Finalized Testing Plan for ME486C

Modified to Include Project Risks and Summary

Hydropower Collegiate Competition – 2024

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Disclaimer

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1 Design Requirements Summary

The following customer requirements have been iteratively updated throughout the capstone course based on the characteristics of the site selected and the components used for the overall facility design.

1.1 Customer Requirements

CR1. Environmental Impact Mitigation: Support environmental rehabilitation and passage for existing aquatic life.

CR2. Project Expenditures: Create a viable solution for clean energy generation that proves to be financially viable through levelized cost of energy.

CR3. Accessibility: Ensure site has sufficient access to support construction and maintenance.

CR4. Co-Development Proposal: Create a co-development opportunity to integrate into the hydropower dam conversion design.

CR5. Energy Production: The converted dam must generate between 1-10 MW.

CR6. Community Engagement: Engage with the community to spread awareness about the benefits of hydropower and gauge success through metrics.

1.2 Engineering Requirements

ER1. Mitigated Environmental Impacts: Create a site that supports fish passage, the existing ecosystem and provides opportunities to rehabilitate the existing state of the river through an innovative design.

ER2. Financial Feasibility: Ensure that the cost of the project is reasonable by investing incentives and the most cost-effective solution when modifying the dam.

ER3. Site Interconnectivity: Connection with the existing grid, transmission lines must be close to the proposed site so minimal transmission line additions are required.

ER4. Co-Development Opportunities: Create a unique co-development opportunity that supports renewable energy generation and fits well with the proposed design and at the site.

ER5. Energy Output: Verify that the anticipated generation will be within the range of 1-10 MW through calculations based on the river's flow history.

ER6. Affected Population: Create a solution that will benefit the community through clean power generation, increased recreational benefits and aim to improve the existing ecosystem.

2 Top Level Testing Summary

The Hydropower Collegiate Competition (HCC) requires us to provide an assessment of our impact mitigation approaches in both siting and design. This testing summary section of the assignment has been modified to outline the recent risks assessed with cyber security threats to American power systems, which were not outlined in our midyear submissions. By identifying these risks, we hope to provide something to our competition report and presentations that will help put us ahead of other teams and further analyze the feasibility of our hydropower design.

2.1 Potential Threat Actors:

The following list includes threats that can pose a risk to the security or functionality of the hydropower infrastructure (ER6).

- **Nation-states**: Possess advanced cyber capabilities such as hacking, well-funded cyber warfare units, and extensive resources. There are many varying reasons these pose potential threats such as geopolitical rivalry, economic competition, espionage, political influence, ideological conflicts, interest in intellectual property, undermining national security, sowing chaos, deterring military action, and even manipulation of public opinion.
- **Cybercriminals**: There are many reasons for cybercriminals to have an interest in disrupting the American power infrastructure. This includes financial gain (ransom payments), energy theft, fraudulent billing, disruption of service, data theft and espionage, and supply chain attacks to undermine and bypass traditional security measures.
- **Hacktivists**: This poses a potential threat due to ideological or political beliefs that come from many outside motivations like disruption, or social and environmental protest.
- **Insiders**: Insiders, such as an employee or contractor with legitimate access to American power systems, can pose a significant threat due to their insider knowledge, access privileges, and potential motivations to exploit vulnerabilities or engage in malicious activities. Some motives for an insider to be a potential threat include financial motives, disgruntled employees or contractors, espionage, or even just human error and negligence.

Table 1: Potential Threat Actor Likelihood and Impacts

Likelihood and Impact	Negligible Impact	Low Impact	Moderate Impact	High Impact	Catastrophic Impact
Highly Unlikely					
Unlikely		Hacktivist Threat			
Possible			Cybercriminal Threat	Insider Threat	
Likely					
Highly Likely					Nation-State Threat

2.2 Vulnerabilities and Risk Factors Present in Power System Infrastructure:

The following identify which aspects of the hydropower infrastructure are most susceptible to risks. This connects with ER6 due to the affect a security risk could have on the community and CR2, since the project security measures need to be considered while focusing on keeping costs down.

