Siting and Design Justification – Final Report

NAU Hydropower Collegiate Competition
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Abstract

In the United States, where over 80,000 non-powered dams (NPDs) present an overlooked opportunity, we seek to harness this potential for clean electricity generation in a cost-effective manner. The Department of Energy's Hydropower Collegiate Competition (HCC) [1] challenges us with assessing the feasibility of one of these sites in the Siting Challenge and a conceptual design of a small-scale hydropower facility ranging between 1-10 MW for the Design Challenge. After our assessment, Lock and Dam #4 on the Kentucky River was identified to be a viable site with potential to generate roughly 1.346 MW of power. We aim to solve the challenge of underutilized water infrastructure by leveraging the dam's existing structure for the installation of a Voith StreamDiver turbine, thus tapping into a new source of renewable energy with minimal environmental intrusion. Our approach is grounded in comprehensive technical feasibility calculations and considers the environmental and economic impacts of non-powered dam conversion. The anticipated outcome is a revitalized dam that not only supports local power demands, particularly the adjacent wastewater treatment plant, but also serves as a model for cost-efficient renewable energy projects. The broader implications of our work extend to fostering community engagement in renewable energy initiatives, contributing to a diverse energy grid, and supporting the hydropower industry's growth. By adhering to stringent engineering requirements, such as robustness, cost-effectiveness, and environmental compatibility, our project stands as a testament to the innovative and sustainable application of engineering principles in pursuit of a clean energy future.

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1 Siting Justification

The site selection process began with defining customer and engineering requirements, which led to identifying key criteria for preliminary site selection. After assessing numerous sites nationwide, Kentucky River Lock and Dam #4 was chosen as the final site due to its favorable attributes, including adequate year-round flow, proximity to existing transmission lines, and minimal environmental impacts. Furthermore, utilizing the existing flume infrastructure from an old water wheel will allow for cost savings and reduced construction concerns. This aligns with our project's goal of leveraging existing infrastructure for hydropower generation.

1.1 Approach and Methodology to Site Selection

At the very start of this project, our initial steps were to define clear project goals and anticipate possible outcomes. Understanding the objectives and framework of the competition provided the direction needed to embark on the crucial first phase of site selection. With over 80,000 non-powered dams across the United States to consider, it was essential to establish a rigorous set of criteria that could effectively streamline our search and align with the competition's expectations.

To systematically approach this task, we developed nine key criteria, each chosen for its impact on the potential success of a hydropower conversion project. These criteria were carefully weighted to reflect their relative importance in achieving our project goals while adhering to the competition's guidelines. The criteria not only helped in narrowing down the candidates but also ensured a balanced evaluation of each site's technical feasibility, environmental impact, and community integration potential. Our key criteria included:

1. **Potential Energy:** Assessing an NPD's potential energy requires a more thorough understanding of the environment, existing structure, and flows. So, for preliminary estimate, we utilized the potential generation formula below to estimate the maximum potential [5]. This factor received a substantial weight of 25% in our decision matrices due to the competition's focus on generation capacity.

$$Potential\ Annual\ Generation = \frac{Q \times \Delta H \times \eta}{11{,}800} \quad \text{MW}$$

    a. Where η=0.85 is assumed efficiency, Q is annual mean flow rate, and ΔH is assumed head.

2. **Flow Rate:** We established a baseline flow rate of 1000 cubic feet per second (cfs), deducing that at least 10 feet of head would be required to generate 1 MW. Sites with higher flow rates were preferred for their increased design flexibility and potential for higher energy output.

3. **Distance to Existing Power Infrastructure:** Recognizing the limitations imposed by remote locations on small hydro projects, we set a cap of 10 miles from existing power infrastructure to preserve project viability, with closer sites deemed more favorable.

4. **Dam Ownership Type** The likelihood of collaboration from dam owners was evaluated, with consideration given to the time and financial implications associated with obtaining project consent and initiating development.

5. **Potential Environmental Impact:** Scores were derived from recent inspection data of dams, supplemented by additional research to ensure a comprehensive environmental assessment, such as endangered species within the area and current water quality.

6. **Dam Integrity:** The integrity of dams was evaluated based on their construction year and the extent of recent refurbishments, ensuring that selected sites maintain structural soundness.

7. **Dam Type:** Conversations with industry experts revealed that certain dam types, notably concrete, offer superior benefits in terms of conversion feasibility and risk mitigation, influencing our selection process.

8. **Accessibility:** The feasibility of ongoing maintenance and operations was closely tied to each site's proximity to necessary infrastructure, with more accessible sites scoring higher.

9. **Local Community Need:** Economic factors, including job availability and the financial health of local communities, were researched at promising sites to determine the potential socio-economic benefits of the project.

Our search for a site began in the Southwest, where we had an advantage due to our connection to Northern Arizona University and our prior knowledge of the area's hydropower environment, which included famous dams like Hoover Dam and Glen Canyon Dam. We started our site selection process in Arizona by looking at larger, more ambitious projects involving dams like the Imperial Dam and Bartlett Lake Dam in addition to low-head, run-of-river hydropower choices. This diverse scope was purposeful, designed to explore a spectrum of hydropower potentials, from harnessing modest flow in smaller rivers to capturing the robust energy of the Colorado, Salt, and Gila Rivers. We considered a variety of hydraulic structures, from canal headworks suitable for StreamDivers to imposing dams where we analyzed scenarios involving the raising of dam heights for increased hydraulic head. The prospects of situating powerhouses and assessing the civil engineering challenges formed part of our comprehensive evaluation. However, in the context of the competition's 1-10 MW generation capacity scope, we soon recognized the disproportionate complexity and financial demands associated with larger dams. These often require extensive civil works and faced formidable construction challenges compared to their lower-head counterparts.

Therefore, when assessing the final array of dams in our Arizona investigation, Granite Reef Dam, located on the Salt River near Mesa, Arizona, emerged as a compelling candidate. Our initial enthusiasm was bolstered by the dam's strategic position and infrastructure. Preliminary design assessments (see Appendix A1 – Arizona ArcGIS Pro Layouts for ArcGIS analysis) were conducted to foresee the integration of StreamDiver units, utilizing the dam's function as a diversion point to the Southern and Arizona Canals. When performing an in-depth investigation into the Granite Reef Dam, we were aided by SRP-provided data on flow rates and as-built drawings, which was crucial in shaping our understanding of hydropower feasibility in the region.

The dam's primary function as a diversion point for the Salt River into two canals was initially perceived as an opportunity. However, as we delved deeper into the site's characteristics, critical challenges surfaced. Mainly, there was a realization that the head available at the canal headworks fell significantly short of the 20 feet we presumed was pivotal. The attached images (Figure 1 and Figure 2) illustrate the dam's structure, which seldom sees the kind of overflow that would provide the 30 feet of head present at the main section of the dam, reserved primarily for flood events.

Figure 1: Granite Reef Diversion Dam Arizona Canal headworks.

Figure 2: Granite Reef Diversion Dam full view. Note where water diverts into two canal systems, where we initially explored installing StreamDivers at.

Additionally, the Southwest's fluctuating water regime, marked by stark periods of flooding and drought, posed significant risks to consistent power generation. This volatility, compounded by our discovery of the actual head available at Granite Reef Dam (substantially less than initially estimated) prompted us to reassess the viability of Arizona's sites. Our resolve was to widen our search radius, extending beyond the initial geographical preference, informed by our refined understanding of the importance of consistent water availability for hydropower.

The insights gleaned from scrutinizing the Granite Reef Dam—regarding flow rates, head availability, and construction feasibility—extended beyond Arizona. These findings influenced our subsequent nationwide search, where the delicate balance between civil work complexity, environmental considerations, and financial feasibility remained at the forefront of our site assessment criteria. It taught us to critically evaluate the intricacies of site data and underscored the significance of head and flow rate consistency for power generation. Additionally, the principles we derived from assessing the viability of larger-scale dams and the logistical simplicity favored by low-head sites, particularly those that are run-of-river, laid the groundwork for our evaluations in a variety of other states.

1.2 Nationwide Site Exploration

Having encountered the complexities of site selection in Arizona, we shifted our focus to a broader, nationwide search. Armed with an enhanced ArcGIS Pro tool, refined from our experiences in Arizona, and recalibrated decision matrix criteria (Table A2.2 in Appendix A), we cast a wide net over the western states of Washington, Idaho, Colorado, California, and Oregon. Despite the high number of dams previously assessed for hydropower, our revised criteria prioritized potential energy, flow rate, and proximity to existing power infrastructure as key determinants, with each criterion assigned a weighted score based on its relative importance.

Our comprehensive search incorporated sophisticated geospatial techniques, leveraging databases like the NPDamCAT to ensure a thorough examination of NPDs across these states. The resulting evaluation, guided by a recalibrated scoring system, was critical in identifying sites with overlooked hydropower potential. Simultaneously, our research highlighted a significant yet underutilized hydropower corridor along the Kentucky River's Locks 1 through 14. This revelation, underscored by insights from a small hydro developer in the area, steered our assessment towards the realization of practical, sustainable hydropower solutions that had previously been neglected. While we did find some dams with potential (as outlined in Tables A2.3-A2.9 in Appendix A2), our scoring process culminated in the identification of three prominent sites: Fish Barrier Dam in Washington, Mishawaka Fish Ladder in Indiana, and Kentucky River Lock & Dam #4. Each location presented unique opportunities and challenges, setting the stage for an in-depth evaluation of their respective hydropower potential.

1.2.1 Fish Barrier Dam, Washington

Located in a region managed by Tacoma Power Utilities (TPU) and not subject to state regulation, Fish Barrier Dam stood out with the potential to generate up to 5 MW. In the initial evaluation, the proximity to Cowlitz Salmon Hatchery, another TPU-managed facility, suggested a compelling case for co-development, capitalizing on tourism and local energy needs. Yet, the site's rural locale introduced substantial challenges. The nearest grid connection lay nearly two miles away, complicating the financial justification for development due to the cost of extending infrastructure to such a remote location. Moreover, with Mayfield Dam situated upstream, providing a robust 162 MW capacity, the incremental addition from Fish Barrier Dam risked being negligible in the context of regional power generation.

Figure 3: Aerial image of Fish Barrier Dam in Washington, located next to Cowlitz Salmon Hatchery.

Complicating matters further, the dam's primary function as an environmental steward for salmon migration and spawning introduced significant constraints. Repurposing the dam for hydropower would not only be difficult to justify but also required careful consideration of the potential ecological impacts. The integration of hydropower needed to be weighed against the possibility of altered water quality and temperature, critical factors for the hatchery's operations and the health of the salmon population. Furthermore, despite the potential operational benefits of two proximate power-generating facilities, such as shared resources and enhanced grid stability, these advantages were overshadowed by the recent $11 million investment in the dam's infrastructure. This substantial expenditure raised questions about community and stakeholder appetite for further development and the likelihood of facing stringent regulatory frameworks designed to protect the dam's conservation efforts.

Fish Barrier Dam's multipurpose function in fish conservation, environmental dangers, grid connectivity, and recent investments the complexity of proposing a multi-purpose hydropower development at Fish Barrier Dam. With a team consisting solely of mechanical and electrical engineers, it became evident that striking a balance between increased power generation and the required environmental preservation would be challenging. This meant creating a design that minimized ecological disruption to comply with competition, regulations, and community expectations.

1.2.2 Mishawaka Fish Ladder, Indiana

The Mishawaka Fish Ladder in Indiana emerged as another prospective site with notable potential for our hydropower project. Located in a region undergoing significant urban development, the Mishawaka site offered consistent flow rates and an opportunity to integrate with the city's development plans. However, the local development, while presenting potential for public engagement and support, also posed risks related to construction approval and logistical complexities. Initially, we considered the installation of StreamDiver units adjacent to the existing fish lift, capitalizing on the site's flow characteristics. However, a significant transformation of the area into a recreational park posed new challenges that shifted the viability of our initial plans. The redevelopment of the park near the fish lift made it clear that gaining approval for construction in this newly revitalized community space would be complex.

We also contemplated utilizing the headworks of the old canal on the other side of the dam for hydropower generation (Figure 4), but the lack of specific head data and the complexities associated with construction access in a developing urban area prompted us to reconsider. Technological advancements in the field of hydropower, such as the development of StreamDiver units, promised the opportunity for economic development even with lower heads. However, without detailed head data and given the intricate mesh of urban development plans, we determined that our resources would be better allocated to sites where the path to implementation was clearer and where the project could complement, rather than compete with, local priorities.

Figure 4: Aerial image of Mishawaka Fish Ladder in Indiana. Note the existing infrastructure that was discussed being used to integrate StreamDiver units.

While we recognized that while the site held promise, the current urban development trajectory and our team's specialization were not conducive to the project's success. The site's integration with the natural ambiance and city development was envisioned as harmonious, yet it required a thorough understanding of the local plans and careful design considerations to ensure a seamless blend of functionality and aesthetics. Overall, the convergence of the Mishawaka site's recent transformation and the critical lack of head data steered our decision to seek alternative locations where our hydropower solutions could fully align with local needs and capabilities.

1.2.3 Lock and Dams Along the Kentucky River

When searching along the Kentucky River for development, we found a diverse array of locks and dams, each with its own unique potential and set of challenges. Locks 7 and 9-14 were already in various stages of development with approved preliminary FERC permits, narrowing our search for suitable locations. The exploration of the remaining locks uncovered operational challenges and material limitations; particularly, the stone construction of the abandoned locks posed significant civil engineering hurdles. Without the expertise to securely anchor the stone walls against hydrostatic pressures during dewatering, the risk associated with these locks, such as Lock & Dam #8, became prohibitively high.

However, Lock & Dam #4 quickly captured our interest. While the lock is still in use, the Kentucky River Authority (KRA) stated that a water wheel was previously used to power a hemp mill on the property that is currently abandoned (outlined in Figure 5). The flume associated with this abandoned water wheel symbolizes an unrealized potential of infrastructure from a time when hemp farming was a major industry in Franklin County. Despite the mill's closure in 1952, the infrastructure still exists and presents a prime opportunity for hydroelectric redevelopment. Our assessment recognized the flume as an existing breach in the dam, an asset invaluable to hydropower initiatives. Our proposal would not rely on the aging structure itself but would see new cofferdams erected within its bounds, creating a dry work environment to excavate to bedrock and lay down new concrete foundations with horizontally oriented draft tubes. This approach aims to reinvigorate the dormant infrastructure with a sustainable purpose, integrating it into the future of renewable energy.

Figure 5: Existing flume structure visible along the bank of the river [5].

1.2.4 Top 3 Sites with Finalized Decision

During our final search for the ideal hydropower site, the consistent water supply and minimized development risks were pivotal factors that the Arizona sites lacked. Through rigorous analysis and weighted assessments, as outlined in our decision matrix (Table 1), Lock #4 emerged as the clear leader. Scoring 67.35, it outpaced its counterparts, Mishawaka Fish Ladder and Fish Barrier Dam, which scored 57.20 and 58.91 respectively.

Table 1: Decision matrix for final three sites selected.

Criterion	Weight	KR Lock & Dam #4 KY03016		Mishawaka Fish Ladder IN00806		Fish Barrier Dam WA00769	
		Score out of 100	Weighted Score	Score out of 100	Weighted Score	Score out of 100	Weighted Score
1. Potential Energy	25%	32	8	16	4	40	10
2. Flow Rate	10%	90	9	75	7.5	32.9	3.29
3. Distance to Existing Power Infrastructure	10%	90	9	60	6	96	9.6
4. Dam Ownership Type	5%	80	4	60	3	50	2.5
5. Potential Environmental Impact (risk)	10%	80	8	60	6	50	5
6. Dam Integrity (age)	12%	45	5.4	80	9.6	46	5.52
7. Dam Structure	13%	90	11.7	70	9.1	100	13
8. Accessibility Access	5%	85	4.25	60	3	100	5
9. Local Community Need	10%	80	8	90	9	50	5
Total	100%		67.35		57.2		58.91
Relative Rank		1		2		3	

Lock #4's superior score can be attributed to its blend of historic infrastructure, ready for a sustainable revival, and the availability of multiple energy distribution avenues. The site presents a rich tapestry of past and future, where the existing flume and proximity to power infrastructure minimize construction costs and maximize potential energy capture. The foresight to co-develop with solar power further underscores its renewable energy potential, resonating with our philosophy to repurpose historical assets for modern energy needs. Thus, guided by our comprehensive evaluation and the strategic advantages Lock #4 offers, we have identified it as the optimal site for hydropower development. It stands as a beacon of opportunity where innovation in renewable energy converges with cost-effective implementation and community enrichment.

