HCC Final Report

Final Design Report Template

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DISCLAIMER

EXECUTIVE SUMMARY

This project evaluates the feasibility of retrofitting a non-powered dam with a modular hydropower system through an integrated siting and design approach. Three candidate sites, (John C. Stennis Lock & Dam, Peoria Lock & Dam, and Coon Rapids Dam) were assessed using a weighted decision framework incorporating hydraulic performance, infrastructure availability, environmental constraints, regulatory complexity, and economic potential.

While several sites demonstrated strong individual advantages, the selection process emphasized overall feasibility rather than maximizing a single metric such as power output. Based on this analysis, Coon Rapids Dam was selected as the optimal site, offering a balanced combination of moderate hydraulic potential, existing infrastructure, favorable energy market conditions, and manageable environmental constraints.

Following site selection, the team chose the StreamDiver, a modular, low-head turbine system designed for scalable deployment with minimal structural modification to the existing dam. The system enables controlled flow diversion through multiple turbine units, allowing flexibility in installation while maintaining environmental flow requirements.

Engineering analysis was conducted using site-specific conditions, including a net head of approximately 5 meters and a controlled flow rate of 10 m^3/s, to estimate power output and identify optimal operating conditions. A scaled prototype was fabricated and tested using a recirculating flow loop and prony brake system to measure torque and rotational speed. Experimental results validated modeled performance trends and provided insight into system behavior across operating ranges.

An economic assessment was performed using levelized cost of energy (LCOE) as the primary feasibility metric. The final design achieves an installed capacity of 2.17 MW, generating approximately 12,699 MWh annually with a LCOE of $79.61/MWh. This configuration was selected as optimal due to its balance between energy production, structural feasibility, and economic performance under site-specific constraints.

Key challenges include regulatory constraints associated with the dam's function as a fish barrier, limitations on flow diversion, and uncertainty in capital costs. However, the modular design enables phased deployment and provides flexibility in addressing these constraints.

Overall, this project demonstrates that modular hydropower systems can provide a viable pathway for converting non-powered dams into renewable energy assets, with Coon Rapids representing a strong candidate for implementation due to its balance of technical, economic, and environmental considerations.

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1 BACKGROUND

1.1 Project Description

This project focuses on the evaluation and design of a hydropower retrofit system for an existing non-powered dam (NPD), with the goal of generating renewable energy while minimizing environmental and structural impact. The work was conducted as part of the 2026 Hydropower Collegiate Competition, which challenges teams to develop feasible solutions for converting existing infrastructure into sustainable energy sources.

Following an initial screening of multiple candidate sites, the team selected Coon Rapids Dam in Minnesota based on its favorable hydraulic conditions, existing infrastructure, and overall feasibility. The site features low-head, high-flow characteristics, making it well-suited for a modular turbine installation.

The proposed solution utilizes a modular low-head turbine system designed to operate efficiently under site-specific conditions. A turbomachinery-based modeling approach was used to estimate system performance, including power output and optimal operating conditions. These predictions were further supported by prototype testing using a recirculating flow system and prony brake setup to evaluate torque and rotational behavior.

In addition to technical design, the project includes economic and feasibility analysis using levelized cost of energy (LCOE) as a key metric. The final system configuration demonstrates that non-powered dam retrofits can provide a viable pathway for renewable energy generation while leveraging existing infrastructure and minimizing environmental impact.

1.2 Deliverables

The primary deliverables for this project were defined by the NAU mechanical engineering capstone program (ME486C). These requirements served as the main criteria for project completion and evaluation, ensuring that the team developed a technically rigorous and fully validated engineering solution.

In addition to capstone requirements, the project also aligned with the 2026 Hydropower Collegiate Competition (HCC), which provided supplemental deliverables related to industry engagement, outreach, and competition-specific reporting.

For the capstone course requirements, the team completed the following primary deliverables:

- **Design Progress and Manufacturing Milestones (33% / 67% / 100%)**
  Iterative development of the prototype, progressing from initial fabrication stages to full system completion, along with procurement of necessary components.
- **Testing Plan and Demonstration**
  Development and execution of a finalized testing plan, including prototype evaluation using a hydraulic test setup and prony brake system.
- **Computer-Aided Design (CAD) and Bill of Materials (BoM) Packet**
  Completion of detailed CAD models and a finalized bill of materials for both the prototype and full-scale system design.
- **UGRADS Symposium Participation**

Presentation of project work and results at the undergraduate research symposium.

- **Final Design Report**
  Submission of a comprehensive report detailing all aspects of the project, including siting, design, modeling, testing, and feasibility analysis.

To support and enhance the capstone project, the team also completed the following HCC-related deliverables:

- **Advisor and Industry Mentor Engagement**
  Weekly meetings with faculty advisors and biweekly meetings with industry mentors to guide project development and ensure alignment with industry practices.
- **Mid-Year Submissions**
  Interim reports documenting progress in site selection, system design, and outreach efforts.
- **Siting and Design Report**
  A report summarizing siting decisions, system design, and overall feasibility.
- **Community Connections Report**
  Documentation of outreach activities and engagement with the community related to renewable energy education.
- **Build and Test Deliverables**
  Completion of prototype fabrication and experimental testing to validate system performance.

Overall, the capstone deliverables served as the primary measure of project success, while HCC deliverables provided additional structure, industry relevance, and opportunities for external validation.

1.3 Success Metrics

The success of this project is defined by the ability to design and evaluate a hydropower retrofit system that is technically feasible, economically viable, and environmentally responsible. Success is assessed through the extent to which the proposed design satisfies key customer requirements (CRs) and their corresponding engineering requirements (ERs).

From a customer perspective, success includes delivering a reliable power supply, maintaining structural integrity of the existing dam, achieving a competitive cost of energy, minimizing environmental impact, ensuring long system lifespan, and meeting all regulatory requirements. These criteria represent the primary goals of the project and guide all design decisions.

To evaluate these goals quantitatively, the CRs are translated into measurable engineering requirements. System performance is assessed using analytical and modeling approaches, including flow duration curve (FDC) and power duration curve (PDC) analysis, hydraulic calculations, and levelized cost of energy (LCOE) modeling. Additional considerations such as grid connection feasibility, flow diversion limits, and structural compatibility are also incorporated into the evaluation.

A successful design is one that meets the defined engineering requirements within acceptable tolerances while satisfying the underlying customer needs. The following section outlines the specific customer requirements and engineering requirements used to evaluate overall system performance.

2 REQUIREMENTS

This section identifies the customer and engineering requirements for the Hydrojacks hydropower retrofit project and explains how those requirements guide the technical design process. It summarizes the needs of competition sponsors, regulatory agencies, and community partners, then translates those needs into measurable design parameters. The section concludes with an overview of the House of Quality, which maps the relationships between the two sets of requirements and provides the framework for later design decisions.

2.1 Customer Requirements (CRs)

CR-1 Reliable Power Supply

The system must provide consistent and dependable energy generation under varying flow conditions. This requirement is evaluated by analyzing power output as a function of flow rate using power duration curve (PDC) modeling. A reliable power supply ensures the system can contribute meaningful and predictable energy to the grid.

CR-2 Structural Integrity

The retrofit must maintain the structural stability of the existing dam and avoid compromising its integrity. This requirement is assessed through evaluation of the dam structure, including concrete condition and compatibility with turbine integration. Ensuring structural integrity is critical for both safety and long-term operation.

CR-3 Competitive Cost

The system must produce energy at a cost that is competitive with other renewable energy sources. This is evaluated using levelized cost of energy (LCOE) modeling, which incorporates capital, operation, and maintenance costs. A competitive cost is essential for economic feasibility and stakeholder acceptance.

CR-4 Low Environmental Impact

The design must minimize ecological disruption, particularly with respect to river flow and aquatic habitats. This requirement is evaluated through environmental impact considerations and by limiting the flow diversion ratio. Maintaining low environmental impact supports regulatory approval and community acceptance.

CR-5 Long Life Expectancy

The system should be designed for long-term operation with minimal degradation. This is assessed through material selection, durability considerations, and alignment with dam safety benchmarks. A long operational lifespan improves overall project value and reduces lifecycle costs.

CR-6 Regulatory Compliance

The project must comply with all relevant regulatory frameworks, including environmental and energy permitting requirements. This is evaluated by ensuring the design aligns with NEPA, FERC, and MNDNR guidelines. Regulatory compliance is necessary for project approval and implementation.

These customer requirements are translated into quantitative engineering requirements (ERs), which are used to evaluate system performance through modeling and analysis. The following section defines the engineering requirements used to determine whether the proposed design satisfies these success criteria.

2.2 Engineering Requirements (ERs)

ER-1 Generation Capacity

A target generation capacity of 1–10 MW was established to align with small hydropower classification and project feasibility constraints. The calculated capacity of 2.17 MW falls within this range, demonstrating that the proposed system can produce meaningful power without requiring excessive infrastructure modifications. This confirms the design is appropriately scaled for the site. This requirement was verified through MATLAB analysis utilizing flow and head data from the USGS website [1].

ER-2 Levelized Cost Of Energy

An LCOE target of $0.08/kWh (± $0.03/kWh) was selected to ensure economic competitiveness with other renewable energy sources. The S.A.M model calculated value of $0.0796/kWh meets this requirement, indicating that the system is financially viable and capable of producing cost-effective electricity over its lifetime. This metric is critical for stakeholder acceptance and long-term project justification.

ER-3 Flow Availability

A minimum flow threshold of 50 m^3/s was required to ensure sufficient water availability for consistent power generation. Flow duration curve analysis through MATLAB shows that flows exceed 90 m^3/s for 90% of the time, significantly surpassing the requirement. This indicates strong hydrologic reliability and supports a high capacity factor.

ER-4 Flow Diversion Ratio

The diversion ratio was constrained to 10–25% to balance energy generation with environmental and regulatory considerations. The selected value of 15% ensures adequate flow remains in the natural channel, minimizing ecological disruption while still capturing sufficient energy. This metric is particularly important for permitting and environmental compliance.

ER-5 Grid Connection Distance

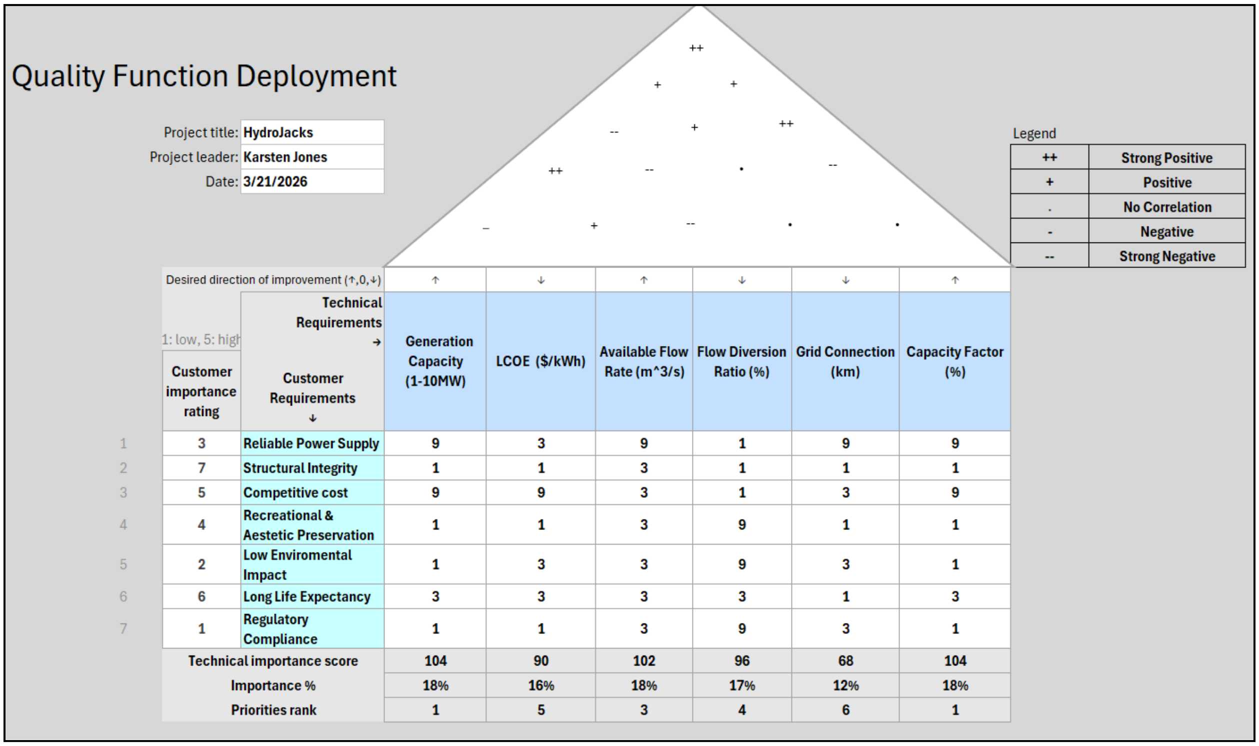
A maximum distance of 2 km (with a tolerance of +0.5 km) was chosen to limit transmission infrastructure costs. The measured distance of 0.6 km verified through GIS modeling is well within this limit, confirming that grid interconnection is practical and will not significantly impact project cost or complexity.

ER-6 Capacity Factor

A target capacity factor of 40–80% reflects the expected operational efficiency of a run-of-river hydropower system. The MATLAB calculated capacity factor of 67% demonstrates strong performance and effective utilization of available flow. This result reinforces the reliability of the site and the effectiveness of the selected turbine configuration.

2.3 House of Quality (HoQ)

The House of Quality serves as a structured framework that connects stakeholder needs with the specific engineering characteristics of the proposed small-scale hydropower retrofit dam. It begins with identifying the customer requirements, which represent the voices of the primary stakeholders, including the local community, environmental regulators, and utility authority. These requirements emphasize key project goals such as reliable power generation, competitive cost, environmental sustainability, and regulatory compliance. Each of these "what's" expresses what the project must achieve from a user or societal perspective.



Quality Function Deployment

Project title: HydroJacks
Project leader: Karsten Jones
Date: 3/21/2026

Legend

++	Strong Positive
+	Positive
.	No Correlation
-	Negative
--	Strong Negative

	Desired direction of improvement (↑,0,↓)		↑	↓	↑	↓	↓	↑
	1: low, 5: high Customer importance rating	Technical Requirements → Customer Requirements ↓	Generation Capacity (1-10MW)	LCOE ($/kWh)	Available Flow Rate (m^3/s)	Flow Diversion Ratio (%)	Grid Connection (km)	Capacity Factor (%)
1	3	Reliable Power Supply	9	3	9	1	9	9
2	7	Structural Integrity	1	1	3	1	1	1
3	5	Competitive cost	9	9	3	1	3	9
4	4	Recreational & Aestetic Preservation	1	1	3	9	1	1
5	2	Low Enviromental Impact	1	3	3	9	3	1
6	6	Long Life Expectancy	3	3	3	3	1	3
7	1	Regulatory Compliance	1	1	3	9	3	1
	Technical importance score		104	90	102	96	68	104
	Importance %		18%	16%	18%	17%	12%	18%
	Priorities rank		1	5	3	4	6	1

Figure 2.3.1: House of Quality Model

As mentioned in the HOQ matrix, generation capacity, capacity factor, and flow availability are the top drivers in the design at 18% importance each, followed by flow diversion ratio and then LCOE.

3 Research Within Your Design Space

3.1 Benchmarking

Benchmarking was performed to evaluate existing technologies, construction methods, and operational strategies relevant to non-powered dam retrofits and small hydropower systems. The research focused on two categories: state-of-the-art companies developing modular or low-impact turbines and retrofit case studies that demonstrate integration with existing infrastructure.

The team examined modern hydropower systems from Finnrunner [2], Littoral Power Systems [3], Kinetic NRG [4], Powerturbines [5], and RheEnergise [6]. These examples demonstrate how small-scale hydropower companies are advancing turbine efficiency, modularity, and transportability.

Finnrunner and Littoral Power Systems specialize in compact low-head units that operate efficiently in shallow or slow moving waterways. Kinetic NRG and Powerturbines focus on prefabricated systems that minimize construction time and site disruption. RheEnergise uses pumped energy storage principles to store and release hydropower dynamically, highlighting the trend toward adaptable, distributed energy solutions.

