Design Selection and Justification – Midyear Submission

NAU Hydropower Collegiate Competition

Riley Frisell
Evan Higgins
Evie Melahn
Zonghua Ouyang
Trevor Senior
Winston Steele

Faculty Advisor
Carson Pete

Word Count
1437

Table of Contents

Introduction

In undertaking the Design Challenge, our team has opted for a comprehensive examination of the proposed hydropower site through Facility Conceptual Design (Track 1). This strategic direction capitalizes on our interdisciplinary team's internships and expertise in mechanical and electrical engineering. Our objective is to gain an in-depth understanding of hydropower facility development, integrating environmental, economic, and technical aspects into a unified design model. Additionally, the selection of components, including the Voith StreamDiver turbines, will be substantiated through rigorous analysis and detailed justification.

1 Design Track Selection Process

The rationale behind selecting Track 1 is rooted in our team's strong capabilities and the strategic partnerships we've established with developers, consultants, O&M managers, and researchers in the industry. These relationships provide us with unique insights into the practical aspects of site development and equip us to address the intricacies of integrating a hydropower facility into the existing grid infrastructure. Our decision is also influenced by the unique attributes of the three final potential sites, each presenting an opportunity for a holistic design approach that leverages the StreamDiver turbine's benefits and aligns with our run-of-river concept.

Opting for Facility Conceptual Design allowed us to focus on a plan that reflects our collective expertise in mechanical design and electrical systems. It encompasses critical elements such as environmental considerations for fish passage and the strategic placement of control houses. These decisions are made considering the operational advantages of the StreamDiver turbines and their fit with the environmental and infrastructural context of our selected sites, ensuring minimal impact on the riverine ecosystem and optimal flood risk management.

1.1 Design Justification

While our power modeling and conceptual design journey is ongoing, our team has diligently explored key design components pertinent to small-scale hydroelectric generation. Through careful consideration of the StreamDiver technology and associated power modeling, we have identified potential risks and strategized mitigation plans. This preparatory work lays a robust foundation for the intricate design work that will continue throughout the semester.

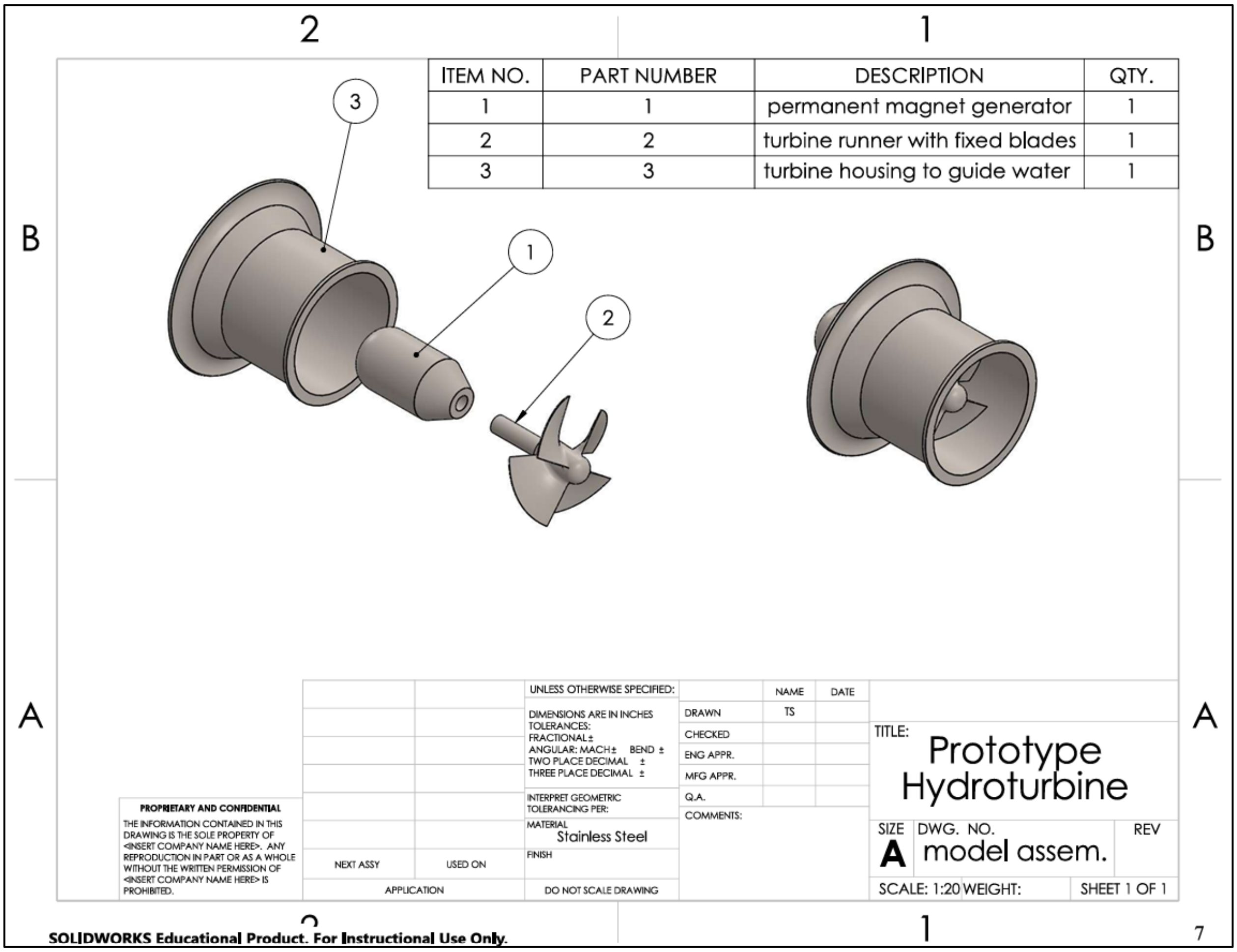
1.1.1 Turbine Selection:

Our choice of the Voith StreamDiver turbine aligns with the generation needs and ecological considerations of our final three sites. The StreamDiver's modular design requires minimal civil construction, is less intrusive, and is delivered pre-assembled, reducing on-site labor and resources compared to conventional Kaplan turbines [1], as detailed in Table 1, and visually displayed by our team (Figure 1). These features are particularly beneficial for our run-of-river and abandoned lock dam projects, like the Kentucky River Lock and Dam #4 and the Fish Barrier Dam, where environmental sensitivity and cost-effectiveness are paramount.

Table 1: Turbine Selection Justification

SteamDiver Turbine	Conventional Kaplan Pit Bulb Turbines
• No concrete required above flange; minimal civil work • Adapted for flood resilience; low maintenance • Unit assembled and tested prior to site delivery	• Concrete-intensive; significant on-site civil work • Increase size, weight, and maintenance • Requires on-site welding; extensive assembly

Our sites are predisposed to flooding, which the StreamDiver can handle without damage due to its innovative design that integrates with existing spillways. This, alongside the ecological benefits of its oil-free operation and proven fish-friendly design, reinforces our decision. Fish passage and geographical characteristics continue to be important factors in our design as we choose our ultimate site, and we are leaning toward a fish ladder to enhance the environmental benefits of the turbine. Additionally, positioning the control house away from flood risks ensures the protection of critical electrical components.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1	permanent magnet generator	1
2	2	turbine runner with fixed blades	1
3	3	turbine housing to guide water	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL Stainless Steel
FINISH
DRAWN TS
TITLE: Prototype Hydroturbine
SIZE A DWG. NO. model assem. REV
SCALE: 1:20 WEIGHT: SHEET 1 OF 1

Figure 1: CAD StreamDiver Model

1.1.2 Power Modeling

In large-scale hydropower plants, synchronous generators are the standard, producing electricity precisely at the grid frequency. These generators, while effective for high-capacity installations, tend to be overly complex and less efficient for smaller-scale applications. The Voith StreamDiver turbine incorporates a permanent magnet generator, which offers a distinct operational mode not reliant on frequency stability provision by the grid. Voith's documentation indicates that StreamDiver generators can operate as both asynchronous (fixed speed) and variable speed generators. The earlier type, however more prevalent, introduces an inductive load that may reduce grid frequency stability.

