Tapping Municipal Water Supply Systems for Low-Impact Hydropower Growth

By Scott DeNeale, Lindsay Ashworth, Antonia Chu and Shih-Chieh Kao

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Conduit hydropower is a form of low-impact hydropower that uses existing water infrastructure, such as canals or pipelines, to capture what would otherwise be wasted energy. Agricultural conduits convey irrigation water across vast stretches of the U.S., primarily in the west, and are well-suited for hydrokinetic power capture within the flow stream or for hydro potential power capture where excess pressure exists. Drop structures within irrigation canals are suitable candidates for this type of hydropower development and have been retrofitted across a large number of sites over the past few decades.

Municipal and industrial conduits, on the other hand, supply water for a variety of purposes, including those in Figure 1. Industrial systems can consist of a variety of facilities, including thermoelectric stations and mining operations. Municipal systems include facilities that provide water for civilian use, encompassing raw water conveyed from a natural or manmade water body to a water treatment facility, treated water supplied to residential or commercial customers, and outflow from a wastewater treatment facility before returning to another natural or manmade water body.

<<Figure 1>>

Figure 1. Conceptual sketch of a water distribution system, including canals/conduits and potential hydropower development locations. Source: Modified from Bekker et al.[1]

This article focuses on hydropower development for municipal water supply conduits, extending from the initial water body diversion to the residential or commercial users. Opportunities for this form of hydropower include tapping hydro potential along supply pipelines servicing water treatment plants and within the distribution network. Pressure-reducing valves (PRV) are used to decrease incoming water pressure to an appropriate, safe level for maintaining service function. These PRVs are the primary target for hydropower development, as the energy dissipated by these devices could instead be captured by a spinning turbine to produce renewable energy.

Existing and potential hydropower from public water supply systems

Oak Ridge National Laboratory (ORNL) has led conduit hydropower research for over a decade, including work by Sale et al.[2] Subsequent work on development opportunities and challenges started through an initial pilot study formulated to assess development potential in Colorado and Oregon, completed in 2018,[3] which then led to a broader resource assessment, completed in 2022. Since that time, follow-on research efforts have yielded additional insights.

According to ORNL's 2024 Existing Hydropower Assets dataset,[4] there are 338 hydropower plants operating as canals or conduits, and these plants have a total installed capacity of 836 MW. Of this total, 217 projects, totaling 337 MW, are estimated to fall under the municipal public water supply category. Although municipal conduit hydropower has been around for some time, the associated facilities are relatively newer than the overall fleet. According to available information on the operational year, such facilities are, on average, younger: 84% of municipal conduit projects have been developed since 1980, compared with only 35% for the hydropower fleet at large. Most of the municipal conduit hydropower projects documented were built in the 1980s, and only 25% have been built since 1990, which is still greater than the 13% figure for the overall hydropower fleet.

ORNL's 2024 Hydropower Development Pipeline dataset[5] tracks hydropower projects in the permitting/licensing/exemption phase and yet to be developed. Within the dataset are 25 projects listed as "conduit," and we estimate that 15 projects (totaling 68.2 MW) in the development pipeline are for municipal water supply systems. Of these, two projects account for a combined 61.5 MW, and no other project is above 1 MW. Thus, the vast majority of conduit hydropower projects assumed to be proposed for public water supply systems are small-scale. Among the 15 projects in development, 2 are in Alaska, 5 in California, 4 in Colorado, and 4 in Oregon.

To evaluate new conduit hydropower opportunity, a 2022 study funded by the U.S. Department of Energy Water Power Technologies Office (WPTO) and led by ORNL focused on estimating potential across the United States. The results indicated that about 1,414 MW of power could be captured within municipal, agricultural and industrial water conduits. Of this untapped resource, an estimated 374 MW is available from municipal conduits (see Figure 2 for a map). Of this portion, 337 MW (90%) is from public water supply systems, and the remainder is from wastewater systems.

