2024 Hydropower Collegiate Competition

Initial Design Report

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NORTHERN ARIZONA UNIVERSITY

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DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

EXECUTIVE SUMMARY

Northern Arizona University's mechanical engineering capstone team is competing in the 2024 Collegiate Hydropower Competition. The competition is structured around siting a non-powered dam (NPD) that has the potential to be converted into a hydropower dam. The competition features a siting challenge, design challenge and a community connections challenge. The siting challenge is where potential sites will be evaluated and eventually chosen based on the challenge requirements for power generation between one and ten megawatts. For the design challenge, an overall conceptual design of the full powerhouse will be modeled. Finally, the community connections challenge will connect the team to the hydropower community, students, and the local Flagstaff community. Members of our team have traveled to Clean Currents 2023 conference in Cincinnati, Ohio, and gained valuable connections with professionals in the hydropower industry. The mechanical engineering team and the electrical engineering sub-team have utilized various software such as Oak Ridge National Laboratory's NPD Explorer and ArcGIS Pro software to map out potential dam sites.

The project's design is driven by six key customer requirements, emphasizing effective risk mitigation, cost optimization, environmental impact mitigation, scalability, efficient energy production, and community engagement. These requirements were carefully quantified and equipped with specific targets to ensure alignment with the customer's needs and competition standards. Engineering requirements are the technical prerequisites guiding the project, and each is quantifiable with specific targets. These requirements include energy output (1-10 MW), aquatic ecosystem preservation, plant efficiency, hydrologic data utilization, feasibility, and site interconnectivity. The House of Quality (QFD) provides a tool for understanding the correlations between customer and engineering requirements. Through systematic assessments, we rated the degree to which each requirement influences others and established their absolute technical importance. The insights gained have helped us make well-informed decisions and understand how changes in one technical requirement impact other aspects of the project.

Throughout the rest of the report, we delve into the mathematical modeling, literature review, benchmarking, and decision matrix selection criteria. This extensive exploration forms the bedrock of our project. The mathematical modeling section lays the foundation for our design by applying mathematical principles, hydropower engineering theories, and environmental impact assessments. Concurrently, our literature review provides a comprehensive overview of existing research and technical resources, incorporating valuable insights from previous work in the field. We leverage this knowledge to ensure our project builds upon the expertise of past researchers and engineers.

As we advance, the report unveils the results of our benchmarking efforts, unveiling industry best practices and areas for improvement. The functional model offers a visual representation of the project's critical functions and processes, providing clarity regarding how the system operates. The concept generation phase is guided by a set of established selection criteria, enabling us to identify the most promising ideas and innovations. Our evaluation of each concept using these criteria is presented, marking a clear direction for our project's development. Additionally, we present the current state of our CAD drawings, showcasing the tangible progress made toward realizing a transformative hydropower project. At the time of writing this document, our project has achieved significant milestones and is pushing forward in the Siting Challenge and Design Challenge.

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1 BACKGROUND

This chapter lays the foundation for our capstone project, which is structured within the parameters of the Hydropower Collegiate Competition (HCC) and NAU's capstone course. Our problem statement, which is in line with the core objectives of the HCC, states that we want to locate and convert a non-powered dam (NPD) into a hydroelectric plant. Examining the deliverables, we determine the essential milestones that direct the development of our project and group them into tasks that are specific to the competition, the client, and the course. In addition, we establish the success metrics, which include a variety of competition-based elements and will ultimately determine the project's success.

1.1 Project Description

Our capstone project is a dynamic response to the Hydropower Collegiate Competition (HCC), a distinguished platform sponsored by the United States Department of Energy's (DOE) Water Power Technologies Office (WPTO). The HCC wants our interdisciplinary team of undergraduate and graduate students to actively participate in their described sequence of various competition challenges that have the potential to change the hydropower industry. With this, our primary goal is to select and convert a non-powered dam (NPD) to a hydroelectric dam, which falls under the mandate of the HCC. This topic resonates with the hydropower industry's current demands and untapped potential, as it contains a possibility to harness clean energy from over 80,000 NPDs in the United States. Additionally, our project aligns perfectly with the broader HCC and federal government's goal to attain a carbon-pollution-free power sector by 2035. With this, we aim to efficiently create sustainable electricity while assisting local communities by repurposing existing infrastructure.

In addition to the competition, our project serves as our capstone initiative, which requires us to adhere to a strict budget and fundraising goals. The HCC provides an established funding schedule, which we will strictly adhere to. It includes cash incentives of up to $20,000 for participating in various competition phases, ensuring that our project has the resources to proceed forward effectively. Our budget and fundraising strategy includes working with our faculty advisor, Carson Pete, who will help with financial planning and resource allocation through organizations like Equal Partners in Inclusive Community (EPIC) and National Renewable Energy Laboratory (NREL). By adhering to the funding schedule, securing additional financial support, and aligning with the clean energy objectives of the HCC, we are able to make a meaningful impact in the field of hydropower. Our project demonstrates not only our commitment to sustainability, but also our dedication to inspiring the next generation of engineers who will drive the clean energy revolution ahead.

1.2 Deliverables

The deliverables for our project can be divided into three categories: competition-specific, client-specific, and course-specific. These deliverables enable a seamless integration of our academic course requirements, the demands of our client (The US Department of Energy) and the objectives of the competition. They also serve as milestones to steer the project's progress. In this section, we elaborate on these deliverables, offering a disciplined framework for carrying out our capstone project successfully.

1.2.1 Course Deliverables

Our academic course requirements mandate the fulfillment of numerous deliverables, which include:

1. Staff Meetings: Periodic updates on project progress, difficulties encountered, and potential solutions are provided during staff meetings, assuring compliance with the goals and milestones of the course.
2. Oral Presentations: As part of the academic assessment process, scheduled presentations to the course instructors and classmates highlight the project's development, outcomes, and conclusions.
3. Written Reports: Complete project reports that outline the research, methodologies, findings, and recommendations in order to demonstrate academic proficiency and understanding of the project's intricacies.

1.2.2 Client Deliverables

These deliverables are designed to meet the expectations and requirements of our Faculty Advisor, Carson Pete, who plays a critical role in guiding and supervising the team throughout the course and the competition:

1. Regular Team Updates and Meetings: The team will schedule regular meetings with the Faculty Advisor to provide updates on project progress, discuss challenges, and receive guidance and feedback.
2. Advisory Support: The Faculty Advisor will provide advisory support to help students develop the skills necessary to compete effectively in various aspects of the competition.
3. Guidance on Compliance: The Faculty Advisor will ensure that the team's activities and deliverables align with the competition's guidelines and requirements.
4. Communication Liaison: The Faculty Advisor will serve as the primary point of contact between the team and the competition Prize Administrators, disseminating relevant information and ensuring clear communication.
5. Assistance in Decision-Making: The Faculty Advisor will offer guidance and insights to assist the team in making critical decisions related to the project, challenges, and competition strategies.
6. Input on Project Planning: The Faculty Advisor will provide input on project planning, budgeting, and fundraising targets, ensuring alignment with the course and competition objectives.

1.2.3 Competition Deliverables

The Hydropower Collegiate Competition (HCC) encompasses various challenges, each with specific deliverables that contribute to our overall participation in the competition. These deliverables are classified into midyear submissions and presentations for the various challenges. Here, we outline the major deliverables required for each challenge in the competition:

1. <u>Siting Challenge:</u>
    a) Midyear Submission: The Site Selection and Justification document that includes the team’s down-select process in determining a site, risk identification, and the approach to

minimizing risk.

b) Presentation: Teams will present their Siting Challenge and Design Challenge results.

c) Poster: A visually appealing poster representing their Siting Challenge and Design Challenge activities.

2A. Design Challenge (Track 1 - Facility Conceptual Design):

a) Midyear Submission: The Design Selection and Justification document that details the selected design challenge, planned approach, associated risks, and risk management strategy.

b) Presentation: Teams will participate in a presentation describing their design activities.

c) Poster: A visually appealing poster summarizing their Siting and Design Challenges.

****OR****

2B. Design Challenge (Track 2 - Hydropower Component Deep Dive):

a) Midyear Submission: The Design Selection and Justification document, similar to Track 1.

b) Presentation: Teams will participate in a presentation describing their design activities.

c) Poster: A visually appealing poster summarizing their Siting and Design Challenges.

*** **Note:** Whether we choose 2A or 2B as Design Challenge deliverables will depend on our project's direction and objectives heading into the end of the semester, as we've directed most of our focus towards the siting challenge over the first half of this semester. ***

3. Community Connections Challenge:

a) Midyear Submission: This includes the team roster, team story, and details on the team's project, objectives, and game plan. Additionally, hydropower industry interview slides and thoughts on the competition experience are required.

b) Presentation: A presentation showcasing the team's community engagement activities and educational webinars, if applicable.

4. Optional Build and Test Challenge:

a) Midyear Submission: Teams opting for this challenge will need to submit a Build and Test Strategy document outlining their proposed testing and experimentation strategy, materials to be purchased, risk identification, and risk minimization strategies.

b) Presentation: A presentation describing their build and test activities, including video footage or photographs of testing and/or experimentation.

By explicitly outlining these deliverables, we establish a comprehensive framework for our project execution. These deliverables ensure that we achieve both academic standards and competition objectives, as well as the expectations of the Hydropower Collegiate Competition.

