Low Head Dam Modification Prioritization

Final Report

Prepared for:
Colorado Water Plan Grant
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American Whitewater
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Introduction

Low head dams, often referred to as “drowning machines”, can create uniform hydraulics, inescapable by most river recreationists. Opportunities exist to develop projects at existing low head dam sites that: minimize public safety risk, improve river ecological health and improve or restore infrastructure efficiency. This study identified the multi-benefit potential, how each benefit can be quantified, and which low head dam projects rise to the top to maximize those benefits.

American Whitewater serves on the leadership committee for the National Low Head Dam Task Force, a group of dam safety and restoration professionals from around the country seeking to complete a robust inventory of low head dams in the continental United States. This project serves as a leading example to utilize inventory information and use it to best address public safety hazards at these structures.

The proposed project supports the goals and values of Colorado’s Water Plan by aiming to find low head dam update projects that maximize multiple benefits across municipal and industrial, agricultural, recreation, and conservation water user groups. This project developed and applied a framework for evaluating the multi-stakeholder benefit potential of each of these projects to assist DNR in strategically allocating funds. This framework can facilitate the projects identified in various Basin Implementation Plans by investigating the multi benefit potential of desired low head dam renovation.

The project provides for the identification and development of multi-stakeholder benefit projects and methods that increase public safety, benefit environmental and recreational water needs. This project provides a framework capable of assessing such initiatives in terms of their tangential benefits and costs to all stakeholders and associated regional economic outcomes. This project built on the efforts, funded by water plan grants, of Colorado Department of Natural Resources to inventory all low head dam structures in the state, support public awareness campaigns and signage installation projects at high-risk low head dam sites.

Background

There is a small, but growing body of literature documenting the occurrence of LHDs and their profound effects on riverine ecosystems and public safety. These studies collectively demonstrate the combined effects of LHDs as potentially dangerous barriers and habitat manipulators that impact species richness and species abundances, disrupt hydrologic connectivity, and lower recreation quality and potential. Opportunities exist to develop projects at existing low head dam sites that minimize public safety risk, improve river ecological health and improve or restore infrastructure efficiency. In this project, we explored the impacts of LHDs on four major categories: public health, watershed condition, aquatic habitat, and recreation. This project assesses the consequences of removing or retrofitting a dam for each impact category. This provides a quantitative prioritization framework that can operate as a generalizable platform for comparing and contrasting many potential projects across the state of Colorado.

Public Safety Background Data

Because of their small size and low storage capacity, LHDs have largely gone unnoticed in US dam safety assessments (Fostvedt et al., 2020). In 2019, Colorado Department of Natural Resources (DNR) announced an initiative to improve the safety around LHDs and examine viable means to mitigate LHD risks, funded in part by a grant from the Federal Emergency Management Agency. A comprehensive inventory of structures located on Colorado waterways identified a total of 1,103 LHD structures in the Colorado Low-Head Dam Inventory project (Zimmer, 2019). Of these, approximately 793 have been identified as potentially hazardous in-stream structures (diversion dams). It should be noted that not every structure is necessarily life-threatening at all times of the year. An LHD can go from being relatively safe to extremely hazardous with a single rainfall episode as streamflow conditions change. This can occur overnight, or within a matter of a few hours. In 2014, a database of fatalities at LHDs across the United States was created to both increase public awareness and generate public support for remediation efforts (Kern, 2014). There have been 622 total recorded fatalities across the US and 13 recorded fatalities involving LHDs dams in Colorado since 1986, although the true number is likely larger. The American Whitewater accident database lists 8 fatal incidents of rafters or kayakers going over an LHD.

Watershed Condition

LHDs can create distinct physical and ecological conditions relative to free-flowing lotic reaches, despite the relatively small size of LHDs. Watershed condition describes the aquatic network quality of a segment containing an LHD, based on qualities such as network length, network complexity, and surrounding land cover (SARP, 2020). Functional aquatic networks are the stream and river reaches that extend upstream from a barrier or river mouth to either the origin of that stream or the next upstream barrier. When LHDs are present, distinct conditions are created upstream and downstream, lowering the overall quality of the aquatic network. Stretches of rivers with LHDs can often be characterized by deeper, broader channels, deposits of loose sediments, reduced current velocities, and macroinvertebrates characteristic of lentic habitats (Smith et al., 2017). The spatial extent of dam impacts can extend beyond the immediate vicinity of the LHD structure (Fencl et al., 2015).