1.3 Final Selected Site – Kentucky River Lock & Dam #4

As discussed, our final selected site, Kentucky River Lock and Dam #4 (KR L&D#4) stands out not only for its historical significance but also for its strategic location at the heart of Kentucky's capital region, as depicted in Figure 6. The site benefits from its proximity to Frankfort, which provides both logistical conveniences and potential for significant stakeholder engagement due to its high visibility and accessibility. Its position, nestled close to key utilities and the local community, adds to its feasibility for development and aligns with our criteria for robust community connection and minimal environmental disruption.

Figure 6: Kentucky River Lock and Dam #4 [28].

For this project to enter development, our team understands that preliminary actions, including detailed surveys and consultations with local authorities, are needed to ensure that all developmental activities at KR L&D#4 are in harmony with the region's plans and policies. Beyond this, Lock #4 presents enticing opportunities for energy distribution. Buffalo Trace Distillery, located just upstream, emerged as a prospective client, offering the possibility of direct power supply to promote bourbon created by green energy. This direct line to the distillery, complemented by the proximity of a 69 kV transmission line and the potential to connect to the Frankfort Wastewater Treatment Plant, illuminated the site's potential as a multifaceted energy hub. This also opened the door for potential for co-development with solar power, as land being leased at this site would serve as the backbone for development.

1.4 Risk

Narrowing down these three selected sites (Table 2) by their imposed risks allowed our team to compare these sites and weigh the criteria out of a score of 10, with the lower score being a more viable site.

Table 2: Risk identification matrix for Fish Barrier Dam and Mishawaka Fish Ladder.

Fish Barrier Dam, Washington

Washington Risk	Possible Impact	Chance	Cost	Risk	RISK SCORE (Max individual)	RISK SCORE (Total Score)
Protected Species	there are a multitude of protected species in the state	6	8	5	30	19
Earthquakes	washington is near a tectonic plate	8	10	10	30	28
Floods	storm and snowmealt season in the PNW	10	5	8	30	23
Sedimentation	erosion from nearby mountains	7	5	7	30	19
Wildfires	the US has seen an increase in wildfires	6	7	6	30	19
Debris Flow	happens from heavy floods	5	4	5	30	14
Invasive Species	possiblity	4	8	3	30	15
Structural Failure	not likely	1	10	1	30	12

Mishawaka Fish Ladder, Indiana

Indiana Risk	Possible Impact	Chance	Cost	Risk	RISK SCORE (Max individual)	RISK SCORE (Total Score)
Natural Disasters	Tornadoes and severe winds	6	8	7	30	21
Erosion	Harsh weather	5	5	5	30	15
Floods	Storm and flood season	10	5	8	30	23
Sedimentation	Build up from erosion	6	5	7	30	18
Water Quality	Agriculture runoff and other risks posed to dam water	6	7	6	30	19
Debris Flow	Happens from heavy floods	5	4	5	30	14
Invasive Species	Zebra muscles and invasive carp	4	8	3	30	15
Structural Failure	not likely	1	10	1	30	12

Table 3: Risk identification matrix for Kentucky River Lock and Dam #4.

Kentucky River Lock and Dam #4

Kentucky Risk	Possible Impact			RISK SCORE
Natural Disasters	Tornadoes and severe winds			Max individual **30**
	Chance	Cost	Risk	Total Score
	6	8	**7**	**21**
Erosion	Harsh weather and errosion of embankments			Max individual **30**
	Chance	Cost	Risk	Total Score
	6	6	**6**	**18**
Floods	Storm and flood season			Max individual **30**
	Chance	Cost	Risk	Total Score
	10	6	**8**	**24**
Sedimentation	Build up from erosion and agriculture runoff			Max individual **30**
	Chance	Cost	Risk	Total Score
	6	5	**7**	**18**
Water Quality	Agriculture runoff and other risks posed to dam water			Max individual **30**
	Chance	Cost	Risk	Total Score
	6	7	**6**	**19**
Debris Flow	Happens from heavy floods			Max individual **30**
	Chance	Cost	Risk	Total Score
	5	4	**5**	**14**
Invasive Species	Invasive asian carp and more			Max individual **30**
	Chance	Cost	Risk	Total Score
	4	8	**3**	**15**
Structural Failure	Not likely			Max individual **30**
	Chance	Cost	Risk	Total Score
	1	10	**1**	**12**

The integrated licensing process (ILP) administered by the Federal Energy Regulatory Commission (FERC) streamlines the licensing procedure for hydropower projects in the United States [3]. This process aims to integrate various regulatory requirements, stakeholder inputs, and environmental considerations into a comprehensive plan, facilitating efficient project development while protecting environmental resources. The ILP involves several key stages, beginning with the Pre-Application Consultation (PAC) phase. During PAC, project developers engage with relevant stakeholders, including federal and state agencies, tribes, and non-governmental organizations, to identify potential issues and develop a collaborative approach to the licensing process. Following PAC, applicants must submit a Preliminary Licensing Proposal (PLP), which outlines the project's scope, potential impacts on the environmental resources, and proposed measures to mitigate adverse effects. This document serves as the basis for further analysis and public involvement.

The ILP incorporates vigorous environmental review procedures, including the preparation of a comprehensive Environmental Assessment (EA). This document asses the project's impact on various resources, such as water quality, aquatic habitat, cultural resources, and recreational opportunities. Stakeholder engagement and public input are integral to this process, ensuring that diverse perspectives are considered in decision making. Upon completion of the licensing process, FERC issues a final license containing conditions designed to protect environmental resources and address stakeholder concerns. Overall, the Integrated Licensing Process provides a structured framework for hydropower development that balances energy generation objectives with environmental protection and stakeholder interests.

The Disposition Study [4] provided comprehensive analysis for the potential impacts on aquatic habitats, water quality, sediment transport dynamics, erosion rates, and terrestrial ecosystems resulting from the disposition of locks and dams along the Kentucky River, particularly Locks & Dam 1, 2, 3, and 4. The study emphasizes the significance of understanding these environmental factors in decision-making processes, highlighting the correlation between various ecological components.

Alterations to water flow patterns, sediment transport, and habitat connectivity could jeopardize the distribution and abundance of mussel species. Furthermore, changes in water quality parameters such as sedimentation rates and nutrient levels may compromise the overall health of the river ecosystem, impacting its ability to sustain aquatic life. Sediment transport alterations and increased erosion rates could negatively affect habitat quality, riverbank stability, and channel morphology, potentially leading to downstream consequences. Moreover, changes in hydrology or sedimentation may extend their reach to terrestrial habitats adjacent to the Kentucky River, including forests, wetlands, and agricultural lands, impacting the species they support.

The rehabilitation of endangered mussel species emerges as a critical conservation priority within this context. Rehabilitation efforts typically consist of habitat restoration, population monitoring, captive breeding, and reintroduction programs. Strategies such as habitat restoration, propagation and captive breeding, translocation, community engagement and education, and regulatory protections are essential in the recovery of endangered mussel populations. Implementing measures to mitigate adverse impacts and foster ecological resilience is pivotal for the long-term sustainability of the Kentucky River ecosystem and the preservation of its biodiversity.

Since these longer-term studies on mussels talk about how the sediment buildup from dams can burry existing mussel beds, the environmental damage to all species has essentially already been done, so our design will not increase damage to ecosystems of the Kentucky River. By creating a flume with fish-safe turbines, fish passage will be increased, and mussels will be able to pass more freely on the host fish. Since the lock on the river is also still functional, fish can pass upstream and downstream by swimming into the lock.

1.4.1 Co-Development Opportunity

The solar co-development opportunity became an integral part of our project when we recognized the available land adjacent to Lock & Dam #4 could be utilized for a solar power plant. This integration of solar with hydropower would not only increase the overall energy output but also provide a more consistent power generation profile. Solar panels could generate electricity during daylight hours, while the hydropower installation would balance production, maintaining energy supply during periods of lower solar intensity or at night.

Therefore, Lock & Dam #4 stood out not just for its hydropower potential but also for its compatibility with solar energy production. The vision for a dual-faceted renewable energy site, harnessing both the flow of the river and the sunlight bathing Kentucky's landscape, epitomizes a forward-thinking approach to sustainable energy development. By embracing the historical context of the site, utilizing available property at this site, and aligning it with modern renewable energy technologies, we aim to set a new standard for multi-use renewable energy projects.

1.5 Relation to Design Challenge

In the Siting Challenge, our objective was to identify a site that could utilize existing infrastructure for cost-effective hydropower conversion. In our case, we've selected a dam that aligns with our focus on a run-of-river dams with low heads, utilizing the existing infrastructure as much as possible was a big focus to save cost and time when converting the dam for hydropower generation. Moving into the Design Challenge, we opted for Track 1: Facility Conceptual Design, which called for a comprehensive vision of the hydropower assets necessary to transform the non-powered dam (NPD) into a power-producing facility. This approach, from "water to wire," necessitated a detailed conceptual design encompassing all required components, considering the water supply, the turbine, the generator, and the connection to the power grid.

For Kentucky River Lock & Dam #4, our design concept builds on the existing flume structure (Figure 5), envisioning an extension to enhance the capture of the river's flow. This retrofit will house the appropriately sized Voith's StreamDiver turbine units outlined in our design assessment. These modular units are specifically tailored for the kind of low-head conditions found at Lock & Dam #4, and their placement into the extended flume will leverage the river's current with efficient, cost-effective generation. Moreover, the site's proximity to Frankfort ensures straightforward access for construction and delivery, streamlining the installation process.

Incorporating the co-development opportunity identified in the Siting Challenge, our facility design integrates a solar power component, leveraging nearby land to establish a renewable energy complex. This dual generation concept not only optimizes the site's power production throughout varying weather and daylight conditions but also serves as a testament to our innovative approach to renewable energy. The selected equipment and the engineering strategies we've delineated in our design proposal are expected to meet the feasibility and thoroughness criteria set forth by the competition's reviewers. The accuracy of our modeling work and the critical design considerations reflect the comprehensive planning that embodies our proposal.

In summary, the selection of Kentucky River Lock & Dam #4 directly influenced our Facility Conceptual Design, guiding our choices in technology and layout to ensure an environmentally and economically viable hydropower solution that harmonizes with the surrounding community and ecosystem. The culmination of our siting activities with the proposed design solutions forms a coherent approach to hydropower development. It exemplifies how a carefully selected site, with its inherent attributes and strategic advantages, can directly inform and shape the design of a hydropower facility. By prioritizing the refurbishment of existing structures and ease of accessibility, we have established a foundation for sustainable and economically viable hydropower generation.

1.6 Key Takeaways

Although our team had little prior knowledge of hydropower when we started this project, it has been a transformative learning experience. For us, converting non-powered dams to hydropower facilities was unheard of then. Preliminary research on hydropower and methods relating to siting a location were reliant on the resources provided by NREL, specifically NPD Explorer software from Oak Ridge National Laboratory [23]. We began to cross reference this software with ArcGIS Pro [7] (since the NPD Explorer data is from 2012). We quickly realized despite there being over 80,000 non-powered dams in the United States, most of them (despite having potential) are not suitable for hydropower generation due to their financial and environmental feasibility. Due to this, we had previously thought hydropower was a dying industry since renewables such as wind and solar are more commonly covered in our undergraduate courses. However, the 2023 Clean Currents Conference opened our eyes to the tangible success stories of NPD conversions and introducing us to the network of industry veterans whose insights were invaluable. It was there that we learned about low-head hydropower solutions, like the StreamDiver turbine by Voith, a choice that was informed by both its suitability for our site and its potential to revolutionize the industry.

Our siting journey was met with two significant hurdles: the accuracy of existing dam specifications and the procurement of precise streamflow data. The latter was especially crucial to ensure reliable energy generation estimates, as we ran into this issue at a dam in Arizona where we were set on moving forward with design until we discovered our operational head was significantly lower than expected. Furthermore, if we were to take this project from a theoretical analysis and move forward with it, one of the first steps would be to verify streamflow data from hydro acoustic equipment, like a current meter. We would also need to have the existing flume inspected since we have been basing our design off information and as-built drawings we found through research and industry professionals in that region. These challenges underscored the importance of on-site verification with advanced tools like hydroacoustic current meters and a thorough inspection of the existing infrastructure.

Through our engagement with this project, we have shifted our perception of hydropower from an antiquated field overshadowed by wind and solar, to a dynamic and evolving industry brimming with opportunity, particularly in small-scale community-focused projects. The industry's drive towards innovative, efficiently constructed generation sites has highlighted the indispensable role of thorough theoretical analysis. Our application of mechanical and electrical engineering principles to the project has not only bolstered our interest in hydropower but also demonstrated the demand for a new wave of skilled professionals in the sector. From theoretical calculations to detailed cost analysis, our educational foundation has already proven instrumental, and we foresee significant opportunities to further apply and expand our expertise within the industry.

In conclusion, this journey has provided us with a deep appreciation for the complexities of hydropower siting and development. Especially, studying the benefits that small scale hydropower can bring to a community has shown us that there are numerous projects to be competed which have huge potential. Since the industry is focused on more generation sites that are better and are constructed faster, theoretical analysis is critical. Learning how we can apply our skills from our backgrounds in mechanical engineering and electrical engineering on hydropower projects have caused us to be very interested in the hydropower industry, since there is going to be a great demand for a new generation of workforce. We've gained a clear vision of the sector's future and the critical role emerging engineers like us can play. We step forward from this project more knowledgeable, prepared, and eager to contribute to the hydropower industry's promising trajectory.

2 Design Justification

Selecting Track 1, our team has performed a conceptual design concept of the complete facility from our selected site in the Siting Challenge. During the year 2022, the average amount of electricity sold and purchased by a single USA household was 10,791 kWh. Our dam is positioned to produce roughly **4,122 MWh** with hydropower and **883 MWh** produced with solar, with **totals around 5,000 MWh** for overall production (Table 4). Our design aims to power approximately 450 households annually in Frankfort, Kentucky, where the demand for electricity continues to rise due to increasing reliance on electronic devices. Despite the region's heavy dependence on coal for power, our project marks a step towards fostering trust in renewable energy sources within the community. While our system may not replace large coal-fired plants, it signifies a shift towards cleaner energy production.

2.1 Design Objective and Feasibility Assessment

The selection of the Voith StreamDiver significantly influenced the design and modeling of our dam. This horizontal turbine, paired with a permanent magnet synchronous generator, is widely used in low head, low flow hydroelectric designs. The StreamDiver's modularity allows for customization to match specific location requirements, enhancing its adaptability and efficiency. Additionally, our plan to establish an acre-sized solar farm aims to contribute nearly 1% to Kentucky's total solar generation profile. Solar is only ~0.004% of Kentucky's total purchased power, and this helps addressing the need for renewable energy expansion in the region [15]. By diversifying energy sources and fostering trust in alternative methods, we aim to reduce reliance on coal, create job opportunities, and drive future renewable energy developments within the community. Our comprehensive cost analysis confirms the feasibility of our design, presenting a significant opportunity for a community in need of modern developments.

Steam Diver Turbine

- No concrete is required above the flange; minimal civil work
- High efficiency for low head and flow rates
- Adapted for flood resilience; low maintenance
- Unit assembled and tested before site delivery
- No use for control mechanisms within the turbine
- Oilless lubrication, river water cooling of bearings and magnets

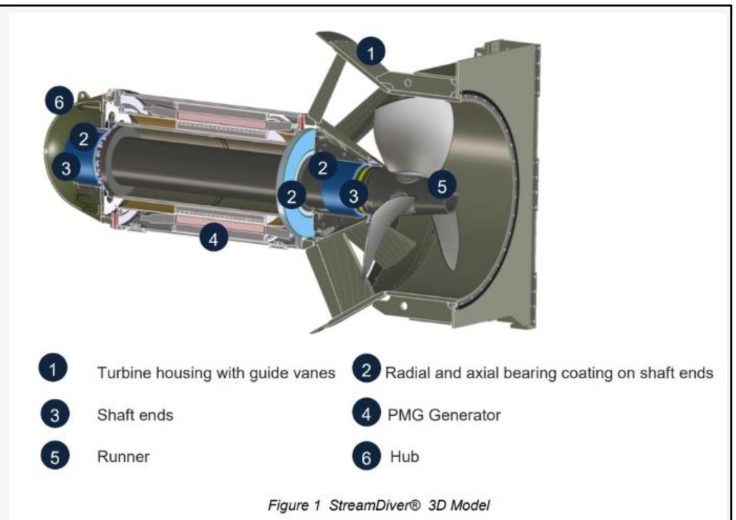


Figure 7: Stream diver benefits and contributions to the system design [2].