- **SCADA (Supervisory Control and Data Acquisition) systems:** SCADA is one of the major threats to the American power grid as it operates nearly all remote monitoring and control of power systems including power generation, transmission, and distribution with vulnerabilities including outdated software, unpatched systems, weak authentication measures, lack of encryption, interconnectedness dependency, legacy infrastructure, human error and insider threats, and supply chain risks of third party vulnerabilities.
- **Industrial Control Systems (ICS):** Control systems pose major vulnerability to power infrastructure due to their important roles and mass use with risks including, internet reliance on PLCs (Programmable Logic Controllers), RTUs (Remote Terminal Units), and HMIs (Human Machine Interfaces), control of various interconnected critical components, cascading failures, supply chain risks with counterfeit and third-party components, insider threats, and lack of security controls with many lacking or designed with cyber security issues in mind.

- **Smart grids**: As technology advances and we rely more on smart grids with mass interconnected parts many vulnerabilities are introduced. Including factors such as dependence on networked infrastructure, vast amounts of data and electricity consumption, supply chain and third-party component risks, physical security with much infrastructure, and vulnerability to attacks and vandalism.
- **Human factors**: Employees, contractors, or vendors with access to critical systems may pose insider threats including, social engineering attacks, phishing attacks, poor cybersecurity hygiene, lack of training, over-reliance on technology, and physical security breaches.
- **Third-party vendors**: Third-party vendors are part of the supply chain for power infrastructure, providing hardware, software, components, and services to utilities and power companies with risks including supply chain risks, vendor security practice, access and privilege management for maintenance and instillation, data handling, contractual and legal risk, and geopolitical consideration.
- **Geopolitical tensions**: Geopolitical tensions pose significant risks and vulnerabilities to cybersecurity in American power infrastructure with risks and vulnerabilities like supply chain issues with trade restrictions and sanctions, espionage and cyber-attacks, information warfare, and cyber weaponization.
- **Emerging technologies**:
    - **AI**: sophisticated cyber-attacks, adversarial machine learning, data privacy and bias, dependency on AI systems, and lack of AI security standards.
    - **Quantum computing:** breaking cryptography, data breaches and information disclosure, intellectual property theft, hardware tampering, algorithmic vulnerabilities, disruption of further advancements in AI and machine learning, and financial implications for preparedness and upgrades.
- Solar flares or Coronal mass ejections (charged particles).
- Nuclear electromagnetic interference or electromagnetic pulses.

Table 2: Vulnerabilities in Power System Infrastructure Likelihood and Impacts

Likelihood and Impact	Negligible Impact	Low Impact	Moderate Impact	High Impact	Catastrophic Impact
Highly Unlikely					EMPS or nuclear risk
Unlikely				Solar flares/CMEs	
Possible				Smart Grid SCADA Vulnerabilities	Geopolitical tensions
Likely			Third Party Vendor Risks	Control system Vulnerabilities AI/Quantum computing	SCADA Vulnerabilities
Highly Likely			Human Factors		

3 Detailed Testing Plans

As requested by Professor Willy, we have modified this section of the testing plan to summarize our analyses and the remaining work that needs to be done to ensure a sustainable facility design.

3.1 Analysis Summary

Throughout this project, we've tried to prove the feasibility of this small-scale hydropower project from a financial perspective and design perspective. In this section we lay out the types of analysis we're currently doing in for our siting and design challenge for HCC.

3.1.1 Electrical Interconnection System Modeling

- **Design Requirements (DRs) Tested:** Establishing an efficient, reliable electrical connection and control system for the hydropower facility.
- **Objective:** To validate the electrical system's capability to handle generated power and integrate it into the existing grid.
- **Tools/Software Used:** CAD software for professional drawing, IEEE 5 bus transmission model, Simulink for PMSG model.
- **Variables Measured:**
    - Power flow and voltage levels in the IEEE 5 bus transmission model.
    - Performance characteristics of the PMSG (Permanent Magnet Synchronous Generator) in variable operating conditions.
- **Derived Variables/Outcomes:**
    - Optimal configuration for system reliability and efficiency.
    - Anticipated electrical losses and stability of the system under different load conditions.

3.1.2 Turbine Performance and Energy Production Estimation

- **Design Requirements (DRs) Tested:** Appropriate sizing and operational efficiency of turbines.
- **Objective:** To determine the most suitable turbine units and evaluate their performance across various flow and head conditions.
- **Tools/Software Used:** Voith's StreamDiver turbine specifications, operational data analysis tools.
- **Variables Measured:**
    - Turbine efficiency at specified operating points.
    - Daily generation potential based on yearly flow and head points.
- **Derived Variables/Outcomes:**
    - Daily, monthly, and annual energy production estimates.
    - Performance metrics for optimal turbine operation and maintenance scheduling.