1.3 Success Metrics

Several crucial parameters that coincide with the competition's main aims and objectives will determine the success of our project in the Hydropower Collegiate Competition. The following are the essential success metrics that align with the overarching goals and objectives of the competition:

1. Performance Testing: Our prototype will undergo extensive testing in real-world settings to assess this. The ability to generate electricity within the designated range of 1–10 MW, power generation capacity, and system efficiency are the main characteristics that need to be evaluated. Our capacity to attain and maintain the desired power output under a range of operating situations will serve as the yardstick for success in this respect.
2. Cost Efficiency: Extensive cost assessments, encompassing capital and operating expenditures, will be undertaken to ascertain this. Our capacity to provide a solution that maximizes costs within the specified restrictions and produces clean electricity will serve as a barometer of our success in this field.
3. Environmental Impact: Reducing negative effects on the nearby ecology, making sure water is used efficiently, and using eco-friendly products and technology are all part of our site's environmental sustainability. Compliance with sustainability standards and adherence to environmental regulations will be key indicators of success.
4. Community Engagement: Given the Community Connections Challenge, our success will be influenced by our ability to foster strong connections with local communities and industry professionals. Our ability to effectively communicate with stakeholders, explain the advantages of hydropower, and inform the public about clean energy options will be an indication of our success in this project.
5. Safety and Reliability: To ensure sure that our infrastructure will operate safely under a variety of circumstances, everything will be evaluated using risk assessments and strong design computations. The system's ability to adhere to strict safety requirements will serve as a sign of success.
6. Competition Objectives: This includes the successful completion of all deliverables for the Siting Challenge, Design Challenge, Community Connections Challenge, and the Optional Build and Test Challenge. Our ability to meet these deliverables based on the scoring criteria outlined in the HCC rubric, as well as our ability to effectively present our work, will determine our success and competition placement.

Each of these measures will be carefully handled and quantified as the project advances, resulting in the establishment of a successful and sustainable hydropower project.

2 REQUIREMENTS

Moving forward with the project our team had to identify the project requirements, and specifically those set by the completion deliverables. These requirements, including energy output and feasibility, are the technical prerequisites that will enable us to meet the customer's expectations and competition standards. The final subsection, Section 2.3, unveiled the House of Quality (QFD), a pivotal tool in understanding the relationships between customer and engineering requirements. The knowledge gained through these sections illustrates the critical significance of our requirements, highlighting why they are the cornerstones of our project's success.

2.1 Customer Requirements (CRs)

This section examines the fundamental customer requirements that form the basis for the project. These requirements are critical in establishing our strategy and determining the project's success using the metrics outlined in Section 1.3. The ranked customer requirements outlined below define the important components of the project that must be followed, ensuring compliance with competition deliverables and laying the groundwork for a sustainable and impactful hydropower conversion.

1. Effective Risk Mitigation: While feasibility is crucial, teams will be scored based on the thoroughness and transparency of their assessment, allowing for a high score if reasonable assumptions are made and the quantitative analysis is accurate. Therefore, this requirement calls for a thorough assessment of the selected non-powered dam site, focusing on how and why the location was chosen and the identification and mitigation of potential risks related to power generation systems' installation. Risks include high-level costs, resource and generation availability, dam safety, grid integration, transportation access, environmental factors, cultural effects (e.g., historical landmarks), etc. The project should demonstrate a comprehensive evaluation of the site's suitability and provide insights into the decision-making process.
2. Cost of Development/Economic Viability: Cost is a critical aspect of the project, focusing on budget adherence and fiscal responsibility. Furthermore, economic viability must be evaluated, with an emphasis on the project justifying a return on investment for stakeholders and the community. To ensure an economically feasible solution, the cost of development should be optimized while considering elements such as startup capital, operational expenses, and long-term profitability.
3. Environmental Impact Mitigation: To meet this requirement, the project should focus on minimizing the environmental impact of hydropower dam conversion. This includes strategies for ecological conservation, reduction of negative effects on local ecosystems and habitats, efficient water use, and adherence to environmental regulations and sustainability standards.
4. Scalability/Co-Development: Scalability remains an essential requirement, ensuring that the project has the potential to be adapted and expanded to different geographical locations or other non-powered dams. These co-development opportunities include but are not limited to hybrid designs (combining wind, solar, etc., with hydropower), environmental improvements, recreation, species rehabilitation, tourism, workforce development/education, and more. The project must explore and outline how these opportunities can be integrated with hydropower, ensuring adaptability and scalability to other geographical locations or non-powered dams.
5. Energy Production: This requirement entails the primary objective of the project – generating

electricity efficiently. The system should be designed to produce a specific range of energy, ideally within 1 to 10 megawatts (MW), adhering to the competition standards. The energy production should also be sustainable and reliable, ensuring a consistent power output within the specified range under various operating conditions.

6. Community Engagement: In line with the Community Connections Challenge, the project must actively engage with the local community, industry professionals, and stakeholders. Effective communication, educational webinars, and community outreach programs should be employed to inform and engage the community in the benefits of hydropower and clean energy alternatives.

These customer requirements define the key objectives of the project, serving as a roadmap for meeting the expectations and standards set by the Faculty Advisor, Carson Pete, the Hydropower Collegiate Competition, and the capstone course. In the subsequent sections, a detailed House of Quality (QFD) is provided, correlating these customer requirements with the engineering requirements explored in Section 2.2. By fulfilling these requirements, the project aims to create a sustainable and impactful hydropower solution while meeting academic and competition objectives.

2.2 Engineering Requirements (ERs)

The engineering requirements serve as the backbone of the project, guiding its design and development to meet the essential criteria set by the competition. Each requirement is carefully quantified, equipped with specific targets, and aligned with the corresponding customer requirements. Each of the engineering requirements below are the cornerstones of the project's technical success, interwoven with customer demands for energy production, environmental impact mitigation, economic viability, and scalability.

1. Energy Output: This requirement focusses on the primary objective of the project, which is to generate electricity efficiently within the range of 1-10 MW. Achieving this target ensures alignment with the customer's demand for energy production. It also correlates with customer requirements regarding economic viability, as meeting this energy production goal is essential for a return on investment.
    a. Units: Megawatts (MW)
    b. Target: 1-10 MW as specified by the competition standards
2. Aquatic Ecosystem Preservation: The team is dedicated to preserving aquatic ecosystems surrounding hydropower dam sites, with the aim of minimizing the impact and preserving as many square miles of habitat as possible. This engineering requirement, quantified in square miles, necessitates comprehensive data collection and analysis, employing tools like flow duration curves and hydrological modeling to assess the project's environmental impact. However, quantitative data alone cannot address the complete spectrum of aquatic ecosystem preservation; consequently, qualitative assessments will be required to achieve this technical requirement. Water temperature management, shoreline vegetation preservation, seasonal/daily flow changes, and other factors will all necessitate qualitative assessments.
    a. Units: Square Miles
    b. Target: Minimize the impact on aquatic ecosystems to preserve as many square miles of habitat as possible
3. Plant Efficiency: Efficiency is a critical engineering requirement that ties into customer needs for energy production and environmental impact mitigation. Achieving high turbine efficiency is vital for maximizing power output, ensuring that energy production is reliable. The capacity factor is also an

indicator of the system's efficiency in producing power relative to its maximum potential. Meeting these efficiency targets will be essential for calculating the Levelized Cost of Energy (LCOE) and evaluating the project's feasibility.

  a. Units: Percentage (%)
  b. Target: Turbine Efficiency > 70% & Capacity Factor > 30%

4. Hydrologic Data Utilization: This engineering requirement relates to customer needs for hydrologic engineering data. The effective utilization of hydrologic data, including streamflow information and flow duration curves, is crucial for site selection, design, and assessing environmental impact. Accurate use of hydrologic data will be instrumental in performing calculations related to flow curves, spillway design, and water resource assessments.
   a. Units: Cubic Feet per Second (cfs)
   b. Target: Accurate utilization of hydrologic data, as required for project design and environmental impact assessment.
5. Feasibility: The feasibility engineering requirement focuses on determining the project's financial viability. It comprises a thorough examination of project costs, financial projections, and investment returns to ensure the project's economic viability. The team will evaluate the minimum cost of generating to market-level factors such as baseload power pricing using financial modeling and computations such as the Levelized Cost of Energy (LCOE) and Power Purchase Agreements (PPA). This study is crucial to meeting customer expectations and establishing the hydropower project's economic viability, while also ensuring that development costs are minimized and a return on investment is justified for stakeholders and the community.
   a. Units: 2023 US Dollars ($)
   b. Target: A feasible project with a return on investment justifiable through cost optimization.
6. Site Interconnectivity: Site interconnectivity is essential for effective power distribution and grid integration. Achieving the target in MW ensures that the project can interconnect with the grid and contribute power effectively. This engineering requirement aligns with customer requirements for scalability and community engagement, as grid interconnectivity enables the project to adapt and expand to different geographical locations and engage with local communities through effective power distribution.
   a. Units: Megawatts (MW)
   b. Target: Ensure grid interconnectivity with a capacity of MW.

These engineering requirements are not isolated elements; they are interconnected facets that will be central to the successful completion of the hydropower project. The House of Quality (QFD) will highlight the relationship between these engineering criteria and the related customer demands in the following section, offering a formal framework for evaluating how well the project design matches with customer expectations.

2.3 House of Quality (QFD)

In our pursuit of designing an effective and well-structured hydropower project, we have created a House of Quality (QFD) diagram, which can be found in **Appendix A.1**. Our analysis has revealed significant insights into the technical importance of each engineering requirement relative to the customer needs, reflecting the challenges and priorities inherent in our project. Our initial focus during this study was on evaluating the correlations between each engineering requirement and how they relate to other technical criteria. By using a systematic rating system that includes strong positive correlations ("++" QFD cells), positive correlations ("+"), no correlation (blank QFD cells), negative correlations ("-"), and strong negative correlations ("--"), we were able to precisely determine the degree to which each requirement influences other technical aspects of the project. For example, boosting energy output could have a beneficial effect on plant efficiency (labeled with “++”) but a negative effect on the maintenance of aquatic ecosystems (labeled with “-”). This degree of specificity and the interdependencies between the needs are crucial for helping us make well-informed decisions during the project's design and development. It also helps us understand how changing one technical requirement can have an impact on other project components.