2.1.1 Estimating Annual Generation

Our approach to sizing the Voith StreamDiver units required innovative problem-solving due to the lack of direct downstream flow and head data. The key to unlocking our turbine sizing lay in the interpretation and extrapolation of upstream gauge data provided by United States Geological Survey (USGS), and fluid mechanics hydrostatic assumptions.

2.1.1.1 Predicting head and flow on river

We began with as-built drawings indicating a static hydraulic head of 13.22 feet at zero flow, derived from elevations in 1995. Assuming an inverse relationship between flow and head, we inferred that this represented maximum head at zero flow. We then hypothesized a polynomial relationship between upstream gauge height and flow rate. Using regression analysis, we established a correlation between gauge height and flow rate, enabling us to infer the inverse relationship for gross head. Adjusting our model based on the principle of decreasing head with increasing flow, we recalibrated below the inflection point of 13.22 feet at zero flow to reflect hydraulic head's behavior across varying flow rates.

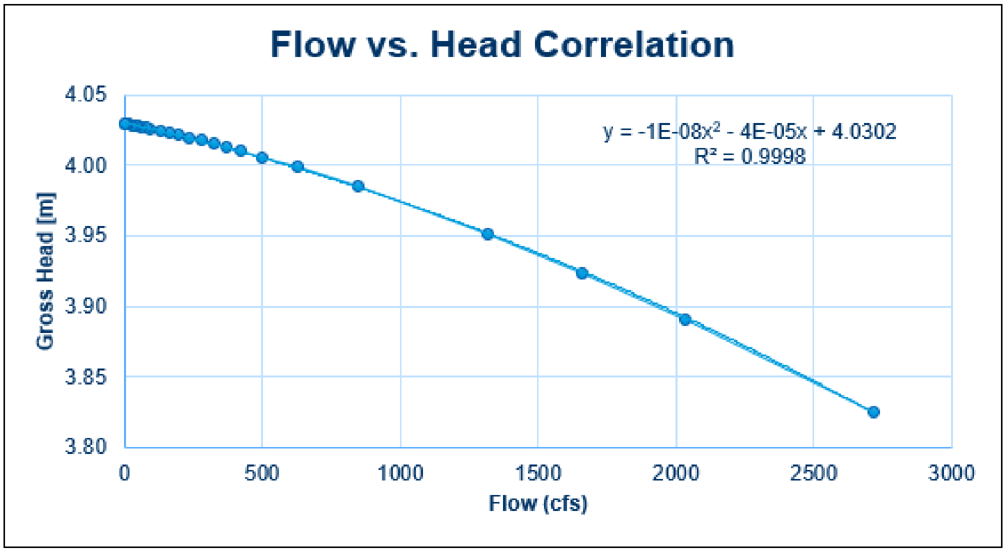


Figure 8: Regression curve that helped find interpolated values of head with operational flow rates.

This revised regression curve enabled us to interpolate thousands of operational flow and head values, effectively converting the upstream gauge data into a downstream hydraulic profile. These interpolated values form the backbone of our generation curve, represented in the graph Figure 8. While this method required a degree of assumption, it was validated by comparative analysis with other projects on the river, ensuring a credible and defensible set of data for our turbine sizing and anticipated energy generation.

Building on this foundation, we further refined our understanding of the river's behavior with a targeted hydrostatic analysis. Employing the principles of steady, incompressible, and uniform flow, and under the assumption of frictionless conditions, we were able to predict the operational flow directed towards the turbine. This analysis, based on specific cross-sectional dimensions and hydrostatic pressure distributions (Figure 9), calculated an operating flow, distinct from the total river flow, of approximately **19.16 m^3/s** for each turbine. This critical figure was then cross verified with Voith to ensure its accuracy, underscoring our proactive role in the analytical process rather than relying solely on external computations.

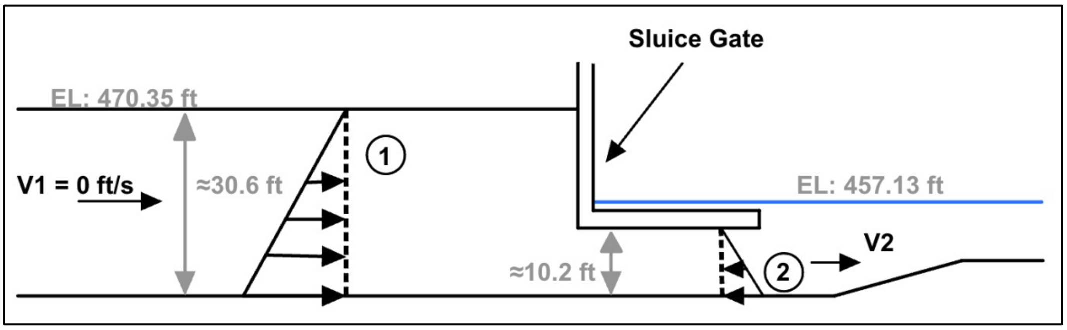


Figure 9: Schematic of hydrostatic analysis with pressure distribution profiles and inlet velocities given appropriate assumptions.

This precise determination of operational flow forms a key input to our system design and aligns closely with the values used by Voith in their performance modeling, validating our approach and reinforcing the collaboration in this engineering challenge.

2.1.1.2 Sizing StreamDiver Units

In the pursuit of optimal sizing for the StreamDiver units, our efforts were complemented by Voith's expertise, applying their specialized models to our empirical data. Our comprehensive analysis, documented in Table B12. of the appendices, supplied interpolated head and flow metrics, which Voith utilized to determine the most efficient unit configuration under our project's specific conditions. Through this collaborative process, we were able to ascertain that the StreamDiver units, each receiving an operational flow of approximately 19.16 m^3/s, would function within their productive capacities.

Despite the StreamDiver's ability to reach outputs up to 1.7 MW, the site-specific low head constrained the maximum production to about **820 kW** combined for both units. Our integrated analysis confirmed the StreamDiver units' capacity to generate **0.82 MW of power**, verifying the viability of our design and demonstrating a customized approach to harnessing the hydrological conditions at Kentucky River Lock and Dam #4. This process illustrates not just the application of a third-party model, but the integration of localized data with advanced hydrodynamic simulations. By doing so, we've achieved a level of precision in our final design that is not only sustainable but also tailored for maximum efficiency within the given environmental parameters.

2.1.1.3 Annual Generation Estimation

To estimate annual energy production for our hybrid hydropower and solar facility, we utilized interpolated head and flow data to create a representative hydraulic profile for the StreamDiver units. Figures 10 and 11 illustrate the concurrent hydro and solar power generation and cumulative output over an average year. Hourly flow rates from five years were averaged to establish a 'typical year' scenario, forming the basis of our generation predictions. Integration of Voith's unit profiles with averaged flow data enabled calculation of hourly power output and anticipation of operational patterns.

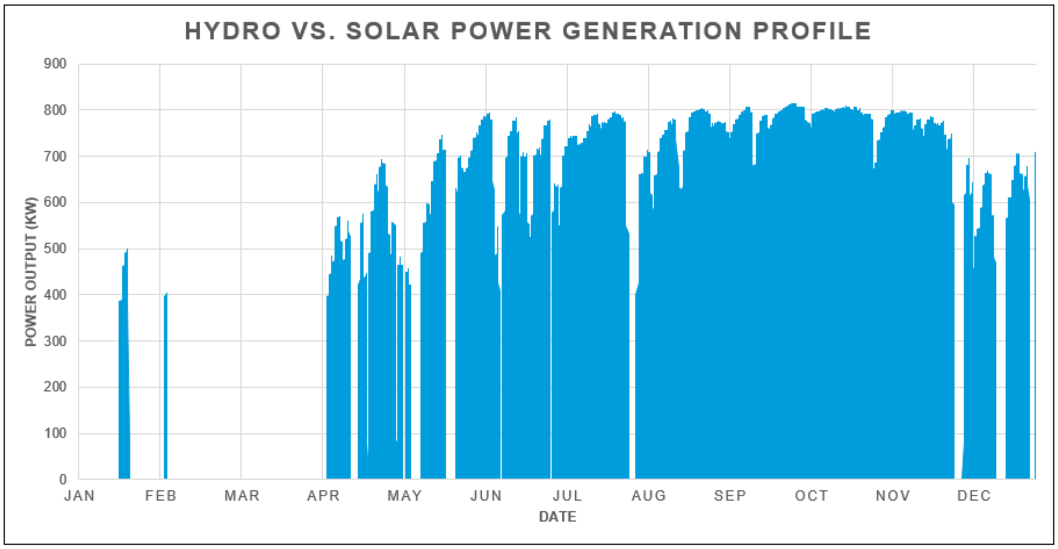


Figure 10: Average hydropower yearly generation profile.

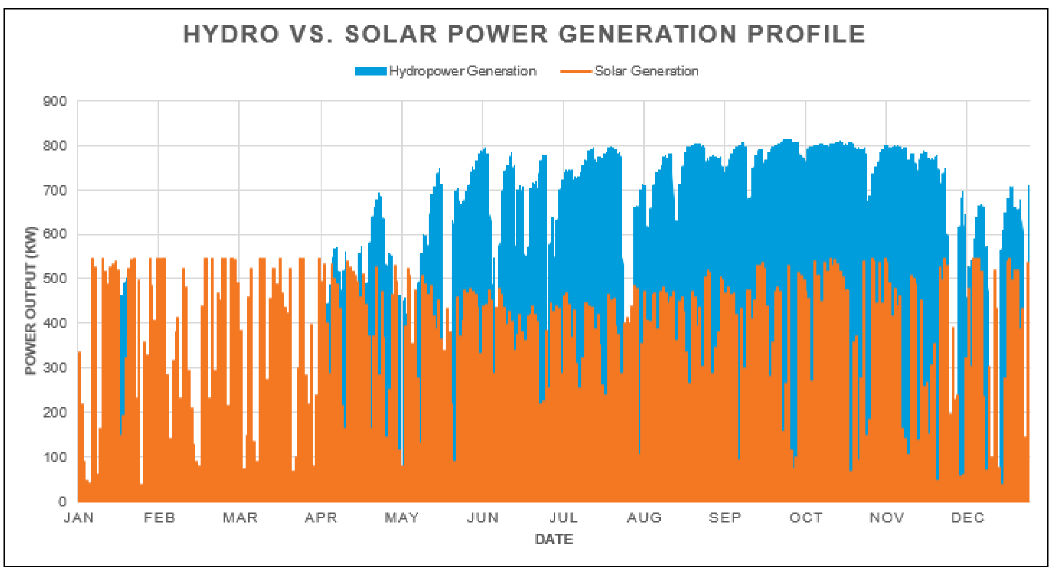


Figure 11: Hydropower vs. solar power year generation profile.

In our model, we incorporated a crucial condition simulating turbine operation: units cease functioning at head levels below approximately 10 feet, common during floods, ensuring unit integrity and realistic operational constraints. As head nears this threshold, output decreases linearly, with up to an additional 15% efficiency loss at 10 feet to accommodate reduced flow and turbine efficiency.

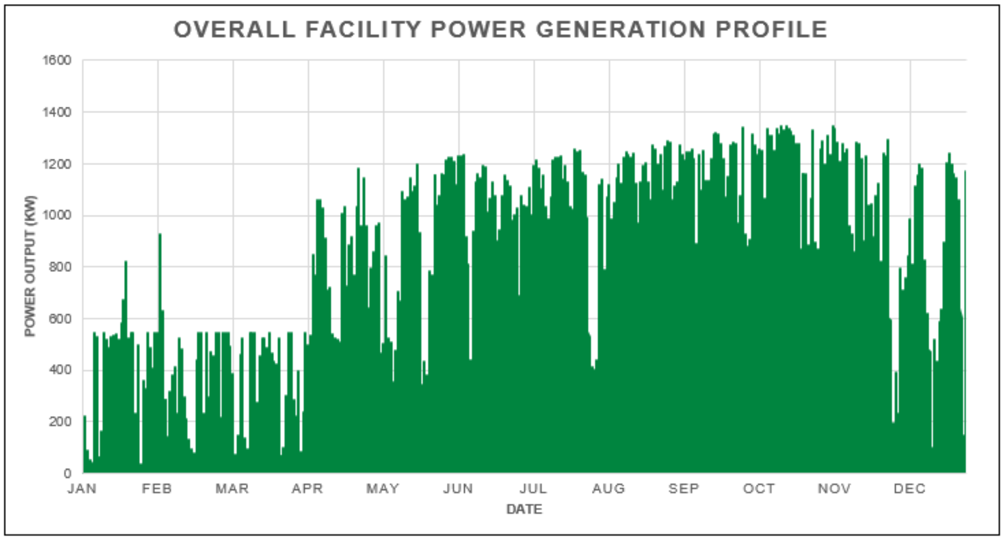


Figure 12: Total facility power generation profile for a typical year (including solar and hydropower).

Additionally, our energy generation analysis also extended to creating detailed hourly profiles for both solar and hydropower production, as presented in Figure 11 and Figure 12 respectively. These profiles are constructed by reorganizing our interpolated hydro and solar data to calculate the average energy output for each hour across the entire year. For solar energy, this reorganization created a bell curve as seen in Figure 13, which naturally aligns with the diurnal pattern of sunlight availability. The average output at each hour is an aggregate of all corresponding hours from the 365 days, capturing the essence of solar energy's dependency on sunlight.

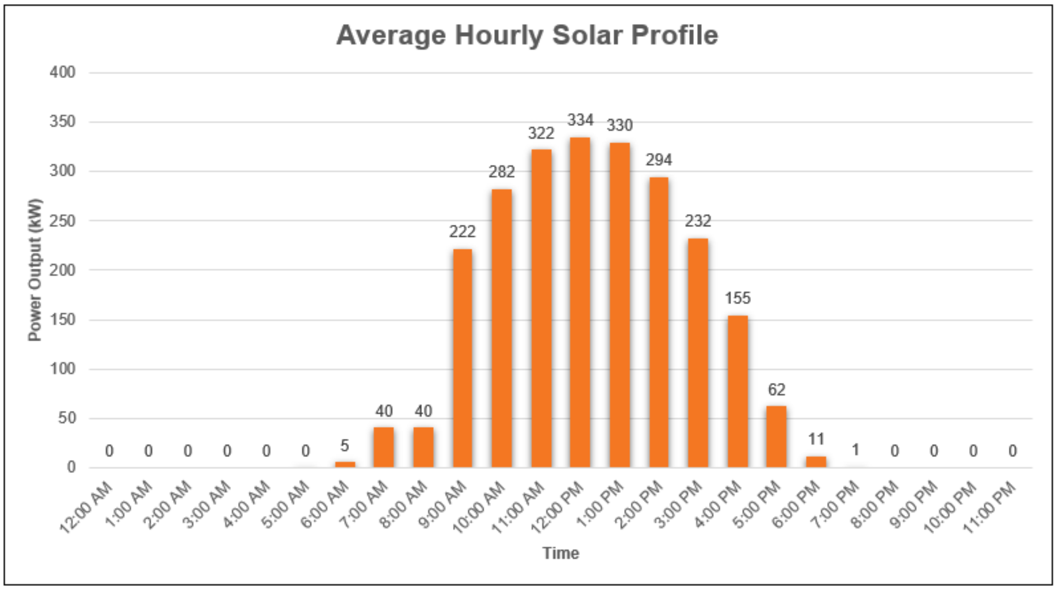


Figure 13: Average hourly solar generation profile (for one average day).

Conversely, the hydropower generation profile depicted in Figure 14 demonstrates a consistent output across the hours of the day, reflective of the constant flow of a run-of-the-river dam system. Yet, it also captures seasonal variations in generation due to operational adjustments during periods such as winter floods, where the units are non-operational. The area plot conveys the story of these variations effectively, with the different colors marking significant shifts in production, particularly the reduced output in the orange segment from January through March compared to the peak outputs in the blue segment from July through September.