<<Figure 2>>

Figure 2. Map of municipal conduit hydropower power potential, by state. Source: Kao et al.[6]

Identifying challenges and establishing a knowledge base

Recent WPTO funding to ORNL has been geared toward identifying challenges, establishing a deeper knowledge base, and supporting conduit hydropower development. For this, ORNL is working with Small Hydro Consulting, an engineering consulting firm with experience in conduit hydropower and other forms of hydropower, particularly on the small scale. In its first year, key activities have included conducting a virtual stakeholder webinar on all sectors of conduit hydropower as well as developing case studies and a cost analysis associated with the municipal water supply sector.

In April 2024, ORNL hosted a virtual webinar with over 60 attendees that dove into the opportunity and challenges associated with conduit hydropower development in the United States. The workshop agenda included presentations by WPTO and ORNL, an overall brainstorming session, and breakout sessions for the municipal/industrial sectors and the agricultural sector. Thirty-six attendees participated in the municipal/industrial breakout, and the participation provided useful insights around such topics as identifying top challenges associated with financing and power sales, internal and external stakeholder engagement, and permitting and licensing. Notably, one insight gained is that despite the reduced 45-day FERC regulatory approval process available for qualifying conduits, there are still regulatory hurdles. Analytically, variations were seen in the perceived level of challenge among the various stakeholder types for different categories, as documented in Figure 3, in which a level of 1 is "not at all challenging" and 5 is "very challenging."

<<Figure 3>>

Figure 3. Level of challenge by development phase and stakeholder type for municipal/industrial conduit hydropower. Source: DeNeale et al.[7]

For more information on the workshop, see the summary report by DeNeale et al.[7] Insights from other stakeholders who were not present at the workshop would be highly valuable to our research efforts, and we welcome and will seek additional engagement. Please consider contacting us at hydropower@ornl.gov or denealest@ornl.gov for more information and to get connected.

While case studies are still being developed, the general idea is to summarize a project by presenting an owner/utility overview, a site profile, a feasibility assessment, development considerations, lessons learned and a community profile. This sort of information provides a snapshot of a project that can be used to educate stakeholders and serve as a platform to conduct future stakeholder engagement. Although this approach is being developed for operational projects, similar information could be leveraged to assess proposed projects, given that relevant information is available. Moreover, ORNL hopes to collaborate with one or more stakeholders to analyze system potential for municipal conduit hydropower opportunity.

And a cost analysis is being performed to better understand the cost of developing conduit hydropower. ORNL's 2023 Baseline Cost Model[8] is an empirical model used to estimate the cost of all types of hydropower including canal/conduit projects. This model was tested with recently developed municipal conduit project costs and performed quite well. The model generally provides a lower bound on expected project costs, and cost distributions scale with size (i.e., smaller projects have a higher per-kW cost than larger projects), although site-specific additional requirements can create costs in excess of that modeled. Figure 4 provides a plot of actual vs modeled costs for 14 recent planned and constructed conduit projects, with power equation trendlines shown.

<<Figure 4>>

Figure 4. Comparison of actual and modeled municipal conduit hydropower project cost.

Toward new tools and resources

Various resources exist to support conduit hydropower development. Current literature offers perspectives for domestic development,[9,10] and the concept of conduit hydropower for water supply systems is well-understood as a low-impact technology with multiple benefits. Still, challenges remain, particularly related to education and awareness among relevant stakeholders, including municipalities, utilities, and the general public. Therefore, ORNL is working with WPTO to define future research efforts. While details are being refined, we expect that more rigorous stakeholder outreach and engagement will be key to accelerating development. Additional insights on best practices could also be useful. Also, an assessment of feasibility across different regions of the U.S. would support decision-making.

While conduit hydropower is indeed small, it can serve an important role in supplying low-impact and reliable renewable energy now and into the future. Because it leverages existing infrastructure without disrupting the environment, municipal conduit hydropower provides a logical solution for delivering smart energy solutions. Room for innovation in this space exists, and additional technological breakthroughs could improve deployment.

We welcome additional input from stakeholders. If you have thoughts on priorities for federally funded efforts to support conduit hydropower for public water supply systems, we would be glad to connect and discuss.