To determine the relative importance of each engineering requirement, we assigned numerical values to their associations with the customer needs, including strong associations marked as 9, medium associations rated at 6, weak associations designated with 3, and no associations represented by blank cells in the QFD. These ratings were calculated based on the correlations between the engineering requirements and the customer needs, as established during the QFD analysis. As we examined the correlations between customer needs and engineering requirements, it became evident that feasibility, assessed in 2023 dollars, holds the highest absolute technical importance score of 721.3. This high ranking of relative technical importance is not only a reflection of its intrinsic importance but also stems from its strong alignment with customer needs. Assessing the site’s feasibility directly addresses critical customer concerns related to risk mitigation. validating its worth in terms of return on investment and associated risks. In the case of site interconnectivity, its high ranking acknowledges its vital role in aligning with customer requirements for scalability and community engagement. A high score for aquatic ecosystem preservation underscores our strong commitment to minimizing environmental impacts, which is essential for the sustainability and reputation of the project.

These findings are invaluable in prioritizing our technical efforts and allocating resources effectively to address customer needs and meet competition expectations. The QFD diagram not only provides us with a clear understanding of these relationships but also guides us in setting targets, constraints, and ultimately, designing a hydropower project that successfully aligns with the demands of our customers and competition criteria. Going forward, this QFD will remain a pivotal tool for tracking our project's progress and ensuring we meet the key requirements of our stakeholders, while section 3.1, Benchmarking, will delve further into benchmarking analysis, offering an additional dimension of comparison and validation for our project's performance and technical importance.

3 Research Within the Design Space

3.1 Benchmarking

[Describe System-level benchmarking identifying at least three systems that you consider state-of-the-art. Describe all other sub-system-level benchmarking. Cite each benchmarked system/sub-system per IEEE citation style.]

- Headgate Rock Dam
- Red Rock Dam

3.2 Literature Review

A comprehensive literature review is an essential phase in any research project, as it establishes a strong basis by identifying the existing knowledge and the gaps that the project aims to address. Under this circumstance, thorough research and annotation is critical to our decision-making process in selecting a site, determining its feasibility, and developing new hydropower design components. It is crucial that we evaluate the current hydropower landscape, the components involved, and the potential hurdles in order to effectively traverse these complex competition challenges. With this, our group began this semester by completing extensive research on hydropower and an in-depth review of the competition rules document. In the subsections that follow, we explore each team member's literature review of sources, which includes books, peer-reviewed papers, and additional resources such as online articles, videos, testing codes, and more.

3.2.1 Evan Higgins

Books:

1. "The Guide to Hydropower Mechanical Design" [1]

   This comprehensive reference offers a detailed exploration of mechanical design aspects, components, and design considerations in hydropower systems. It covers critical topics such as turbine selection, material choices, and mechanical design practices. Our focus on repurposing non-powered dams (NPDs) into hydroelectric dams requires an in-depth understanding of mechanical design to ensure system efficiency and sustainable energy generation. This source will be instrumental in our component selection and design choices.

2. "Design of Hydroelectric Power Plants – Step by Step" [2]

   This textbook serves as a useful resource for understanding the planning and design phases of hydropower projects. It covers various aspects, including types of studies, layouts, conveyance, and equipment considerations. By providing a step-by-step method to project creation, we have an industry-standard guide to planning and designing our NPD conversion, which is critical to the success of our campaign.

Papers:

3. "Design models for small run-of-river hydropower plants: a review" [3]

This paper discusses modest run-of-river hydropower plant design models and considerations. It discusses critical components such as penstock design, turbine choices, and cavitation models. This source is useful for our HCC project as it gives certain design models that we may use to our project. Our goal of repurposing NPDs into hydropower dams necessitates comprehensive design considerations, and the insights in this study will help us make educated design decisions.

4. “A high-resolution hydro power time-series model for energy systems analysis: Validated with Chinese hydro reservoirs” [4]

   The paper presents a high-resolution hydro power time-series model for energy system analysis that has been tested using Chinese hydro reservoirs. It includes models and graphs that can be used to analyze energy systems, such as power production modeling and daily inflow statistics. This source is important for our HCC research since it helps us analyze energy systems. It enables us to predict electricity generation, evaluate inflow data, and optimize our system while taking wind, solar, and carbon reduction into account.

5. “Hydropower development potential at non-powered dams: Data needs and research gaps” [5]

   This source analyzes the possibilities for hydropower development at non-powered dams, emphasizing data requirements and research gaps. It provides insights into emerging technology, socioeconomic factors, and successful NPD retrofit initiatives. Our HCC project closely resonates with this source because we are committed to converting NPDs into effective hydropower dams. This reference provides us with a variety of knowledge spanning from technological breakthroughs and economic evaluations to an in-depth understanding of the numerous parties engaged in the hydropower development process.

Other:

6. “ASME PTC 18-2011” [6]

   The performance testing and measurement guidelines for hydropower systems are included in this publication, ASME Performance Test Codes. It describes the requirements to guarantee effectiveness and performance. This reference is essential to our HCC project because it acts as a performance testing guide. It assists us in making sure that our hydropower system satisfies industry standards and runs effectively.

7. “Hydropower dams make a fish-friendly slash” [7]

   This website article provides important insights into the ecological aspects of hydropower, focusing on the abundance of hydropower plants in Europe and their effects on upstream fish migration. Since the goal of our HCC project is to convert NPD into sustainable energy, understanding ways of assessing the ecological impact is crucial to the accuracy of our site assessment. We can decide on the ecological viability of our project by carefully considering the data linked to fish-friendly hydropower measures and the findings in the article.

8. “How a hydro generator works” [8]

   This animated YouTube video is a great way to get visual help for understanding the fundamentals of hydropower systems. It provides a thorough grasp of the essential elements and processes involved in the production of hydropower. This document helps our HCC project by providing an explanation of these basic principles to external stakeholders as well as team members. It is essential for laying the groundwork for a solid grasp of hydropower and for efficient project comprehension and communication.

3.2.2 Riley Frisell

[Create an annotated bibliography of your references for the project. This is simply the reference title followed by a paragraph summarizing the material in the reference and how it applies to your project. Cite each reference per IEEE citation style. Separate sections per student along with their name (Example: 3.2.1 John Doe). At this point you should have ***7+ references per student****.]*

**PUT REFERENCES IN NUMERICAL ORDER THROUGHOUT REPORT*

Books:

1.

Papers:

2.

Other:

3.

3.2.3 Trevor Senior

Books:

1. "Small Hydropower Design and Analysis" [19]

   This book is a powerful resource for many design aspects of a hydropower dam, specifically on the smaller scale which our project is based on. The book provides detailed classifications of components, and multiple approaches to dam design based on head, discharge and flow and capacity analysis.

2. "Renewable Energy Volume 131" [20]

   This textbook helps with calculations relating to fluid dynamics. There is information on head losses, volumetric flow rate and applying them to analyze the arrangements of system components inside a hydropower dam. It will especially be useful in the coming weeks as we being to gather flow data on our selected site.

Papers:

3. "Combined-Cycle Hydropower Systems – The potential of applying hydrokinetic turbines in the tailwaters of existing conventional hydropower stations" [21]

   This paper includes an in-depth analysis of the feasibility of the addition of hydropower generators and the math that is needed to validate these selections. This recourse also includes other types of renewable energy generations which can be used to validate our selections and will also benefit our design by giving us ideas for additional sustainable energy generation at the site.

4. "Non-Stationary Hydropower Generation Projections Constrained by Environmental and Electricity Grid Operations Over the Western United States" [22]

This paper provides research on the electricity grid and how current proposed additions to hydropower generation would impact the current electric grid. Since our dam selection is close to transmission lines, this recourse will be vital to the proposed integration of new electric generation into the grid.

5. “Dams and Tribal Loss in the United States” [23]

   This paper identifies areas where misuse of land and property have taken place. Specifically, it researches the ownership of dams and talks about how the United States has acquired the land which current dams have been built upon.

Other:

6. “Oak Ridge National Laboratory Website – NPDamCAT” [24]

   This is an online tool that is used to assist the site selection process. We have utilized this tool to check hazard classifications, potential energy generation and numerus other dam specifications. Our team has used this tool, along with ArcGIS Pro to compare sites and filter out non-powered dams across the United States to those within Arizona since we decided to site a dam in Arizona.

7. “Ownership Responsibility and Liability” [25]

   This site helps with dam safety research. It will be especially beneficial for research on the safety of our selected dam as it will provide us with failure and losses research. The article also provides insight into various owner classifications and their roles in maintenance and upkeep of the dam.

3.3 Mathematical Modeling

In this section, mathematical models and data analysis tools are employed to validate the feasibility and potential of our hydropower initiative. It commences with the development of a MATLAB code, enabling the assessment of available power for the converted dam by considering critical parameters such as turbine efficiency, water flow rate, and head height, all vital in ensuring our power generation aligns with the competition's stringent range. Additionally, mathematical equations and assumptions come to the forefront, empowering the estimation of potential energy output at Non-Powered Dams (NPDs) within our design space. This modeling lays the foundation for crucial assessments, including the capacity factor, which gauges energy harnessing efficiency. While using these equations, we outline the significance of ArcGIS Pro, a Geographic Information System (GIS) software tool, in streamlining the selection process for potential NPDs. It provides a systematic and data-driven approach to narrowing down the extensive dataset, ensuring a concise and informed selection of viable hydropower sites.

3.3.1 Modeling Available Power in MATLAB – *Trevor Senior*

To validate whether the power generation by our converted dam falls within the required range of one to ten megawatts of power, a MATLAB code seen in **Figure A.2.1 (Appendix A.2)** was created to accept inputs of turbine efficiency, water flow rate, and head height. This code outputs the available power produced to quickly allow us to verify the result and decide if it is worth moving forward with the dam.