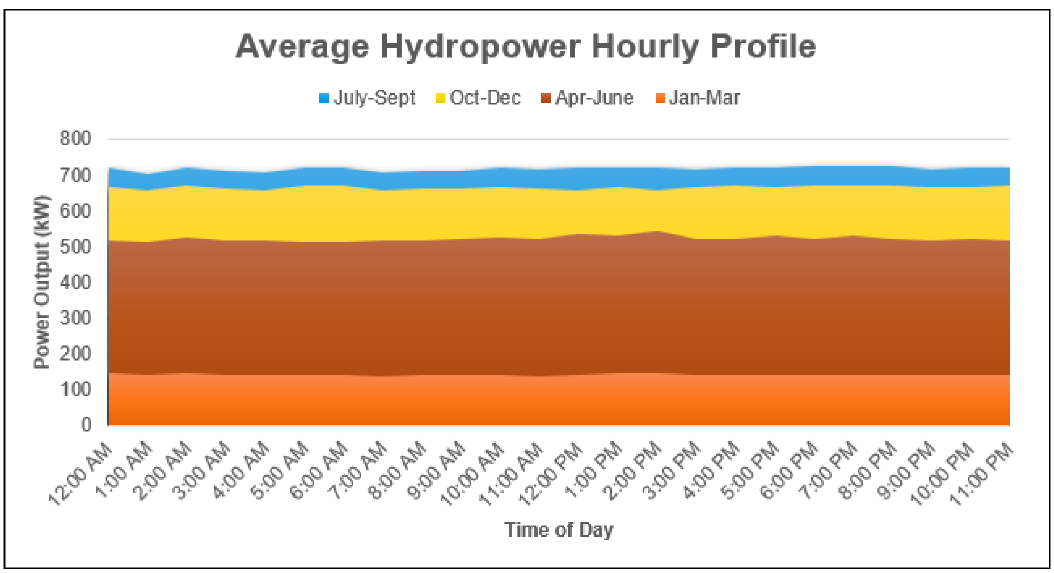


Figure 14: Average hydropower hourly profile (based on the quarter year).

The synthesis of our data into hourly and seasonal profiles, as depicted in the graphs above, articulates the dynamic interplay between solar and hydro generation at our facility. These profiles encapsulate a year's worth of energy output, affirming our facility's capability to deliver a stable and diversified supply of renewable energy.

Table 4: Summary of overall facility output during a typical year.

Overall Power Generation			
	Hydropower	Solar	Overall
Generation (MWh)	4122	883.1	5005
Average Output (MW)	0.4706	0.1008	0.5714
Capacity Factor	57.87%	18.46%	42.45%
LCOE	42.40 ¢/kWh	4.8 ¢/kWh	47.20 ¢/kWh

2.1.2 Financial Feasibility

In the initial phase of our project, we engaged in an exhaustive consultation process to accurately compile the capital costs. Collaborating with the Kentucky River Authority, experienced local developers, Voith's concept specialists, and construction managers, along with guidance from FERC, we've synthesized a comprehensive cost analysis. Refer to Table B1 in Appendix B for a detailed breakdown.

Our projections estimate a total capital expenditure that positions us for completion in 2033, reflecting a forward-adjusted budget of **$13,982,642** to account for anticipated inflationary trends. The narrative of our financial strategy is one of meticulous planning and strategic partnerships, grounded in industry best practices and local expertise. The financial scaffolding of our project is built upon a foundation of credible cost projections, sensible revenue assumptions, and prudent borrowing, ensuring not just viability but also profitability and sustainability in the long term.

2.1.2.1 Operational and Revenue Stream Establishment

Turning our focus to operational sustainability, we meticulously charted out the ongoing costs and potential revenue streams. The power sales rate, benchmarked at $72/MWh, and the REC Sales Rate, determined at $28/MWh, are derived from current standards in the Kentucky energy market, specifically referenced from the Frankfort Plant Board website. These rates align with the prevailing ones for lock and dam hydropower conversion projects ranging from Kentucky River’s Lock 9 to Lock 14. The operational expenses, modeled through the solar SAM model and corroborated by discussions with local stakeholders, encapsulate all necessary costs, including insurance, O&M, and property taxes. Our revenue, calculated from power sales and REC revenues, compared against the outlined operational costs, yields an annual net income of **$356,367.52**. See Table 5 for the complete list of project revenue and operational expenses.

Table 5: Project revenue and operations in 2024 USD value

Project Revenue and Operations (2024 Dollars)		
Annual Generation (MWh)		6,795
Power Sales Rate ($/MWh)		72.00
Power Sales Revenue	$	489,266.08
REC Sale Rate ($/MWh)		28.00
REC Sales Revenues	$	190,270.14
Total Revenue	**$**	**679,536.22**
Annual Operation/Site Expenses (2024 Dollars)		
Property Tax	$	70,000.00
Liability Insurance	$	9,000.00
Property Insurance	$	60,000.00
Professional Accounting Fees + Headwaters Benefit Fee	$	33,000.00
FERC Fee	$	1,400.00
KRA Leasing Fee	$	10,880.00
County Fee	$	8,000.00
Voith Bearing Replacement (Once every 12 years)	$	30,000.00
Land lease cost (lease to own - 10 years)	$	1,044.36
Hydropower O&M	$	120,000.00
Solar O&M ($15/kW)	$	9,828.00
Total Annual Expenses (2024)	**$**	**323,152.36**
Total Project Net Income	**$**	**356,383.86**

2.1.2.2 Net Income Realization

In our financial projections for the hydropower and solar project, inflation was a key factor. We determined a **3.58% average inflation rate** based on historical USEIA energy price data. By applying the confidence interval formula and historical price data, we established a 95% confidence interval for this rate. With t-values derived from standard references [13], a sample standard deviation over 50 years, and data point count (N), we calculated the intervals as shown in Table 6.

$$CI = \pm t_{v,p} \frac{s_x}{\sqrt{N}} (P\%)$$

where $t_{v,p}$ is the student t-value from the tables outlined in the textbook [13], s_x is our sample standard deviation over 50 years, and N is our number of data points.

Table 6: Calculating 95% CI and 99% CI for inflation of energy prices given by the USEIA website.

Confidence Interval Calculations		
Customers	Calculated Values	Infaltion Percentage
Total	Avg	3.58%
	Sample Std Dev (s_x)	4.86%
	Std Dev of Means ($s_{\bar{x}}$)	0.69%
	Uncertainty (99% CI)	**1.84%**
	Uncertainty (95% CI)	**1.38%**
	Therefore: *Inflation = 3.58% ± 1.38%*	

This analysis set our uncertainty margins at 1.38% for 95% confidence and 1.84% for 99%. This statistical rigor justifies our adoption of a 3.58% inflation rate for projecting energy price increases, allowing for future market variability. Our projections, depicted in Figure 15, incorporate expected costs, like the turbine bearing replacements every 12 years at $30,000, against the backdrop of increasing energy prices. The data shows a consistent revenue increase, affirming the project's financial viability and supporting ongoing debt servicing and long-term investment planning with Rural Utilities Service (RUS).

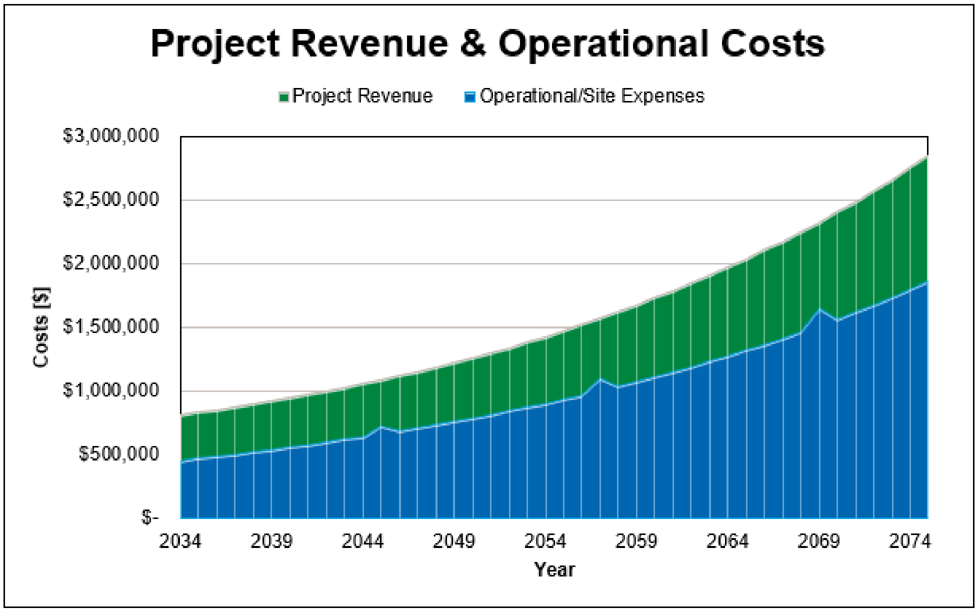


Figure 15: Revenue and operation cost trends over 40 years of operation.

2.1.2.3 RUS Loan Computation and ROI

The RUS loan calculation underpins our financing strategy, ensuring project viability through substantial loan support. With an established annual net income of **$356,367.52**, as shown in Table 5, we have judiciously mapped out a loan repayment strategy that reflects an industry standard Debt Service Coverage Ratio (DSCR) of 1.25.

Table 7: Outline of calculating our annual loan amount.

RUS Loan Calculation	
Minimum Debt Service Coverage Ratio (DSCR)	1.25
Interest Rate	3.75%
Term (years) - Amortization	25
Loan Amount	$ 7,601,629
Principal and Interest Payments	($285,065.64)
Net Income or Profit	$ 356,367.52
Project DSCR	1.25
Maximum Loan Amount	$ 285,094.02
Profit After Debt	**$ 71,301.88**

After servicing debt, we anticipate a yearly profit of **$71,301.88**. With a calculated repayment of **$285,094**annually (Table 7), this conservative financial model ensures cash flow stability and aligns with industry loan servicing standards. Significantly, these calculations project a ROI within an 18-year period, an indicator of the project's solid financial foundation and its appeal to investors seeking both stability and profitability in renewable energy ventures.

In conclusion, the financial architecture of our project has been meticulously constructed to ensure its success. From securing tax incentives and navigating RUS loan intricacies to establishing a clear pathway to profitability, every step has been guided by a stringent analytical process and strategic foresight. The financial feasibility of converting Kentucky River Lock and Dam #4 into a productive and sustainable hydropower and solar facility is robust, and our projections confirm the project's promising financial outlook.

2.2 Electrical and Interconnection Analyses

2.2.1 IEEE 5 Bus System

To analyze the influence of our power plant on the grid, we built a Simulink model based on the IEEE 5-Bus System.

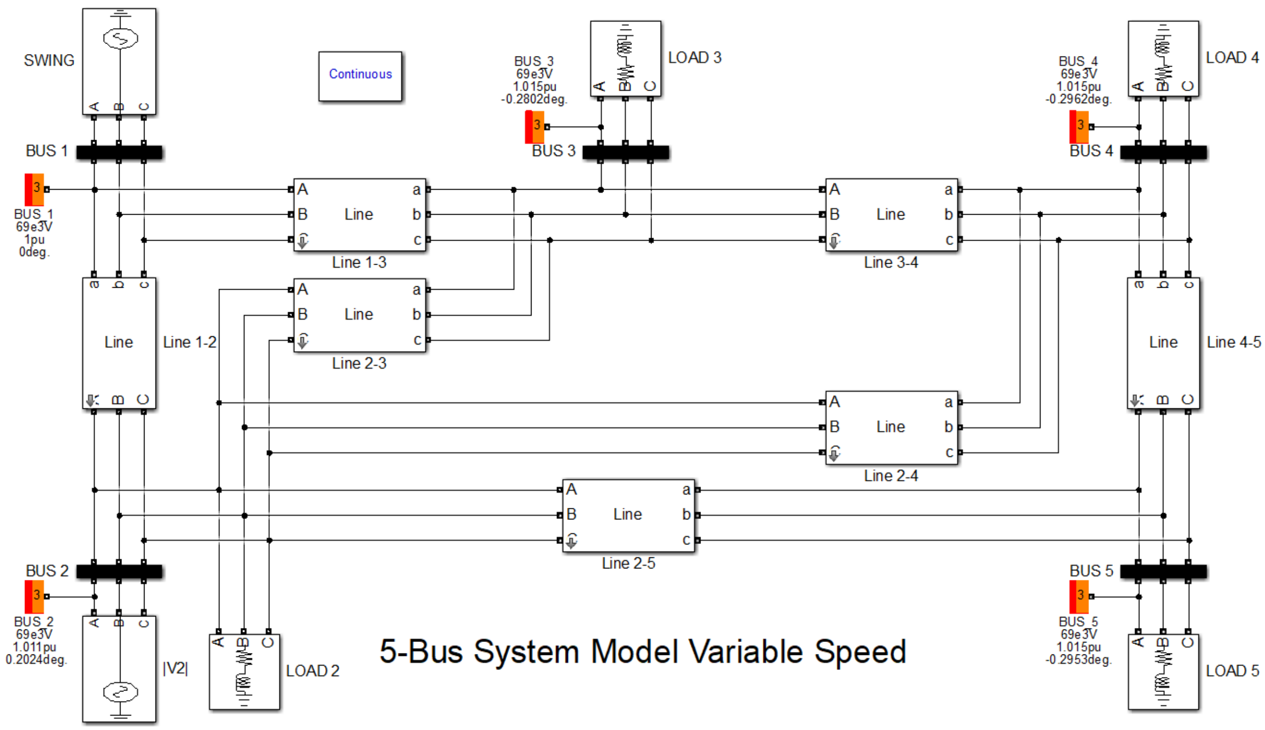


Figure 16: IEEE 5-Bus System.

The generator on bus 1 represents the power plants that already exist, and the generator on bus 2 represents our hydroelectric plant (Figure 16).

There are 3 types of buses in the system, PV, PQ, and slack or swing. The voltage magnitude on the bus is specified, while the reactive power is to be solved. A PQ bus has the real power and the reactive power consumed or provided, while the voltage on the bus is to be solved. There is only one swing bus in the system, which is assumed to be bus 1. The swing bus has a fixed voltage magnitude and voltage angle, with undetermined real power and reactive power.

In our 5-bus system, there are n_{PV} PV buses, n_{PQ} PQ buses, and 1 slack bus. We have the following equation, $(n_{PV} + n_{PQ})$, where P is specified and n_{PQ} equations where Q is specified. Therefore, there are a total of $(n_{PV} + 2n_{PQ})$ equations. Similarly, we have n_{PQ} unknown voltage magnitudes, and $(n_{PV} + n_{PQ})$ unknown voltage angles. Thus, there are a total of $(n_{PV} + 2n_{PQ})$ unknown variables.

The generator in our hydro plants can function as either an asynchronized or variable-speed generator. In the asynchronized generator model, direct grid connection without voltage control devices results in it being set as a PQ generator. Conversely, in the variable-speed generator model, connection to the grid occurs through back-to-back 2-stage power conversion, allowing for terminal voltage regulation and setting it as a PV generator. Our analysis indicates that the asynchronized configuration has a more significant impact on bus voltage and tends to reduce grid frequency stability due to the addition of an inductive load.

2.2.2 Power Flow Diagram

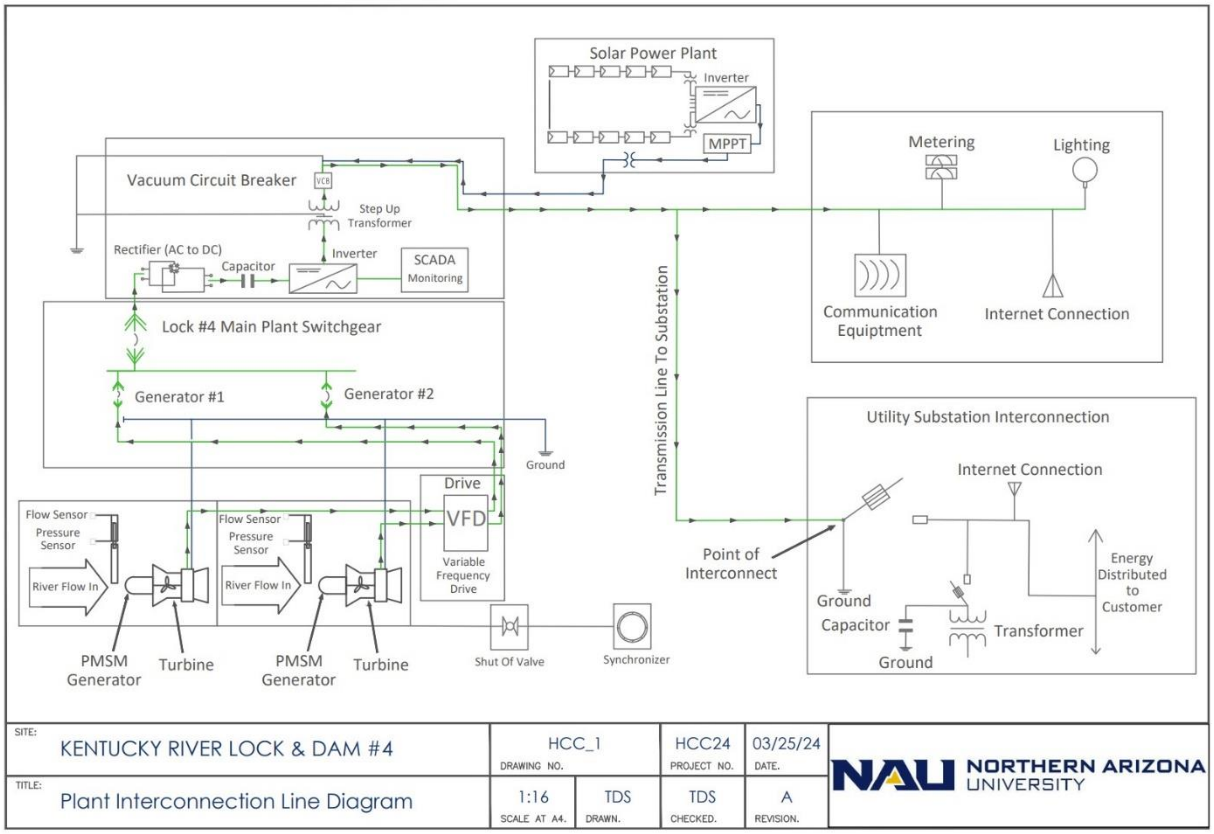


Figure 17: Power flow diagram CAD model.