Retrofit projects at Red Rock [7], Uniontown [8], and Holtwood [9] were reviewed to understand how established facilities have incorporated new turbines into existing dam structures. These studies emphasized the importance of matching turbine type to head and flow conditions while maintaining ecological compliance. Red Rock demonstrated how medium-scale 36 MW addition retrofit can maintain river navigation and fish passage but requires high cost, while Uniontown showed a small 5 MW capacity increase on a run of river style system can benefit community scale power while minimizing environmental impact

Holtwood added a 125MW conversion and showed how bigger upgrades can improve efficiency, extend dam life and distribute power to entire areas while mitigating environmental effects.

Table 3.1.1: NPD Benchmarking

(1-low, 5-high)	RedRock	Uniontown	Holtwood
Reliable Power Supply	5	4	5
Structural Integrity	5	4	4
Competitive cost	3	5	4
Recreational & Aesthetic Preservation	3	4	4
Low Environmental Impact	4	4	4
Long Life Expectancy	5	4	4
Regulatory Compliance	5	5	4

From these benchmarks, Kaplan turbines were identified as optimal for low-head, high-flow sites such as Peoria Lock and Dam, John C. Stennis Lock and Dam, and Coon Rapids Dam. Benchmarking also informed practical goals for efficiency (60–90 percent), system reliability (above 95 percent), and modular construction to control installation costs.

3.2 Literature Review

3.2.1 Anthony Nuzzo

The overview presented by *Student Energy* [10] provides an essential background on the principles of hydropower conversion and classification. It clearly explains the relationship between hydraulic head, flow rate, and power generation, while distinguishing between dammed, run-of-river, and pumped-storage systems. This resource establishes the conceptual basis for selecting an appropriate plant configuration and capacity class. The identification of small hydropower (1–10 MW) as a practical and sustainable range supports the decision to target this scale for the John Sevier Dam retrofit, ensuring consistency with global small-hydro benchmarks.

Chapallaz's *Manual on Pumps Used as Turbines* [11] delivers technical depth on the application of standard centrifugal pumps operating in reverse as turbines. Its experimental correlations, efficiency data, and case studies inform cost-effective approaches for low-head energy recovery. The manual's analyses provide quantitative support for evaluating pump-as-turbine (PAT) units as viable alternatives or supplementary generation modules. These insights contribute directly to minimizing capital costs and simplifying mechanical design while maintaining acceptable performance under varying flow conditions.

Mays [12], in *Water Resources Engineering*, offers a comprehensive treatment of hydrologic and hydraulic processes critical to this project's flow assessment and structural design. The text's methods for developing flow-duration curves, estimating head losses, and routing reservoir inflows are directly applicable to predicting energy yield and assessing operational reliability. Mays's integration of hydrology with infrastructure planning ensures that the hydraulic modeling underlying the design is technically robust and consistent with accepted water-resources engineering practice.

The review by Kaunda, Kimambo, and Nielsen [13] situated hydropower within a sustainable energy context, emphasizing both environmental responsibility and long-term resource management. Their analysis highlights the ecological and socio-economic considerations essential to responsible project development, including sedimentation management, habitat preservation, and climate-resilience measures. These findings reinforce the project's emphasis on environmental integration, supporting the inclusion of fish-passage systems and ecological flow control in the retrofit plan.

Paish [14] provides a global perspective on small-hydropower technology and implementation. His review of turbine typologies, civil works, and control systems offers practical benchmarks for efficiency, flow adaptability, and economic viability. The detailed comparisons of Kaplan, Francis, and bulb turbines validate the selection of a Kaplan-style bulb runner for low-head, high-discharge operation. Paish's discussion of control optimization and part-load behavior directly informs strategies to maintain efficiency across seasonal variations in discharge.

The design management and customer-requirement translation processes employed in this project are guided by Ficalora and Cohen [15], whose *Quality Function Deployment and Six Sigma: A QFD Handbook* provides a structured method for converting stakeholder needs into measurable engineering criteria. Their framework underlies the project's House of Quality, ensuring that priorities such as efficiency, cost, safety, and environmental compliance are quantitatively linked to design parameters. This methodological rigor enhances traceability between performance objectives and engineering decisions.

The case study by Okang, Bakken, and Bor [16] in *Water* (2023) delivers the most directly relevant evidence for the technical and economic feasibility of NPD retrofits. Their analysis of the Buyuk Menderes River Basin demonstrates that repowering existing dams can produce competitive energy output with substantially lower environmental and financial costs than greenfield developments. Their methodology for site screening and cost-benefit analysis has been adapted to the present study, validating the retrofit of the Coon Rapids Dam as both a sustainable and economically justified intervention within regional renewable energy objectives.

The U.S. Energy Information Administration [17] Offers insight for national electricity generation and allows the team to discover which areas could benefit from power generation and where electricity would be most utilized.

C. M. Sasthav et al [18] provides a detailed analysis of low-head, run-of-river hydropower system design with a focus on balancing energy production and environmental impact. It highlights key engineering considerations such as flow allocation, turbine selection, and headpond design, while also emphasizing the importance of minimizing ecological disruption through measures like fish passage systems and minimum flow requirements. The paper is particularly useful for this project because it directly relates to modern low-head retrofit systems and supports design decisions involving power duration curves (PDC), flow constraints, and environmental compliance. Additionally, it reinforces the importance of modeling tradeoffs between power generation and environmental performance, which aligns closely with the project's system-level feasibility analysis.

U.S. Department of Energy [19] focuses on the regulatory and environmental framework governing hydropower systems, particularly in the context of FERC licensing and long-term project operation. It explains how hydropower facilities must balance grid performance with environmental constraints, including flow regulation, aquatic ecosystem protection, and climate-related uncertainties. The source is valuable for this project because it provides insight into how engineering decisions—such as flow diversion, operating strategy, and capacity selection—must align with environmental compliance requirements over the life of the project. It also supports the justification of design constraints and success metrics by linking technical performance to regulatory expectations and sustainability goals

3.2.2 Karsten Jones

Non-powered dams (NPDs) represent a significant opportunity for expanding renewable energy generation in the United States. The U.S. Department of Energy *Hydropower Vision Report* highlights that thousands of existing dams lack power generation infrastructure but possess viable hydraulic conditions for retrofit, making them attractive targets for development [20].

Hansen further quantifies this opportunity through analysis conducted at Oak Ridge National Laboratory, identifying substantial untapped hydropower capacity across the country. This reinforces the feasibility of utilizing existing infrastructure for energy production rather than constructing new dams [21].

Additional support is provided by U.S. Department of Energy hydropower market reports, which emphasize the increasing role of small-scale and modular hydropower systems in distributed energy generation. These findings highlight a growing trend toward adaptable, site-specific solutions [22].

Turbine selection is a critical factor in determining the efficiency and feasibility of low-head hydropower systems. De Siervo and Lugaresi provide a detailed analysis of Kaplan turbine design, emphasizing their suitability for low-head, high-flow environments due to adjustable blade geometry and high efficiency across varying operating conditions [23]. This aligns directly with the hydraulic characteristics of the selected site.

The U.S. Army Corps of Engineers Low-Head Dam Inventory identifies numerous existing dams with suitable hydraulic conditions for retrofit, further supporting the viability of implementing hydropower systems at sites like Coon Rapids Dam [24].

Economic feasibility remains a key consideration in hydropower development. Global cost trends reported by the International Renewable Energy Agency (IRENA) indicate that hydropower remains competitive with other renewable energy sources when high capacity factors and consistent flow conditions are present [25].

The National Renewable Energy Laboratory defines the Levelized Cost of Energy (LCOE) as a function of capital cost, operational cost, and total lifetime energy production, providing a standardized metric for comparing energy systems [26]. This metric is widely used to evaluate the economic viability of renewable energy projects.

Nasir et al. evaluate the use of pumps operating as turbines (PATs), highlighting their lower cost and simplicity as potential advantages. However, the study also identifies limitations in efficiency compared to purpose-built turbine systems, indicating that while cost savings are possible, performance trade-offs must be considered [27].

Williamson et al. present a multi-criteria decision-making approach for selecting low-head turbines, incorporating efficiency, cost, and site-specific constraints. This framework supports structured design selection and highlights the importance of balancing multiple performance factors [28].

The Federal Energy Regulatory Commission Hydropower Primer outlines the key technical and economic factors influencing hydropower system performance, including head, flow rate, and turbine efficiency. These relationships are essential for understanding both system design and cost performance [29].

Finally, guidelines from the U.S. Bureau of Reclamation provide industry standards and best practices for hydropower system design, emphasizing reliability, maintainability, and long-term operational performance as critical factors in overall project success [30].

3.2.3 Dawson Stevens

“Hydraulic Design” by Gemperline and Crane discusses the procedures of hydraulic design and analysis of various elements on the intake systems for hydroelectric plants [31].

“Economics of Energy Generation and Conservation Systems” explains the calculations and equations needed to make the financial justifications for a power plant [32].

The Water section of “Introduction to Renewable Energy” Introduces the basic concepts and vocabulary within hydroelectric design [33].

Hydropower '97's "Dam Safety and Risk Analysis section was used to explain the various considerations and preventative measures that properly designed dams should take into account[34].

"Hydraulics of Hydropower" discusses the mathematics behind the hydraulic design of turbines and how to optimize energy collection from moving water [35].

The ORNL Non-Powered Dam Inventory is a database of several thousand non-powered dams across the continental United States [36].

Electromechanical Equipment in "Micro Hydroelectric Power Stations" explains the equipment needed when translating the mechanical energy of the turbine to electrical energy [37].

"Hydropower Development Guideliness" are the standards used for hydropower projects built in the United States [38]

3.2.4 Nathaniel Holguin

The USGS information was used for major amounts of data collection about the John C. Stennis Dam water. Data was collected from it showing water flow rate averages for every month of the year, as well as average flow for every day of the year. Water level data was also collected for month to month variation by taking the difference in tail water and gauge water levels. [39]

The USACE kept records and a history of seasonal water levels and reservoir behavior. It helped develop general outlines and estimates of how the data to be collected will affect future plans. [40]

The NOAA helped in showing some forecasted data and how it can be affected in the short term. It shows how water levels and flows respond/react to storms and other short term weather conditions. [41]

The graduate project of the anthropogenic impact of the Tennessee Tombigbee Waterway was used to understand the general characteristics of water quality in the basin. It showed how it is better in less disturbed areas but poorer in areas of urbanization and high runoff or agricultural use. [42]

Livingston Daily gives details and specifications of the John C. Stennis Dam. It gives general conditions assessments as well as all height, width, storage, area, and drainage details, allowing for a more in depth understanding of the site. [43]

This organization goes further into detail of where the water quality is getting affected, why it's happening, and its impacts. It goes into detail of certain locations and helps inform the overall quality of the Mississippi River system. [44]

Snoflo Climate research gives a detailed forecast and corresponding water flow effects. It helps show a day to day predicted outflow to see really how minute weather changes will affect the dam conditions. It also has a year to year seasonal comparison to help understand overall long term effects. [45]

3.3 Mathematical Modeling

3.3.1 Turbomachinery Modeling - Karsten Jones

The performance of the proposed hydropower system was evaluated using fundamental turbomachinery relationships and site-specific hydraulic conditions. The primary equation used to estimate hydraulic power output is:

$$P = \rho g Q H \eta$$

where P is power output, ρ is water density, g is gravitational acceleration, Q is flow rate, H is hydraulic head, and η is system efficiency. This equation was used to estimate the theoretical power output of the system based on measured flow and head conditions at the selected site.

For the Coon Rapids Dam site, a representative head of approximately 5 meters and a controlled flow rate of 10 m^3/s were used. Based on these inputs and estimated efficiency values, the system achieves an approximate power output of **390 kW per turbine unit**, resulting in a multi-megawatt system when scaled across multiple units.

To further evaluate turbine performance, the mechanical power relationship was used:

$$P = T\omega$$

where T is shaft torque and ω is angular velocity. This relationship describes how power output is distributed between torque and rotational speed.

Figure 3.3.1.1 illustrates the relationship between shaft torque and runner speed for the selected turbine configuration. The curve shows a strong inverse relationship, where torque is highest at low rotational speeds and decreases as runner speed increases. This behavior is consistent with hydraulic turbine operation, where increased rotational speed reduces the effective hydraulic force on the blades.

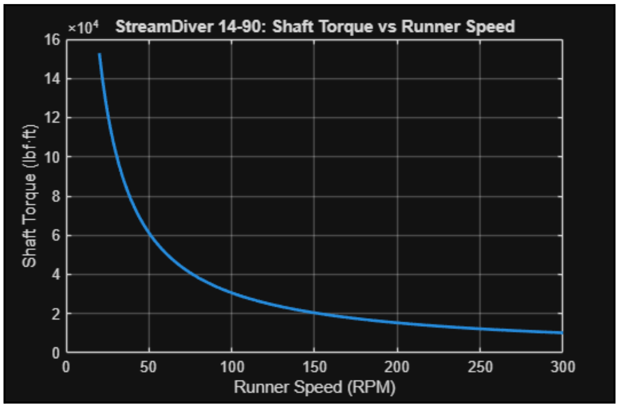


Figure 3.3.1.1: Shaft Torque vs. Runner Speed for StreamDiver

At low speeds (approximately 20-50 RPM), the turbine produces high torque, indicating strong starting capability. As speed increases, torque decreases while overall power output remains viable due to increased angular velocity.

To further characterize performance, the blade speed ratio was analyzed as shown in Figure 3.3.1.2. The blade speed ratio represents the ratio of blade tip speed to incoming flow velocity and is a key parameter in determining turbine efficiency.

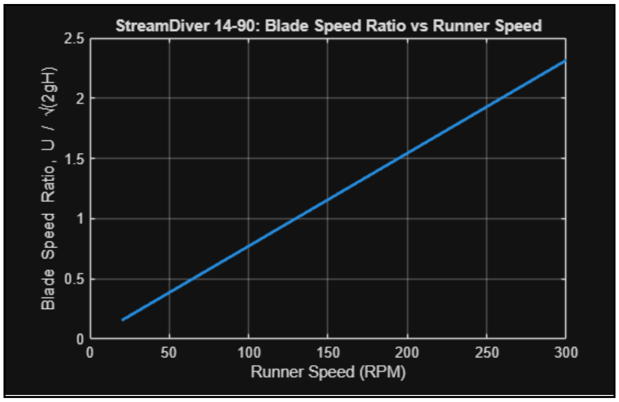


Figure 3.3.1.2: Blade Speed Ratio vs. Runner Speed

The results show that blade speed ratio increases linearly with runner speed, indicating that turbine efficiency is strongly dependent on operating speed relative to flow conditions. This relationship helps identify optimal operating range of the system.

Based on both torque-speed behavior and blade speed ratio analysis, the turbine achieves optimal performance near **120 RPM**, where a balance between torque and rotational speed maximizes power output. This operating point aligns with both modeling results and experimental observations from prototype testing.

Overall, the turbomachinery model provides a consistent framework for predicting system performance, guiding turbine selection, and validating experimental results under site-specific conditions.

3.3.2 Power Analysis - Anthony Nuzzo

Mathematical modeling was used to evaluate the hydrologic resource, estimate power output, and quantify annual energy generation for the proposed hydropower retrofit. The primary modeling tools used in this analysis were the flow duration curve (FDC), power duration curve (PDC), and annual generation profiles, all developed in MATLAB using USGS discharge data as the primary hydrologic input.

Flow Duration Curve (FDC)

The flow duration curve was used to characterize how often specific river discharge values are equaled or exceeded over the available record. In the MATLAB workflow, daily mean discharge values were sorted in descending order and paired with exceedance probability using,

$$P_e = \frac{m}{n+1}$$

where mmm is the rank of the discharge value after sorting and nnn is the total number of observations. The exceedance probability was then converted to percent form for plotting. This allowed key flow statistics such as Q10, Q50, Q90 to be extracted for site characterization. The FDC is important because it shows the long-term availability of flow and forms the basis for turbine sizing and performance estimation.