Aquatic Habitat

Fish and other aquatic organisms depend on high-quality, connected river networks to feed, spawn, and migrate. LHDs segment waterways and act as ecological barriers (Brenkman et al., 2019; Liermann et al., 2012; Wang et al., 2010). Even relatively small dams can create profound differences in habitat quality above and below LHDs, where habitat and water quality can be poorer in the artificial pools created above the dams. Fragmentation due to LHDs prevents species from dispersing and accessing habitats required for their persistence through changing conditions, and population viability could be at risk.

Recreation

In addition to the inherent dangers LHDs pose to recreationalists, LHDs disrupt the connectivity of recreational reaches, forcing recreationalists to forego potentially optimal river stretches for rafting or fishing. Recreational, economic, and aesthetic values associated with free-flowing rivers are foregone when a river is impounded. Public access to certain stretches of river may be denied if LHDs are located on private land. Sport fishing quality may be substandard when LHDs dot the riverways, as fish diversity is negatively affected by fragmented rivers (Díaz et al., 2021). While LHDs do provide habitat for certain fish species in impounded areas upstream, fishing can be enhanced by the wide variety of habitats that result from unregulated rivers and their flows.

Methods

Task 1: Literature review and stakeholder engagement

This task included the review of literature documenting the occurrence of low head dams (LHDs) and their profound effects on public health and recreation, impacts to riverine ecosystems, and need for their industrial utility. This review has been written up in draft form andis included as Appendix A to this report.

For the stakeholder outreach, a web-based stakeholder survey was provided to a small group with experience and/or interest in low head dams to also understand the impact sectors LHD projects effect and to identify potential data sources that could be used in a prioritization framework. We hosted meetings with interested stakeholders to review progress and approach. The first meeting reviewed the proposed scoring framework. The second meeting reviewed initial scores from all inventoried structures. As a result of that meeting, one of the stakeholders identified some mischaracterization of structures from the original DNR inventory. Our team did a visual quality control exercise to verify those structures that had the potential for a submerged hydraulic jump, those that did not, and those that were solely features built as recreational amenities. This was an additional score added to the public safety domain to ensure those structures with the greatest hazard to public safety rose to the top.

Task 2: Develop and project value scoring framework

This task took the information gathered in task one and developed a scoring metric. The public safety interest domain is quantified by the level of danger an LHD structure presents to humans. River network connectivity is a core concept underlying our proposed approaches for evaluating project impact to watershed quality, aquatic habitat and recreation. A summary of all the considerations and data used for each interest domain is laid out in the figure before.

Interest Domains	Considerations	Data
Public Health	Existing hazard likelihood Human activity Submerged hydraulic jump potential	Fatalities/injury reports Recreation reaches Fishery reaches Proximity to population centers Structure type Streamflow
Watershed Quality	Land cover & impervious area Channel alteration Network complexity Network connectivity	Land cover Channel type River size/stream order NHDPlus
Aquatic Habitat	Fisheries Geomorphology Spawning ground Macroinvertebrates	Fisheries Habitat extent Endangered species Invasive species Species richness & abundance
Recreation	Human activity Connectivity barriers Population Access/public property Flow preference	Recreation reaches Fishery reaches Proximity to population centers Streamflow

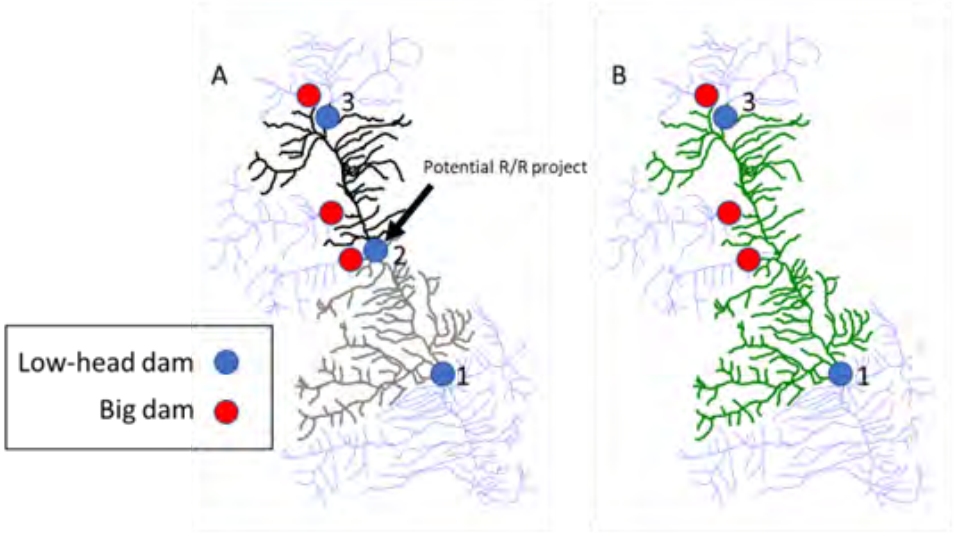
Quantitative metrics provide actionable information to assist in R/R projects. Some of the methods we use to quantify LHD structures have been vetted and used in existing analytical frameworks (Lacy, 2020; SARP, 2022). We build on these individual frameworks and quantitatively assess project potential in each interest domain using appropriate data. In the following section, we discuss the methods utilized to assess available data.