Figure 17 illustrates the electrical system's operation and grid interconnection. Power is generated by PMSGs in the Voith Stream Diver, with intake sensors for optimization. Turbines are controlled by a synchronizer, ensuring efficient operation. Variable frequency drives maintain efficiency under varying conditions. Safety features include disconnects and breakers. Power from PMSGs is converted using a 2-stage rectifier and inverter, while photovoltaic systems use a single-stage inverter. Output is stepped up to 69kV for transmission via nearby lines to local utilities and substations in Frankfort.

2.2.3 PMSG modeling

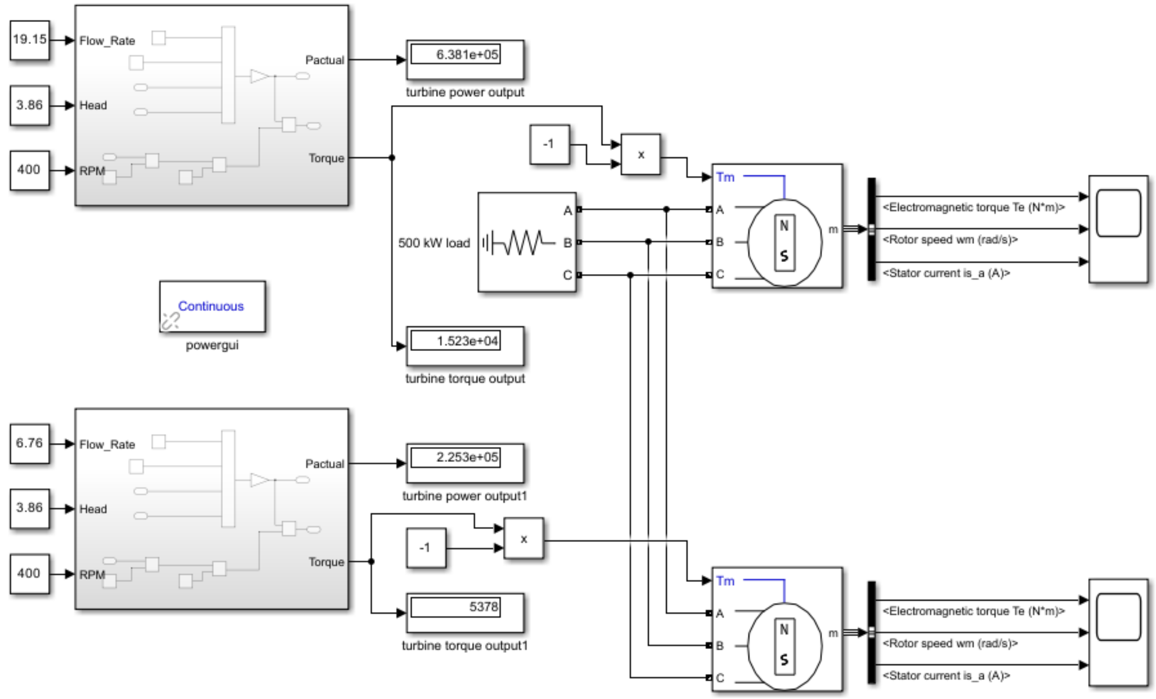


Figure 18: Permanent Magnet Synchronous 2 Generator MATLAB/Simulink model.

The model depicted in Figure 18 was created using MATLAB Simulink software to enhance our comprehension of key operational aspects of our NPD hydroelectric conversion. We opted for a two-generator design after deliberation, prioritizing compatibility with our site's standards. This model serves to deepen our understanding of the planned system, validate Voith's power generation expectations, and accommodate varying flow rates. We incorporated two different generator sizes to maximize efficiency across different flow conditions.

In the process of building this model, one of the main issues that held back creating more accurate modeling of the Streamdiver PMSG is that companies like Voith for obvious reasons do not often open source their performance ratings. Therefore, it was decided that the generic PMSG block was to be used. A subsystem block was created to calculate the turbine output power estimation and the torque input required to simulate the PMSG operation. Scopes were included to display these generation effects and the system's transient response under load.

$$P = \eta \cdot \rho \cdot g \cdot Q \cdot H \qquad \tau = \omega P$$

The figure below (Figure 19) displays the built Simulink subsystem [17], used to produce the power and torque outputs we would get from changing the inputs. To calculate these equations, we needed two known constants, two inputs we were able to recognize following our intensive modeling of flow and pressure at our turbine intake (i), and one estimation was based on common industry standards. By adjusting these parameters, we were able to simulate a power output that was very similar to the estimates supplied by Voith for their stream diver turbines and our calculated flow inputs.

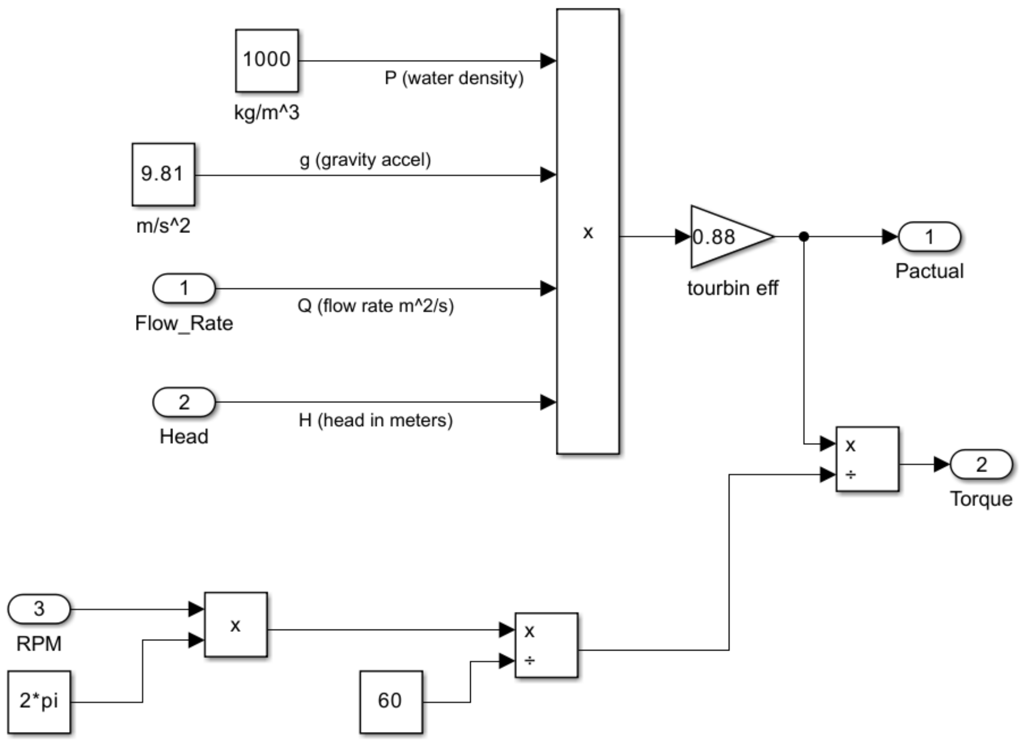


Figure 19: Subsystem developed for power and torque estimations of PMSG input.

<u>Inputs:</u>

Flow rate - The input water flow to the turbine which will change depending on the valve intake and size of stream diver used for generation.

Head - A constant input to both of our turbines and does not change with the stream diver specs as this is dependent on the river and floods, for this simulation the average head over a year experienced at the site was used for simplicity.

RPM - Used to produce the torque output of our system for the PSMG input, the stream diver models are used in the range of 400-800 RPM in industry. However, we chose the lower end of this allowance to properly simulate what would be used in our site's low head and low flow averages.

Turbine efficiency – This value was chosen based on common industry values for turbine efficiency and could be adjusted to allow the output power/torque to match that of the Voith-supplied estimations [25].

Water density – This is a known average constant for the equations that can slightly change depending on environmental conditions like temperature.

Acceleration due to gravity – A well-known constant value of gravity's effect on the surface of the earth.

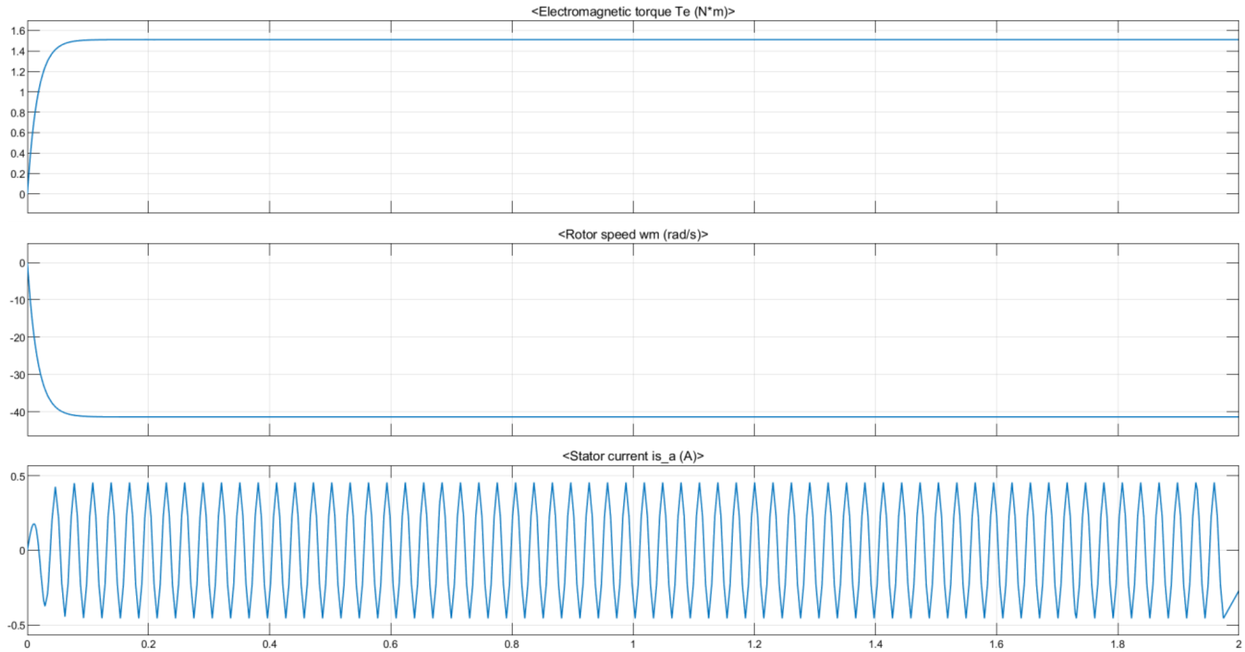


Figure 20: simulated speed and torque of PMSG output.

To streamline Simulink simulations, we significantly scaled down to the model. Instead of using MW and kW values, which resulted in lengthy processes, we simplified the model to include just one PMSG and reduced input values by approximately 100,000 units. Thes adjustments yielded a smooth transient response in Figure 20, where the PMSG reacts to a load by momentary ramping up speed and torque before stabilizing. Stator currents, presented as “a,” demonstrate the induced AC signals from the rotor into the stator coils, facilitating current flow within the generator.

2.2.4 Power converters

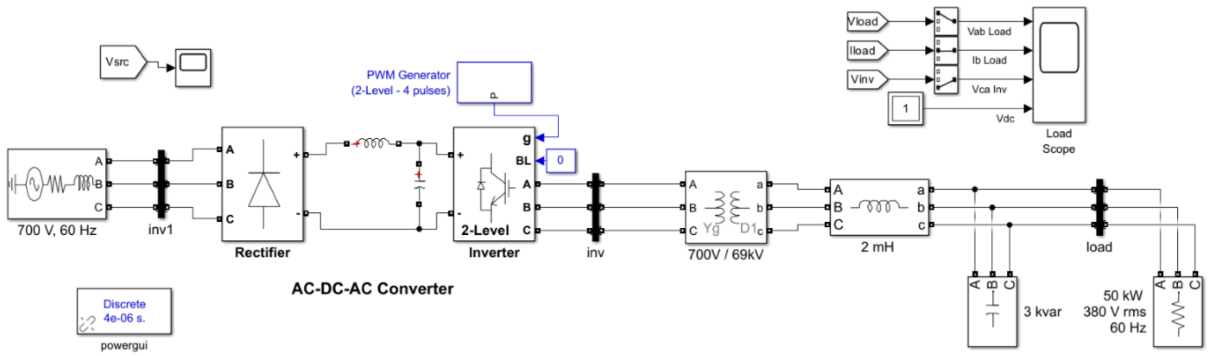


Figure 21: 700v 60 Hz AC source in a 2-stage power converter Simulink model.

This model (Figure 21) was developed to understand how our Hydroelectric stream divers would connect to the grid. This model gives our team a better understanding of how an interconnect would look using a 3-phase power source for power injection [6]. There is also a need we learned from interviews with Voith representatives. While StreamDivers can connect directly to the grid under constant flow and head conditions, Frankfort Kentucky does not provide us with said conditions. Therefore, the inclusion of a modeled power converter provides our design with the ability to produce higher efficiency within our system [17]. The model build contains:

- 700 V, 60 Hz 3-phase source.
- Universal bridge–diode rectifier, AC to DC conversion required for frequency, phase, and amplitude manipulation.
- LC series filter, for further harmonic filtering before inverter.
- Two-level three-phase Inverter with IGBT/diode switching devices for DC to AC power conversion.
- Step-up Transformer ~700/69kV.
- 50 kW sink to produce a load for simulation.

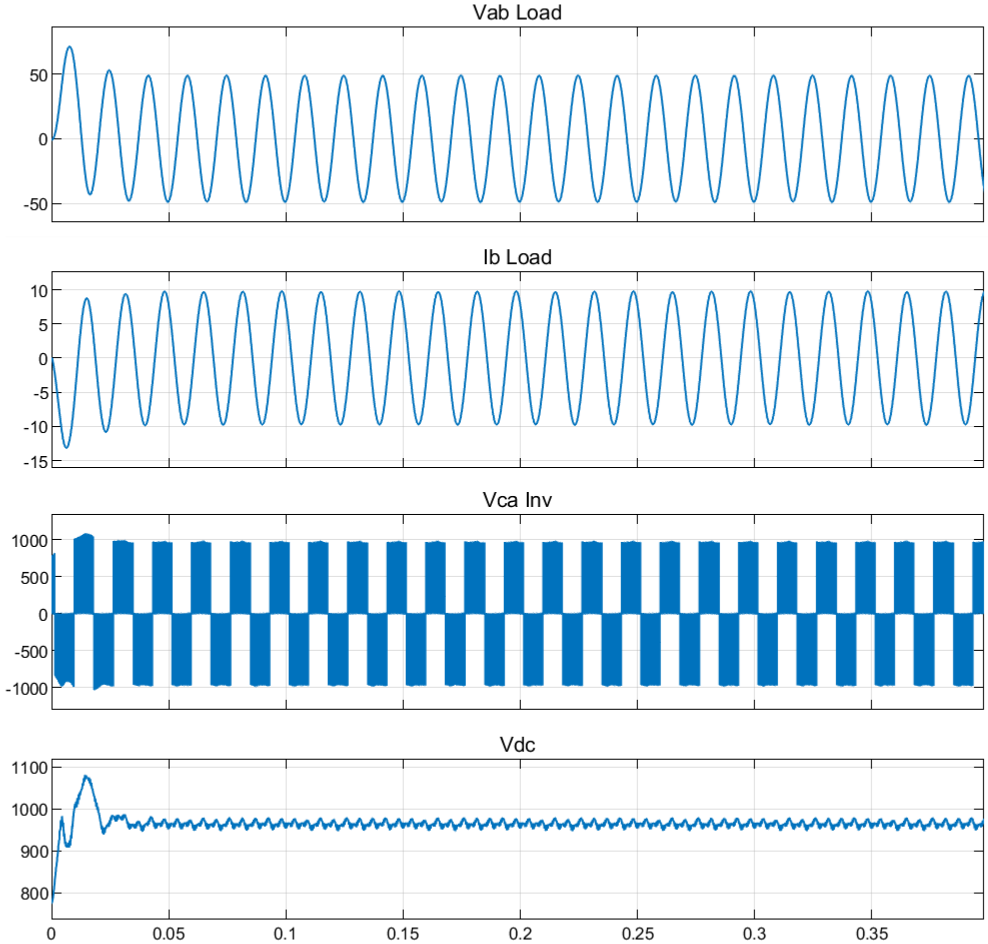


Figure 22: Two-stage power conversion output scopes.