Once our team gathers all the stream flow data, we will expand on this code to accept monthly steam data. This will allow us to analyze when the slow monthly flow takes place and allow us to investigate solutions to maintain consistent generation. We will also be able to use this data to determine where there will be an excess in energy production. The updated code will also create plots of the energy production over the year to better visualize and display the data to back up our potential energy generation.

3.3.2 Estimating Potential Energy – Riley Frisell

In the process of evaluating Non-Powered Dams (NPDs) as potential sites for hydropower generation, we employ a series of mathematical equations and assumptions to estimate the potential energy output at each NPD. These estimations are integral to our decision-making process in selecting the most suitable NPDs for hydropower conversion within the specified design space. Here, we outline how these equations and assumptions relate to the design space and their practical application in modeling potential energy. These equations and assumptions, outlined in the study by National Renewable Energy Laboratory (NREL) [X], provide the foundation for our mathematical model and are rooted in the principles of hydropower generation.

3.3.2.1 NPD Potential Generation

Our mathematical model centers around the calculation of potential hydropower generation. It incorporates parameters such as the flow rate (Q), net head (ΔH), assumed efficiency (η), and the duration of generation (T). The underlying equation allows us to estimate the potential energy output (in megawatt-hours) for each NPD under consideration.

$$Potential\ Annual\ Generation = \frac{Q \times \Delta \mathrm{H} \times \eta \times \mathrm{T}}{11{,}800}\ \ \mathrm{MWh} \qquad (1)$$

Once this potential annual generation is calculated, we can use this value to estimate the capacity factor of the selected site (2). The capacity factor, denoted as C_f, represents the ratio of actual energy generation to the maximum possible energy generation that a hydropower system could produce when operating at its full capacity throughout the year. It considers the temporal variability of water flow and, therefore, plays an essential role in evaluating the feasibility and reliability of a hydropower system.

$$C_f = \frac{Annual\ Generation\ (MWh)}{Installed\ Capacity\ (MW) \times 8760\ hours}\ \ (unitless) \qquad (2)$$

While Potential Annual Generation (MWh) gives us the total energy produced, the capacity factor helps us understand how efficiently that energy can be harnessed throughout the year. Therefore, we employ this metric to gauge the consistency and reliability of hydropower generation at each NPD we assess. This is where we extend our analysis to include Potential Capacity in megawatts. Potential Capacity represents the maximum power output (in megawatts) a hydropower system can achieve based on the estimated energy generation and the corresponding capacity factor. This metric is calculated using the following equation:

$$Potential\ Capacity = \frac{Potential\ Generation\ (MWh)}{C_f \times 8760\ hours}\ \ \mathrm{MW} \qquad (3)$$

By applying this equation, we assess whether the NPDs' potential capacity aligns with the competition's criteria, ensuring that our selected sites are capable of generating power within the specified range of 1-10 MW. We display the top 6 dams assessed using these equations from a screenshot of our Excel model in Appendix A.2.

3.3.2.2 NPD Hydraulic Height Assumptions

Four key assumptions regarding hydraulic height are applied in our assessment, as outlined in "An Assessment of Energy Potential at Non-Powered Dams in the United States" [15]. These assumptions are vital in our analysis due to the limitations in the available data and the need to ensure consistent and accurate estimations of hydropower potential. The necessity of these assumptions stems from the inherent data gaps and inaccuracies often encountered in the National Inventory of Dams (NID) database. The four assumptions are as follows:

1. If Hydraulic Height is not provided, use 0.7 * NID Height.
2. If Hydraulic Height and NID Height are both provided and are equal, use 0.7 * NID Height.
3. If Hydraulic Height is provided but is greater than 0.7 * NID Height, use 0.7 * NID Height.
4. If Hydraulic Height is provided and is less than 0.7 * NID Height, use Hydraulic Height.

By accounting for the limitations of the available hydraulic height data, we aim to maintain the accuracy and reliability of our hydropower potential estimates in our study.

3.3.3 ArcGIS Pro Selection Process – Evan Higgins

The successful transition from data collection to data-driven decision-making in our project hinged significantly on the application of ArcGIS Pro, a robust and versatile GIS software tool. The primary challenge we encountered was the sheer volume of available data, which necessitated a systematic approach to filter and identify potential NPDs within the state of Arizona. To achieve this, we utilized ArcGIS Pro to combine and analyze various spatial data layers, including the USACE National Inventory of Dams (NID), National Hydrography Dataset (NHD), Homeland Infrastructure Foundation-Level Data (HIFLD), and others outside the ArcGIS Living Atlas. By integrating these datasets, we created a comprehensive map (**Figure A.2.3 in Appendix A.2**) that provided a visual representation of potential NPDs and their geographic relationships.

ArcGIS Pro allowed us to apply decision queries to the extensive dataset, enabling us to systematically reduce the initial pool of over 80,000 NPDs in the United States to a more manageable count of 174. These filters specifically focused on identifying NPDs in Arizona, excluding those with purposes other than hydroelectric, and incorporating specific criteria such as structural height and acre storage. We also eliminated any streamlines with an annual mean flow rate of less than 4 cfs using these definition queries since these small streamlines are only connected to small creeks that are unsuitable for hydropower generation.

This map serves as a pivotal asset, enabling a clear understanding of potential NPDs and their spatial relationships. Additionally, the software's capabilities allowed for the creation of pop-up text, enhancing the user experience, and providing in-depth information on selected sites. Incorporating pop-up text, we conducted practical analyses on specific dams to highlight the platform's usefulness. For example, we assessed Bartlett Dam located in Mesa along the Verde River. In this initial assessment outlined in **Figures 1-3**, we were able to find that the dam is over 300 feet tall, has a mean annual flow rate of 692 cfs, is near a 345 kV transmission line that would be viable for hydropower conversion.

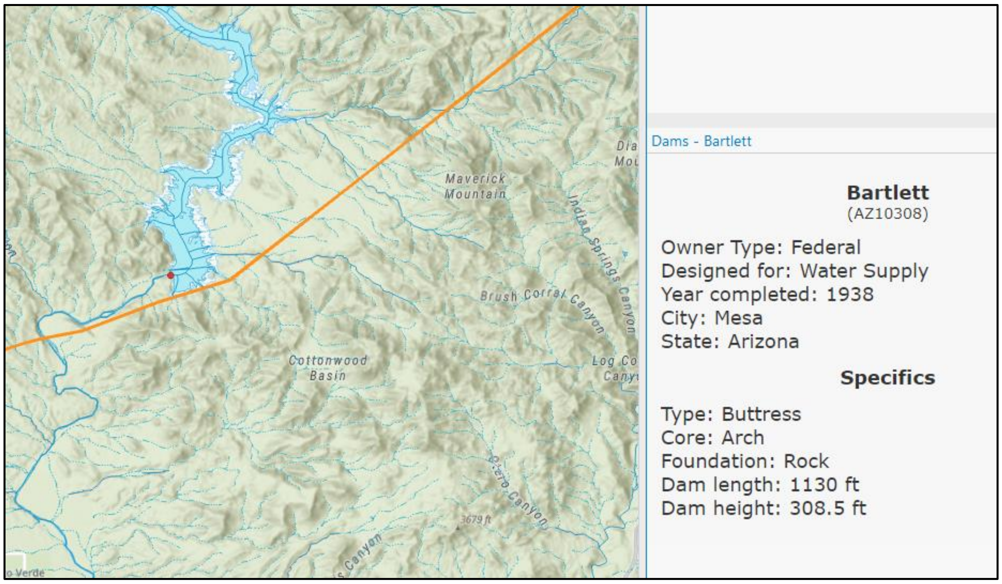

Figure 1: Overall topographic view of Bartlett Dam (red dot) near the 345 kV transmission line (orange line).

Figure 2: Zoomed in aerial view of Bartlett Dam, where we see it's buttress-type structure, and the highlighted blue line that gave us details on an annual mean flow of 692 cfs.

Voltage: 345 (Kilovolts)
(Type: AC; Overhead)

Status: In Service
Owner: Not Available
NAICS Description: Electric Bulk Power Transmission And Control
NAICS Code: 221121
Voltage Classification: 345 (Kilovolts)
Substation 1: Preacher Canyon
Substation 2: Pinnacle Peak Aps

Figure 3: Example of specifications provided when clicking on different shapefiles, such as the orange transmission line.

The use of this GIS tool has laid the foundation for our project's data-driven approach, ensuring that our selection process aligns with the objectives of the Hydropower Collegiate Competition (HCC) while enhancing our understanding of potential NPDs. In the following sections, we will delve into the selection criteria used to examine the performance and viability of various NPDs for hydropower conversion, leveraging the useful insights generated from ArcGIS Pro.

4 Design Concepts

4.1 Functional Decomposition

[Create and discuss a functional decomposition chart (process diagram, functional model, etc.) that depicts the important functions that your project must accomplish. Discuss why your functional decomposition is important for your project, specifically.]

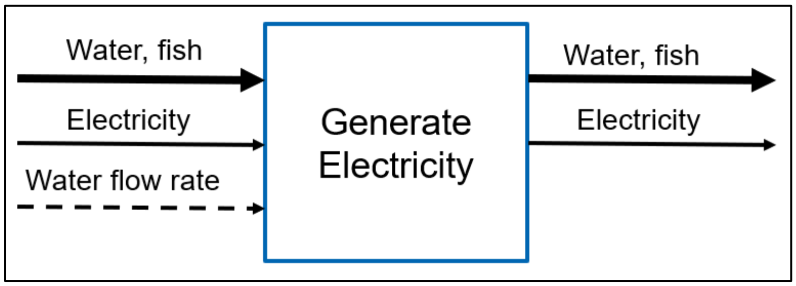

Figure 4: Black Box Model of a simple hydropower plant.