Our design opts for the use of variable speed generators, as shown in the process diagram in Figure 2. This decision allows the turbine to operate at peak efficiency regardless of grid frequency constraints, enhancing overall efficiency without compromising grid stability. Due to the asynchronous nature of the generator's frequency relative to the grid, direct power integration is not feasible. To address this, a power converter is employed to transition the variable frequency AC to DC, then back to AC matching the grid frequency. Additionally, a step-up transformer is incorporated to elevate the voltage to appropriate grid levels.

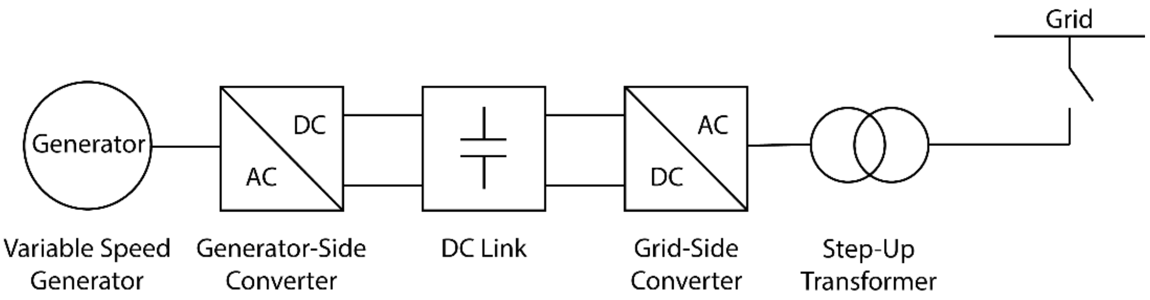


Figure 2: Power Model Overview

2 Risk Identification

Risk management is a crucial component of our hydropower project, integral to navigating the complexities of design and implementation. In this phase, we've developed a provisional risk matrix that delineates potential risks across various domains: construction and civil, energy and grid, technical, mechanical, and environmental. This matrix, while comprehensive, is not static; it represents the beginning of an iterative process that will evolve with our project, capturing lessons learned and adapting to new insights as they arise.

2.1 Risk Identification Process

Our risk assessment process commenced with the identification of key risk areas integral to the development of our hydropower project. These areas include river manipulation, power system installation, dam conversion, co-development, community incorporation, and environmental incorporation. For each identified risk, our interdisciplinary team, leveraging industry best practices, quantified the probability (chance) and potential impact, with a calculated risk score derived by multiplying these two factors (see Tables A1-A3, Appendix A). The resulting risk matrices for each area provide a quantitative framework for our initial risk hierarchy, enabling us to establish early mitigation strategies tailored to the project's specific challenges.

The risk matrices for each site reveal that environmental considerations and construction and civil risks, particularly concerning environment incorporation, dam conversion, and river manipulation, posed the most significant challenges. These areas registered the highest risk scores, underscoring the need for focused mitigation efforts. For instance, dam conversion entails substantial environmental and civil engineering risks due to the need for compliance with environmental regulations and the integration of new structures into the existing operational framework. Similarly, the manipulation of river flows necessitates careful planning to safeguard ecological balance and comply with regulatory standards.

These matrices were essential in developing a hierarchical risk profile, which allowed us to prioritize our mitigation efforts. In recognizing the dynamic nature of project management, our risk matrices are designed to be living documents. They will be revisited and revised regularly, fostering a culture of continuous improvement. Our approach is to preemptively address foreseeable issues while retaining the flexibility to respond to the unforeseen, ensuring that our project remains viable, profitable, and sustainable.

2.2 Approach to Minimizing Risk

Our risk minimization strategy is proactive and adaptive. Preventatively, we incorporate design choices that inherently reduce risk, such as selecting the Voith StreamDiver turbine for its low environmental impact and ease of integration, thereby reducing construction and civil risks. Concurrently, we're developing reactive measures, including contingency planning for high-priority risks like energy grid integration and cybersecurity.