Task 3: Apply scoring framework

The public safety interest domain is quantified by the level of danger an LHD structure presents to humans. Our evaluation of public safety impact is based on three core concepts: 1) historical incident reports, 2) the potential for dangerous submerged hydraulic jumps to manifest near the structure, and 3) the proximity of the structure to major population centers and popular recreational reaches. Historical incident reports of known injuries and fatalities at LHDs provide direct evidence of LHD danger. The presence and persistence of submerged hydraulic jumps, which can entrain humans and cause drowning or serious injury, is an important indicator of the danger of the barrier, and depends on the type of structure that was constructed. Using satellite imagery of the structures, a team of analysts categorized each structure as either having a submerged hydraulic jump potential, no submerged hydraulic jump potential, or no hazard (all structures designed for recreation were removed from this analysis). Lastly, the proximity of an LHD to a population center or popular recreational reaches helps us understand the likelihood that humans are in contact with the structure and its intrinsic dangers. Population proximity may be evaluated using U.S. census data and rudimentary geospatial analysis techniques, and recreational reaches are determined by American Whitewater reaches and Colorado Parks and Wildlife fishing locations. Calculating a total score for public safety is illustrated by the equation and range of values below.

SCORE =	3 x Fatalities +	Hazard +	Population +	Fishing +	Recreation
Range	0 - 12	0 - 4	0 to 1	0 or 1	0 or 1

River network connectivity is a core concept underlying our proposed approaches for evaluating project impact to watershed quality, aquatic habitat and recreation. River network connectivity refers to the network of interconnected waterways (and their attributes) between structural breakpoints. Delineating connected networks adjacent to LHDs can be done with the National Hydrography Dataset (NHDPlus), which provides a high-resolution mapping of the U.S. river and stream network (U.S. Geological Survey, 2019). Using graph analysis computational techniques, we can identify the extent of connected river networks as they exist now and as they may be in the future following R/R project investment. For example, consider the river network in Figure 3A with three LHDs situated along the mainstem. In this network, LHD 2 acts as a connectivity barrier dividing the black network (between LHD 3 and 2) and the gray network (between LHD 2 and 1). If LHD 2 were to be removed, as is shown in Figure 3B, the newly connected area, shown in green, is the sum of the previously divided gray and black networks. The potentially connected network extent in Figure 3B provides a domain extent for subsequent analyses of geomorphic, ecological, hydrological, and recreational attributes of constituent river segments.



A) a segmented river network showing LHDs 1, 2, and 3; B) total connected river network in green between LHD 1 and LHD 3 if LHD 2 were removed

Watershed condition describes the physical and biological integrity of the watershed. Our evaluation of watershed condition impact is based on four main concepts: 1) network connectivity, as described previously, 2) network complexity, 3) natural landcover, and 4) channel alteration, all of which have been adapted from the Aquatic Barrier Prioritization Tool (SARP, 2022). The diversity of stream order within

the connected network measures the level of complexity in the watershed. A more complex network allows for a greater range of habitat and species. Network complexity is evaluated using the NHDPlus network by assigning segments to class sizes based on total drainage area. Watershed condition is also influenced by the amount of natural land cover in the watershed, as LHDs surrounded by fewer impervious surfaces are more likely to contribute to higher quality habitat if a R/R were to occur. Natural land cover is derived from the USDA National Landcover Database (NCLD) and measured from the overall percent of natural land cover throughout the entire connected network. Lastly, channel alteration is a measure of how altered a waterway is compared to natural conditions. Highly channelized reaches have a lower variety and quality of instream habitat. We evaluate channel alteration by identifying reach segments coded as canals or ditches in the NHDPlus HR dataset, and then calculating the percent of altered lengths by the total length of the connected network. Calculating a total score for watershed condition is illustrated by the equation and range of values below.