Figure 22 is 4 different output stages through the two-stage conversion process, with time [seconds] on the x-axis. The top two signals represent the 60 Hz current and voltage after power conversion to our 50-kW load. The third signal is the effect of the inverter and pulse width modulation conversion technique for DC/AC conversion. The last graph shows the rectifier conversion of the PMSG 3-phase AC output to a DC signal for power conditioning and filtering. On this last signal, a large jump can be seen as the 3-phase generator is brought up to speed as fast as possible in the ideal simulation, this leads to a large overshoot that could be corrected with proper control implementation.

2.2.5 Maximum Power Point Tracking

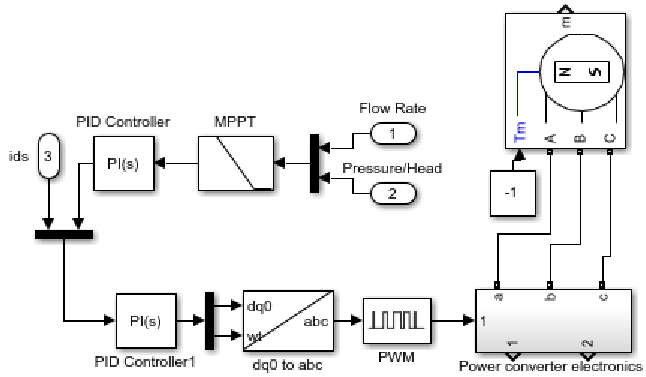


Figure 23: Simple model explaining MPPT use for power conversion (example – not a simulated model).

MPPT control schemes are widely used in industry to enhance power conversion efficiency and extract peak power. Typically, feedback control schemes, utilizing environmental sensors, are employed to gather data relevant to power production in renewable energy system design. Common strategies for PMSG include zero d-axis current control and maximum torque per ampere control [17]. To apply MPPT control in hydroelectric systems, flow sensors, and water-level/pressure sensors would be installed at turbine intakes to provide feedback to power converters (Figure 23).

2.2.6 Flow Intake Control

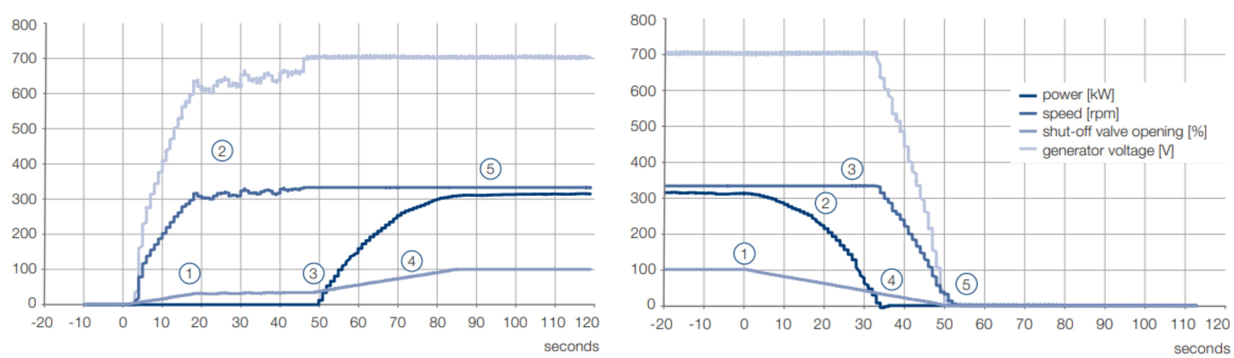


Figure 24: Start/Stop Sequence with shut-off valve control [2].

Synchronization procedure for generator start-up [2]:

1. Synchronization is initiated with a command for the opening of the shut-off valve slowly.

2. The Stream Diver begins running with the opening of the valve until speed, voltage, and frequency values reach the required steady-state values for interconnection.
3. Synchronization is achieved and circuit breakers are closed to form a connection with the grid.
4. Start procedure finished once shut off valve has reached 100% and full power output is achieved.
    4.1. The whole process for a complete steady state takes nearly 90 seconds before interconnection is possible.

Generator shutdown procedure [2]:

1. The Shut-off valve receives the command and begins slowly closing the shut-off valve at flow intake.
2. The Stream Diver power will begin decreasing.
3. Synchronization is maintained with stable speed and voltage.
4. Once power reaches zero, circuit breakers open and rotor speed and generator voltage can decrease as the valve finishes closing.
5. The stop procedure is finished.
    5.1. The whole process for a complete steady state takes nearly ~53 seconds before finished and circuit breakers open after ~34 seconds.

The StreamDiver offers a streamlined hydroelectric NPD conversion tailored to local flow and head analysis. Each unit is programmed with a synchronizer, enabling adjustments to flow intake or number of generator poles during manufacturing for modularity. Instead, strategies discussed in section 2.2.5 on MPPT can enhance power conditioning in the power electronics. Additionally, shut-off valves ensure swift and reliable flow control, serving various industry needs like emergency shutdowns and maintenance.

2.2.7 Co-Development with Photovoltaics

Figure 25: Photovoltaic system layout near Kentucky locks and dam #4 (655.2 kWdc - 4368 m^2).

For our project co-development, we sifted through several ideas ranging from EV charging to tourism and battery storage capabilities. Finally settling on the idea of developing a small-scale photovoltaic farm on the nearby open land lot to supplement our power production estimates. Using PVWatts (Figure 25), an NREL PV development tool, we were able to trace out our expected land usage just to the left of our NPD conversion [19]. This choice was made because our 2-turbine design just slightly fell below the HCC power production requirements of 1-10 MW. With this hybrid hydro-PV design we could easily surpass these requirements reaching a total production estimate of ~1.5 MW.

Because of varying environmental conditions, having multiple choices on how to produce your power allows for a more stable and effective design. We used 2 software systems provided by NREL, PVWatts [19], and SAM [26] to properly assess our PV implementation and generation production estimates. We simulated our design using ‘standard’ modules and a fixed open rack structure with an array tilt equal to the site latitude.

Table 8: PVWatts PV farm losses estimates.

Category	Default Value (%)
Soiling	2
Shading	3
Snow	0
Mismatch	2
Wiring	2
Connections	0.5
Light-Induced Degradation	1.5
Nameplate Rating	1
Age	0
Availability	3

When considering if a PV farm would be possible in Frankfort Kentucky, it is important to consider risk mitigation and losses within the system (Table 8). Kentucky proves to provide a stable environment where PV is a viable solution for renewable power generation.

- Soiling – 2% losses – Dirt and pollution collection upon PV modules is one of the main contributors to O&M in a PV system requiring constant cleaning for maximum power extraction.
- Shading – 3% losses – Losses occurring at any one time due to cloud coverage in the immediate area affecting the irradiance values.
- Mismatch and Wiring - 4% losses – With differences in environmental conditions upon each module the system constantly has mismatches between panels leading to varying voltages and current levels between series and parallel connections.
- Availability – 3% losses – Estimated off time when the PV could be producing power from factors such as damaging weather conditions to typical scheduled maintenance.

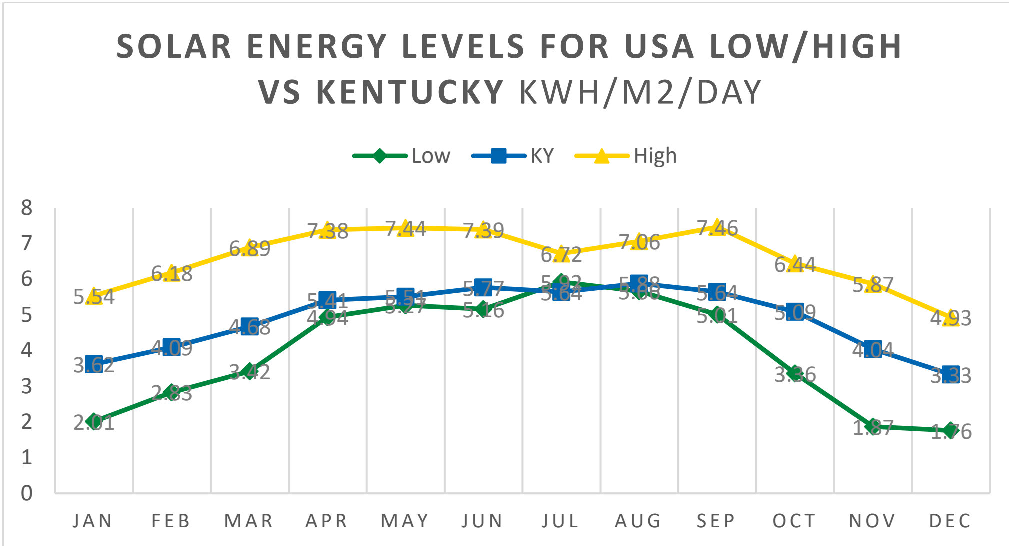


Figure 26: Comparing Frankfort Kentucky irradiance vs USA low and high states WA and NV.

Figure 26 above is a simulated comparison between the solar irradiance month-by-month, to that of the best and worst ranking states in the USA (Nevada and Washington) to our siting location [21]. This quick infographic confirms the viability of solar generation within the state and helps explain the pattern in power generation expectations in the graph below. Two peaks occur in fall and spring with falloffs during their winter months and a slight dip from the heat and rainfall coverage effect on solar panels in the mid-summer temperatures.

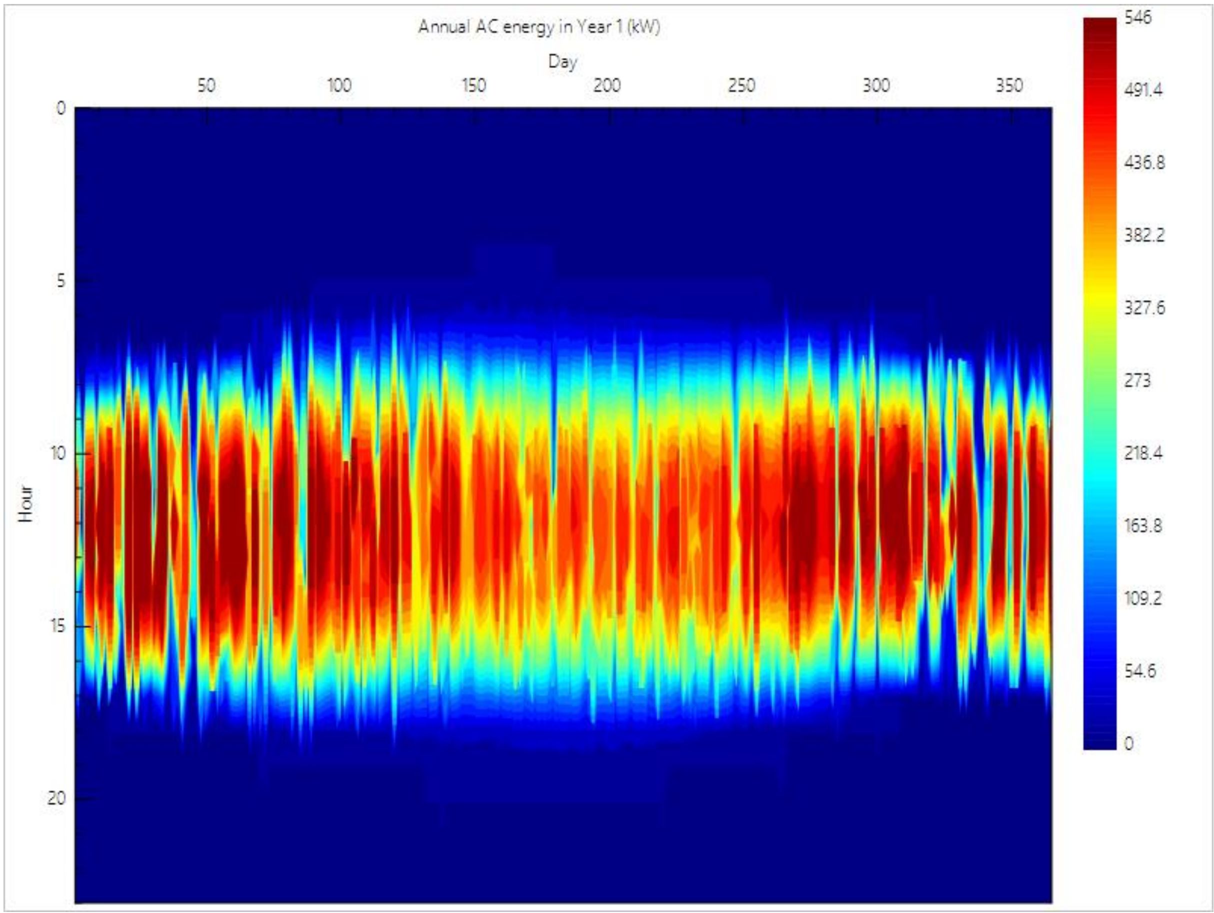


Figure 27: SAM annual AC energy in Year 1 production estimation.

The graph above (Figure 27) from NREL's SAM depicts system operation patterns via a heatmap. It shows peak kW reaching 546 during the day and then drops down to 0 at night. PV output varies with temperature and irradiance, peaking in cooler conditions. Figure 28 and Figure 29 illustrate how voltage and current outputs are influenced by irradiance and temperature.

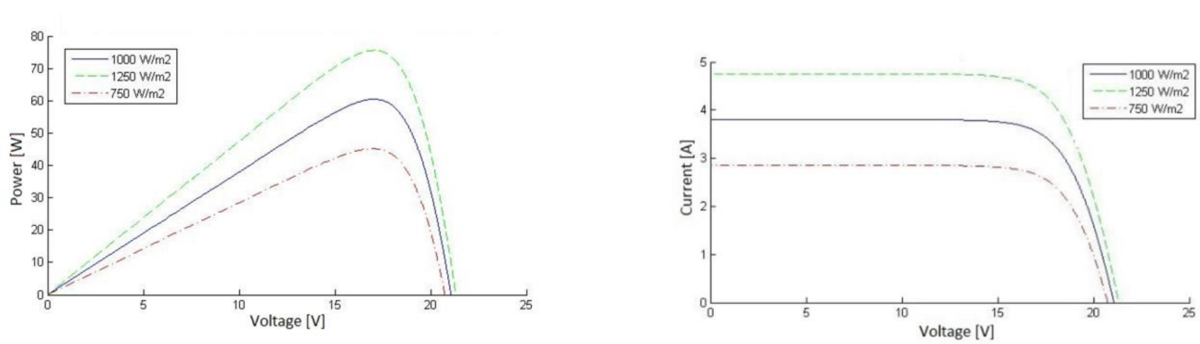


Figure 28: Left-voltage and right-current outputs from varying irradiance levels [22].

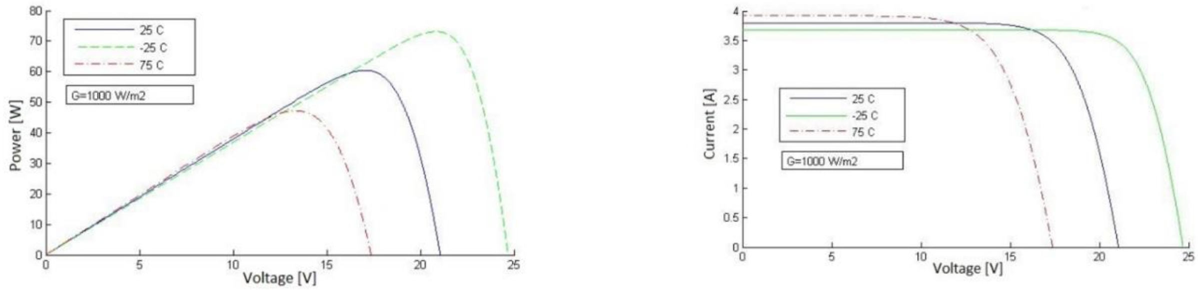


Figure 29: Left-voltage and right-current outputs from varying temperature levels [22].