We have also established a monitoring system to continually assess risk throughout the project’s lifecycle. This dynamic approach ensures that we can adapt to unforeseen challenges, maintaining project viability and stakeholder confidence. Additionally, this helps the team document the efficacy of our strategies and the lessons learned, which will be invaluable for both current and future hydropower projects.

By integrating these risk management practices, we aim to construct a hydropower solution that is resilient, economically viable, and environmentally sensitive. The risk matrices we've developed are evolving tools that will guide our decision-making process as we progress toward project completion.

3 Conclusion

In conclusion, our commitment to Facility Conceptual Design (Track 1) for the hydropower project reflects a strategic choice grounded in our team's expertise and the valuable insights from our industry partnerships. Our thorough analysis of design components, particularly the selection of the Voith StreamDiver turbine and interconnecting it with the grid, demonstrates our dedication to developing an environmentally sensitive, cost-effective, and technically feasible hydropower facility. We have rigorously identified and quantified risks, establishing a proactive framework for mitigation that is both flexible and responsive to the evolving landscape of the project.

However, we recognize inherent risks associated with our efforts, including potential inaccuracies in modeling, unforeseen environmental impacts, and unexpected costs. Future work will entail improving our design through ongoing analysis and simulation, seeking stakeholder input, and conducting thorough feasibility studies for informed decision-making. This approach solidifies our path towards a sustainable, efficient, and successful completion of the hydropower development, with the goal of establishing an accurate model for a future renewable energy project.

References

[1] A. Atzmueller and M. Krane, “Streamdiver,” Voith, https://voith.com/corp-en/hydropower-components/streamdiver.html (accessed Jan. 27, 2024).

Appendix A

Table A1: Dam design risk considerations for Kentucky River Lock & Dam #4.

Design Risk Mitigation Matrix																
Proposed Site: Kentucky River Lock & Dam #4																
RISK DESCRIPTION	**Construction and Civil Risk**			**Energy and Grid Risk**			**Technichal/Other Risk**			**Mechanical Risk**			**Enviromental Risk**			**RISK SCORE**
River Manipulation	Adapting existing flume for StreamDiver			Grid connection disruptions			Construction schedule/planning setbacks			Installation difficulties with turbines/other components			Ecological distrubance			Max individual 500
	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Total Score
	6	8	48	3	6	18	5	8	40	4	6	24	6	9	54	**184**
Power System Installation	Retrofitting existing structures			Integrating with existing grid			Compliance/compatibility issues duirng installation			Mechanical fit and compatibility			Environmental permits for new installation			Max individual 500
	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Total Score
	5	8	40	5	7	35	4	6	24	5	8	40	4	6	24	**163**
Dam Conversion	Conversion while maintaining operations			Energy production variability			Technical retrofitting issues			Downtime/repairs during dam converison			Water rights, permitting, and compliance			Max individual 500
	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Total Score
	6	8	48	4	7	28	5	7	35	5	7	35	6	8	48	**194**
Co-Development	Co-development with Buffalo Trace Distillery			Grid coordination with other current energy projects/infrastructure			Integration with other developments			Not Applicable			Cumulative environmental impact			Max individual 400
	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Total Score
	4	7	28	2	5	10	2	5	10	0	0	0	4	7	28	**76**
Community Incorporation	Encountering high-priority easements in development			Community enery disruption			Local infrastructure adaptations			Not Applicable			Water supply managemnet			Max individual 400
	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Total Score
	3	6	18	2	4	8	2	3	6	0	0	0	4	7	28	**60**
Environment Incorporation	Enivonrmental regulation compliance affecting development			Eco-friendly energy system challenges			Not Applicable			Facility equipment impact on surrounding environment			Ecological system disturbances			Max individual 400
	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Total Score
	5	8	40	4	7	28	0	0	0	3	6	18	6	9	54	**140**
															Total Risk Score (out of 2200)	**817**

Table A2: Dam design risk considerations for Mishawaka Fish Ladder, Indiana.