Note: Functional Model of a simple, single turbine, hydropower plant in Appendix.

4.2 Concept Generation

For the concept generation section, our team created a morphological matrix [**Table A.2.1 in Appendix A.2**]. Our group began researching which dams were most beneficial for their location, the dam type chosen was solely based on its purpose and location. One of the most common dam structures is an arch dam great for tall, narrow canyons and strong since they support large bodies of water. The strength comes from the arch shape which disperses the weight of the water into the canyon walls. While we initially looked at some of these dams, most of these are already hydroelectric dams. Another structure we looked at were buttress dams, which rely on the vertical columns in from of the dam to resist the pressure of the water behind it. Narrowing our dam selection down to Arizona excluded most of these types of dams. Rockfill is another type of dam structure that uses earth materials to create a wall blocking off an area for a reservoir. The rockfill structure is a cheap option but is not as strong as the opposition. Our last selection was a gravity dam which relies on its weight to resist the pressure of the water behind it. Since we are looking for a site to convert to small-scale hydropower, arch and rockfill were mostly excluded from our potential sites since those are used primarily for large dams, which would produce power exceeding our range.

Looking at intake systems, we saw a few common options. First off, the capped intake controlled the water coming out of the reservoir for efficient utilization. It also helps with deterring fish from entering the penstocks. The intake tower is also a popular dam intake, but mostly for large-scale dams. The intake tower is effective at allowing water to be sucked into the penstocks, without taking debris and sediment. Direct flow intakes are a basic but effective intake system, but they are more prone to debris and fish getting trapped or sucked into them.

For the turbine selection, we looked at the three main types of turbines. Francis, Pelton, and Kaplan. The Francis is one of the most popular turbines due to its wide range of head and flow requirements. It also has one of the highest efficiencies. The Pelton turbine is effective at taking high heads without as much flow, maintaining a high efficiency as well. Lastly, Kaplan turbine operates best with higher flow rates, but allowing a lower head than some of the others.

Lastly, we examined fish passage and the possible routes of moving fish from either the top of the dam downstream, or upstream past the dam. One of the methods of transporting juvenile fish is the bypass system that acts as a long water slide to gradually transport them down. This is a good option for movement downstream but does not allow the fish to travel up it. An option that allows for movement in both directions is the fish ladder which acts as little waterfalls for fish to jump up until they reach the reservoir. Sluiceways and spillways with a raised weir allow fish to swim over the top of the dam and slide down to the bottom without harming themselves. This passage is limited to downstream passage only for fish.

Our concept generation combined options which fit together the best, by researching real world dams that utilize these features. We made a few concepts and ranked them in a Pugh chart [**Table A.2.2 in Appendix A.2**]. While it was a requirement for the second presentation, it does not apply directly to our competition. This is because we are sitting in an existing location and designing the dam based on the features and specifications of that location. So, the dam type will already be established. At this point, the concept generation can help us create the unique features of the dam. Specifically, we will be designing the method of fish passage, updating, or constructing a new water intake and selecting the ideal turbine for the dam based on its characteristics.

4.3 Selection Criteria

We've developed a thorough set of selection criteria that meet both customer and engineering requirements for NPDs that could potentially be used to generate hydropower. These criteria encompass a wide array of quantitative and qualitative factors, each playing a distinct role in our evaluation. Every criterion is vital to our decision-making process and has been given a particular weight according to its relative significance. They are quantifiable through calculations and specifications, which provide us with a systematic and structured approach to rank and assess each NPD. Our focus on quantitative criteria involves rigorous calculations, such as estimating potential energy, flow rate, distance to existing infrastructure, and other key parameters. These calculations draw upon industry-standard formulas and specifications, allowing us to quantitatively evaluate each NPD. For qualitative criteria, we delve into complex and nuanced aspects like dam ownership type, potential environmental impact, and community support. These factors influence our decision matrix, guiding us toward the selection of NPDs with the highest potential for successful hydropower conversion. Additionally, we emphasize that these criteria, based on specified data, align with the broader objective of identifying NPDs that are not only promising in terms of energy potential but also meet sustainability and safety standards. Below is a further breakdown of these requirements:

4.3.1 Quantitative Criteria

1. Potential Energy (5%):

This component, which accounts for 5% of our decision matrix (**Appendix B.1**), is primarily responsible for an NPD's capacity to produce hydropower. Our research has demonstrated that potential energy is quantified in megawatts (MW), and the calculation method outlined in our literature review [15] helps determine the power generation capacity of each NPD. Despite being one of the main indications of hydropower potential, it is given less weight in our matrix since potential energy values must fall inside a specific range (1–10 MW) as specified by the competition requirements. Furthermore, if a dam has little to no community impact or is not feasible for upgrades, its greater potential energy score is meaningless, regardless of whether it generates 1 MW or 10 MW.

2. Flow Rate (8%):

   Flow rate is an important quantitative factor that accounts for 10% of our choice matrix since it has a large impact on the NPD's ability to generate hydropower. Furthermore, a larger flow rate means more water availability, which improves energy generation reliability. This criterion is based on the NHD database's mean annual flow rate of water flow at each NPD, measured in cubic feet per second. Naturally, as flow rate directly affects hydropower generation capacity and consistency, greater flow rates translate into higher scores. With this, our assessment aims to ensure that NPDs with strong flow rates receive a higher ranking.

3. Distance to Existing Electrical Infrastructure (15%):

   Proximity to existing infrastructure, specifically transmission lines and substations, is the most important selection criteria in our assessment, accounting for 15% weight in our decision matrix. Shorter distances to these infrastructure components lower transmission losses and increase energy distribution efficiency. Transmission line construction can be expensive, with expenditures ranging from $2 million to $7 million per mile. Reducing the requirement for major infrastructure construction improves our project's cost-effectiveness. Closer proximity to transmission lines and substations obtains greater scores in this area because it is a direct indicator of infrastructure benefits.

4. Distance to Alternative Energy Sources (7%):

   The availability of complementary energy sources near an NPD, such as solar power (which is abundant in Arizona), could influence our site choices. The proximity of these various sources offers potential collaboration and shared infrastructure, potentially improving operational efficiency. As a result, NPDs located near alternative energy sources may obtain a higher score in this category. While assessing this is difficult, it still bears a relatively high weight since it directly affects our customer's requirement to maximize the utilization of existing infrastructure and resources that favor hydropower generation.

5. Distance to Nearest City (5%):

   The distance from an NPD to the nearest city or town is an influential factor in assessing accessibility and community impacts, accounting for a 5% weight in the decision matrix. This measured distance was acquired from the NID database and is analyzed in our raw data collection using color-coded cells and conditional formatting in Excel. This metric aids in the reduction of construction and maintenance difficulties, which may improve cost-effectiveness. As a result, NPDs located near urban centers perform better in this area, indicating improved accessibility for project development and maintenance.

6. Amount of Watershed (7%):

   The size and extent of the watershed area significantly impacts the flow consistency and potential of an NPD for hydropower generation. This criterion is quantitative because we have data on the watershed area in square miles from the NID. A bigger watershed area often indicates a more stable and continuous flow of water, which improves hydropower generation reliability. NPDs with greater watershed areas score higher, indicating a better fit for our project.

7. Water Storage Capacity (4%):

   Our decision matrix also includes a 4% weight for water storage capacity, which measures the reservoir's storage capacity in acre-feet. Adequate storage capacity is required for efficient water resource management. NPDs with larger water storage capacities score better in this category because they can store water for longer periods of time, which benefits the project's energy generation and reservoir management. However, given the limited supply of water in Arizona, high water storage isn't as vital as ensuring that the dam has adequate water supply on hand. It was therefore given a lower weight than the other elements.

4.3.2 Qualitative Criteria

1. Dam Ownership Type (7%): Dam ownership can significantly influence the ease of collaboration and obtaining necessary permits for hydropower projects. Federal-owned NPDs are subject to specific regulations, permitting processes, and funding mechanisms, depending on the agency responsible. For instance, dams owned by the Bureau of Reclamation may have different protocols compared to those owned by the Bureau of Indian Affairs. Private ownership involves negotiations with individual dam owners, and their willingness to convert to hydropower may vary. Local government-owned dams may require community approvals, but they can be more adaptable to local development initiatives, and the ease of obtaining permits may depend on the specific locality and its policies.
2. Potential Environmental Impact (10%):

   Dams can have a substantial impact on local ecosystems, thus assessing the potential environmental impact is critical. Understanding the environmental impact of an NPD requires assessing the presence of endangered species nearby. Dams can also affect ecosystems by altering water flow and sediment movement. Understanding the broader environmental impact requires assessing how the dam may affect fish migration and local aquatic life. On top of this, since this is outlined as a heavy deliverable in the competition rulebook, we are forced to weigh the criteria much higher than the others. Furthermore, we must give this a significantly greater weight than the other criteria because the competition rulebook lists it as a substantial deliverable.
3. Dam Integrity (4%):

   The long-term operation, safety, and viability of hydropower generation of a dam depend heavily on its structural integrity. The safety of a dam and any future improvements are directly impacted by its hazard categorization (low, significant, and high). Furthermore, the dam's overall integrity depends on how well-maintained it is and when improvements were last implemented. In general, an NPD with a track record of well-kept infrastructure is more advantageous. The examination of known structural problems is crucial since they directly affect the longevity and integrity of the dam, such as seepage or concrete degradation. We cannot, however, give this dam more weight than other criteria because all of our options were constructed no later than 1960, which means that the integrity of this dam will likely have to be evaluated regardless.
4. Cost of Development/Economic Viability (10%):

   The project's economic viability will be evaluated using a Levelized Cost of Energy (LOCE) study. To ascertain if the project is competitive and cost-effective in the energy market, the LOCE considers a number of factors, including development, maintenance, and operating expenses. An additional component of the economic study is assessing the possibility of signing Power Purchase Agreements (PPAs) with nearby utilities. The production of revenue and the overall return on investment can be greatly impacted by a PPA. Additionally, doing sensitivity assessments on variables such as building costs and energy prices will contribute to a more thorough understanding of the project's financial risks and economic viability. For now, while only considering site selection and not future analysis, we can assess cost of development by simply assessing the dam type and height of the dam, as the taller dams would tend to cost more to upgrade and require more civil work as compared to a small dam.