With the land estimated and losses and environmental factors taken care of, we can investigate the long-term effects of solar modules. Figure 30 below shows the 25-year span where it is estimated that solar panels will lose about 10% or 0.4% per year in production estimates [26]. This factor can come from wide-ranging reasons but boils down to environmental wear and tear on outdoor electrical and mechanical systems.

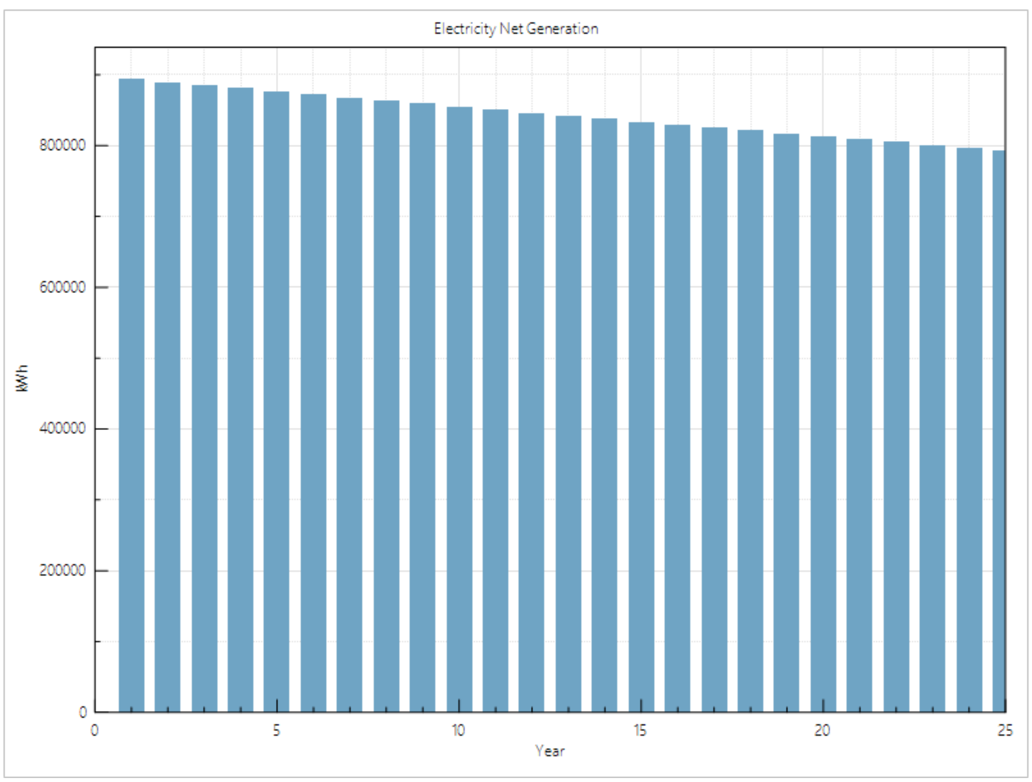


Figure 30: SAM 25-year estimation of power production losses - 0.4% per year [26].

In our model, simplicity and cost-effectiveness are key for solar power. Thus, we prioritize affordable and suitable options for power conditioning and controls in PV systems. For this project, a single-stage conversion suffices to filter and convert energy for grid injection. The straightforward design, depicted in Figure 31 below, features a DC/DC disconnect isolating the PV system, connected to a single inverter for MPPT and DC to AC conversion, facilitating grid interconnection via a step-up transformer.

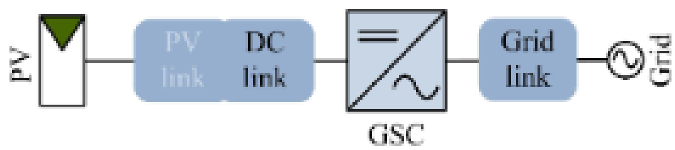


Figure 31: Simple PV single-stage power conversion for power injection to the grid.

Within the inverter, we would have the typical SCADA and MPPT control and tracking mechanisms to deal with system harmonics and changes in environmental conditions. Change in irradiance in a PV field by changing environmental conditions results in large fluctuations in power production, this leads to wide ranges in operating conditions when using current for MPP, voltage is only slightly affected by such changes and provides the optimal solution.

2.3 Proposed Technology

As mentioned earlier, we have integrated Voith StreamDiver turbines due to their eco-friendly design, integration flexibility and since they are optimal for small scale hydropower. This technology uses a water-lubricated drivetrain, which eliminates the need for oil ensuring aquatic environmental compatibility. Since StreamDiver's are assembled off-site, the installation process is streamlined. These turbines excel in small-scale hydropower scenarios due to their modular design, housing the generator internally, which streamlines installation and minimizes civil works. Their water-lubricated drivetrain precludes oil use, enhancing aquatic environmental compatibility. StreamDivers, designed for resilience, can also be shut down during drought or flooding, restarting autonomously post-event.

Our hydropower design revitalizes an existing flume, reinforced to manage water flow efficiently (Table 10), while the control house is strategically positioned above flood levels. The solar array across the river employs high-efficiency panels, ideally tilted at 38° to capture maximum sunlight, incorporating photovoltaic cells with anti-reflective coatings to perform under varying light conditions. This thoughtful integration of StreamDiver technology, despite concerns about limiting creativity, actually enhances our project's ecological and economic feasibility, presenting a compelling argument for its adoption.

2.4 Engineering Diagrams

Our final site design shown below in Figure 32 utilizes the section of the existing flume through the dam with a flume addition upstream to capture more of the river's flow. The control building is about 30 feet above the turbines, above the 100-year flood plain. Across the river is our selected co-development opportunity, a solar power plant to aid in clean energy generation utilizing the available land within the U.S. Government property boundary.

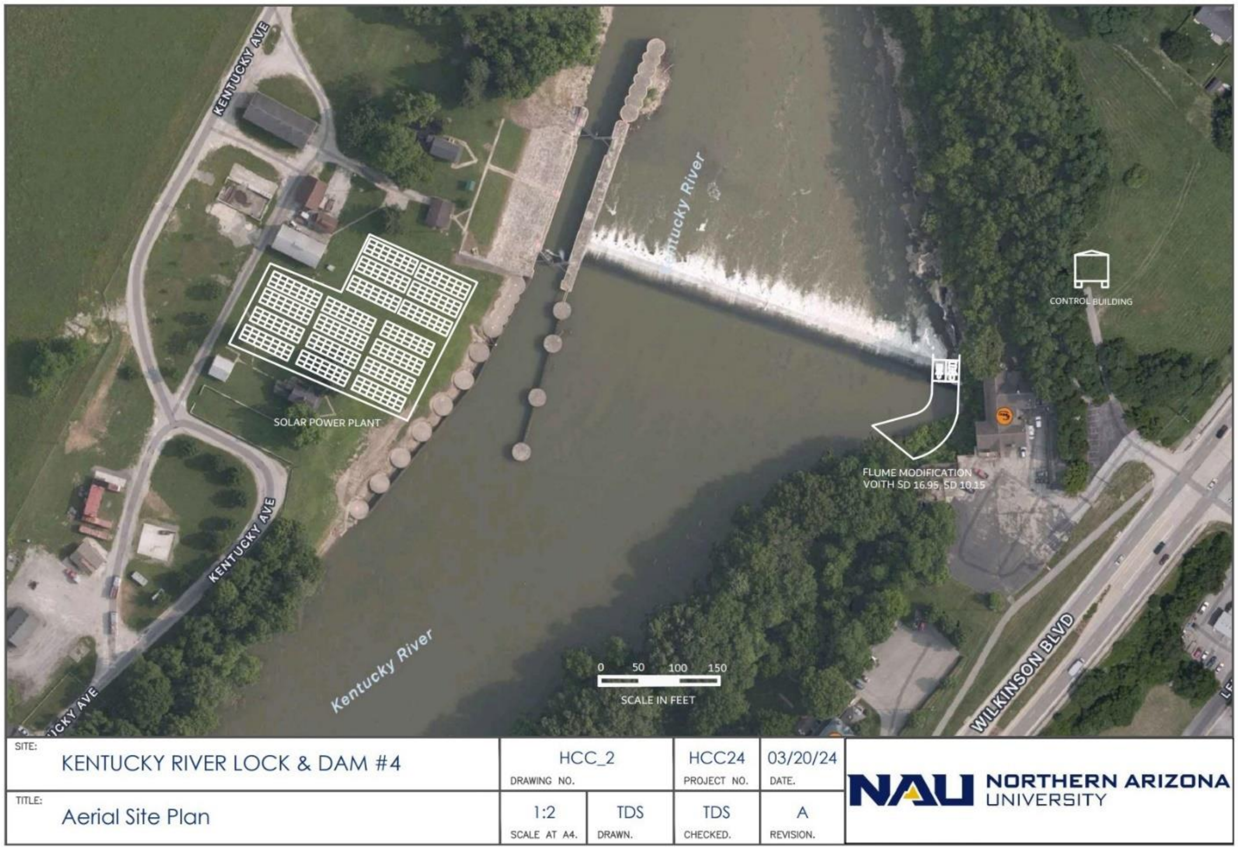


Figure 32: Aerial site plan.

The following figure (Figure 33) showcases the dimensions [feet] for our flume addition. Using the section of the existing flume, the addition follows the boundary of the river. The curve of the flume was optimized for minimal head loss as discussed in Section 2.5. The two StreamDiver turbines placed into the flume are the Voith SD 16.95 and 10.15. The larger diameter turbine is placed on the side closest to the bank of the river to harness the increased flow from the outer wall of the flume for maximum power generation.

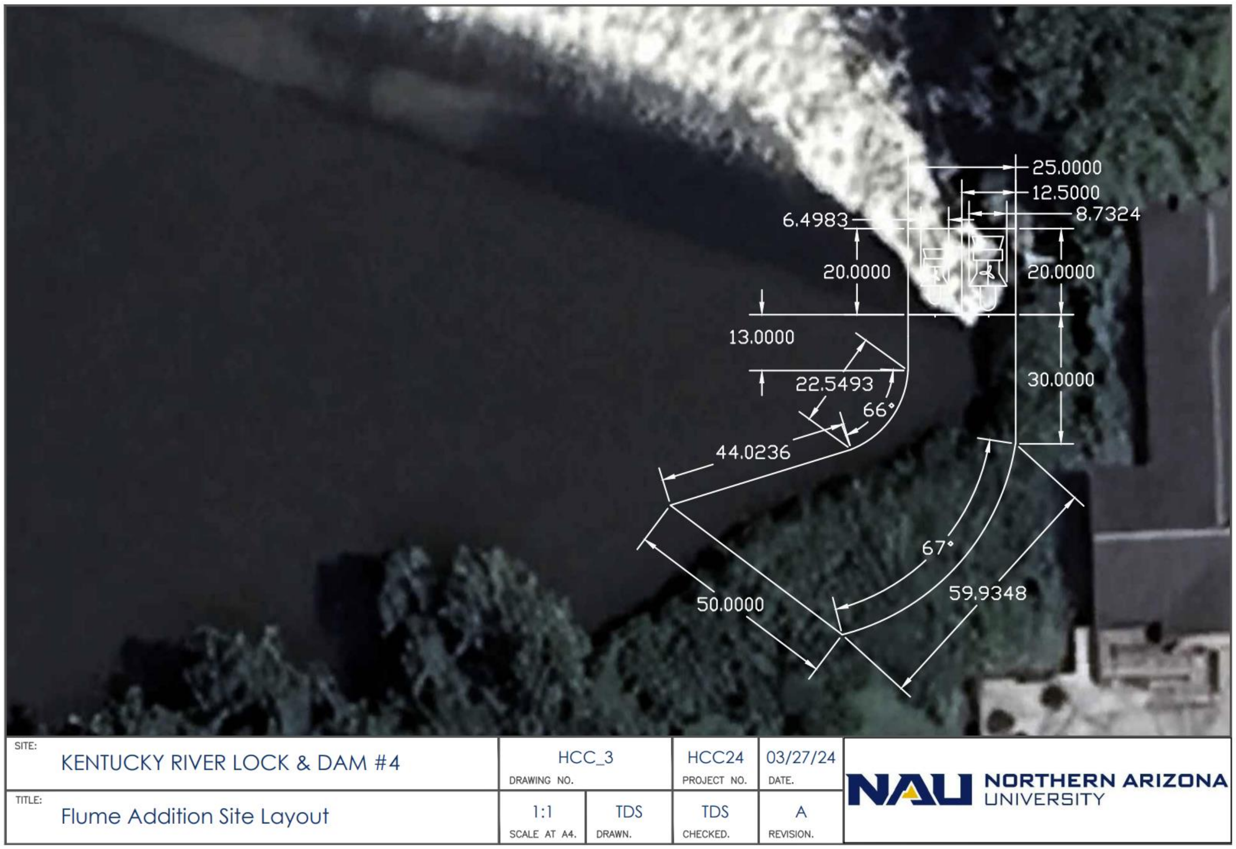


Figure 33: Flume addition site layout engineering drawing in feet.

The full detailed site plan in Figure 34 below shows the U.S. property line, a through section of the existing functional lock, the dam structure, and our modified flume design.

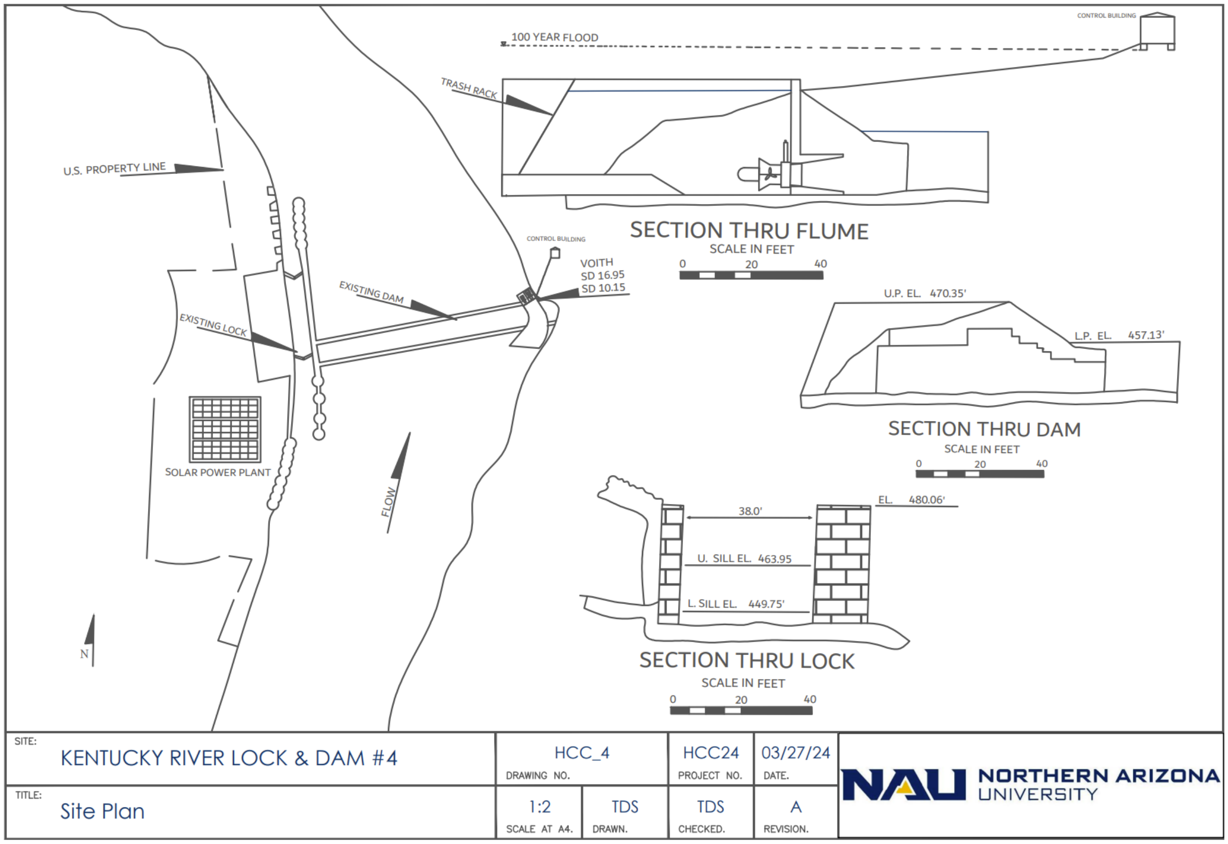


Figure 34: Final site plan containing through section views.