3.1.3 Financial Feasibility Analysis

- **Design Requirements (DRs) Tested:** Economic viability of the hydropower project.
- **Objective:** To assess the financial performance of the project over a 50-year operating period.

- **Tools/Software Used:** Advanced spreadsheet models for cost, revenue, and operational expenses.
- **Variables Measured:**
  - Capital costs including licensing, construction, and equipment.
  - Revenue from power and REC sales, operational expenses.
- **Derived Variables/Outcomes:**
  - Net present value (NPV), internal rate of return (IRR), and payback period.
  - Sensitivity analysis to understand the impact of variables like power sales rate, DOE incentives, and operational costs on financial viability.

3.2 Procedure

Based on the three major analyses that we have listed above (which will be presented in our final report and competition), we have listed out a procedure for each analysis that each team member can read and help contribute to.

3.2.1 Electrical Interconnection System Modeling

1. Implement the IEEE 5 bus transmission model to simulate the electrical grid integration.
2. Utilize the PMSG Simulink model to analyze the behavior of the permanent magnet synchronous generator under various operational conditions.
3. Develop detailed CAD schematics representing the electrical layout, highlighting interconnections and relay settings.
4. Perform sensitivity analyses to evaluate the system's response to changes in load, generation, and fault conditions.
5. Analyze protection schemes to ensure proper coordination and reliable operation.

3.2.2 Turbine Performance and Energy Production Estimation

1. Import and preprocess USGS discharge data to align with the operating points provided by Voith.
2. Apply the operational data to simulate the turbine performance across different flow and head conditions.
3. Estimate the energy output for each data point to construct an annual energy profile.
4. Calculate the capacity factor by comparing the actual energy output with the maximum possible output.
5. Determine the LCOE considering the capital and operational costs, and the expected energy generation.
6. Construct a load curve to visualize the potential energy production over time.

3.2.3 Financial Feasibility Analysis

1. Compile all capital costs, including equipment, construction, engineering, licensing, and environmental mitigation measures. Additionally, compile quantitative values for each of the DOE incentives our small-scale project will be eligible for.
2. Project operational expenses for the next 50 years, taking into account maintenance, staffing, insurance, and other ongoing costs.
3. Estimate revenue streams based on energy sales rates, REC sales, and potential for capacity payments or ancillary services.
4. Calculate the LCOE to determine the cost competitiveness of the hydropower facility.

5. Apply financial models to estimate the NPV and IRR, assessing the overall investment attractiveness.

3.3 Anticipated Results

3.3.1 Electrical Interconnection System Modeling

- Confirmation of electrical efficiency across all operating points.
- Identification of stability margins and mitigation strategies for potential instabilities.
- Verification of grid compatibility, including voltage levels and power factor norms.
- Detailed protection coordination plan ensuring system integrity under fault conditions.

3.3.2 Turbine Performance and Energy Production Estimation

- A detailed prediction of the annual energy generation, with an analysis of variations due to seasonal and temporal changes in water flow. Current annual generation is estimated to be around 5,000 MWh.
- Calculation of the capacity factor, offering insight into how often the turbines will be generating power at different times of the year. Based on operations of hydropower at further downstream, we expect a capacity factor of around 50%.
- A precise estimate of the LCOE, reflecting the economic feasibility of the project.
- A load curve that demonstrates the expected power production in relation to the demand patterns.

3.3.3 Financial Feasibility Analysis

- Capital costs estimation within the range of $15-$20 million. It's important to note that despite these fairly high costs, our project would qualify for a transferrable treasury grant of around 40% of the project cost.
- Projection of a return on investment within 15-20 years, indicating a favorable payback period.
- Determination of an NPV that reflects the project's profitability over its lifetime.
- An IRR that surpasses the average industry benchmarks for renewable energy projects.

3.4 Conclusion

The three major analyses we outlined are not only the foundation for a robust hydropower facility but are also pivotal in validating the project's technical and economic viability. Our EE-sub team has done a great job utilizing the IEEE 5 bus and PMSG Simulink models. In the upcoming weeks, we will use their results to build an interconnection/relay flow diagram and ensure that our facility's integration into the power grid is both seamless and compliant with current industry standards. As for the mechanical team, now that we have our current StreamDiver turbine units sized, we're hoping to use this data to get a more accurate prediction of annual energy generation, capacity factor, and LCOE to help our placement in the competition. Finally, we want to prove at competition that it doesn't matter how good your design idea is, if it's not financially feasible, it will never be a real project. We think that by accounting for financial projections of capital costs, operation expenses, and potential revenue, we can deepen our analysis on site feasibility and also determine the project's attractiveness to investors in the long run. We are very confident that our multi-faceted approach will demonstrate the project's alignment with the industry's forward-thinking objectives and our team's innovative capabilities.