5. Availability of Historical Flow Data (3%):

   This metric is critical in assessing what types of turbines we will install here and the efficiency and capacity factors of power here. However, most nonpowered dams with potential between 1-10 MW have limited data access anyway, so chances this won't heavily influence our dam selection. Regardless, we would still have to do more digging into actually finding that data, so we can't base our selected site based on the fact that we haven't looked in the right places for data.

6. Accessibility (5%):

   This criterion encompasses a variety of factors, including the condition and accessibility of access roads leading to the dam site. Efficient access to the site is essential for transporting equipment, machinery, and construction materials. Additionally, the ability to access and maintain the dam structure itself is crucial. In our assessment, we will evaluate the existing infrastructure for access, assess the condition of access roads, and consider any necessary modifications or improvements to ensure the smooth implementation and long-term maintenance of the hydropower facilities.

7. Local Community Support (5%):

   We aim to assess community engagement, which includes the local population's willingness to endorse and contribute to the project. To achieve this, we plan to engage with local stakeholders to understand their perspectives and address their concerns. Additionally, the social impact of the project on the community, such as the potential for job creation, infrastructure enhancements, and overall improvements to the quality of life, will be considered. In cases where the NPD potentially holds historical significance in terms of cultural heritage, we will study its impact on local heritage. Understanding these social dynamics and fostering positive community relationships is paramount for the long-term sustainability and success of the project.

8. Technical Feasibility (4%):

   The technical feasibility criterion comprises multiple crucial elements, such as the physical structure of the dam's suitability, its capacity to convert hydropower, and the area that is available for the infrastructure that is required. Since we can't evaluate this as thoroughly as we'd like to for numerous dams at once, we've given it a lesser weight in our decision matrix for site selection. However, in the future we want to carry out site-specific engineering studies to evaluate this criterion for the Siting Challenge. These studies will include a detailed assessment of the dam's structural integrity, geological and geotechnical conditions, and hydraulic analysis. This will assist us in assessing if building hydroelectric facilities in accordance with technical, safety, and environmental standards is feasible. In the event that we come across major technical challenges throughout the evaluation process that make a location not feasible, we may consider reevaluating the selected site from further consideration.

4.4 Concept Selection

In Chapter 4, we shift our focus from broad assessments to specific dam selections by employing a comprehensive Decision Matrix. This tool, which is based on the weighted criteria described in Section 3.3, directs our search for Arizona Non-Powered Dams (NPDs) that meet customer expectations and engineering standards in the competition's design space. Our in-depth analysis of five selected dams helps us spotlight promising candidates, such as Granite Reef Diversion, and address challenges presented by others, setting the stage for a future powered by sustainable and efficient hydropower generation. Furthermore, the chapter acknowledges our shift towards considering purchased turbines and collaborative industry engagement, enhancing the project's practicality, and aligning it with recognized standards.

4.4.1 Decision Matrix

A key component of our selection process is the decision matrix, based on the criteria listed in section 4.3. As discussed, each criterion was carefully weighed to represent its importance in meeting engineering requirements and customer needs. It offers a methodical framework for assessing and prioritizing Arizona's prospective NPDs, ensuring that our selection is in line with the allotted design space. The decision matrix, which is shown in **Appendix B**, ensures that the qualitative and quantitative considerations covered above have been appropriately assessed in relation to our dam selection.

The initial evaluations have provided crucial insights into the feasibility of different dams for small-scale hydro upgrades. By referring to the comprehensive decision matrix, we conducted a detailed assessment of five selected dams: Granite Reef Diversion, Palo Verde Diversion, Bartlett Dam, Horseshoe Dam, and Morelos Dam. Among the assessed dams, Granite Reef Diversion has emerged as the most promising candidate, ranking first in our decision matrix. This NPD combines several favorable attributes, including a structural height of less than 30 feet, a high flow rate of 1966 cubic feet per second (cfs), and a potential energy output of approximately 4 MW. These factors align perfectly with our design space, making it a front-runner in our selection process. While Granite Reef Diversion emerges as the leading candidate, Palo Verde Diversion shows significant promise with its exceptionally high flow rate of 11,068 cfs and structural height of 50 feet. However, we are cautious of its potential deviation from the energy potential range specified by the competition, indicating a need for further evaluation.

While Bartlett Dam and Horseshoe Dam, ranked third and fourth, exhibit some merit, they face significant challenges. The structural height of Bartlett Dam exceeds the competition's recommended range, and the mean annual flow rate is just 692 cfs, resulting in a cost-prohibitive scenario with limited energy returns. While Horseshoe Dam has a relatively high structural height, it is also over eight miles from the nearest transmission line, resulting in significant installation costs. As previously mentioned, we applied acceptable assumptions and concluded that taller dams result in greater complexity in construction and civil work, resulting in a very high estimated cost of development. These findings compelled us to carefully evaluate dam potential for small-scale hydro enhancements. The ownership and logistics constraints of the Morelos Dam, which is located outside of the United States, caused significant obstacles. We prioritized dams within our authority based on this important information.

We are committed to ensuring that our chosen NPDs are not only technically viable but also closely connected with customer needs, engineering requirements, and competition stipulations as we go forward with the search. To make educated decisions, we will constantly modify our assessments, considering both quantitative and qualitative data. The extensive selection criteria provide us with a solid framework for narrowing our list of NPDs and setting the stage for the project's succeeding stages. Furthermore, our benchmarked small-scale hydro concepts, such as the Voith StreamDiver, will inform our design approach. By matching our project with benchmarked concepts and drawing on industry expertise, we hope to ensure that our chosen dams not only fulfill but exceed the standards of the competition, producing an efficient and sustainable source of electricity. With our decision matrix serving as a foundation for our selection process and our partnership with key industry players, we are well-positioned to achieve success in our pursuit of sustainable hydropower generation at the identified NPDs. Our approach is rooted in thorough evaluations, robust assessments, and careful consideration of the engineering and customer demands, paving the way for a future powered by clean, renewable energy.

4.4.2 Current state of CAD drawing

To highlight our projected model, a Francis Turbine was drafted to visualize our preliminary design seen in **Figures A.2.5 and A.2.6 in Appendix A**. Moving forward, the team has shifted directions and will be looking at utilizing purchased turbines that would be easily available if necessary. Since our team will be generating a report to highlight the feasibility of our selection, using a turbine that can be purchased as needed is a key to making our proposal possible. Our team has also been looking into using small-scale hydropower through a company Voith, which members met at Clean Currents 2023. Due to the shift of direction, the team will not be moving forward with this model.

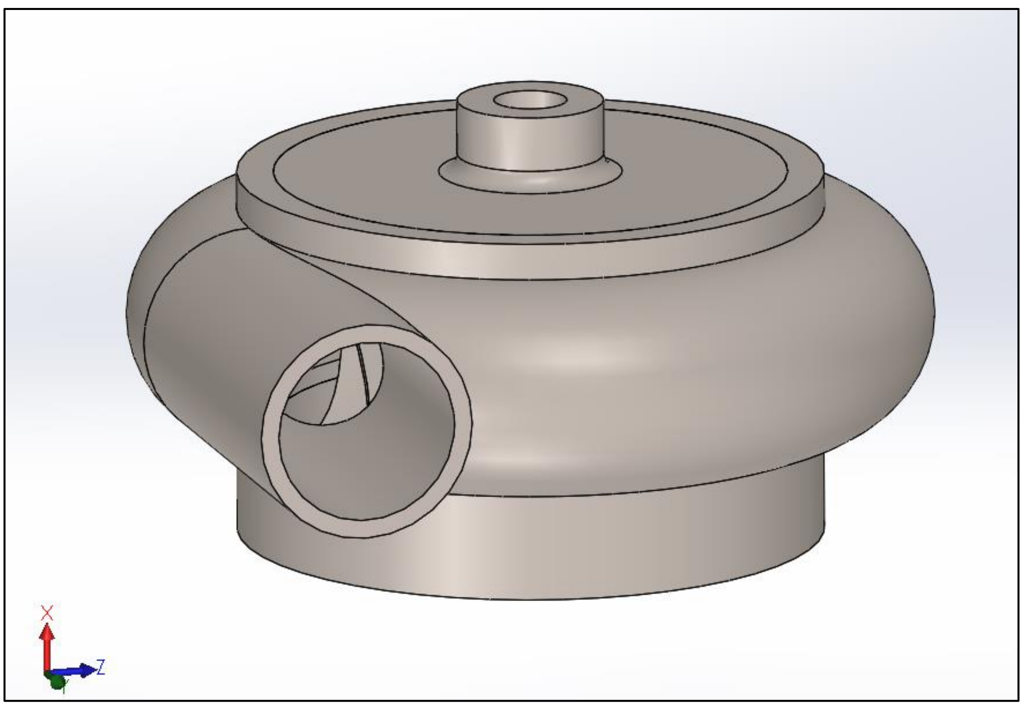

Figure 5: Francis turbine for draft of CAD model

5 CONCLUSIONS

In summary, our project is driven by a profound commitment to the 2024 Collegiate Hydropower Competition's objectives. We have meticulously assessed the critical customer and engineering requirements that guide our design, ensuring that our hydropower project aligns with the client's needs and competition standards. This holistic approach has allowed us to grasp the intricate interplay between various technical aspects and the customer's expectations.