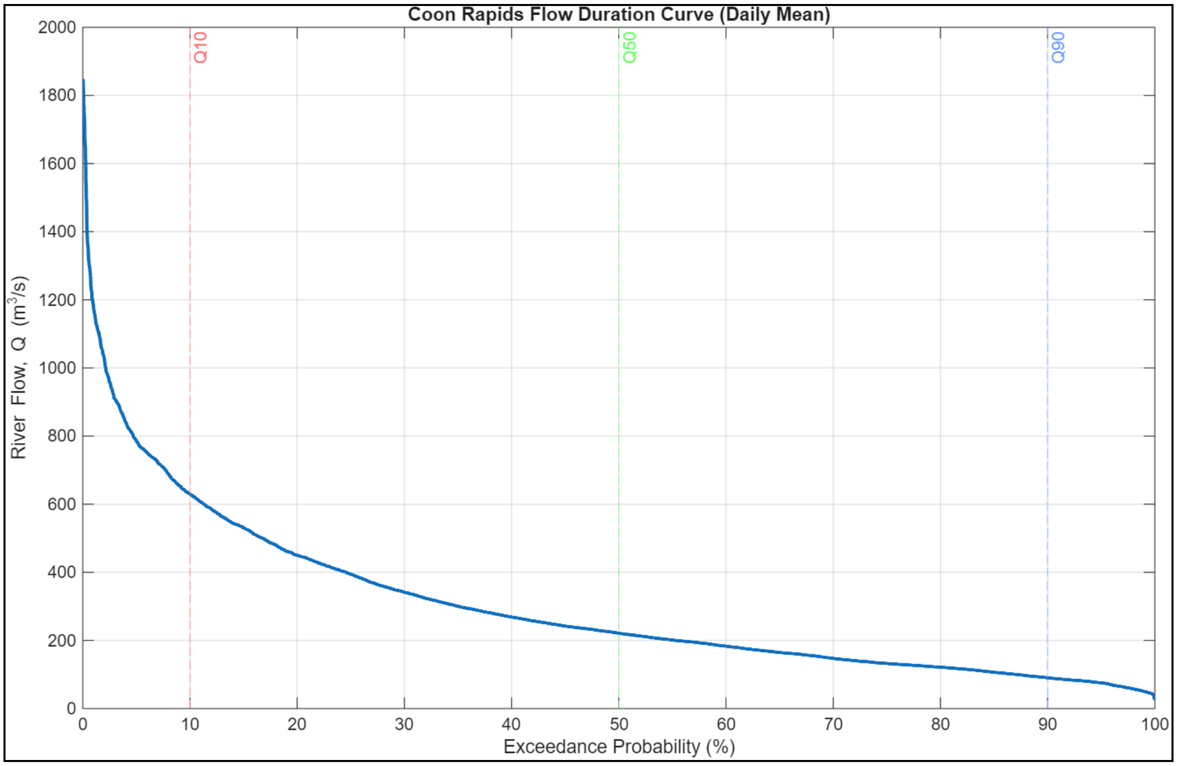


Figure 3.3.2.1: Coon Rapids Flow Duration Curve

Available Flow And Diversion Constraints

to reflect environmental and operational constraints, the total river flow was reduced using both a bypass requirement and a maximum diversion fraction. The available turbine flow was modeled as,

$$Q_{avail} = Q_{river}(1 - b_f)$$

where b_f is the bypass fraction. A diversion-limited flow was also imposed:

$$Q_{div,lim} = f_d Q_{river}$$

where f_d is the maximum diversion fraction. The actual turbine flow used in the model was then taken as the minimum of the environmentally available flow, the diversion-limited flow, and the total installed turbine capacity:

$$Q_{used} = min[Q_{avail}, Q_{div,lim}, Q_{cap,total}]$$

This step is important because it ensures the modeled generation remains physically and environmentally realistic.

Power Duration Curve

The power duration curve was developed by converting the available flow into electrical power output across the full exceedance range. The governing hydropower equation used in the model was:

$$P = \rho g Q H_{net} \eta$$

where ρ is water density, g is gravitational acceleration, Q is turbine flow, Hnet is net head, and η is overall turbine-generator efficiency. In this model, net head was based on gross head adjusted for losses:

$$H_{net} = H_{gross}(1 - loss\,fraction)$$

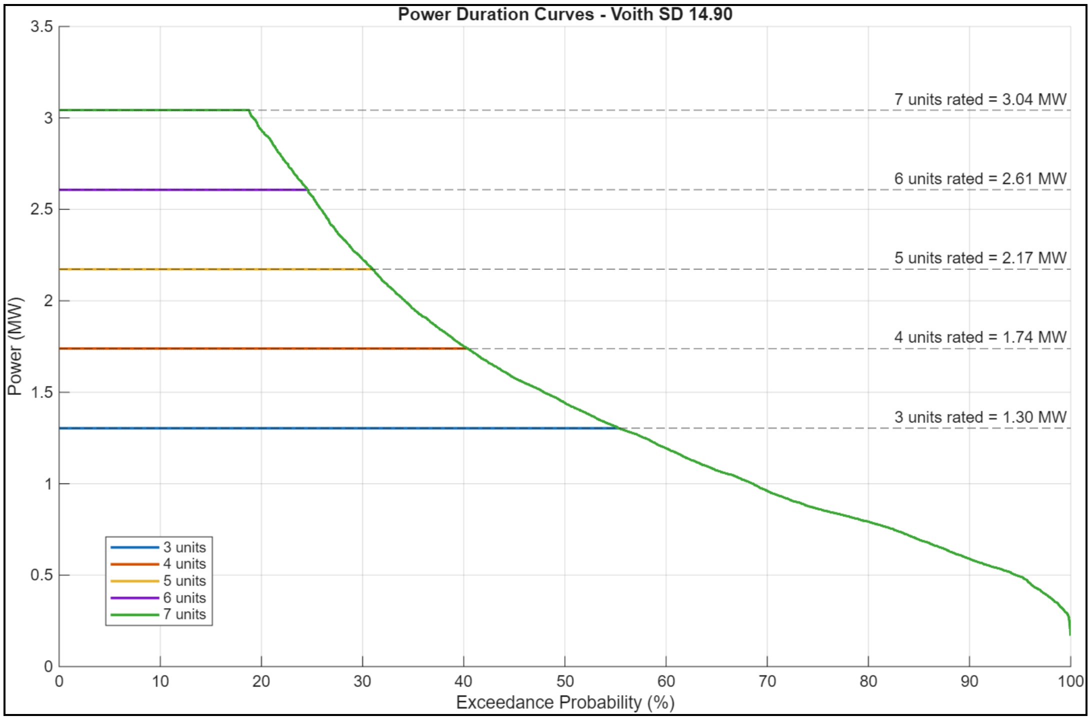


Figure 3.3.2.2: Power Duration Curve

The PDC shows how much power the system can produce and how frequently that power level can be maintained. This is especially useful for comparing different installed configurations, such as the 3–7 unit layouts considered in the model.

The PDC shows how much power the system can produce and how frequently that power level can be maintained. This is especially useful for comparing different installed configurations, such as the 3–7 unit layouts considered in the model.

Installed Capacity and Multi-Unit Modeling

The model evaluated multiple turbine configurations by varying the number of installed StreamDiver units. Total installed flow capacity was defined as:

$$Q_{cap,total} = N_{units} Q_{per\ unit}$$

This made it possible to compare how the number of units influences rated power, average power, annual energy, and capacity factor. By sweeping across multiple cases, the model supports selection of a practical design point rather than relying on a single assumed installation. This practice was implemented in the PDC curve estimate to better understand the site's behavior.

Annual Energy Generation

Annual energy production was estimated from the average modeled power output using:

$$E_{annual} = P_{avg} * 8760$$

where Pavg is the average power in MW and 8760 is the number of hours in a year. This gave annual generation in MWh/year. For the hourly hydro profile, raw discharge data were converted directly into hourly power output and then summed over the year to estimate annual generation more explicitly. These annual generation results were used to evaluate the energy benefit of additional unit counts.

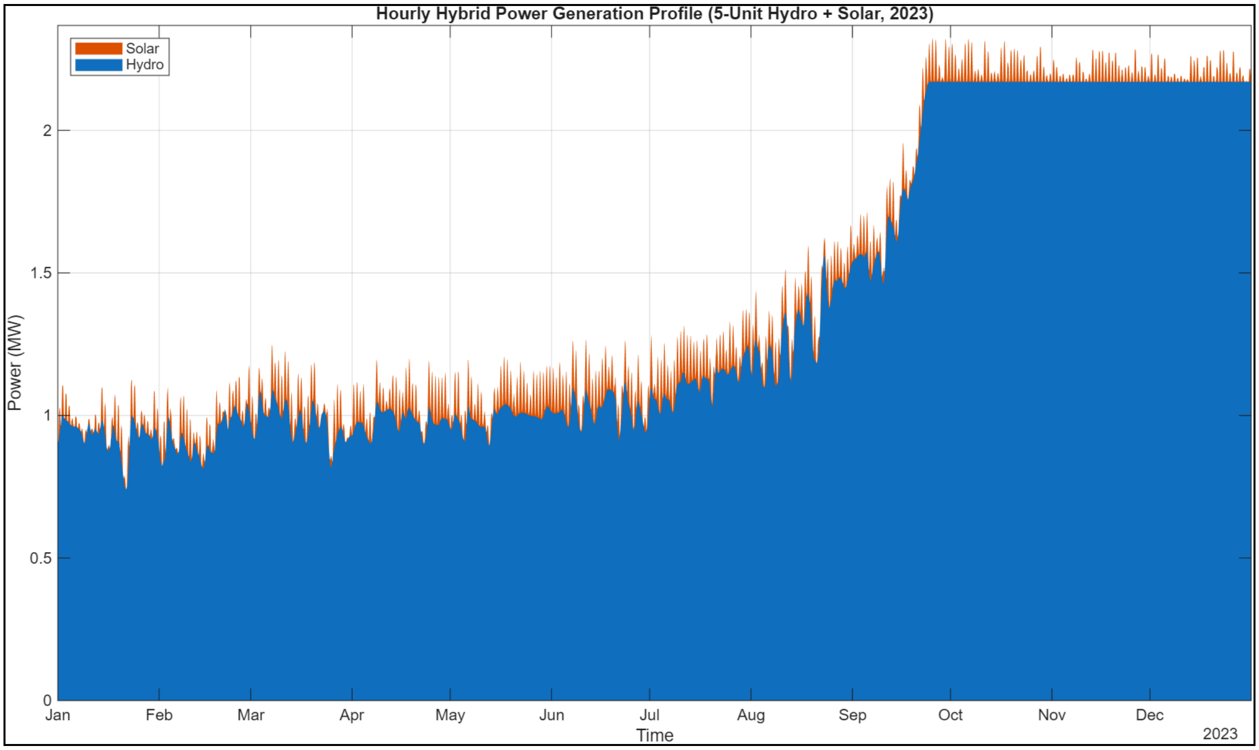


Figure 3.3.2.3: Hourly Hybrid Power Generation Profile

3.3.3 Solar Field Analysis - Anthony Nuzzo

Utilizing the site layout mentioned by Tim Chambers, solar recreation has been a concept that was considered implemented but the time was never really given to the idea. In this mathematical section, a detailed solar pv plant was modeled using the SAM software.

The plant required just under a full acre to utilize, and is located near the XCEL substation south of Coon Rapids Dam.

To summarize the design, the key metrics are as follows:

- Installed capacity: 305 kWdc / 250 kWac
- Annual generation: 415 MWh/year
- Capacity factor: 15.5%
- Specific yield: 1,361 kWh/kW-yr
- LCOE: ~ 12.2 ¢/kWh
- Installed cost: ~ $560k

The monthly AC energy in the first year was modeled to give a visual about the distributions of power per month, this solar addition satisfies the competition's copower requirement and this plant contributes just around 3.7% annually for the hybrid system.

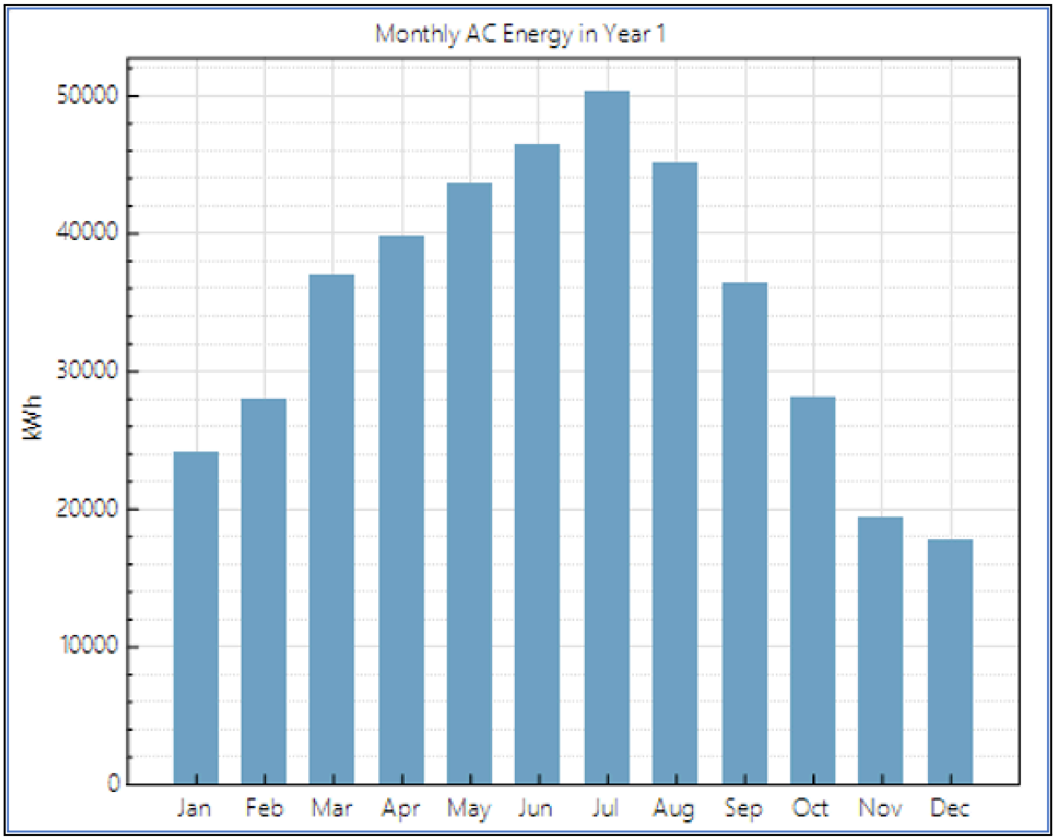


Figure 3.3.3.1 Solar Monthly AC Energy In Year 1

3.3.4 Economic Analysis - Karsten Jones / Anthony Nuzzo Hill

Economic feasibility was evaluated using the levelized cost of energy (LCOE), which represents the cost per unit of electricity generated over the system lifetime [26].

Cost estimates were derived using outputs from the JEDI model, including capital expenditures (CAPEX) of approximately $10.5 million and annual operational expenditures (OPEX) of approximately $313,000 per year. These values were used in conjunction with projected energy production to evaluate overall system cost effectiveness through LCOE. For the selected configuration of five turbine modules, the system achieves a capacity of approximately 2.17 MW and generates 12,699 MWh annually, corresponding to a capacity factor of 67%.

Table 3.3.4.1: Summary of Economic Results for turbine system

Units	Capacity	Energy (MWh/yr)	CF	CAPEX	OPEX	LCOE ($/MWh)
5	2.17	12,699	67%	$10.5 Million	$313,000/yr	$79.61

CAPEX represents the dominant cost driver, with structural integration and turbine installation accounting for the majority of total project cost, while OPEX remains relatively low due to minimal ongoing operational requirements.

The resulting LCOE for the system is approximately $79.61/MWh, which aligns with the project target of $80.00/MWh, indicating that the system meets its economic design objective. This value is consistent with the expected range for small hydropower installations [25], reflecting the additional costs associated with structural integration and modular deployment. This value is competitive within the small hydropower sector, where LCOE typically ranges from $60 to $120/MWh, supporting the economic viability of the proposed system.