SCORE	=	Length	+	Complexity	+	Alteration	+	Landcover
Range		0 to 1		0 to 1		0 to 1		0 to 1

Aquatic biota is a prime indicator of overall stream health (Herman and Nejadhashemi, 2015). Thus, the extent of quality habitable waters for endangered species, trout, and other aquatic biota in Colorado waters is an important consideration in LHD R/R projects. To evaluate the aquatic health interest domain, we propose the following considerations: 1) network connectivity, as described above, and 2) cumulative habitat condition indices (HCI). Habitat condition indices exist for every river reach in the coterminous United States, and measure aquatic health quality while considering human disturbances and the natural landscape. We quantify aquatic health condition by averaging HCI scores for every river segment upstream of each LHD. Calculating a total score for aquatic health is illustrated by the equation and range of values below.

SCORE	=	Length	+	HCI Index
Range		0 to 1		0 to 5

The recreation interest domain quantifies the abundance of quality recreational opportunities. In addition to network connectivity, which would allow for uninterrupted boat passage, we also evaluate this interest domain by considering the proximity of LHDs to river access points and existing popular recreation reaches (whitewater stretches and gold medal waters), as well as to a town or city center. Successful whitewater parks built within the last 30 years are often built near population centers who regularly seek them out. Therefore, this domain may be evaluated simply by proximity to recreational reaches (such as documented American Whitewater segments and the Colorado Parks and Wildlife Gold Medal Fishing waters) and State of Colorado municipal boundaries. Calculating a total score for recreation is illustrated by the equation and range of values below.

SCORE	=	Length	+	Municipality Prox	+	Recreation	+	Gold Water
Range		0 to 1		0 to 1		0 to 1		0 to 1

In order to compare an LHD's potential impact to another, we synthesize the individual impact scores into a composite, total score. Interest domains can be weighted more or less in a composite score, based on user institutional or structural knowledge about the LHD of interest. An evaluation of the net impacts of a portfolio of LHDs can give decision makers the ability to identify groups of LHDs that may not receive high impact scores individually, but could approach a maximum future value if all underwent a R/R project. This scenario is conceivable when there are multiple LHDs close to each other on a single stretch of river, and removing all of them could significantly increase network connectivity and the potential impact across all interest domains.

CWCB funding was used to support contractor services to create the prioritization framework and web-based dashboard. See the actual breakdown below on spending towards project expenses.

Results

The final product is the Colorado Low Head Dam Prioritization Dashboard that can be access publicly at this link: https://lynkertech.shinyapps.io/aw_lhd_app/#section-introduction

Conclusions and Discussion

The objectives of this project were fully met. The prioritization successfully elevated the most hazardous and impactful identified low head structures in the state. It has allowed for the identification of projects that American Whitewater is seeking to take on.

As a result of this project, American Whitewater is working with partners to stand up a Colorado Aquatic Connectivity Team who would utilize the information and data analysis provided in this project. The vision for Colorado Aquatic Connectivity Coalition is to create a collaborative group representing agencies, nonprofits, businesses, and other practitioners working to identify, prioritize, and retrofit or remove obsolete dams and other barriers to aquatic connectivity in Colorado and upgrade infrastructure to improve public safety and allow for the movement of aquatic organisms and humans.

Actual Expense Budget

Actual Expenses
Prepared Date: 11/24/2023
Name of Applicant: American Whitewater
Name of Water Project: Low Head Dam Modification Prioritization Framework
Project Start Date: September 17, 2021
Project End Date: September 30, 2023

Task No.	Task Description	Actual Expense	Actual Matching Fund Expenses	Actual Project Total	Grant Funding Request	Match Funding	Total
1	**Literature review and stakeholder engagement**	$17,310.00	$5,565.00		$17,310.00	$5,770.00	$23,080
2	**Develop and project value scoring framework**	$23,040	$8,200.00		$23,040	$7,680	$30,720
3	**Apply value scoring framework**	$21,000	$7,000.00		$21,000	$7,000	$28,000
							$0
							$0
	Total	$61,350	$20,765	$82,115	$61,350	$20,450	$81,800

Appendix A

Low Head Dam Impact and Prioritization White Paper

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