Applying Multi-objective Evolutionary Algorithms to Modernize and Optimize Dam and Reservoir Operations in the Columbia River Basin
(Technical Topic)

Defining a Framework for Public Utilities to Ensure Economic Viability through Ethical Price Point Setting
(STS Topic)

A Thesis Project Prospectus Submitted to the

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Bachelor of Science, School of Engineering

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

Since settling in the region, both in modern and pre-modern times, humans have established a deep dependence on the Columbia River. This is a stark contrast to usual human behavior of bending nature to their whim. Instead, society and the Columbia River have coexisted, with people dependent on the system in a multitude of ways. These include electric and water supply needs, navigation, historical and culture relevance, recreation, and an ecosystem defining species in salmon (U.S. Bureau of Reclamation). These many dependencies lead to a complicated system in an unstable balance. Current hydrology practices in this system are many years outdated as they fail to implement information technology advancements, with the health of the entire system at risk. Operations are well below optimal standards. This shortcoming is understandable when viewing the deep complexity of multi-objective systems (Reed et al., 2013).

In order to focus on a project of such large scale, the prospectus will consider two major topics. As competition to hydroelectric power strengthens, steps must be taken to ensure it does not fall out of favor for wind and solar power (Su et al., 2017). In order to do this, the reigning authority over the system, the Bonneville Power Administration (BPA), must find an ethical, fair, and economically viable way to set its price point to customers. Through viewing similar cases and the human factors specific to the system, this prospectus aims to set a framework to aid the BPA, a private corporation supplying public utilities, in setting stable and considerate pricing for their own long-term viability. Building off financial implications, the BPA must also confront its technological shortcomings and adopt a systems, data-aided approach to their operations. Without an overhaul of dam and reservoir operations, forecasts expect at least one of their objectives to fail (Jones, 2020). In order to avoid a catastrophe in any of the previously

mentioned objectives, this prospectus will propose how to integrate Multi-objective Evolutionary Algorithms (MOEA) into hydrology infrastructure operations.

Technical Topic: Applying Multi-objective Evolutionary Algorithms to Modernize and Optimize Dam and Reservoir Operations in the Columbia River Basin

To ascertain why MOEA can benefit the operations of the Columbia River system, this prospectus will first aim to understand multiple objectives. The available water supply is determined by rainfall throughout all Columbia's tributaries which is subject to seasonal and yearly variances. This water supply is reduced to generate electricity, optimally only enough electricity to meet market demand. Yet discovering such optimal levels poses a great challenge as peak demand changes not only throughout the day but also the year ten reservoir Federal Columbia River Power System (FCRPS), detailed in Figure 1, make up 91% of the hydroelectric energy generation in this system (Tan, 2017, p.72). The river's water flow must also not fall below a certain threshold to allow seasonal salmon runs, keeping the Columbia as one of the world's most productive salmon fisheries (Aillery, 1999, p. 16). Meeting these three objectives, water supply resiliency, electricity production optimization, and salmon population health simultaneously, calls for advanced methods. The consequences of failure in any of the three objectives are tangible to the region and are the driving force behind the improvements expected from MOEA. Flood protection, recreational usages and navigation are also considered when

operators affect the water supply, however they are not the focus of this prospectus.

