspect for scour and repair streambed material and boulders as necessary. Accessible from north bank.	Remove dam and construct a new grade control structure	Yes	Place rock ramp within main channel. Improved sediment transport conditions upstream of the dam, some local deposition in the channel downstream of rock ramp	Permanent	$2.9 million
Alt 3: Vertical slot ladder (bypass)	Clearing debris from ladder and trash rack. Accessible from north bank	Will **not** require dam removal or replacement	No	Minimal instream impacts	Permanent	$1.5 million[1] to $4.2 million[2]
Alt 4A: Larinier (bypass)	Occasional clearing debris from Larinier structure. Accessible from north bank	Will **not** require dam removal or replacement	No	Minimal instream impacts	Permanent	$1.5 million[1] to $4.2 million[2]
Alt 4B: Larinier (in-stream)	Adjust height of structure during irrigation and non-irrigation season. Accessible from north bank	Will **not** require dam removal or replacement	No	Minimal instream impacts	Permanent but seasonally adjusted	$750,000[1] to $3.5 million[2]
Alt 5: Concrete Pool and Chute Fish Ladder (in-stream)	Frequently clear pools of sediment and woody debris	Will require removing and replacing the dam with another concrete structure	No	Minimal instream impacts	Permanent	$5 million

*Opinion of Probable Cost are order of magnitude construction costs for a relative comparison of alternatives. Future stages of the design process will hone the Opinion of Probable Costs.

[1]Cost estimate assuming existing structure remains in place without repair or replacement.

[2]Cost estimate assuming the existing structure is removed and replaced as part of the project.

3.5 Fish Screening

While not part of this current scope, NHC and NID engineers briefly discussed the feasibility of incorporating a fish screen on the Hemphill Diversion entrance to exclude migratory salmonids and other native fish from entering the canal. NID expressed interest in adding a fish screen to the entrance of the existing diversion canal to exclude fish from entering the canal. Installing fish screens on the Hemphill diversion could be an alternative to existing alternatives of piping diversion flow from upstream or installing an infiltration basin and diversion pump along the bank (Kleinschmidt, 2016). Although the infiltration basin alternative would inherently provide fish screening; potential clogging of the basin by fine sediment could require costly maintenance relative to fish screens. Two fish screen options that would work with Alternatives 1 through 5 (elevations would have to be adjusted depending on alternative designed at the am) would be a flat plate screen (Figure 3-9) and a cone screen (Figure 3-10).

A flat plate screen could be installed on-channel (along the riverbank, parallel to the river's direction of flow) or in-canal (offset from the river located some distance down the diversion canal). Assuming a maximum diversion of 15 cfs, and 3 feet of submergence, the flat plate screen would be approximately 20 feet long. NHC opinion of probable cost for the materials and installation of a flat plate screen is approximately $400,000. A benefit of an in-canal flat plate screen is that should any major flood events flank the dam again, an in-canal screen would largely be protected from the flood, with relatively minor repairs to the diversion intake itself; however, it would require a bypass pipe to return any fish back to the river downstream of the dam. An in-canal screen also has the added benefit of being partially shielded from sediment accumulation. The screen could be designed to allow sediment to sweep past it and down the bypass pipe. The screen could also be perched on a concrete "mud sill" that would prevent sediment for directly impacting the screen itself.

An on-channel screen would not require a bypass pipe for fish, but it would be more susceptible to damage during a high flow event; it may also be inundated by sediment, especially if the diversion intake was lowered (Alternatives 1 and 2). Additionally, the flat plate screens may be overtopped during a high flow event allowing fish to pass over the top of the screens and into the canal. A cone screen, on the other hand, is fully submergible without allowing fish to enter the canal. An on-channel cone screen could be installed along the bank at the current diversion entrance; however, it is possible that fine sediment would inundate the screen. Assuming a maximum diversion of 15 cfs, and a fully-submerged screen, the base of the cone screen would be approximately 8 ft in diameter. NHC's opinion of probable cost for the materials and installation of a cone screen is approximately $300,000. Regardless of the final fish screen design, we recommend conducting a hydraulic analysis of the preferred alternative to understand the hydraulics and sediment transport in and around the screen.

Both screen options could likely be designed to either have a water-powered or electric (assuming on-site power) brush system. Figure 3-9 shows a water-driven paddle wheel that turns as water flows into the diversion, thus driving the screen brushes shown in the left-hand photo. The brushes on the cone screen in Figure 3-10 are driven by an internal water-powered impeller. If on-site power is available, the brush cleaning systems could be fully electric reducing headloss through the facility.

Figure 3-9. Example of a flat plate screen. NHC designed and installed this screen for Deer Creek Irrigation District in Tehama County, CA in 2019.

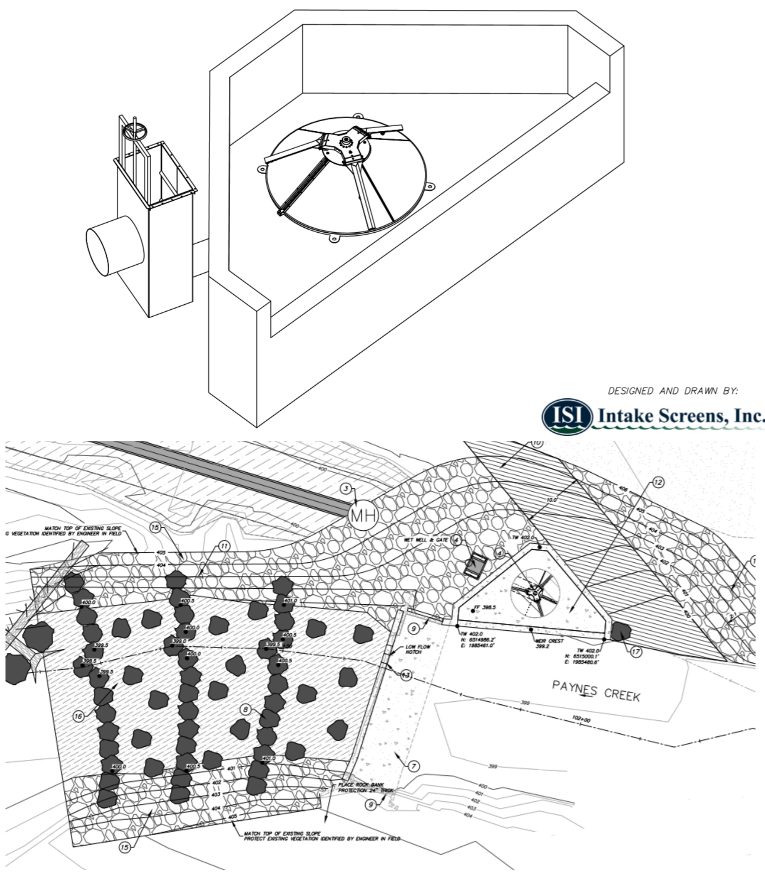

Figure 3-10. Example of a cone screen. NHC is currently designing this cone screen for Bend Water Users in Tehama County, CA

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