Notes

1Bekker et al. 2021, https://doi.org/10.1016/j.jclepro.2020.125326

2Sale, M.J., et al., "Opportunities for New Energy Development in Water Conduits," ORNL/TM-2014/272, Oak Ridge National Laboratory, Oak Ridge, TN, Aug. 2014.

3Kao and Johnson 2018, https://www.ornl.gov/file/assessment-energy-potential-public-drinking-water-systems-initial-report-methodology/display

4Johnson et al. 2024, https://hydrosource.ornl.gov/dataset/EHA2024

5Johnson and Uria-Martinez 2024. https://hydrosource.ornl.gov/dataset/us-hydropower-development-pipeline-data-2024

6Kao et al. 2022, https://doi.org/10.2172/1890335

7DeNeale et al. 2024, https://doi.org/10.2172/2369213

8Oladosu and Sasthav 2023, https://doi.org/10.21951/BCM2023/1968485

9Sari et al. 2018, https://doi.org/10.1016/j.jenvman.2018.08.078.

10CEC 2020, https://www.energy.ca.gov/publications/2020/californias-conduit-hydropower-implementation-guidebook-compendium-resources

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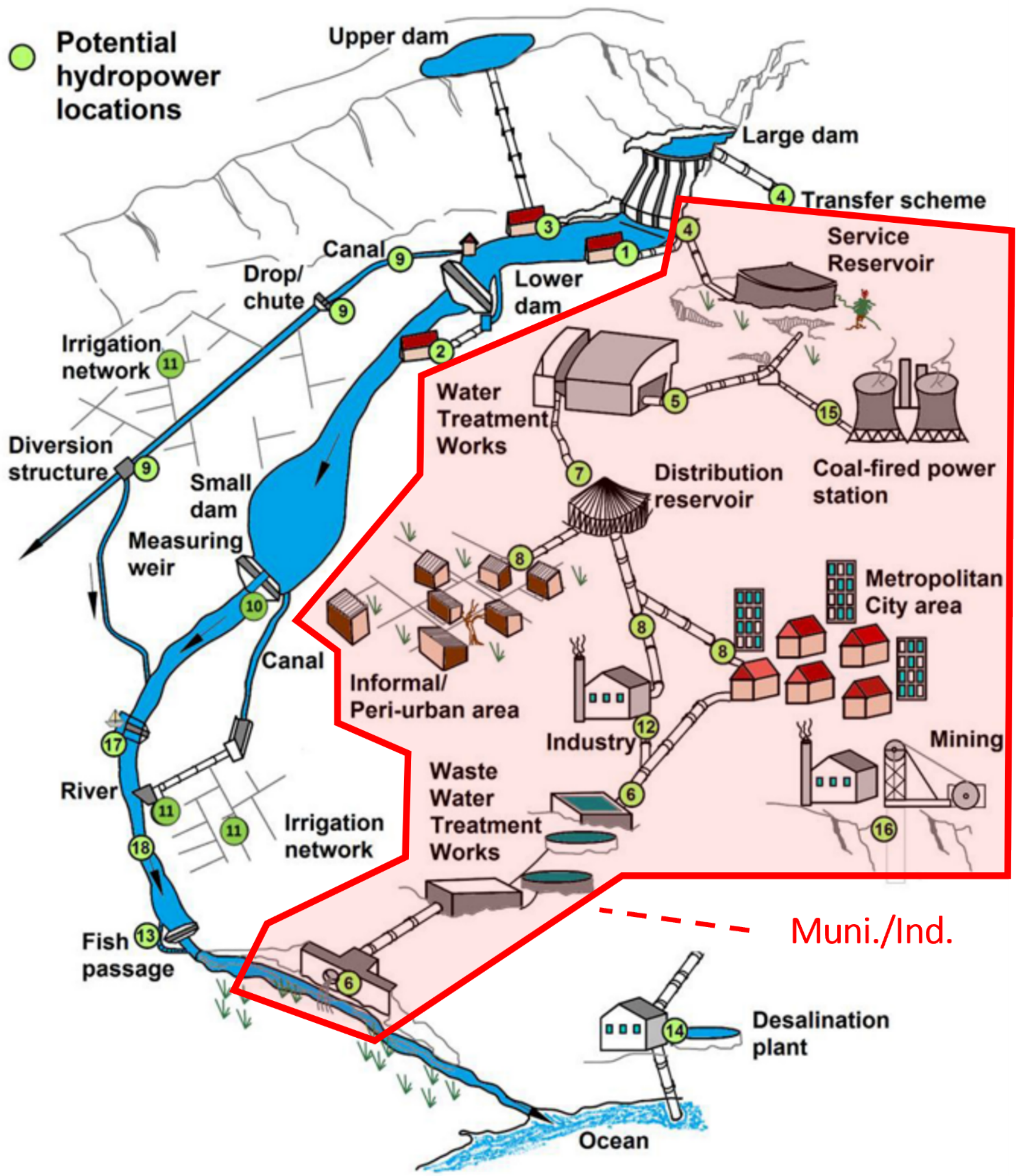
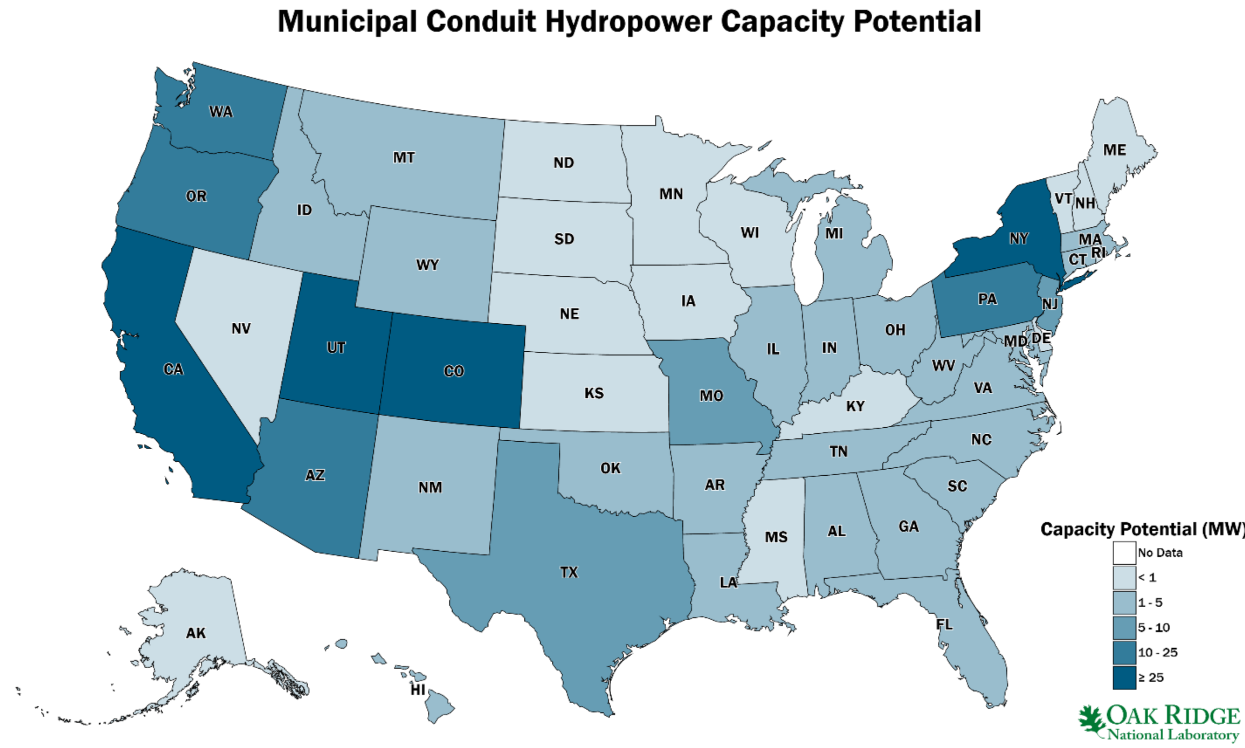
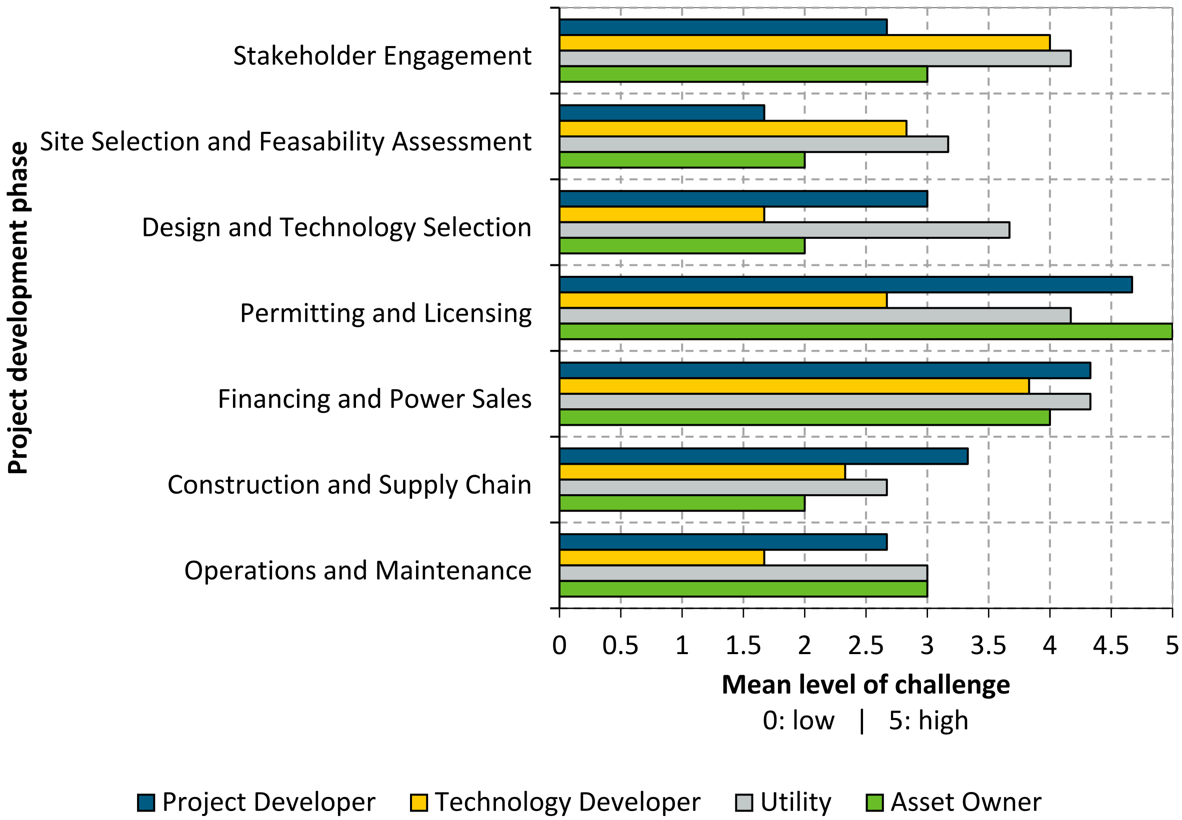