Economic performance is sensitive to the number of turbine modules. Increasing the number of turbines improves total energy output but results in higher capital costs due to additional structural modification. This tradeoff demonstrates that increasing turbine count beyond the selected configuration results in diminishing economic returns, reinforcing the selection of five turbines as the optimal balance between energy production and capital cost. This economic behavior directly supports the system configuration selected in Section 2.3, linking cost performance to design optimization.

To conceptualize the system's total energy output, the annual generation of 13,479 MWh was compared to the average residential electricity consumption in Minnesota [17]. Based on average household usage of 712 kWh per month (8,544 kWh annually), the proposed hydropower system is capable of supplying energy to approximately 1,550 homes per year as shown in Table 3.3.3.2.

Table 3.3.4.2: Energy Production and Residential Impact

Parameter	Installed Capacity (MW)	Capacity Factor (%)	Annual Energy Production (MWh/yr)	Annual Energy Production (kWh/yr)	Avg. MN Household Consumption (kWh/yr)	Equivalent homes Powered
Hydro	2.17	67	12,699	12,699,000	8,544	1,490
Solar	.25	15.5	480	480,000	8,544	56
Hybrid	2.42	61.9	13,479	13,479,000	8,544	1,546

This comparison provides a practical measure of system impact, demonstrating that the proposed design can supply energy to approximately 1,550 homes annually while maintaining a relatively small environmental footprint.

3.3.5 Environmental Analysis - Dawson Stevens

To conduct this analysis, the Hydropower Environmental Decision Support (EDS) Toolkit, developed by the Oak Ridge National Laboratory (ORNL) and the U.S. Department of Energy, was used. The Hydropower Environmental Decision Toolkit was created for the purposes of streamlining the decision-making process around environmental consideration within the hydropower industry [51]. Below are brief breakdowns of each category:

- Biota & Biodiversity – The site does not contain any endangered or protected species, however, Silver Carp, an invasive fish, is found in the Mississippi River [52]. Additionally, the dam acts as a barrier to prevent the carp from moving upstream. As long as proper precautions and safety measures are taken, the biology of the surrounding water system should not impede construction.
- Hydrology – Due to this project being a renovation project, little change to the hydrology should occur. The only notable issue in this category is the possibility of interrupting the flow of the dam during the construction process. A solution to this would be to schedule the construction during

the site's dry season.

- Landscape – Similar to hydrology, there should be minimal effects on the landscape besides that already affected by the pre-existing structure. The team is currently investigating the co-development of a solar power plant next to the dam. This would occupy more land, potentially interrupting nearby habitats, however a sizable plot of land with minimal vegetation exists alongside the dam. Using this plot would minimize habitat disruption.
- Water Quality – The main concern of water quality has to do with the amount of dissolved oxygen in the tailwater. When water is turbulently discharged through a dam, atmospheric gases can dissolve into it, increasing the oxygenation of downstream water. Since the proposed dam only diverts a portion of the total water flowing through the dam, any oxygenation effects should be minimal.
- Geomorphology – Due to the scope of the project, geomorphology will be minimally affected. No further considerations outside of minimizing habitat impact need to be implemented in this regard.
- Connectivity & Fragmentation – The project will have minimal effect on the connectivity of the river as no further fragmentation should occur besides that already caused by the existing dam structure.

The downstream waters of the site have invasive carp that must not migrate past the dam. To prevent this from happening, fish screens can be added to the turbine entries. These will prevent fish migration during turbine downtime. The current site has no fish bypass system for downstream migration, which means no action needs to be taken to allow such fish movement.

Table 3.3.5.1: Recommended Environmental Precautions

Issue	**Solution**
Invasive carp must not move upstream	Add fish screens and ensure the stoplog system is sufficient during construction
River contains an active fishery	The fish screen will prevent fish entering the system

3.3.6 Seasonal Outflow - Nathaniel Holguin

It is known that the outflow can vary a lot over the course of the year so monthly average data was collected from 1900-2014 excluding a couple of years due to missing data [40]. Taking the average flow rates for each month and putting them into a graph gives the following Figure 3.3.6.1. The x axis number is the corresponding month of the year.

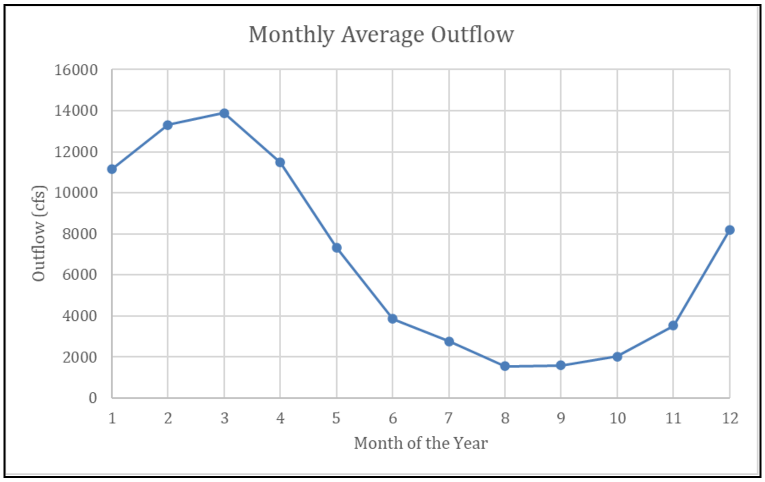


Figure 3.3.6.1: Monthly Average Outflow

As seen in Figure 3.3.5.1 the flow at the dam follows a gradual path, having a high December through March and then dipping low May through November. This is due to clear seasonal trends where higher rainfall occurs in the winter and spring months and slows down in the summer and early fall months where precipitation is lower.

This gives the team a good outline to understand how outflow will change throughout the year and how the team might manage that. Even using a turbine that is attuned to capture low flow or a variety of flow, the energy produced during the low season would be insufficient and need a way to counteract it. Some options might include having more turbines run in these months, though that would be a superficial way to keep energy output up. Another option could be being operationally flexible, running as a run of water facility where power is only generated if there is adequate water supply. This might be able to be done seeing as the John C. Stennis Dam has gates that could be used to mitigate how much water flow goes through the system. A similar method to keep up energy through the low season would be to instead of saving water, saving power in a battery of some sorts so that ideally there would always be enough to distribute. There is only so much that can be done about low flow rates though, so in times of low flow the best option might just be to turn off some turbines and save some energy and environmental stability while letting a portion of the turbines do all the work. In this scenario other energy sources would be supplemented so that users would not be affected by seasonal outflow variations.

To understand the total outflow in a given year, data was collected for an average of every day of the year from 1900 to 2014 [40]. This data was used to make an outflow duration curve as seen below in Figure 3.3.5.2.

Figure 3.3.6.2: Outflow Duration Curve

The outflow duration curve helps visualize how often outflow will be at different levels so teammates can better understand this topic. As seen on the curve, about 80% of the time outflow will be at least 2000cfs and only 20% of the time it will reach above 12000cfs.

Although outflow is more important, the difference between headwater and tailwater or water drop affects the energy output as well. Below in Table 3.3.6 is data collected for 9 years [40] of head and tail water.

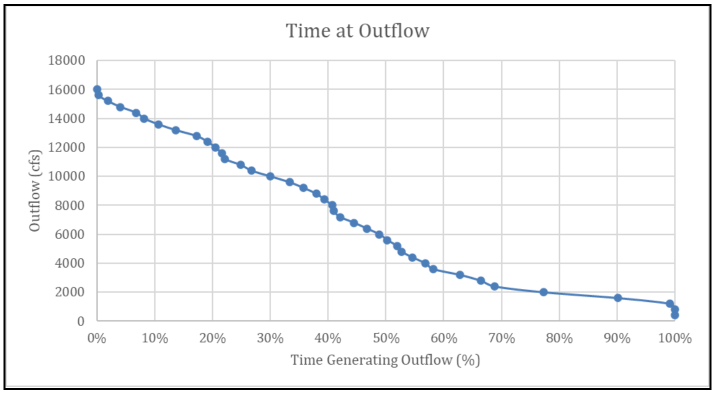
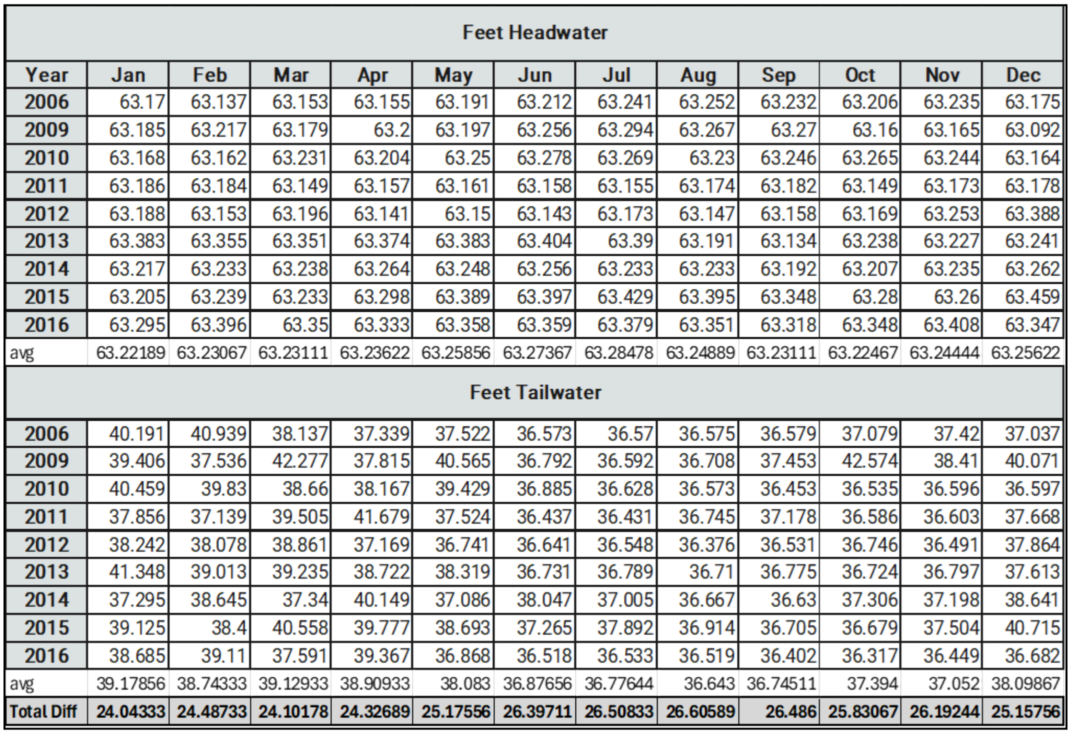


Table 3.3.6: Head and Tail Water



Feet Headwater												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2006	63.17	63.137	63.153	63.155	63.191	63.212	63.241	63.252	63.232	63.206	63.235	63.175
2009	63.185	63.217	63.179	63.2	63.197	63.256	63.294	63.267	63.27	63.16	63.165	63.092
2010	63.168	63.162	63.231	63.204	63.25	63.278	63.269	63.23	63.246	63.265	63.244	63.164
2011	63.186	63.184	63.149	63.157	63.161	63.158	63.155	63.174	63.182	63.149	63.173	63.178
2012	63.188	63.153	63.196	63.141	63.15	63.143	63.173	63.147	63.158	63.169	63.253	63.388
2013	63.383	63.355	63.351	63.374	63.383	63.404	63.39	63.191	63.134	63.238	63.227	63.241
2014	63.217	63.233	63.238	63.264	63.248	63.256	63.233	63.233	63.192	63.207	63.235	63.262
2015	63.205	63.239	63.233	63.298	63.389	63.397	63.429	63.395	63.348	63.28	63.26	63.459
2016	63.295	63.396	63.35	63.333	63.358	63.359	63.379	63.351	63.318	63.348	63.408	63.347
avg	63.22189	63.23067	63.23111	63.23622	63.25856	63.27367	63.28478	63.24889	63.23111	63.22467	63.24444	63.25622
Feet Tailwater												
2006	40.191	40.939	38.137	37.339	37.522	36.573	36.57	36.575	36.579	37.079	37.42	37.037
2009	39.406	37.536	42.277	37.815	40.565	36.792	36.592	36.708	37.453	42.574	38.41	40.071
2010	40.459	39.83	38.66	38.167	39.429	36.885	36.628	36.573	36.453	36.535	36.596	36.597
2011	37.856	37.139	39.505	41.679	37.524	36.437	36.431	36.745	37.178	36.586	36.603	37.668
2012	38.242	38.078	38.861	37.169	36.741	36.641	36.548	36.376	36.531	36.746	36.491	37.864
2013	41.348	39.013	39.235	38.722	38.319	36.731	36.789	36.71	36.775	36.724	36.797	37.613
2014	37.295	38.645	37.34	40.149	37.086	38.047	37.005	36.667	36.63	37.306	37.198	38.641
2015	39.125	38.4	40.558	39.777	38.693	37.265	37.892	36.914	36.705	36.679	37.504	40.715
2016	38.685	39.11	37.591	39.367	36.868	36.518	36.533	36.519	36.402	36.317	36.449	36.682
avg	39.17856	38.74333	39.12933	38.90933	38.083	36.87656	36.77644	36.643	36.74511	37.394	37.052	38.09867
Total Diff	**24.04333**	**24.48733**	**24.10178**	**24.32689**	**25.17556**	**26.39711**	**26.50833**	**26.60589**	**26.486**	**25.83067**	**26.19244**	**25.15756**

Thankfully these values do not have as much seasonal variation as outflow, so the energy output will not be affected too greatly. The total difference in water height at a monthly average sits around 24 to 27 feet, only having about a 3 foot variation. This low variation does not impact the energy output even a percentile as much as the outflow so in turn it will be neglected to deal with the much more pressing issue.

4 Design Concepts

4.1 Functional Decomposition

The functional decomposition of the Hydrojacks system identifies the major operations that must occur for a non-powered dam retrofit to generate reliable hydropower. It breaks the overall objective of clean, small-scale power production into a series of mechanical, electrical, and environmental sub-functions. At the highest level, the system must convert the potential energy of water stored behind a dam into rotational and then electrical energy while maintaining flow continuity and minimizing ecological disturbance. This includes the intake of water, its controlled passage through the turbine assembly, and the safe discharge of flow downstream.

The decomposition shown in Figure 4.1 illustrates how these primary operations are divided into subsystems. Flow capture and regulation ensure debris protection and navigational safety; turbine energy conversion achieves high efficiency in a low-head range; and the generator converts mechanical power into stable AC electricity. The power-conditioning system maintains grid compliance, while environmental and structural integration functions support fish passage, sediment control, and dam accessibility. Each function connects directly to a set of engineering requirements—efficiency, reliability, cost, and environmental impact—that together define system performance objectives.

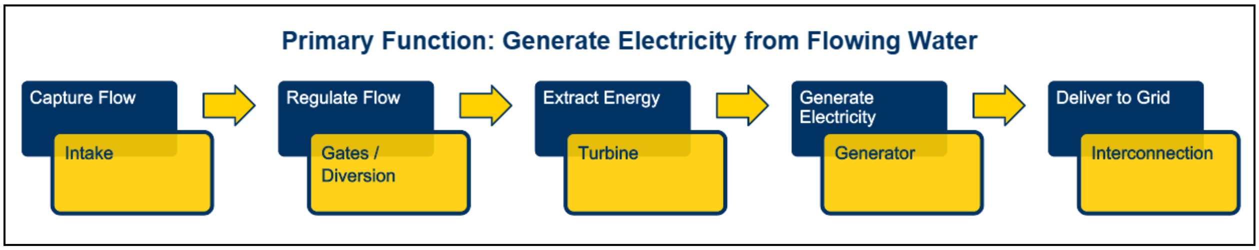


Figure 4.1.1 Functional Decomposition of a NPD Conversion

4.2 Concept Generation

<u>Peoria Lock & Dam</u>

Figure 4.2.1: Peoria Lock & Dam [48]

Located in Peoria, Illinois, this dam is one of the few wicket dams in the United States. It stood out for having both a consistent head around 3.05 meters, and flow data around 268 m^3/s generating around 2.99 MW, at least according to the ORNL database [21]. Additionally, the site is about .8 km away from the nearest grid connection. The team also managed to obtain the as-built drawings of the dam. However, after interviewing Matthew Traver, the lockmaster of the dam, the team learned that the site has a severe flood season that would often submerge much of the structure underwater. That, combined with the difficulty of integrating a turbine system into such an unusual type of dam, made this a less than ideal site for the project, but a strong initial contender.