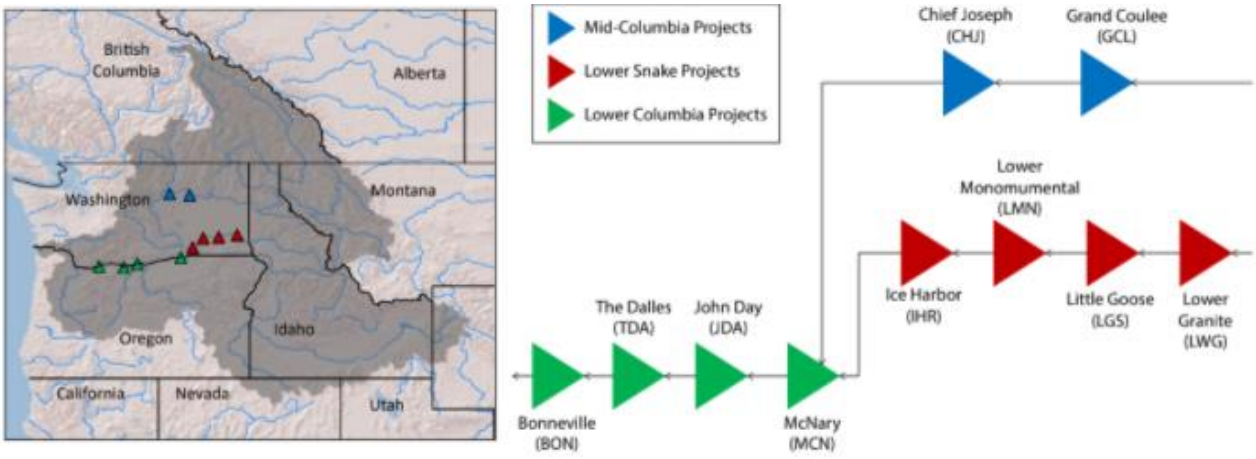

Figure 1: Overview of the 10 reservoirs in the FCRPS (Quinn, 2020). This schematic provides both a geographical view and a reservoir to reservoir layout.

The adoption of MOEA's have been slow and gradual for a number of reasons. Tenured reservoir operators are hesitant to follow anything besides their own judgement and the simulation models they are comfortable with. However, with advancements in computing and information technology, researchers expect optimization models to not just be a theoretical solution but a real-life improvement to these operations and usable for operators (Labadie, 2004, p.94). Evolutionary algorithms have been around since the 1960's in the fields of genetic algorithms and evolutionary strategies. By using an "iterative search process to modify and evolve a population of candidate solutions… particularly effective at solving nonlinear, nonconvex, multi-modal and discrete multi-objective problems" (Quinn, 2017, p.130), MOEA's are computationally exhaustive even past a few objectives. Two multi-objective methods have been applied using this iterative evolutionary approach. Intertemporal methods optimize a time series, in this case the water released at each reservoir. Direct policy search (DPS) differs as it does not aim to optimize the release of water but rather the reservoir policy as a function of the system state. Because DPS is able to reevaluate the system state with new information, it is more

adaptive and responsive yielding solutions that consistently outperform the intertemporal method either in maximizing reliability or benefits or both metrics (Quinn, 2017, p.132).

DPS considering the system state throughout the process is also helpful for another reason that has been identified as a growing uncertainty for the Columbia River System. Climate change is expected, as a modest estimate, to double the yearly probability of electric supply shortfall. Seasonality of shortfalls is also expected to shift to winter months, increasing the winter months' shortages in magnitude and frequency (Turner, 2019, p.3). While climate change might be the specific force beneath growing uncertainty, MOEA's and specifically DPS methods respond well to any uncertainty regardless of the source. For this reason, in conjunction with their success at optimizing the listed objectives at the current state, MOEA's are the clear future for the Columbia River System. While it is important to understand the limitations of computational methods and the information modelers can provide, MOEA's can be directly fed the intent of the decision makers and still allow for operators to use their experience. The STS portion of the prospectus will elaborate further, but the BPA is willing and able to embrace methods that improve their performance in any way, and MOEA's have the potential to provide stability for the Columbia River's complex system.

STS Topic: Defining a Framework for Public Utilities to Ensure Economic Viability through Ethical Price Point Setting

In the United States, governments allow, with supervision, private monopolies on public utilities usually operating in a single state. Given that the Columbia River Basin encompasses much more than just energy production, the BPA does not follow this template. It is a government agency, a subsidiary of the U.S. Department of Energy in the Pacific Northwest Region producing electricity mostly through the Columbia River. The BPA, beyond representing

the needs of the government, publicly takes into consideration the needs of its customers, the land and environment itself. Finding a balance between its stakeholders, the agency aims for long-term economic viability while still considering its social and ethical responsibilities (BPA 2018-2023 Strategic Plan). This provides useful insight into the problem context: a considerate and self-conscious agency in control of pricing over a monopolized public utility has no obvious method in setting its price point.

BPA's ability to set a fair and stable price point is a necessity as wind and solar power becomes more affordable and prominent in the market. When oversupply events occur, times at which operators are forced to run turbines, wind producers are usually asked to stop production and BPA must compensate them for their losses. Eventually, this cost is still passed on to the consumer (Su et al., 2017, p. 174). Paying money to one of their competitors, especially with the frequency and magnitude of oversupply events expected to increase, is not a blueprint for continuous economic viability. However, as climate change threatens an increasing variance in hydrometeorological processes, models for pricing are conducted with the goal of optimizing "how much generators would be paid to sell their electricity in each hour" (Su et al., 2020, p.4). Strangely, the BPA is conducting its pricing modelling as if it were a private entity with the goal of optimizing profits when, as previously mentioned, it is not their sole objective.