As we navigate the mathematical modeling, literature review, benchmarking, and concept selection phases, we have gained valuable insights from existing research, industry practices, and our own rigorous analysis. The functional model serves as a visual blueprint for our project's essential functions, providing clarity on the operational aspects. Granite Reef Diversion was our top choice after thorough assessments utilizing our Decision Matrix. With a structural height of under thirty feet, a strong flow rate of 1966 cubic feet per second (cfs), and the capacity to produce about 4 MW of electricity, Granite Reef Diversion fits into our design space very well and satisfies engineering and customer standards. It is the perfect location for our project because of its close proximity to infrastructure and its advantageous environmental features. The culmination of this meticulous work has brought us closer to realizing a transformative hydropower project, with CAD drawings serving as a testament to our tangible progress.

At this juncture, our project stands at a pivotal stage, advancing within the Siting Challenge and Design Challenge of the competition. This initiative aims to shape a sustainable energy future in addition to maximizing the potential of hydropower. We are persistent in our commitment to bridging the gap between engineering restrictions and design needs. With this project, we hope to significantly impact the field of small-scale hydropower generation and meet the growing demand for clean, renewable energy sources. The journey is far from over, and we are excited to see the project continue to evolve and make strides toward a sustainable energy future.

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7 APPENDICES

7.1 Appendix A.1 – House of Quality (QFD)

#	Technical Requirement	1	2	3	4	5
1	Energy Output					
2	Aquatic Ecosystem Preservation	-				
3	Plant Efficiency	++				
4	Hydrologic Data Utilization	+	++	+		
5	Feasibility	+	-	+	++	
6	Site Interconnectivity	+		+	+	+

Legend	
A	Dam 1
B	Dam 2
C	Dam 3

#	Customer Needs	Customer Weights	Weight %	Energy Output	Aquatic Ecosystem Preservation	Plant Efficiency	Hydrologic Data Utilization	Feasibility	Site Interconnectivity	1 Poor	2	3 Acceptable	4	5 Excellent
				Technical Requirements						**Customer Opinion Survey**				
1	Community Engagement	5	10.64		6		3	9	6					
2	Cost of Development/Economic Viability	9	19.15	6	3	6	3	9	6					
3	Effective Risk Mitigation	10	21.28		6		3	9	9					
4	Energy Production	6	12.77	9		9	3	6	6					
5	Environmental Impact Mitigation	8	17.02		9	3	6	3						
6	Scalability/Co-Development	7	14.89	6	3	6		9	9					
	Technical Requirement Units			MW	Sq. Miles	%	cfs	2023 $	MW					
	Technical Requirement Targets			1-10 MW		>= 70%								
	Absolute Technical Importance			319	447	370	294	721	581					
	Relative Technical Importance			5	3	4	6	1	2					

Figure A.1.1: HCC House of Quality analysis.

7.2 Appendix A.2: Referenced Figures and Images

```
% Practically Available Power Calculations
clc;
u = input('Enter efficiency in decimal form: '); %efficiency
p = 1000; % kg/m^3
q = input('Enter water flow in m^3/s: '); %flow rate
g = 9.81; % gravity in m/s^2
h = input('Enter the head height (m): '); %head hight

Pa = u*p*q*g*h; %formula for power

%prints the result
fprintf('The practically available power (Pa) in Watts is: %d \n',Pa)
```

Command Window

```
Enter efficiency in decimal form: 0.76
Enter water flow in m^3/s: 5
Enter the head height (m): 10
The practically available power (Pa) in Watts is: 372780
fx >>
```

Figure A.2.1: Initial MATLAB code

Dam Name	Hydraulic Height (ft)	NID Height (	Assumed Net Head (ft	NHD Streamflows (cf	Estimated Annual Generation (MWh)	Potential Capacity (MW)	Year Completed
Granite Reef Diversion	23	29	20.3	1966	25184	3.194	1907
Rio Salado Town Lake	16	40	16.0	1967	19859	3.778	1997
Palo Verde Diversion		50	35.0	11068	244443	46.51	1958
Horseshoe	175	202	141.4	667	59514	11.32	1945
Coolidge		250	175.0	658	72662	13.82	1931
Bartlett	211	309	211.0	692	92136	17.53	1938

Figure A.2.2: Initial Assessment of NPD Energy Potential in Arizona (see section 3.2.2.1)

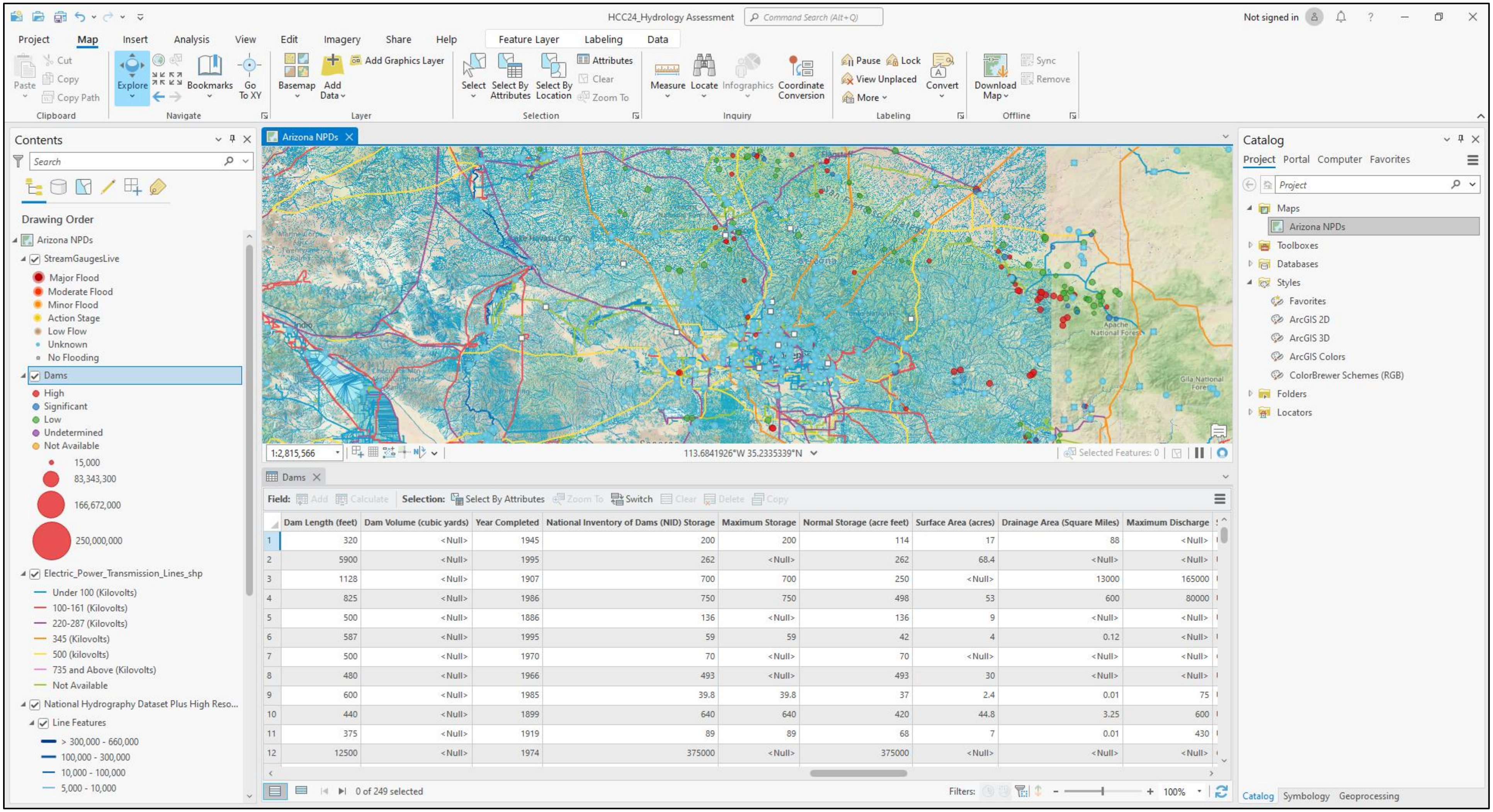


Figure A.2.3: Overview of comprehensive map in ArcGIS; contains attributes table with over 60 columns of raw data from NID database, all streamlines relative to each dam (blue lines), all transmission lines, stream gauges, and more to accurately assess our site selection process.