Design Risk Mitigation Matrix																
Proposed Site: Mishawaka Fisk Ladder, Indiana																
RISK DESCRIPTION	**Construction and Civil Risk**			**Energy and Grid Risk**			**Technichal/Other Risk**			**Mechanical Risk**			**Enviromental Risk**			**RISK SCORE**
River Manipulation	Difficulty in riverbed modificatoin			Grid connection disruptions			Construction schedule/planning setbacks			Installation difficulties with turbines/other components			Ecological distrubance			Max individual 500
	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Total Score
	4	7	28	3	6	18	5	8	40	3	6	18	5	9	45	**149**
Power System Installation	Installation complexity			Integrating with existing grid			Compliance/compatibility issues duirng installation			Mechanical failure/malfunctions during installation			Environmental impact			Max individual 500
	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Total Score
	4	8	32	7	7	49	5	6	30	3	8	24	3	5	15	**150**
Dam Conversion	Structural conversion challenges			Energy production variability			Technical retrofitting issues			Downtime/repairs during dam converison			Water rights, permitting, and compliance			Max individual 500
	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Total Score
	5	8	40	4	7	28	3	5	15	2	6	12	6	10	60	**155**
Co-Development	Joint development hurdles			Grid coordination with other current energy projects/infrastructure			Integration with other developments			Integrating mechanical systems with recreation			Cumulative environmental impact			Max individual 500
	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Total Score
	3	6	18	3	5	15	2	5	10	1	5	5	4	7	28	**76**
Community Incorporation	Encountering high-priority easements in development			Community enery disruption			Local infrastructure adaptations			Not Applicable			Community environmental concerns			Max individual 400
	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Total Score
	4	7	28	3	4	12	2	3	6	0	0	0	3	7	21	**67**
Environment Incorporation	Enivonrmental regulation compliance affecting development			Sustainable energy integratoin			Not Applicable			Facility equipment impact on surrounding environment			Ecological system disturbances			Max individual 400
	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Total Score
	4	7	28	3	5	15	0	0	0	2	6	12	7	9	63	**118**
															Total Risk Score (out of 2300)	**715**

Table A3: Dam design risk considerations for Fish Barrier Dam, Washington.

Design Risk Mitigation Matrix

Proposed Site: Fish Barrier Dam, Washington

RISK DESCRIPTION	**Construction and Civil Risk**			**Energy and Grid Risk**			**Technichal/Other Risk**			**Mechanical Risk**			**Enviromental Risk**			**RISK SCORE**
River Manipulation	Difficulty in riverbed modificatoin			Grid connection disruptions			Construction schedule/planning setbacks			Installation difficulties with turbines/other components			Ecological distrubance			Max individual 500
	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Total Score
	3	6	18	3	7	21	6	8	48	5	6	30	6	10	60	**177**
Power System Installation	Installation complexity			Integrating with existing grid			Compliance/compatibility issues duirng installation			Mechanical failure/malfunctions during installation			Environmental impact			Max individual 500
	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Total Score
	6	8	48	4	7	28	6	8	48	2	8	16	4	6	24	**164**
Dam Conversion	Structural conversion challenges			Energy production variability			Technical retrofitting issues			Downtime/repairs during dam converison			Water rights, permitting, and compliance			Max individual 500
	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Total Score
	6	8	48	5	7	35	2	5	10	2	5	10	7	9	63	**166**
Co-Development	Joint development hurdles			Grid coordination with other current energy projects/infrastructure			Integration with other developments			Not Applicable			Cumulative environmental impact			Max individual 500
	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Total Score
	3	6	18	2	5	10	2	4	8	0	0	0	4	7	28	**64**
Community Incorporation	Encountering high-priority easements in development			Community enery disruption			Local infrastructure adaptations			Not Applicable			Community environmental concerns			Max individual 400
	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Total Score
	3	6	18	3	5	15	5	8	40	0	0	0	5	8	40	**113**
Environment Incorporation	Enivonrmental regulation compliance affecting development			Sustainable energy integratoin			Not Applicable			Facility equipment impact on surrounding environment			Ecological system disturbances			Max individual 400
	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Chance	Impact	Risk	Total Score
	6	8	48	4	5	20	0	0	0	5	7	35	7	10	70	**173**
															Total Risk Score (out of 2200)	**857**