This prospectus proposes a new way of finding economic viability for the BPA. By producing 60% of the region's hydroelectric power, the BPA carries immense market power. "Other utilities are 'price-takers' who make their decisions based upon the market price, which they cannot affect," according to Tan (2017, p. 73). As explained in the technical portion, often times reservoir operations demand that, to meet other objectives, water be allowed to flow. This sometimes yields an energy surplus in the market and causes the scenario where BPA must pay

competitors, described in Figure 2. Ideally, optimized reservoir practices will reduce these occurrences, however BPA can also respond differently. A method proven to be successful in Texas is increasing transmission capacity to reach new markets, in this case natural gas dependent California (Su et al., 2017, p. 180). High variations in natural gas prices drive California's energy market, and in the hopes of spending to avoid losses, the BPA could flatten prices for consumers in an additional market. Their current market would also benefit, with renewable options able to gain a larger, stable market share and become increasingly viable when competing with the outgoing fossil fuel industries.

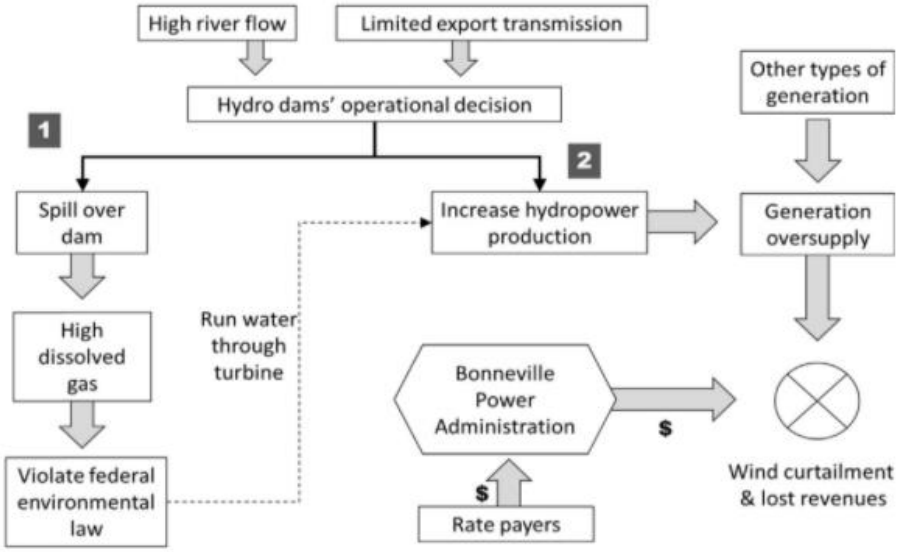

Figure 2: Overview of Oversupply Events Limiting the BPA's Viability (Su, 2017, p. 174). The occurence of oversupply events is simplified in the prospectus but is the end result of a longer process.

The BPA has heavily considered this option. However, this is just one example of proactive solutions that the BPA, and other federal agencies in similar situations, should pursue. The aforementioned example is beneficial in many facets, to many stakeholders. The BPA, while not required to drive a profit, can stabilize their ability to do so. This protects taxpayers from subsidizing their operations. Economically speaking, consumers benefit from increased

competition. While that might not seem immediately in line with the BPA's goals, as a federal agency, it serves the American people's best interests. Additionally, in the context of assuring economic viability, the technical topic's modeling technique has one less goal to consider which drastically improves its ability. This approach requires multiple government and corporate entities to work together and often some creativity. But with decision makers willing to view their organization's goals in broader context and realize that their stakeholders' benefit is also their own, this ethically responsible framework can yield immense success.

Conclusion

This prospectus has discussed only a limited number of objectives and considerations encompassed by the Columbia River System. In reality, there are many more that add to the complexity experienced in both topics. The decision makers in both contexts appear to confront these challenges. While mostly in the research phase, MOEA's promise reservoir operators long term success in meeting their multiple and varied objectives. And the BPA is considering creative solutions that allow for the growth of other renewable energy sources as well as their own, realizing that the BPA's benefit is often derived from other parties. The ideas proposed in this prospectus aim to build the optimal Columbia River Basin, one that is healthy, resilient, and inclusive of all parties. For a system so important for the environment and ingrained into culture and society, optimizing the Columbia River is a necessity.

Word Count: 1852

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