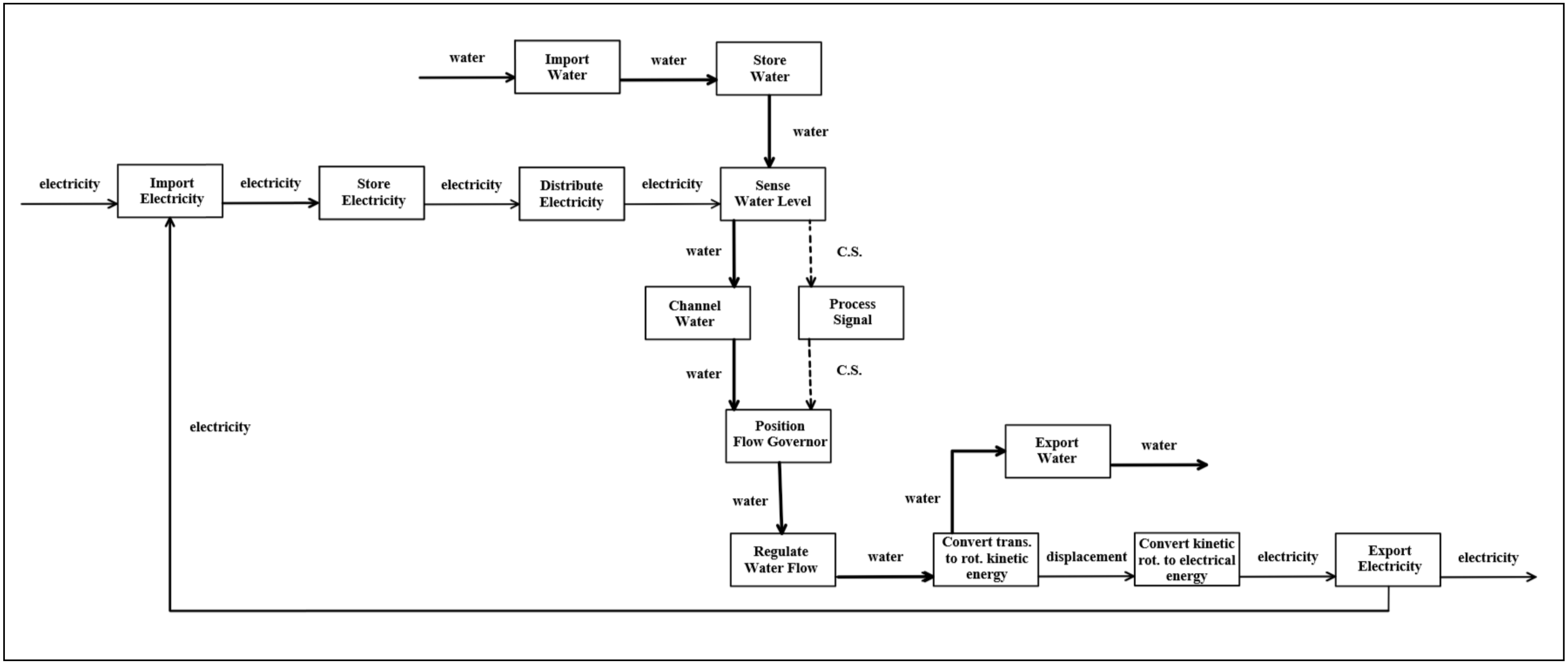


Figure A.2.4: Functional Model of a simple, single turbine, hydropower plant.

Table A.2.1: Morphological Matrix

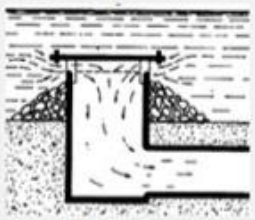
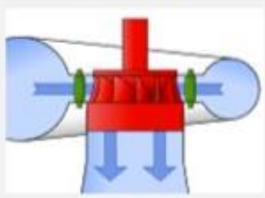
Concept	Option 1	Option 2	Option 3	Option 4
Dam Structure	Arch	Buttress	Rockfill	Gravity
The primary function is to resist the pressure of the water behind it				
Water intake	Capped intake	Intake tower	Direct flow intake structure	
Controlled and efficient utilization of the water coming out of the reservior				
Turbine	Francis	Pelton	Kaplan	
Converts the kinetic energy from the flowing water into mechanical energy for electricity generation				
Fish Passage	Juvenile Bypass System	Fish Ladder	Sluiceways	Spillway with raised Weir
Allows fish to pass through the dam without harming them				

Table A.2.2: Pugh Chart

Pugh Chart - Hydropower Collegiate Competition					
Dam Conversion Top Concepts					
		Concept			
		1	2	3	4
		Buttress, Capped Inate, Kaplan, Fish ladder	Arch, Intake Tower, Francis, Sluiceway	Gravity, Direct flow intake, Francis, Spillway with raised weir	Rockfill, Intake tower, Pelton, Juvenile Bypass System
Criteria	Energy Production	S	DATUM	+	-
	Environmental Impact Mitigation	+		+	S
	Community Impact	-		-	S
	Site Interconnectivity	S		-	S
	Cost	+		S	+
	Structure	S		S	-
	Sum of +'s	2		2	1
	Sum of -'s	1		2	2
	Sum of S's	3		2	3
	Total	**1**		**0**	**-1**

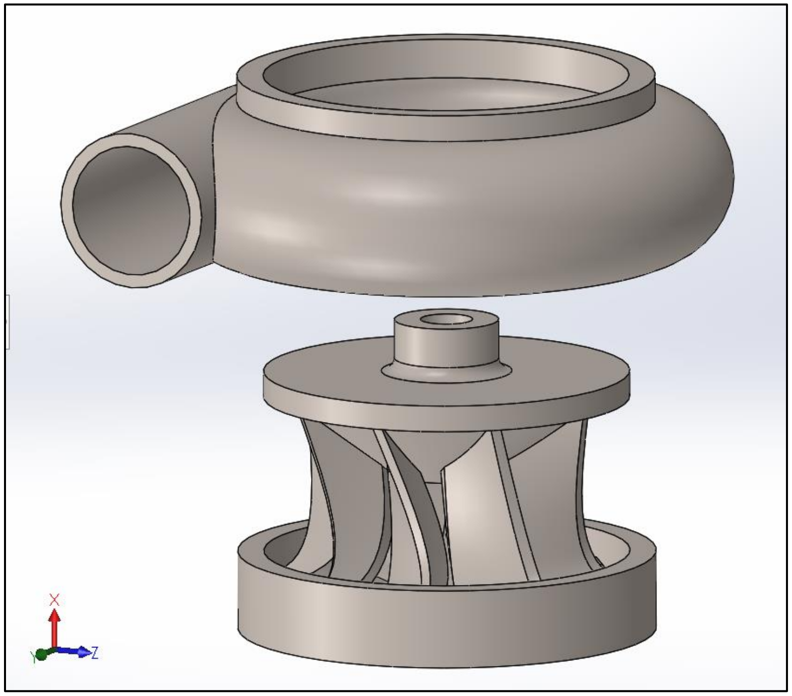


Figure A.2.5: Expanded View of CAD model.

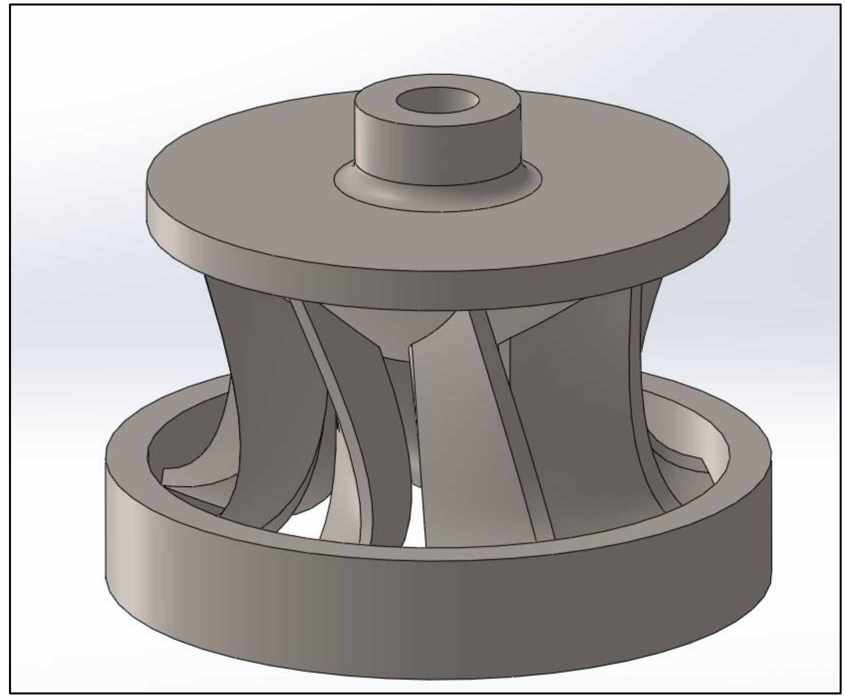


Figure A.2.6: Francis Turbine CAD model.

7.3 Appendix B: NPD Selection Decision Matrix

Table B.1: Decision Matrix with weighted selection criteria (outlined in Section 4.3) and scores for top 4 dams (excluded Morelos Dam due to its location in Mexico and struggle for attaining historical data).

Criterion	Weight	Bartlett Dam		Granite Reef Diversion		Horseshoe Dam		Palo Verde Diversion	
		Score out of 100	Weighted Score	Score out of 100	Weighted Score	Score out of 100	Weighted Score	Score out of 100	Weighted Score
1. Potential Energy	5%	70	3.5	40	2	65	3.25	95	4.75
2. Flow Rate	8%	35	2.8	72	5.76	35	2.8	100	8
3. Distance to Existing Infrastructure (transmission lines/substations)	15%	57	8.55	88	13.2	5	0.75	62	9.3
4. Distance to Alternative Energy Sources	7%	30	2.1	38	2.66	0	0	24	1.68
5. Distance to Nearest City	5%	33	1.65	70	3.5	38	1.9	88	4.4
6. Amount of Watershed	7%	43	3.01	38	2.66	7	0.49	35	2.45
7. Dam Ownership Type	7%	80	5.6	85	5.95	75	5.25	80	5.6
8. Potential Environmental Impact	10%	60	6	75	7.5	35	3.5	65	6.5
9. Dam Integrity	4%	33	1.32	23	0.92	31	1.24	40	1.6
10. Cost of Development/Economic Viability	10%	30	3	85	8.5	3	0.3	60	6
11. Water Storage Capacity	5%	90	4.5	65	3.25	83	4.15	68	3.4
12. Availability of Historical Flow Data	3%	75	2.25	73	2.19	70	2.1	69	2.07
13. Accessibility (ease of access for construction and maintenance)	5%	30	1.5	68	3.4	35	1.75	54	2.7
14. Local Community Support	5%	43	2.15	76	3.8	22	1.1	55	2.75
15. Technical Feasibility	4%	38	1.52	63	2.52	43	1.72	72	2.88
Total	**1**		**49.45**		**67.81**		**30.3**		**64.08**
Relative Rank			**1**		**2**		**3**		**3**