John C Stennis Lock & Dam

Figure 4.2.2: John C Stennis Lock & Dam [40]

John C. Stennis Lock & Dam, located on the Tombigbee-Tennessee Waterway was another strong competitor. It has a much higher head around 5.5 meters and an average flow of about 226 m^3/s, with a more manageable flood season compared to some of the early contenders [21]. This site does have a dry season during autumn, but would still provide ample output throughout the year with a mean of about 3.042 MW. In terms of co-development opportunities, the dam being located in a park with unutilized plots adjacent to it gave us plenty of space for either a solar or recreational projects alongside the turbine installation. Another addition to the site would be the intertie distance of about .9 kilometers, which was within the constraints we set for the site.

When interviewing the Navigation Manager of the waterway, Roger Wilson, he stated a big issue any renovation project at the site would run into would be the conflict between navigation and energy uses, as the reservoir and tailwater have very strict heads to maintain throughout the year. Additionally, the localized cost of energy was not ideal for a profitable site. For these reasons, the team decided to perform a third round of site selection, this time with the cost of energy as a higher priority.

Coon Rapids Dam

Figure 4.2.3: Coon Rapids Dam [46]

Coon Rapids Dam, located in Coon Rapids, Minnesota, is a former hydroelectric dam. Built in the early 1900s, the powerhouse has since been dismantled and the turbines removed. The dam and its surrounding area is now a park. Fortunately, the turbine housing is still intact, though sealed off, and the onsite substation structure is also present. From the ORNL database shows the site is low-head around 5.8 meters and high-flow with an average around 300 m^3/s [21]. Furthermore the intertie distance would be just under .6 kilometers cutting the expenses to a more favorable region. Another benefit when compared to the previous two dams is that Coon Rapids is not used for navigation or flood control, meaning less compromise would need to be made between uses when installing a turbine system.

After contacting the dam, we were able to obtain the original engineering drawings of the dam from the site owners and talk to the current site manager, Tim Chambers. Chambers gave us valuable information regarding the current state of the dam and the local importance of the site and surrounding park to the city of Coon Rapids.

4.3 Selection Criteria

The selection criteria used during site selection to create a decision matrix are explained in detail below. Note, some criteria were added and/or modified during the team's three rounds of site selection, the list below only shows the final form of the criteria.

Estimated Output: Scores were found using output estimations (P) from the ORNL NPD Inventory [1]. These estimations assume 100% efficiency and are not accurate to what is realistically achievable at each side, rather this value serves as a potential meter for how much available energy is at the site. Since the main goal of our project is to generate power, this category has the largest weight in the decision matrix. More power output means a more profitable dam.

$$Estimated\ Output\ Score = P \times 10,\ if\ P > 10 \rightarrow Score = 100$$

Flow & Head Consistency: Scores were found using monthly head and flow data from the ORNL NPD Inventory [36]. The coefficient of variance (CV) was calculated for both head and flow rate for each dam. This value gives us an idea for how reliable the input for a turbine system would be at the site. Similar to estimated output, this category has a large weighting in the matrix. This was decided as creating a dam that only generates meaningful output for a fraction of the year is both less economical and more difficult to justify.

$Consistency\ Score = 1 - CV$, used for head and flow scores

Infrastructure Proximity: Infrastructure proximity evaluates the availability of existing structures and grid access that would support turbine integration. Sites with nearby substations, transmission lines, or existing hydropower infrastructure were scored higher due to reduced installation complexity and cost. Scoring was based off proximity to substations/transmission lines in miles, D. If the nearest connection point was on the same property as the dam, a score of 100 was assigned.

$$Infrastructure\ Score\ = 100 - (D \times 10)$$

Ownership & Regulation: This criterion assesses the complexity of ownership and regulatory requirements associated with each site. Factors considered include ownership structure, permitting difficulty, and potential regulatory barriers. Due to the qualitative nature of this criteria, scoring was determined through research and comparison to other sites, with the final score being determined by the team's opinion following this research. Dams owned by organizations such as the US Army Corps of Engineers were favored due to the ease of contact and the availability of information regarding the site.

$$Ownership\ Score\ = Team\ Decision$$

Dam Structure: Dam structure evaluates the physical configuration of the dam and its compatibility with the proposed turbine system. This includes considerations such as geometry, available installation locations, and the presence of flow control mechanisms. The type of dam structure (concrete, in-fill, etc.) as listed by the National Inventory of Dams was also considered in scoring [50]. Generally, concrete dams were prioritized and dams with pre-existing hydropower structures were given full or near-full scores.

$$Structure\ Score\ = Team\ Decision$$

Risk: The risk criterion captures potential barriers to successful implementation that are not fully represented by other criteria. This includes environmental constraints, regulatory uncertainty, structural limitations, and data uncertainty. For scoring, the Hazard Potential Classification made by the National Inventory of Dams was used [50]. This classification has three levels (HC), which were used to determine each dam's score in this category ($low\ HC\ = 1,\ high\ HC\ = 3$).

$$Risk\ Score\ = 100/HC$$

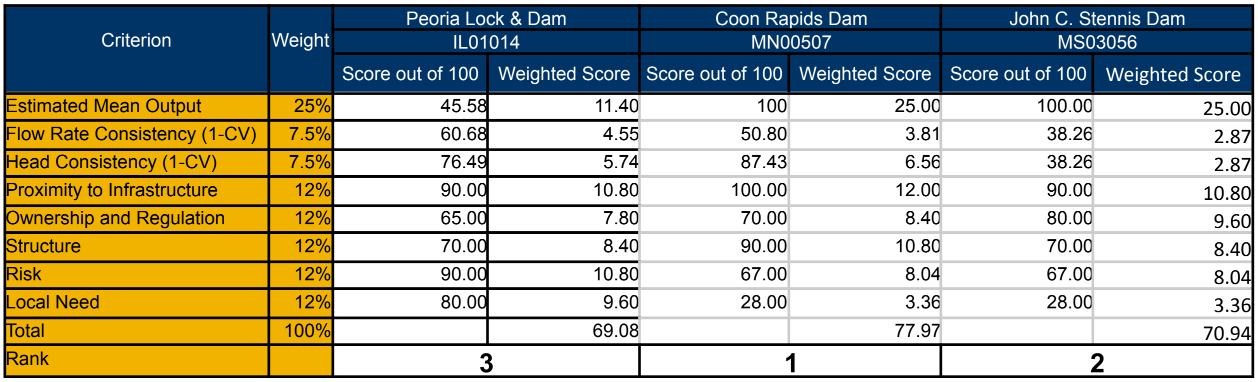
Local Need: Local need reflects the potential value of energy generation at the site, considering factors such as regional electricity pricing, demand, and community benefit. For scoring, the percent difference in dollar per kWh from the national average for each site's respective county was used (CoE) [42]. Sites with energy costs exceeding a 50% difference from the national average were either given a 0 (lower) or 100 (if higher).

$$Need\ Score\ = 50 \times (1 \pm CoE)$$

The infrastructure, ownership, risk, and local need scores all share the same weight of 12%. The reason for this was to minimize bias from the team, given that often qualitative nature of these categories. Realistically, these categories would not have equal weight, but due to the nature of this competition and the experience level of the team, this decision was meant to give us a better feel for these categories in future work. Together, these criteria capture both technical feasibility and practical implementation considerations, reflecting the multidisciplinary nature of hydropower development.

4.4 Concept Selection

Table 4.4.1: Summarized Decision Matrix



Criterion	Weight	Peoria Lock & Dam		Coon Rapids Dam		John C. Stennis Dam	
		IL01014		MN00507		MS03056	
		Score out of 100	Weighted Score	Score out of 100	Weighted Score	Score out of 100	Weighted Score
Estimated Mean Output	25%	45.58	11.40	100	25.00	100.00	25.00
Flow Rate Consistency (1-CV)	7.5%	60.68	4.55	50.80	3.81	38.26	2.87
Head Consistency (1-CV)	7.5%	76.49	5.74	87.43	6.56	38.26	2.87
Proximity to Infrastructure	12%	90.00	10.80	100.00	12.00	90.00	10.80
Ownership and Regulation	12%	65.00	7.80	70.00	8.40	80.00	9.60
Structure	12%	70.00	8.40	90.00	10.80	70.00	8.40
Risk	12%	90.00	10.80	67.00	8.04	67.00	8.04
Local Need	12%	80.00	9.60	28.00	3.36	28.00	3.36
Total	100%		69.08		77.97		70.94
Rank		3		1		2	

After reviewing each site, our team decided that Coon Rapids Dam was our strongest option and the decision matrix in Table 4.4 supports this decision. The summarized key strengths of the site and their impact on our design are below:

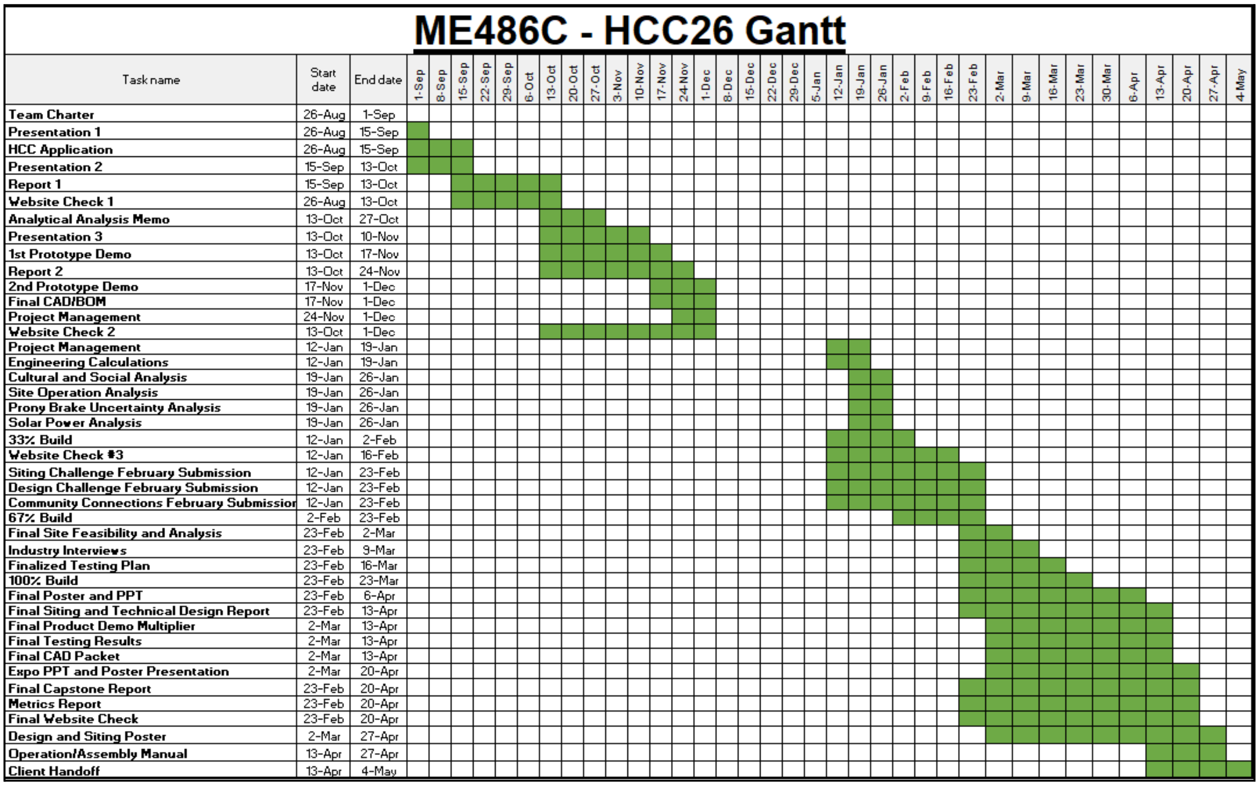
Pre-Existing Hydropower Infrastructure - The remaining powerhouse and onsite substation set allow for significant savings in the cost of retrofitting. Our design strategy was to use the retired turbine housing for our system, ideally with minimal impact on the dam's outward appearance to preserve the surrounding park's aesthetic.

High Flow Rate, Low Head - Coon Rapids Dam has a very high, and fairly consistent, flow rate with a low head of 3-5 meters. This guided our turbine selection towards a Kaplan turbine.

Minimal Conflict Between Uses - Currently, the main use for Coon Rapids Dam is as a fish barrier against invasive carp. To account for this, construction would require a sound stoplog system and a fish screen was incorporated into each turbine housing to prevent upstream migration while the turbines are not operating.

5 Schedule and Budget

5.1 Schedule



ME486C - HCC26 Gantt

Task name	Start date	End date
Team Charter	26-Aug	1-Sep
Presentation 1	26-Aug	15-Sep
HCC Application	26-Aug	15-Sep
Presentation 2	15-Sep	13-Oct
Report 1	15-Sep	13-Oct
Website Check 1	26-Aug	13-Oct
Analytical Analysis Memo	13-Oct	27-Oct
Presentation 3	13-Oct	10-Nov
1st Prototype Demo	13-Oct	17-Nov
Report 2	13-Oct	24-Nov
2nd Prototype Demo	17-Nov	1-Dec
Final CAD/BOM	17-Nov	1-Dec
Project Management	24-Nov	1-Dec
Website Check 2	13-Oct	1-Dec
Project Management	12-Jan	19-Jan
Engineering Calculations	12-Jan	19-Jan
Cultural and Social Analysis	19-Jan	26-Jan
Site Operation Analysis	19-Jan	26-Jan
Prony Brake Uncertainty Analysis	19-Jan	26-Jan
Solar Power Analysis	19-Jan	26-Jan
33% Build	12-Jan	2-Feb
Website Check #3	12-Jan	16-Feb
Siting Challenge February Submission	12-Jan	23-Feb
Design Challenge February Submission	12-Jan	23-Feb
Community Connections February Submissior	12-Jan	23-Feb
67% Build	2-Feb	23-Feb
Final Site Feasibility and Analysis	23-Feb	2-Mar
Industry Interviews	23-Feb	9-Mar
Finalized Testing Plan	23-Feb	16-Mar
100% Build	23-Feb	23-Mar
Final Poster and PPT	23-Feb	6-Apr
Final Siting and Technical Design Report	23-Feb	13-Apr
Final Product Demo Multiplier	2-Mar	13-Apr
Final Testing Results	2-Mar	13-Apr
Final CAD Packet	2-Mar	13-Apr
Expo PPT and Poster Presentation	2-Mar	20-Apr
Final Capstone Report	23-Feb	20-Apr
Metrics Report	23-Feb	20-Apr
Final Website Check	23-Feb	20-Apr
Design and Siting Poster	2-Mar	27-Apr
Operation/Assembly Manual	13-Apr	27-Apr
Client Handoff	13-Apr	4-May

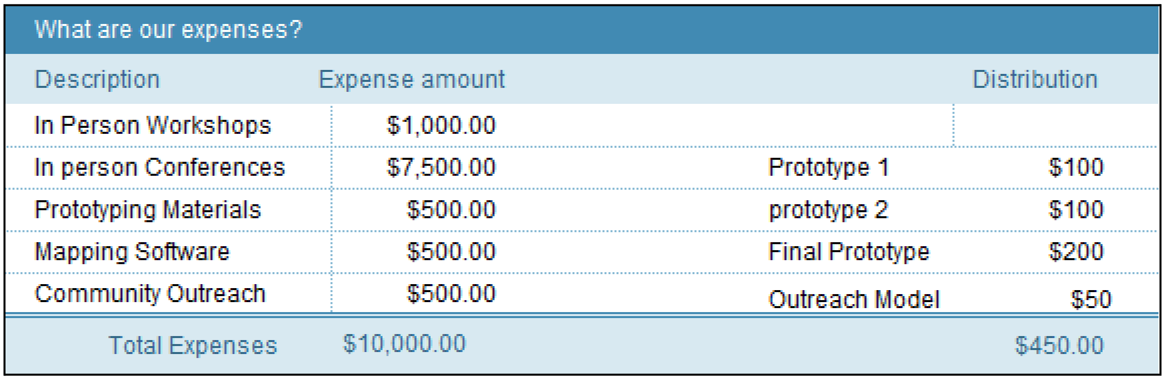
Figure 5.1.1: Gantt Chart

Throughout the process of this year long class and project the team has gone through many competition and class submissions. During the first semester of the academic year there were not many competition deadlines so the focus was on capstone assignments and preparing for the competition with a major focus on site and turbine selection. Along with that there were several separate analyses done to inform the team on potential hazards or areas of interest. A couple final items completed before going on a winter break were a project management plan for going into the next semester, a report showing all the work done up to that point, a CAD demo showing all physical work done so far, and a website check proving the team had a functioning website for the project.