4 Specification Sheet Preparation

The customer requirements (Table 3) have all been met, however the final project expenditures are in progress as we collect more information on cost associated with the complexity of the dam conversion. The community engagement portion of the project is also in progress as we have a couple events planned for April. The engineering requirements (Table 4) do not have quantifiable target values for all the requirements, for example we do not have quantifiable solution to environmental impact mitigation. The end goal however is to create a hydropower solution that maintains and if possible, can improve the ecological impact of the dam in Frankfort, Kentucky through increase fish passage and clean energy generation in the community.

Table 3: HCC CR Summary Table

Customer Requirement	CR met? (y or n)	Client Acceptable (y or n)
CR1 - Environmental Impact Mitigation	Yes	Yes
CR2 - Project Expenditures	Yes/in progress	Yes
CR3 - Accessibility	Yes	Yes
CR4 - Co-Development Proposal	Yes	Yes
CR5 - Energy Production	Yes	Yes
CR6 - Community Engagment	Yes/in progress	Yes

Table 4: HCC ER Summary Table

Engineering Requirement	Target	Measured/Calculated Value	ER met?	Client Acceptable (y or n)
ER1 - Mitigated Environmental Impacts	Maintain/improve existing environment	NA	Yes	Yes
ER2 - Financial Feasibility	~25 million	in progress	Yes	Yes
ER3 - Site Interconnectivity	<1 mile to transmission line infrastructure	0.2 miles to existing transmission line	Yes	Yes
ER4 - Co-Development Opportunities	Solar generation	~200 KW solar generation	Yes	Yes
ER5 - Energy Output	1-10 MW	0.8 MW	No	No, but with addition of solar it is acceptable
ER6 - Affected Population	Improve benefits from the exisitng dam structure	NA	Yes	Yes

For ER5, the estimated energy generation based on using a StreamDiver 16.95 and 10.15 our estimated energy generation is 818 KW which is short of the 1 MW minimum requirement, but we can use our solar generation to supplement this deficit. When we finalize the size of our flume, we can choose to use a larger StreamDiver or add an additional turbine if we find that to be a financially viable option to ensure we are within the competition generation range before the solar generation.

5 QFD

The House of Quality diagram provides us with design targets set by the competition and ties them to technical requirements that our site conversion must meet. The refined QFD (Figure 1) connects the engineering requirements to the customer requirements, and weights them based on their importance. Our QFD uses three other non-powered dams that were converted to a hydropower dam. This provided us with benchmarking to compare our sites needs and requirements to create a unique viable hydropower solution for clean energy generation.

HCC 2024 QFD

Project:	Hydropower Collegiate Competition
Date:	3/21/2024

	Technical Requirement Correlations	1	2	3	4	5	6
1	**Mitigated Environmental Impacts**						
2	**Financial Feasibility**	––					
3	**Site Interconnectivity**	+	++				
4	**Co-Development Opportunities**	–	++	+			
5	**Energy Output**		+	++	+		
6	**Affected Population**	+	+	++	++	++	

Legend	
A	**Red Rock, IL**
B	**Lake Livingston, TX**
C	**Willow Island, WV**

	Customer Needs	Customer Weights	Weight %	Technical Requirements: Mitigated Environmental Impacts	Financial Feasibility	Site Interconnectivity	Co-Development Opportunities	Energy Output	Affected Population	Customer Opinion Survey: 1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
1	**Environmental Impact Mitigation**	10	21.28	9	6	3	6					B	C	A
2	**Project Expenditures**	9	19.15	6	9	6	6	6	3		A	B		C
3	**Accessibility**	8	17.02	3	6	9	3	6	3		A	B		C
4	**Co-Development Proposal**	7	14.89	6	6	6	9		6			C		AB
5	**Energy Production**	6	12.77		6	3		9	6	A		B	C	
6	**Community Engagement**	5	10.64		3	3	6	6	9					C
	Technical Requirement Units			%	2023 $	miles	#	MW	#					
	Technical Requirement Targets			↑	↓	↓	↑	(1-10)	↑					
	Absolute Technical Importance			447	600	491	491	396	370					
	Relative Technical Importance			3	1	2	4	2	5					

Figure 1: HCC QFD