Potential hydropower locations
Upper dam
Large dam
Transfer scheme
Service Reservoir
Canal
Drop/ chute
Lower dam
Irrigation network
Water Treatment Works
Diversion structure
Small dam
Distribution reservoir
Coal-fired power station
Measuring weir
Metropolitan City area
Canal
Informal/ Peri-urban area
Industry
Mining
Waste Water Treatment Works
River
Irrigation network
Muni./Ind.
Fish passage
Desalination plant
Ocean

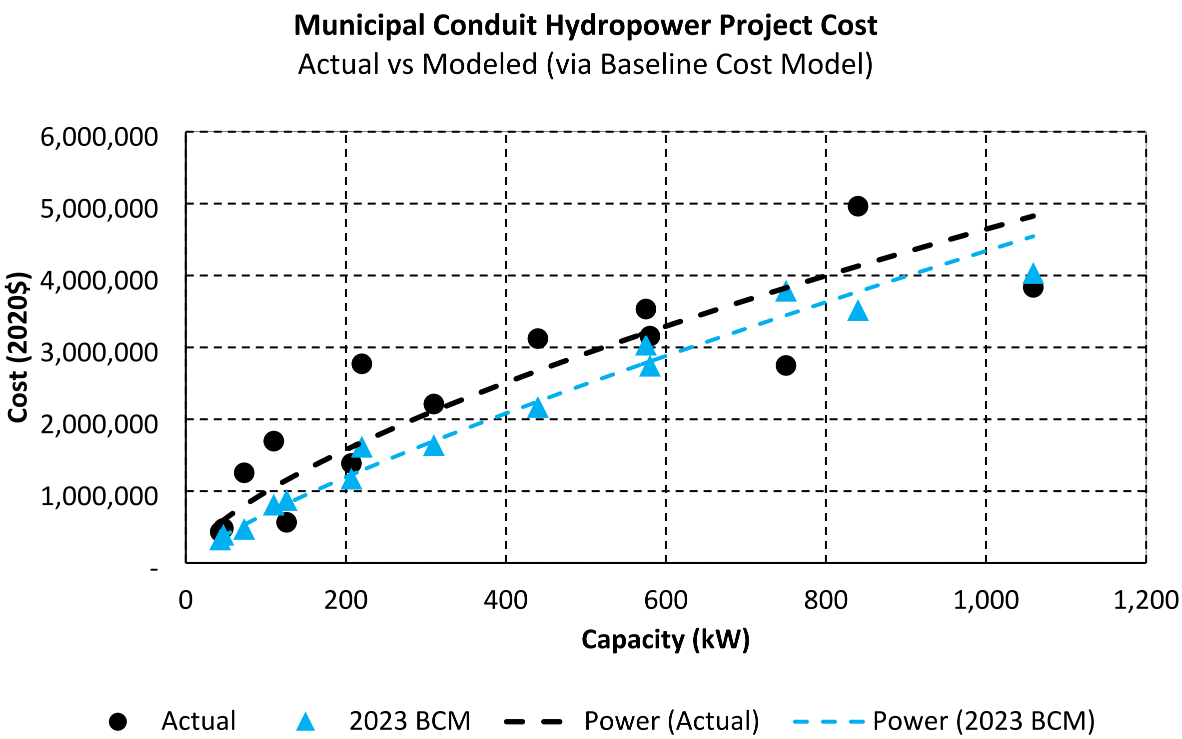
<<Figure 1>>


Municipal Conduit Hydropower Capacity Potential
WA
OR
CA
ID
NV
MT
WY
UT
CO
AZ
NM
ND
SD
NE
KS
OK
TX
MN
IA
MO
AR
LA
WI
IL
MI
IN
OH
KY
TN
MS
AL
GA
FL
SC
NC
VA
WV
PA
NY
NJ
MD
DE
CT
RI
MA
VT
NH
ME
AK
HI
Capacity Potential (MW)
No Data
< 1
1 - 5
5 - 10
10 - 25
≥ 25
OAK RIDGE
National Laboratory

<<Figure 2>>


Project development phase
Stakeholder Engagement
Site Selection and Feasability Assessment
Design and Technology Selection
Permitting and Licensing
Financing and Power Sales
Construction and Supply Chain
Operations and Maintenance
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Mean level of challenge
0: low | 5: high
Project Developer
Technology Developer
Utility
Asset Owner

<<Figure 3>>


Municipal Conduit Hydropower Project Cost
Actual vs Modeled (via Baseline Cost Model)
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
-
Cost (2020$)
0
200
400
600
800
1,000
1,200
Capacity (kW)
Actual
2023 BCM
Power (Actual)
Power (2023 BCM)

<<Figure 4>>