After a month-long winter break the team returned to activities, starting with an individual analysis from each team member, mostly on the site at the time or energy related to it. Soon after in late February, the first main submissions for the capstone were due, being the main focus for the team. Four reports were submitted, one for each category of the competition, going over the process of that category for the team. Around the same time build presentations were required in three steps, showing the process of the teams build and analyses till at 100%. After that the team was required to do testing on a device which was done in the thermal fluids lab. That brings the time to the current day where the final siting and technical design report were due last week and the communications report is due this week. The team is on schedule and preparing to go to the competition in Green Bay next week. Preparing posters and speeches are the next main thing to get done after the reports.

5.2 Budget

The total budget that aligned with our goals would be $15,000 with the multitude of the budget going towards traveling for conferences and workshops. The total is listed below in Figure 5.2 highlighting where the funding goes.



What are our expenses?

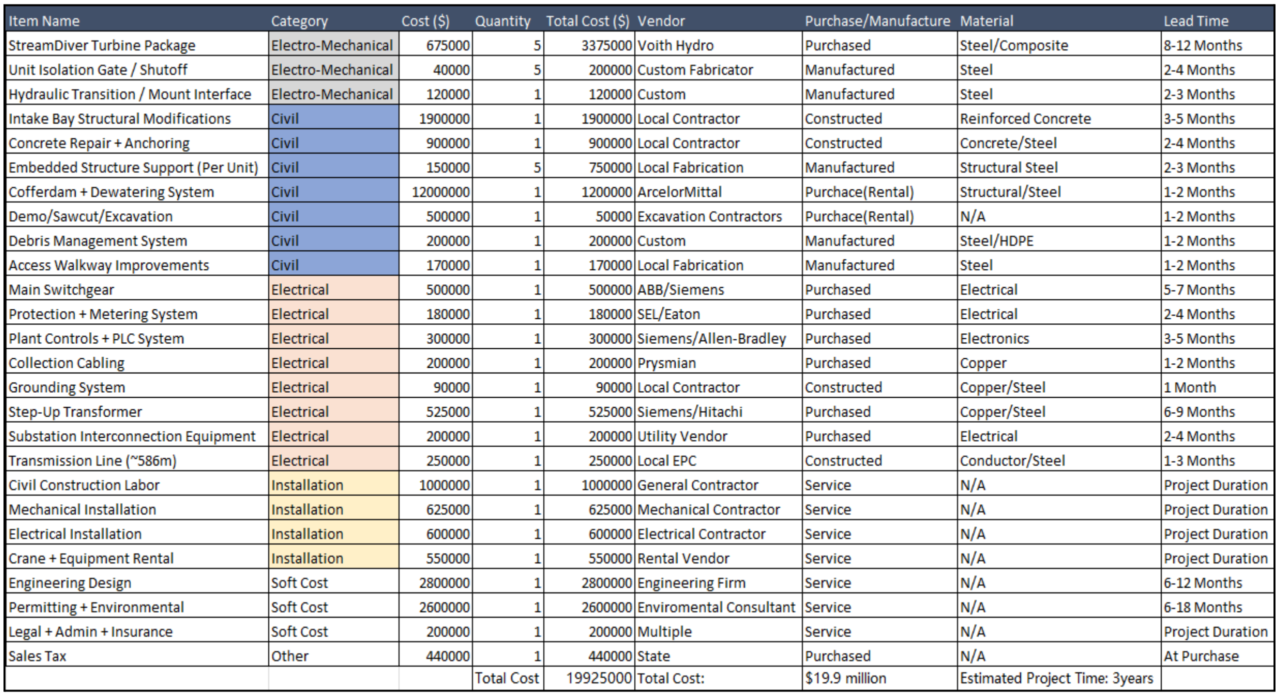
Description	Expense amount		Distribution
In Person Workshops	$1,000.00		
In person Conferences	$7,500.00	Prototype 1	$100
Prototyping Materials	$500.00	prototype 2	$100
Mapping Software	$500.00	Final Prototype	$200
Community Outreach	$500.00	Outreach Model	$50
Total Expenses	$10,000.00		$450.00

Figure 5.2.1 Total Yearly Expenses For HCC26

From this table we can see that we have a remaining $5000 dollars left on our budget that can go to emergency items such as traveling fees, food, and more travel for outreach.

5.3 Bill of Materials (BoM)

The final BOM for our proposed site at Coon Rapids Dam is listed below in Figure 5.3, including electrical, mechanical civil and permitting necessities at the site.



Item Name	Category	Cost ($)	Quantity	Total Cost ($)	Vendor	Purchase/Manufacture	Material	Lead Time
StreamDiver Turbine Package	Electro-Mechanical	675000	5	3375000	Voith Hydro	Purchased	Steel/Composite	8-12 Months
Unit Isolation Gate / Shutoff	Electro-Mechanical	40000	5	200000	Custom Fabricator	Manufactured	Steel	2-4 Months
Hydraulic Transition / Mount Interface	Electro-Mechanical	120000	1	120000	Custom	Manufactured	Steel	2-3 Months
Intake Bay Structural Modifications	Civil	1900000	1	1900000	Local Contractor	Constructed	Reinforced Concrete	3-5 Months
Concrete Repair + Anchoring	Civil	900000	1	900000	Local Contractor	Constructed	Concrete/Steel	2-4 Months
Embedded Structure Support (Per Unit)	Civil	150000	5	750000	Local Fabrication	Manufactured	Structural Steel	2-3 Months
Cofferdam + Dewatering System	Civil	12000000	1	1200000	ArcelorMittal	Purchace(Rental)	Structural/Steel	1-2 Months
Demo/Sawcut/Excavation	Civil	500000	1	50000	Excavation Contractors	Purchace(Rental)	N/A	1-2 Months
Debris Management System	Civil	200000	1	200000	Custom	Manufactured	Steel/HDPE	1-2 Months
Access Walkway Improvements	Civil	170000	1	170000	Local Fabrication	Manufactured	Steel	1-2 Months
Main Switchgear	Electrical	500000	1	500000	ABB/Siemens	Purchased	Electrical	5-7 Months
Protection + Metering System	Electrical	180000	1	180000	SEL/Eaton	Purchased	Electrical	2-4 Months
Plant Controls + PLC System	Electrical	300000	1	300000	Siemens/Allen-Bradley	Purchased	Electronics	3-5 Months
Collection Cabling	Electrical	200000	1	200000	Prysmian	Purchased	Copper	1-2 Months
Grounding System	Electrical	90000	1	90000	Local Contractor	Constructed	Copper/Steel	1 Month
Step-Up Transformer	Electrical	525000	1	525000	Siemens/Hitachi	Purchased	Copper/Steel	6-9 Months
Substation Interconnection Equipment	Electrical	200000	1	200000	Utility Vendor	Purchased	Electrical	2-4 Months
Transmission Line (~586m)	Electrical	250000	1	250000	Local EPC	Constructed	Conductor/Steel	1-3 Months
Civil Construction Labor	Installation	1000000	1	1000000	General Contractor	Service	N/A	Project Duration
Mechanical Installation	Installation	625000	1	625000	Mechanical Contractor	Service	N/A	Project Duration
Electrical Installation	Installation	600000	1	600000	Electrical Contractor	Service	N/A	Project Duration
Crane + Equipment Rental	Installation	550000	1	550000	Rental Vendor	Service	N/A	Project Duration
Engineering Design	Soft Cost	2800000	1	2800000	Engineering Firm	Service	N/A	6-12 Months
Permitting + Environmental	Soft Cost	2600000	1	2600000	Enviromental Consultant	Service	N/A	6-18 Months
Legal + Admin + Insurance	Soft Cost	200000	1	200000	Multiple	Service	N/A	Project Duration
Sales Tax	Other	440000	1	440000	State	Purchased	N/A	At Purchase
			Total Cost	19925000	Total Cost:	$19.9 million	Estimated Project Time: 3years	

Figure 5.3.1 BOM For Coon Rapids Site

6 Design Standards

Design standards play a critical role in ensuring that the proposed hydropower retrofit system is safe, reliable, and compliant with industry best practices. For this project, adherence to established design standards ensures the system can be successfully integrated into existing dam infrastructure while maintaining structural integrity, operational performance, and environmental responsibility.

From a project standpoint, design standards guide key aspects of the system including hydraulic design, structural modifications, electrical integration, and safety considerations. Standards help define acceptable limits for loads, material performance, and system reliability, reducing the risk of failure and ensuring long-term operation. They also provide a consistent framework for validating design decisions, allowing analytical results and modeling assumptions to align with proven engineering practices.

From an industry perspective, design standards ensure uniformity, safety, and regulatory compliance across hydropower installations. Organizations such as the U.S Army Corps of Engineers (USACE), Federal Energy Regulatory Commission (FERC), and American Society of Civil Engineers (ASCE) establish guidelines that govern dam safety, hydraulic structures, and infrastructure design, Additionally, environmental standards such as those are outlined under NEPA help ensure that projects minimize ecological impact and meet permitting requirements.

Adhering to these standards not only improves the technical robustness of the design but also facilitates project approval, reduces liability, and increases stakeholder confidence. Overall, design standards serve as a foundation for developing a system that is both technically sound and aligned with real-world engineering and regulatory expectations.

6.1 Design Standards Research

[53] Federal Energy Regulatory Commission (FERC), Engineering Guidelines for the Evaluation of Hydropower Projects, Washington, DC, USA, 2016.
This document provides comprehensive guidance for the design, construction, and evaluation of hydropower projects in the United States. It outlines requirements for dam safety, structural stability, hydraulic performance, and risk assessment. For this project, FERC guidelines are critical in ensuring that the retrofit design does not compromise the structural integrity of the existing dam and meets federal safety and permitting expectations.

[54] U.S. Army Corps of Engineers (USACE), Engineering and Design: Hydraulic Design of Flood Control Channels (EM 1110-2-1601), Washington, DC, USA, 1991.
This standard establishes best practices for hydraulic design, including flow behavior, energy losses, and channel modifications. It is relevant to this project for evaluating flow conditions at the intake and outlet, estimating head losses, and ensuring efficient turbine operation within the existing dam structure.

[55] American Society of Civil Engineers (ASCE), Minimum Design Loads and Associated Criteria for Buildings and Other Structures (ASCE/SEI 7-22), Reston, VA, USA, 2022.
ASCE 7 provides guidelines for determining loads such as hydrostatic pressure, environmental forces, and structural stresses. This standard supports the structural assessment of the dam and any modifications required for turbine installation, ensuring that added components do not introduce unsafe loading conditions.

[56] Council on Environmental Quality (CEQ), National Environmental Policy Act (NEPA) Regulations, Washington, DC, USA, 1970 (as amended).
NEPA establishes the framework for evaluating environmental impacts of infrastructure projects. For this hydropower retrofit, NEPA is essential for assessing ecological effects such as flow diversion, aquatic habitat disruption, and water quality impacts, ensuring the project meets environmental compliance requirements.

[57] Minnesota Department of Natural Resources (MNDNR), Hydropower Permitting and Dam Safety Guidelines, St. Paul, MN, USA, 2020.
These guidelines provide state-level requirements for dam modifications, water usage, and environmental protection. Since the project is located at Coon Rapids Dam, MNDNR standards are directly applicable for ensuring compliance with local regulations, particularly regarding flow diversion limits and ecological preservation.

[58] International Electrotechnical Commission (IEC), IEC 61116: Electromechanical Equipment for Small Hydropower Plants, Geneva, Switzerland, 2013.
This standard defines requirements for the design, operation, and testing of electromechanical systems in small hydropower installations. It is relevant for ensuring that turbine-generator units, such as the modular StreamDiver system, operate reliably and meet performance expectations.

6.2 Design Standards Used

Design standards were incorporated throughout the development of the proposed hydropower retrofit to ensure safety, reliability, and regulatory compliance. These standards influenced system layout, structural integration, hydraulic modeling, equipment selection, and cost estimation.

Design standards were applied directly in the system layout and conceptual drawings. Hydraulic design guidance from USACE standards informed the intake and outflow geometry, ensuring smooth flow transitions, minimized energy losses, and proper placement of turbine modules. Structural considerations from ASCE loading standards were used to ensure that any modifications to the dam, including intake drilling and module placement, do not introduce unsafe stresses or compromise stability.

Additionally, FERC dam safety guidelines were considered when determining turbine placement within the dam structure to avoid interference with critical structural components. Environmental standards (NEPA and MNDNR) influenced the inclusion of bypass flow regions and limits on flow diversion, which are reflected in the system layout.

Design standards also influenced material selection and component specification within the BOM. Structural materials and construction elements were selected based on durability and safety requirements consistent with ASCE and FERC guidelines, ensuring long-term reliability of the retrofit system.

Electromechanical components, including turbine-generator units, align with IEC 61116 standards for small hydropower systems, ensuring proper performance, efficiency, and operational reliability. Additionally, environmental and regulatory standards influenced the inclusion of features such as flow control structures and monitoring components, which are necessary for compliance and permitting.

Standards were embedded within the mathematical modeling and performance calculations used to evaluate the system. Hydraulic modeling followed principles outlined in USACE design manuals, particularly in estimating flow behavior, head losses, and system efficiency.

The fundamental hydropower equation,

$$P = \rho g Q H \eta$$

was used in conjunction with realistic assumptions for efficiency and head loss, consistent with industry practice. Flow diversion limits and bypass requirements were incorporated into calculations based on environmental guidelines (NEPA and MNDNR), ensuring that modeled performance reflects regulatory constraints.

Capacity factor, annual energy generation, and system performance metrics were calculated using industry-accepted methods, ensuring results are comparable to real-world hydropower projects.

Beyond design and calculations, standards were also applied in system-level decision making. FERC guidelines influenced overall project feasibility and safety considerations, while NEPA requirements guided environmental impact awareness and mitigation strategies.

Grid interconnection considerations and system reliability were also informed by industry best practices, ensuring that the proposed design is not only theoretically feasible but also practically implementable within existing infrastructure and regulatory frameworks.

7 Design Validation and Initial Prototyping

7.1 Failure Modes and Effects Analysis (FMEA) and Risk Assessment

A FMEA was conducted to identify and evaluate potential risks associated with retrofitting the Coon Rapids Dam for hydropower generation. The analysis considers both component-level failures (e.g., turbine and intake system) and system level risks related to site integration, environmental constraints, and construction feasibility.

Each potential failure mode was evaluated using three criteria: severity (S), occurrence (O), and detection (D). These values were used to calculate a Risk Priority Number (RPN), defined as:

$$RPN = S \times O \times D$$

This approach allows for prioritization of risks based on their overall impact on system performance, safety, and project feasibility.

The results of the FMEA are summarized in Table 7.1.1.

Table 7.1.1: FMEA

Coon Rapids Dam Low-Head Hydropower System Site Integration / Turbine System Dam Structure & Turbine Retrofit				HCC26		Page No 1 of 1 FMEA Date 03/01/2026			
Part and Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Cause	Occurance (O)	Controls	Detection (D)	RPN	Recommended Action
Dam Structure, supports retrofit	Structural weakening during modification	Safety risk, structural damage	5	Penetrations, unkown structural conditions	3	Structural analysis, existing drawings	3	45	Limit modifications, reinforce structure
Fish barrier system	Barrier effectiveness reduced	Ecological disruption, regulatory failure	5	Improper flow routing, diversion	4	Flow modeling, design constraints	4	80	Maintain flow paths, coordinate with DNR
Flow diversion system	Excess diversion	Reduced downstream flow / compliance issues	4	Poor control, high flow availability	3	Flow limits, modeling	3	36	Cap diversion ratio, controlled gates
Turbine runner	Cavitation / erosion	Efficiency loss, damage	4	pressure fluctuations, debris	3	turbine selection, design	3	36	optimize blade design, debris control
Intake / trash rack	debris clogging	reduced flow, performance loss	3	seasonal debris	3	trash rack	2	18	maintenance plan, accessible design
Project cost, CAPEX	cost overrun	poor LCOE, reduced feasibility	4	structural unknowns, install complexity	3	cost estimates	3	36	modular design, sensitivity analysis

The analysis identified several high-priority risks associated with the project. The most significant risk is interference with the dam's fish barrier function, which carries both high severity and high occurrence due to the site's role in preventing invasive species migration. This risk directly impacts environmental compliance and regulatory approval, making it a critical design consideration.

Another major risk involves structural modification of the existing dam, where penetrations or alterations to the structure could compromise integrity or increase construction complexity. This highlights the importance of minimizing civil modifications and validating design decisions through structural analysis.

Additional risks include flow diversion limits, which affect both environmental compliance and power generation potential, and turbine related issues such as cavitation and debris clogging, which impact long term performance and maintenance requirements.

Mitigation strategies were incorporated directly into the design process, including limiting diversion ratios, maintaining existing flow paths, utilizing debris control systems, and adopting a modular installation approach to reduce structural impact. These strategies ensure that the highest-risk factors are addressed early in the design phase.

Overall, the FMEA demonstrates that while several high-impact risks exist, they can be effectively managed through informed design decisions and careful consideration of site-specific constraints.

7.2 Initial Prototyping

7.2.1 Original Design Concept

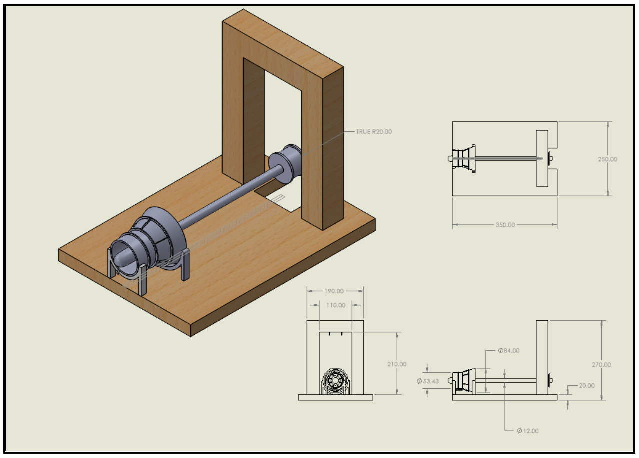


Figure 7.2.1.1: Original Build Design

When originally setting out to test something for our capstone, our team decided it would be best to test a fabricated turbine concept under a controlled laboratory to help understand the system being analyzed. The turbine was conceived under controlled laboratory flow conditions to evaluate its performance in a repeatable, instrumented environment. To do this it was decided a prony brake would best capture the force that wanted to be attained. There in the thermal fluids lab where turbines are already tested at a water bench is where the team is conducting the experiment. The objective is to collect experimental data that validates the performance trends predicted by our digital prototype, rather than to generate full-scale output. Testing will focus on identifying the turbine's effective operating range and its sensitivity to variation in flow rate, enabling characterization of stability and response under changing hydraulic conditions. The resulting data will be used to refine key modeling assumptions, including hydraulic loss terms, thereby improving the accuracy of the design model and informing subsequent iterations of the turbine system.

7.2.2 The Build Process

With the main outline of the build prepared as seen below, the assembly could now begin.

- Aluminum Brake Drum (Lathe Job)
    - Diameter ~ 40 mm
    - Width ~ 30 mm
    - Bore ~ 8 mm
- Wooden Frame/Body (Bought and Assembled) < $30
    - 2x4 Plywood Boards (in)
    - Board up middle to connect frame, drum, and turbine
- Two 50 lb (23 kg) digital fish scales
- Kevlar string connected to tower
- Dead weight on the bottom end
- Neiko 20713A Digital Laser Tachometer (< $30)

- Precision Force Gauge (~$50)
- Turbine:
    - 8mm Ground Stainless Steel Shaft
    - 3D printed fins, 100% infill, ASA filament
    - Center hole of 8.1 mm
    - Two 608-2RS Ball Bearings

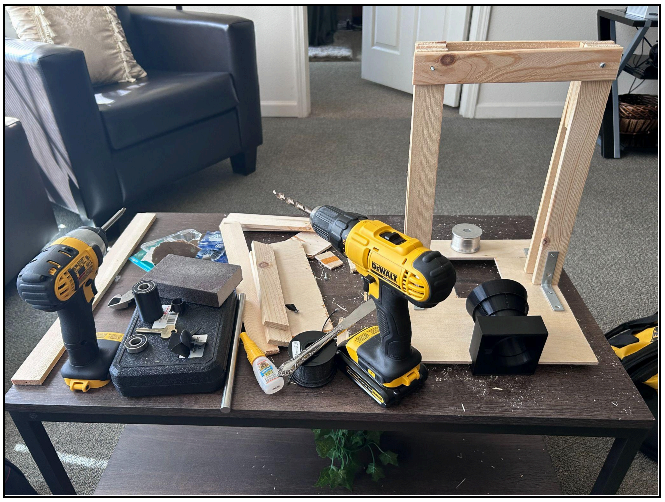


Figure 7.2.2.1: Build Process

The wooden frame was bought and assembled at Home Depot with saws provided there and a drill back at home. It cost less than thirty dollars and provided a good base for the system. The turbine was 3D printed in three parts and attached to the board. A shaft was bought and machined down, the drum was lathed at the machine shop, and the rest of the parts were bought and simply fit on with tight fits and superglue.

7.2.3 First Full Build

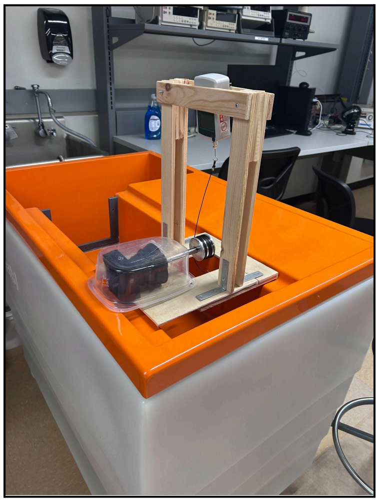


Figure 7.2.3.1: First Build Iteration

The goal was that, during testing, several key performance parameters were to be monitored to characterize the prototype's behavior under controlled conditions. Hydraulic input was to be quantified by measuring flow rate, where instrumentation is available, along with the head or pressure differential across the turbine to determine the effective energy supplied to the system. Rotational speed of the output shaft was also to be recorded, if measurable, to support analysis of the operating efficiency and dynamic performance. Output was to be evaluated through both electrical and mechanical measurements: electrical power will be determined from the generator voltage and current readings obtained via a digital multimeter while charging a battery, and mechanical torque will be assessed using the Prony Brake dynamometer where feasible. Together, these measurements provide a comprehensive dataset for validating performance trends, estimating efficiency, and correlating hydraulic input with mechanical and electrical output. Unfortunately, during the first set of testing the shaft and turbine were not connected efficiently enough and the turbine house when spinning would collect friction along the rudder and shaft. A new version of the system would then be designed and implemented.

7.2.4 Middle Build Iterations

During the process of trying to test this turbine system there were many hiccups. After completely fixing the friction problem, and having the turbine set perfectly in line horizontally, it was discovered that the bearings were not working properly. It was advised that two bearings in the system were needed so a revised build was put under way.

Figure 7.2.4.1: Third Build Iteration

The system now spun smoothly when not in contact with the frame. Only one side would spin efficiently and under any tension the system did not work. The turbine house would not work and needed to be completely replaced.

7.2.5 Final Build Iterations

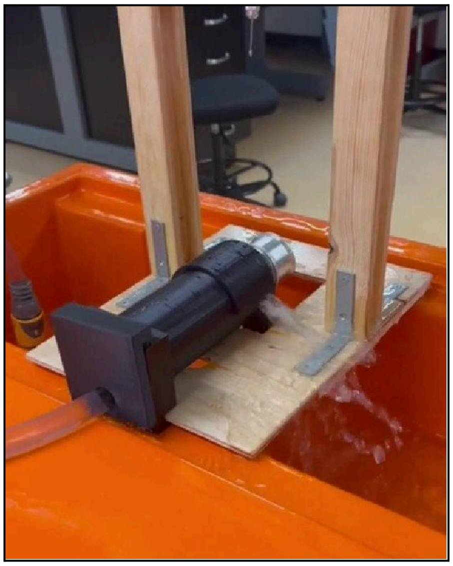


Figure 7.2.5.1: Final Build Iteration

Finally with a slight adjustment to the new gate and water shield, a system that worked smoothly was finished. The water would enter the system, everything spun, and force was collected. The team was able to go into the lab and collect results.

7.3 Engineering Calculations

7.3.1 Equations

Once all the trials have been completed, we will have a data set for all three measurements: force, flow rate, and rpm. With these data values and some other measured ones like weight, tube diameter, and turbine diameter, the power and efficiency can be calculated. Ideally this would also be compared to the electrical power extracted. Like all experiments this experiment relied on and used many important and less important equations. Some equations are used to convert numbers to different units or get a simple calculation to move on with the process. Others are the equations that the experiment will rely on and are setting out to test and understand.

The first couple equations used are just meant to find simple values that were easily found. To get started with the two measured variables: time (t) in seconds, and volume (V) in liters; equation 1 was used to find Volumetric flow rate in Liters per Second.

$$Q = V/t \tag{1}$$

After finding the volumetric flow rate, that value can be used in equation 2 to calculate the velocity (V) of the water in m/s coming out of the nozzle. This is done by dividing that flow rate over the area (A) of the nozzle opening in m^2.

$$V = Q/A \tag{2}$$

The torque output from the turbine was calculated using the net force output measured by the Prony brake multiplied by the radius of the turbine. By multiplying this output torque with the angular velocity of the turbine, a power output (W_O) can be found as seen in equation 3 below.

$$W_O = T \cdot \omega \tag{3}$$

Now all that's needed is to calculate the efficiency of the turbine which will be done by calculating and comparing the power in to the power out. To find the power into the system, we need to know the pressure at the end of the water (p) which can be found by using the density (ρ) and velocity of the water (V) as seen below in equation 4.

$$p = ½ * \rho * V^2 \tag{4}$$

The input power into the turbine can now be calculated using the flow rate of the water jet and the dynamic pressure reading of the tube as seen in equation 5 below.

$$W_i = Q \cdot p \tag{5}$$

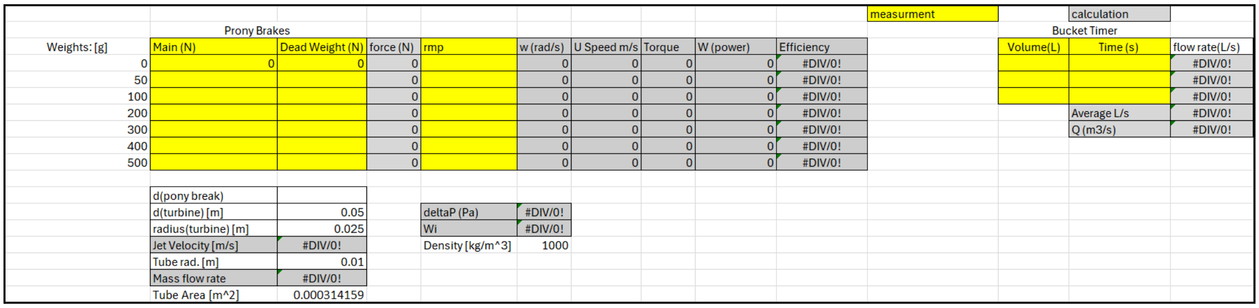
The real efficiency of the turbine can then be calculated using the input power and calculated power output of the turbine as seen in equation 6.

$$\eta = W_O/W_i \tag{6}$$

7.3.2 Theoretical Values

Using some theoretical values for the likely forces attained, rotational speed, and flow rate a potential power output is revealed to us. Since the model is scaled down to such a high degree, the power and efficiency does not show hyper realistic data to what the turbine will actually collect, but through this process it will give a good guideline of how the turbine will react. With that said, the theoretical power range for this experiment is to be inside of 1 Watt of power to 6 Watts of power. It would theoretically peak at around medium weight (~200g) resistance. Lastly, with higher speeds, the work becomes much higher for an efficiency that is lower, giving us an efficiency range of 1% on the quick end and 75% on the slow side. Through actually running this experiment, seeing how efficient the turbine truly runs is helpful for us.

7.3.3 Result Tables



measurment

calculation

Prony Brakes

Weights: [g]	Main (N)	Dead Weight (N)	force (N)	rmp	w (rad/s)	U Speed m/s	Torque	W (power)	Efficiency
0	0	0	0		0	0	0	0	#DIV/0!
50			0		0	0	0	0	#DIV/0!
100			0		0	0	0	0	#DIV/0!
200			0		0	0	0	0	#DIV/0!
300			0		0	0	0	0	#DIV/0!
400			0		0	0	0	0	#DIV/0!
500			0		0	0	0	0	#DIV/0!

Bucket Timer

Volume(L)	Time (s)	flow rate(L/s)
		#DIV/0!
		#DIV/0!
		#DIV/0!
	Average L/s	#DIV/0!
	Q (m3/s)	#DIV/0!

d(pony break)	
d(turbine) [m]	0.05
radius(turbine) [m]	0.025
Jet Velocity [m/s]	#DIV/0!
Tube rad. [m]	0.01
Mass flow rate	#DIV/0!
Tube Area [m^2]	0.000314159

deltaP (Pa)	#DIV/0!
Wi	#DIV/0!
Density [kg/m^3]	1000

Figure 7.3.3.1: Result Table

Figure 7.3.3 above shows how and where we will enter our data when running the experiment. Three of these tables have been used so far for the three different water outputs. The dead weight will remain the same across each water speed but the rest of the yellow boxes will be where data collected will be sent. Force measured from the force gauge will be sent in and rpm measured from the tachometer will be collected for each weight. The bucket timer was also measured three times before the runs as mentioned before. Once the data is collected the results will fill in due to the excel equations already made.

7.4 Future Testing Potential

As far as future testing goes, there are two avenues the team can go down. First is upgrading the turbine once again, possibly increasing total size so that the system can handle more weight under tension. Currently, the system can only collect force and rotational speed under 40 grams of tension, leaving the team with results to be desired. With more weight pushed by the turbine, a better gauge of where the turbine is most efficient can be found.

The other way to go with the experiment is connecting with the Electrical Engineering subteam to connect a generator to the system and collect actual energy collected as volts. The electrical team has recently bought a generator that can be tested, though hard to implement, and have also built a generator. The built generator was tested to fit the turbine and a system to connect the generator to the turbine has been successfully designed. The team just needs to get the generator working which was tested using a drill, able to pick up power. More testing will likely soon take place.

8 Final Hardware

8.1 Final Physical Design

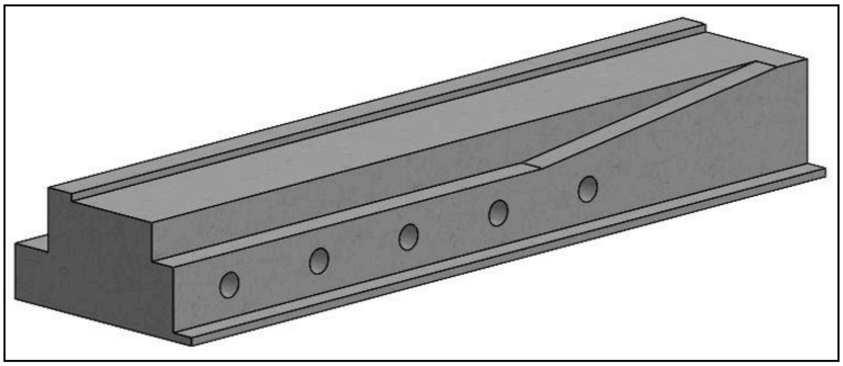


Figure 8.1.1: Full Dam Design

Each unit functions as a self contained module composed of an intake, turbine generator assembly, and outlet. The angled intake and confined flow passage promote gradual acceleration into the turbine region, improving flow consistency and predictability within each unit.

Rather than relying on a single installation, multiple modules are distributed along the dam structure (Figure 5). This configuration allows scalability based on flow availability and structural limitations while reducing the impact of any individual penetration. This reduces localized structural stress compared to a single large penetration and improves system resilience by distributing load and flow across multiple units. This modular approach allows the system to adapt to variable flow conditions while maintaining consistent performance and minimizing structural impact on the dam.

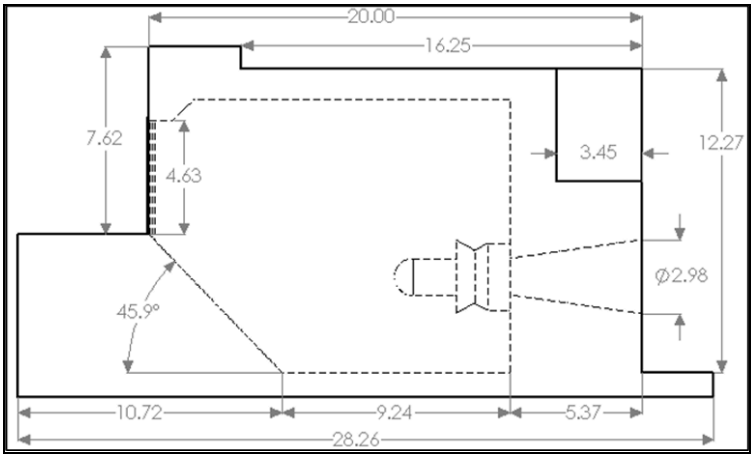


Figure 8.1.2: Turbine Housing Cross-section

The turbine housing design is primarily based on the Voith StreamDiver housing template. The changes made were to minimize the impact to the outward appearance of the dam. Additionally, a fish screen was implemented to prevent fish entry into the turbines. Each StreamDiver unit has a built in stop-valve that can shut down the unit and allow for maintenance.

This design has no control over the flow of water.. This means the output is dictated by the flow of the river (i.e. run-of-river). The reason for this design choice is to minimize the cost of adding the turbine system. Adding a flow control mechanism would allow for some more power to be generated, but it was determined that it was not enough extra power to justify adding control gates.

Table 8.1.1: Hybrid Power Generation Components

	Hydro	Solar	Overall
Generation (MWh)	12,699	480	13,479
Average Output (MW)	1.45	.047	1.497
Capacity Factor	67%	15.5%	61.9%
LCOE (¢/kWh)	7.961	12.16	8.11

Table 8.1 shows what the design would output and the Localized Cost of Energy of the hydro/solar power. This satisfies the customer requirement of 1-10 MW in power generation.

9 Final Testing

9.1 Top level testing summary table

Table 9.1.1: Top Level testing Summary

Experiment/Test	Relevant DRs	Equipment Needed	Other Resources
Part 1 - Turbine spin/Speed test	-Turbine same model as actual -Turbine fits for experiment -Turbine spins	-Hydraulic bench -Turbine w/ all parts -Tachometer -Force gauge	-Access to Thermal Fluids lab -4 teammates for testing
Part 2 - Prony brake/weight test	-Shaft spins smoothly -Drum collects energy efficiently -Doesn't fall apart	-Prony brake made by: shaft, drum, wood parts, bearings, 3D print, & rope	-Crafting equipment -Excel spreadsheet to place results
Part 3 - Energy collection	-Transmitter work -Generator collect energy -Batter save and read energy	-Transmitter -Generator -Battery	-Electrical Engineering subteam
Part 4 - Translation to actual analysis	-The turbine behaves in an expected way	-Turbine -Prony brake -Hydraulic bench	-Real world data

As seen from the top level testing summary, there is no set goal by the leaders of the competition and is up for the team to decide. Understanding energy collection in the turbine system is what the team set out to do.

9.2 Detailed Testing Plan

9.2.1 Testing

By conducting this lab the team set out to learn about the different effects of water speed on our turbine system, possible realistic turbine efficiency, optimal rotation resistance, and potential failure points. This was done using a hydraulic bench at the Thermal Fluids lab with a scaled down turbine and Prony brake. Water at different inlet speeds will be sent through the turbine system and mechanical energy will be collected. Three different water speeds were measured using a bucket timer method from the water bench 0.3 L/s to 1 L/s or maximum output in rough increments of 0.3 L/s. In addition to that, two different dead weights were used to see the effect of tension in the Prony brake on the power. After the experiment was conducted, calculations were made to see the efficiency of the system and compare our results to what they should be theoretically

9.2.2 Summary

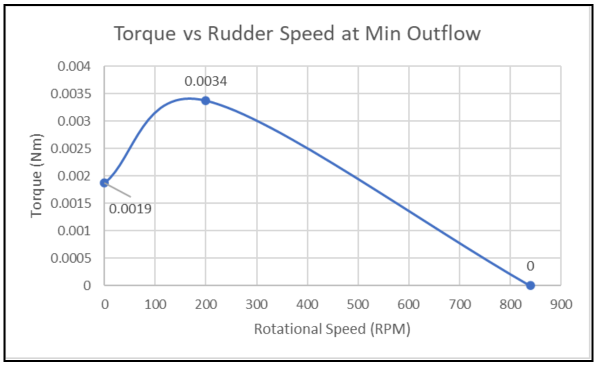


Figure 9.2.2.1: Torque vs Rudder Speed at Minimum Water Outflow

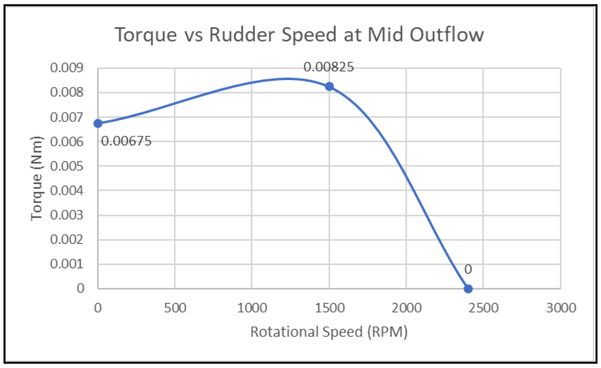


Figure 9.2.2.2: Torque vs Rudder Speed at Medium Water Outflow

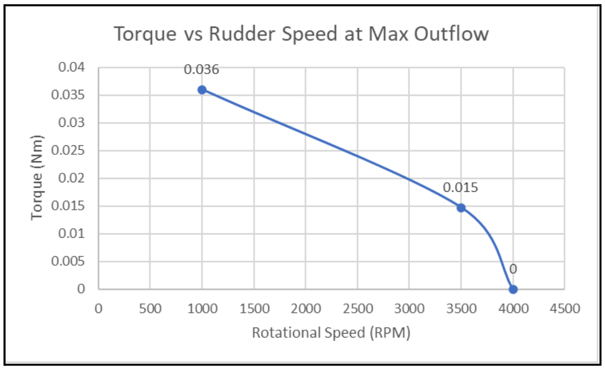


Figure 9.2.2.3: Torque vs Rudder Speed at Maximum Water Outflow

As seen in the figures above, the results of having only two dead weights used could not create a whole scope of view for the system. The first data point is without any tension and just being used as a base of reference. The water could not force the turbine to move under 60 grams of force at any speed and so could not show as many data points. To show a true curve and reveal where the turbine is more efficient, more force and power needs to be collected. The goal to fix this is using an even bigger turbine to collect more force from the water.

9.2.3 Procedure

When setting up for this experiment the first thing that needs to be done is making sure the Prony brake is all set up and ready to go outside of the testing lab. This means that the turbine will be fully mounted onto the Prony brake and the shaft will be connected to the drum snugly and securely. The turbine will be able to spin and pull on the string nice and smoothly.

Once the turbine and Prony brake are ready and the experiment can be tested, the first step is to securely attach the Prony brake setup to the hydraulic bench by using its tight fit into the bench ensuring it stays in place. The water tube will then be placed in front of the turbine by the gate mount.

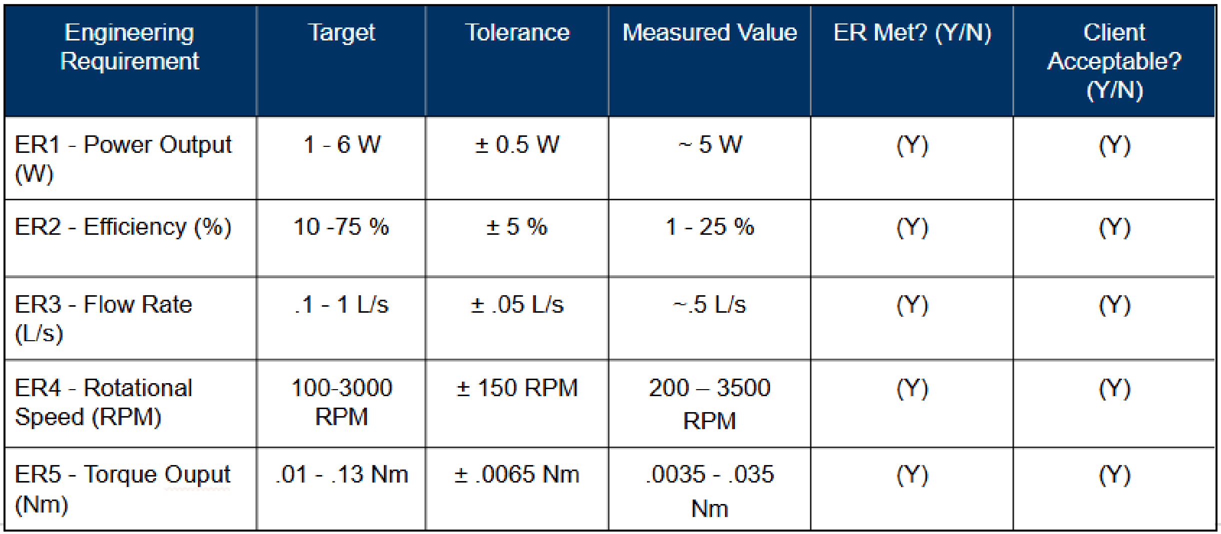
Before the force data is to be recorded the mass flow rate Q (L/s) is recorded using the bucket timer method. This is done by having one individual from the team measure the time taken for the bucket to fill to 5 liters, another team member would write these measurements down,and the last team member would be controlling the bench flow control valve and draining the bucket once the measurement was finished. We will do this three times before each new testing speed to get the new average flow rate.

Once this is all set up the experiment can truly begin. The net force output of the turbine will be measured using the Prony brake which acts on the rotating shaft of the turbine. Greater force applied by this Prony brake will cause the turbine to rotate slower. Two force values will be measured from the brake, one from the force gauge and the other from the dead weight. The dead weight should be increased from 0g to 200g in roughly 20g increments. The dead weight will be attached to the string by a hook through a hole at the end. This carrier and corresponding weights will be provided by the lab. The weight will fall through a hole in the board ensuring it provides tension on the cable. With both forces, the net force output of the turbine is equal to gauge force minus the dead weight force.

Also while collecting force data, one team member will be using the tachometer to measure the rpm of the turbine for its corresponding flow rate and dead weight. This will be done for each run for five total different flow rates and six different dead weights totalling 30 runs for this experiment.

9.2.4 Results

Table 9.2.4.1: ER Spec Sheet and Testing Results



Engineering Requirement	Target	Tolerance	Measured Value	ER Met? (Y/N)	Client Acceptable? (Y/N)
ER1 - Power Output (W)	1 - 6 W	± 0.5 W	~ 5 W	(Y)	(Y)
ER2 - Efficiency (%)	10 -75 %	± 5 %	1 - 25 %	(Y)	(Y)
ER3 - Flow Rate (L/s)	.1 - 1 L/s	± .05 L/s	~.5 L/s	(Y)	(Y)
ER4 - Rotational Speed (RPM)	100-3000 RPM	± 150 RPM	200 – 3500 RPM	(Y)	(Y)
ER5 - Torque Ouput (Nm)	.01 - .13 Nm	± .0065 Nm	.0035 - .035 Nm	(Y)	(Y)

In the end results were gathered that were satisfactory. Given the prospect of the prototype, values were mostly in the predicted range and gave valuable information on how the Kaplan turbine system will react under different conditions. Some more valuable data and information can still be extracted from more testing though that will be conducted shortly.

10 Future work

If this project were to continue, the next step would primarily revolve around the construction process of the dam. Various surveys of the site and surrounding area would need to be done. Below is a list and brief description of these steps:

- Concrete Survey - A study of the condition of the concrete and structure of the current dam would be performed to better understand the conditions of the site.
- Structural Analysis - Determining the structural soundness of the design would need to be done and, if needed, an iteration process of the turbine housing would have to be made until a satisfactory structure is achieved.
- Electrical Layout - A full schematic of the electrical layout of the turbine and solar systems and their connections to the substation would need to be made. As well as a design for the substation itself.
- Construction Plan - A plan detailing the full process of modifying the current dam structure would need to be created.

11 CONCLUSIONS

This project focused on the evaluation and design of a hydropower retrofit system for a non-powered dam (NPD), with the objective of generating renewable energy while minimizing environmental impact and structural modification to existing infrastructure. The work was completed as part of the Northern Arizona University mechanical engineering capstone program and the 2026 Hydropower Collegiate Competition (HCC). Critical requirements for the project included achieving a target generation capacity within 1–10 MW, maintaining a levelized cost of energy (LCOE) near $0.08/kWh, operating within flow diversion limits of 10–25%, and preserving key environmental functions such as fish barrier integrity.

Through a structured site selection process, Coon Rapids Dam in Minnesota was identified as the optimal location due to its low-head, high-flow characteristics, proximity to existing grid infrastructure, and availability of pre-existing hydropower facilities. These factors significantly improved both technical feasibility and economic viability compared to alternative sites.

The final proposed solution consists of a modular low-head hydropower system utilizing multiple turbine units designed to operate efficiently under site-specific conditions. A five-turbine configuration was selected as the optimal design, producing an estimated total capacity of approximately 2.17 MW, with individual turbine output near 390 kW. Hydraulic modeling using flow duration curves (FDC) and power duration curves (PDC) confirmed consistent flow availability and supported a high capacity factor of approximately 67%.

Economic analysis demonstrated that the system achieves an estimated LCOE of $0.0796/kWh, meeting the defined engineering requirement and confirming the financial feasibility of the design. Environmental and regulatory considerations were incorporated throughout the design process, ensuring that critical site functions, including the fish barrier system, are maintained while enabling power generation. Risk analysis further identified key challenges such as structural modification, flow diversion limits, and debris accumulation, all of which were addressed through targeted design strategies.

Prototype testing provided experimental validation of the turbomachinery model and confirmed expected performance trends, including the relationship between torque, rotational speed, and flow conditions. While conducted at a reduced scale, the testing results support the validity of the design approach and provide confidence in full-scale system performance.

Overall, the proposed hydropower retrofit system meets all critical engineering requirements and demonstrates a balanced solution that integrates technical performance, economic feasibility, and environmental responsibility. The results of this project show that Coon Rapids Dam is a strong candidate for hydropower implementation and that non-powered dam retrofits represent a practical and scalable pathway for expanding renewable energy generation.

Despite these positive outcomes, several limitations remain. Economic estimates are subject to uncertainty in construction and installation costs, and long-term performance will depend on site-specific factors such as debris accumulation, seasonal flow variability, and maintenance requirements. Additionally, regulatory approval and environmental permitting introduce constraints that must be addressed in future development stages.

Future work should focus on detailed structural analysis, refined cost estimation, and expanded prototype testing at larger scales. Further development of grid integration strategies and continued coordination with regulatory agencies will also be essential to ensure successful implementation.

In conclusion, this project demonstrates that leveraging existing infrastructure through modular hydropower retrofits can provide a viable, cost-effective, and sustainable energy solution. The methodology and findings presented in this report establish a strong foundation for future hydropower development at non-powered dam sites.

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