Our final site is a hybrid design using two Voith StreamDiver turbines and a solar power plant located next to the river. Based on LCOE, two provided the best power generation for project's cost and environmental impact. The solar design will provide additional load during the day when utilities experience peak demand. The solar power plant covers an area of 47,016 ft^2, making the most of the available government land. Our turbines are design to be at the constriction point of a flume that narrows down from a width of 50 to 25 feet. The depth in this section is 30 feet, and the turbines are separated by a concrete wall with the widths being 12.5 feet on each side. The outlet of the flume maintains a width of 25 feet with a depth of 15 feet. There are two draft tubes are made of cemented steel and concrete and have a length of 15 feet. After the constriction in the flume, there is a 60° steel trash rack which keeps large debris out of the turbines. The top of the flume after the trash rack is covered with a semipermeable grating cover so the large debris carries over the dam and continues downstream.

2.5 Losses Calculations

When calculating the theoretical power output from KRL&D#4, it is important to account for many of the losses that will impact the power generation. The losses accounted for include a trash rack (h_t), friction from the flume (h_f), hydraulic gradient head loss (s), sudden contraction head loss (h_{ex}), and head loss in bends (k_b). The theoretical power generation also does not account for times when the turbine is not running due to floods or low river levels, so it is higher than our actual calculated generation, but it provides a good reference for losses to be accounted for. Using SI units for simplification, calculating the theoretical power (P) in *Equation 1* uses the mass (m) [kg], gravitational constant (g) [m/s^2], the net head (h_{net}) [m] and the efficiency (n).

$$P = m * g * h_{net} * n \tag{1}$$

The trash rack loss (h_t) (*Equation 2*) uses the bar shape (k) (Figure 35), the bar thickness (t) [m], the width between bars (b) [m], approach velocity (V_o) [m/s], g, and the rack incline angle (θ) [degrees].

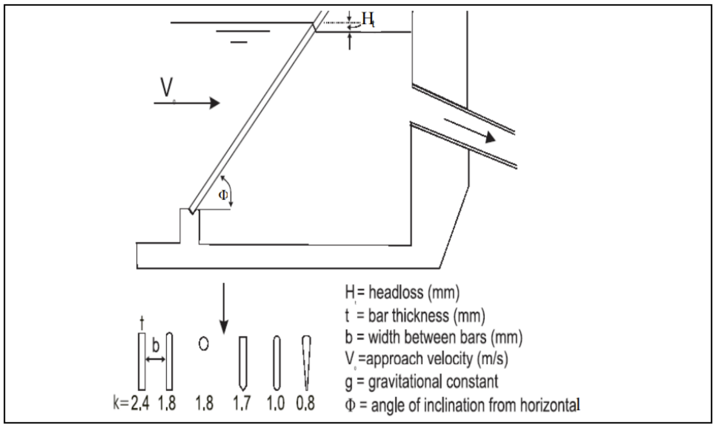


Figure 35: Loss coefficients for trash racks [24].

$$h_t = k * t * \frac{t^{\frac{4}{3}}}{b} * \frac{V_0}{2*g}^{2} * \sin{(\theta)} \tag{2}$$

To calculate h_f, s, h_{ex}, and k_b the variables in Table 9 are required.

Table 9: Loss calculation variables.

Variable	Name	Unit
L	Length	Meters
w	Width	Meters
D	Depth	Meters
h	Height	Meters
C	Hazen-Williams coefficient	Unitless
V	Flow velocity	Meters per second
e	Roughness factor	Unitless
k	Kinematic viscosity	Cubic meters per second
n	Manning's roughness coefficient	Unitless

Using these variables, the average velocity (V_{avg}) is calculated using *Equation 3*.

$$V_{avg} = \frac{V}{2} \quad (3)$$

Using these variables, h_f is calculated by *Equation 4*.

$$h_f = e * \frac{L}{D} * \frac{V_{avg}{}^2}{2*g} \quad (4)$$

To calculate s, *Equation 5* is used.

$$s = \frac{101.59 * n^2 * Q^2}{\pi^2 * D^{\frac{16}{3}}} \quad (5)$$

Finding the values for h_{ex} and k_b use Figure 36 and Figure 37 respectively.

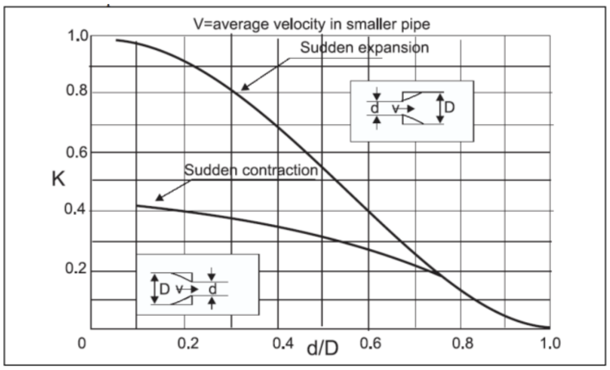


Figure 36: Sudden contraction, k value [24].

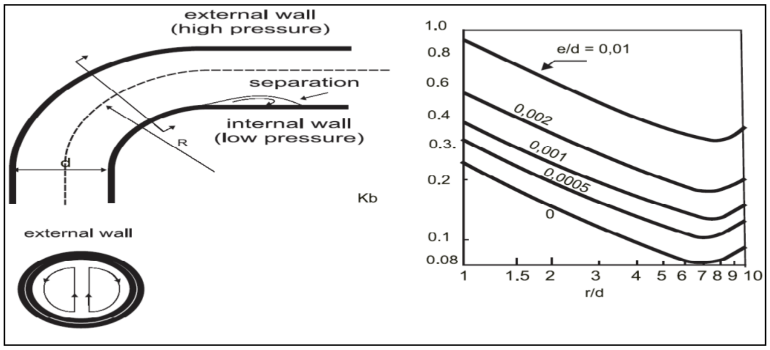


Figure 37: 8 Loss coefficient for flow in bends [24].

Using *Equations 1-5* the calculated values and total losses are below in Table 10.

Table 10: Power generation calculations and losses.

Variable	Name	Value	Unit	**Theoretical Power [MW]**
Q	Flow rate	257.8	m^3/s	8.967
m	Mass	257800	kg	Trash Rack Head Loss [m]
g	Gravitaional constant	9.81	m/s^2	3.18E-05
hnet	Net head height	4.029	m	Friction Head Loss [m]
n	Efficiency	0.88	%	0.002
k	Bar shape	1		Hydraulic Gradient Loss [m]
b	Width between bars	0.1016	m	0.00265
t	Bar thickness	0.01905	m	Sudden Contraction Loss [m]
theta	Trash rack angle	60	degrees	0.32
Vo	Approach Velocity	1	m/s	Flume Bends Head Loss [m]
L	Length	40	m	0.3
w	Width	7.62	m	Total Head Loss [m]
D	Depth	7.62	m	0.6245
h	Height	3.048	m	Adjusted Net Head [m]
V	Flow velocity	12.37	m/s	3.4045
e	Flow velocity	0.00018	m	**Power After Losses [MW]**
n	Manning's roughness coefficient	0.014		7.577
Vavg	Average velocity	6.185	m/s	

While the theoretical power generation calculations don't completely align with our actual generation from our StreamDiver turbines, these calculations back up our flume design dimensions. After calculating five common head losses based on our flume design, the total head loss was only 0.625 meters, bringing the generation down by 1.39 MW, proving why the analysis is important to take into consideration when designing the flume. This result came from optimizing the water approach angle into the turbines by minimizing the curve in the flume and choosing an inlet width of 50 feet which narrows down to 25 feet in the section of the flume that houses the turbines. Lastly, optimizing the trash rack to ensure large debris and aquatic life would not be sucked into the flume while still allowing adequate flow to enter the flume was essential for maximum generation. Our finalized trash rack dimensions only resulted in a head loss of 0.000032 meters which allows for maximum turbine efficiency.

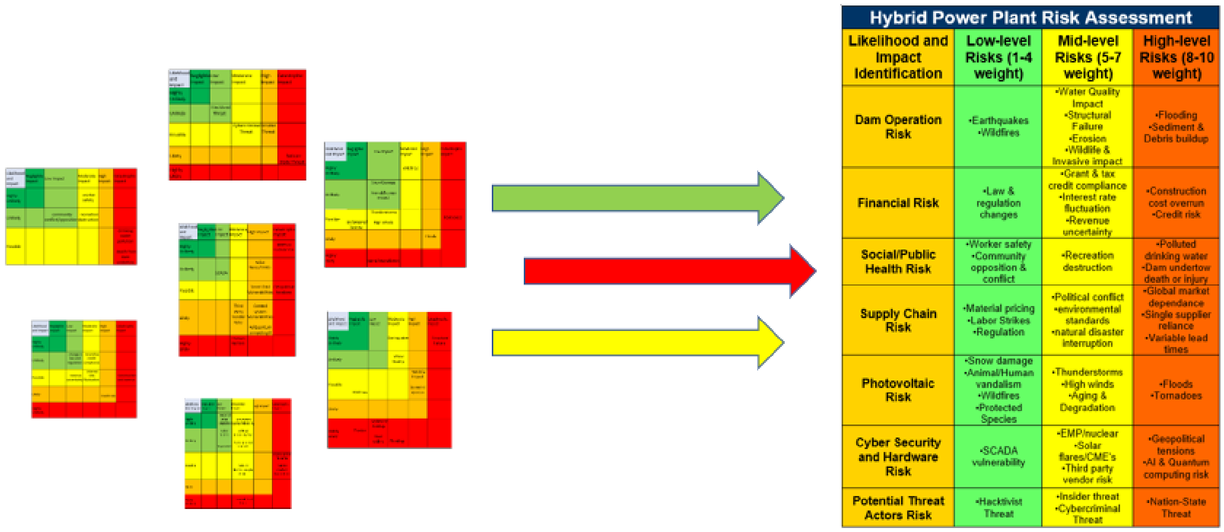
2.6 Risk Mitigation

There are many aspects to consider when constructing or tearing down a dam that can have detrimental impacts on our nation's fragile ecosystems. To be able to recognize and cover all major risk factors in design and implementation it took a lot of investigating of historical and future impacts. We researched 7 main topics of the main risk contributors. These risks were then weighted based on impact on the system and the likelihood of occurrence at our design location (Figure 38).

Likelihood and Impact	Negligible Impact 1	Low Impact 2	Moderate Impact 3	High Impact 4	Catastrophic Impact 5
Highly Unlikely 1	2	3	4	5	6
Unlikely 2	3	4	5	6	7
Possible 3	4	5	6	7	8
Likely 4	5	6	7	8	9
Highly Unlikely 5	6	7	8	9	10

Figure 38: Example matrix for weighted risk level, 1-5 for likelihood and impact.

Once we had determined the weight of each risk factor, we were able to create a more concise and viewer-friendly list of our dam's major risk assessment and level of impact upon our design, Figure 39.



Hybrid Power Plant Risk Assessment			
Likelihood and Impact Identification	Low-level Risks (1-4 weight)	Mid-level Risks (5-7 weight)	High-level Risks (8-10 weight)
Dam Operation Risk	•Earthquakes •Wildfires	•Water Quality Impact •Structural Failure •Erosion •Wildlife & Invasive impact	•Flooding •Sediment & Debris buildup
Financial Risk	•Law & regulation changes	•Grant & tax credit compliance •Interest rate fluctuation •Revenue uncertainty	•Construction cost overrun •Credit risk
Social/Public Health Risk	•Worker safety •Community opposition & conflict	•Recreation destruction	•Polluted drinking water •Dam undertow death or injury
Supply Chain Risk	•Material pricing •Labor Strikes •Regulation	•Political conflict •environmental standards •natural disaster interruption	•Global market dependance •Single supplier reliance •Variable lead times
Photovoltaic Risk	•Snow damage •Animal/Human vandalism •Wildfires •Protected Species	•Thunderstorms •High winds •Aging & Degradation	•Floods •Tornadoes
Cyber Security and Hardware Risk	•SCADA vulnerability	•EMP/nuclear •Solar flares/CME's •Third party vendor risk	•Geopolitical tensions •AI & Quantum computing risk
Potential Threat Actors Risk	•Hacktivist Threat	•Insider threat •Cybercriminal Threat	•Nation-State Threat

Figure 39: Final iteration technique for recognizing major risk for system design and construction.

Below (Table 11) is the final risk matrix where the most applicable risks we could find are listed and ranked into three categories of risk level. We will only discuss those risks that have been deemed high-level or have a high likelihood of occurrence within our dam's location.

Table 11: Final risk matrix recognition table, 7 categories ranked between 3 risk levels.

Hybrid Power Plant Risk Assessment			
Likelihood and Impact Identification	**Low-level Risks (1-4 weight)**	**Mid-level Risks (5-7 weight)**	**High-level Risks (8-10 weight)**
Dam Operation Risk	•Earthquakes •Wildfires	•Water Quality Impact •Structural Failure •Erosion •Wildlife & Invasive impact	•Flooding & Drought •Sediment & Debris buildup
Financial Risk	•Law & regulation changes	•Grant & tax credit compliance •Interest rate fluctuation •Revenue uncertainty	•Construction cost overrun •Credit risk
Social/Public Health Risk	•Worker safety •Community opposition & conflict	•Recreation destruction	•Polluted drinking water •Dam undertow death or injury
Supply Chain Risk	•Material pricing •Labor Strikes •Regulation	•Political conflict •environmental standards •natural disaster interruption	•Global market dependance •Single supplier reliance •Variable lead times
Photovoltaic Risk	•Snow damage •Animal/Human vandalism •Wildfires •Protected Species	•Thunderstorms •High winds •Aging & Degradation	•Floods •Tornadoes
Cyber Security and Hardware Risk	•SCADA vulnerability	•EMP/nuclear •Solar flares/CME's •Third party vendor risk	•Geopolitical tensions •AI & Quantum computing risk
Potential Threat Actors Risk	•Hacktivist Threat	•Insider threat •Cybercriminal Threat	•Nation-State Threat

2.6.1 Dam Operation Risk

Major risks and impacts in the Kentucky River must be accounted for as in potential damage, operational shutdowns due to natural disasters, pollution, and impacts on wildlife [20].

Flooding & Drought: Kentucky faces high flood and drought risks due to intense seasonal weather. Shutdowns are necessary to protect system mechanics and prevent grid blackouts.
Mitigation solutions: Raised powerhouse and mounting structures for PV co-development.

Sediment & Debris build up: Heavy floods bring debris, and sediment, impacting flow and the ecosystem. Trash buildup can damage and decrease efficiency, while sediment accumulation disrupts flow and species habitat.
Mitigation solutions: Hydroelectric environmental risks are well-studied, with safety measures in place. Trash racks are common, as detailed in section 2.5. Sediment buildup is addressed through routine construction maintenance.

2.6.2 Financial Risk

We must anticipate delays and cost increases, considering economic changes and policy shifts. Monitoring factors like interest rates and inflation is crucial for managing expenses [16].

Construction Cost Overrun: Construction poses significant challenges, including coffer dam installation and material delivery delays.
Mitigation solutions: Detailed planning and preparedness are essential to mitigate risks. Flexibility and readiness for setbacks are key in the dynamic environment of hydroelectric projects.

2.6.3 Social Safety & Public Health Risks

Hydropower today faces increased scrutiny regarding its effects on local communities. With historical dam construction often neglecting environmental and health impacts, negative perspectives have emerged. Conducting thorough studies to understand community impacts is imperative for responsible design [27].

Pollution of Drinking Water: Protecting water quality in the Kentucky River is crucial, as it serves as a drinking water source for 750,000 residents.
Mitigation solutions: Ensure components are environmentally friendly, utilize trash racks, and conduct continuous water quality monitoring. Construction practices must minimize disruption and pollution to the local waterway.

Dam Undertow Death or Injury: Low-head small dams pose significant dangers due to recirculating flows, resulting in drownings [9].
Mitigation solutions: Installing warning signs to alert people of the dangers of low-head dams, and implementing engineering solutions such as rock fills or ramps at the base of dams to modify water flow patterns and reduce the risk of entrapment.

2.6.4 Supply Chain Risks

Global supply chain disruptions, exacerbated by events like COVID-19, pose significant challenges for hydroelectric projects. Specialized manufacturers may experience increased lead times and costs, impacting project timelines and expenses.

Single Supplier & Global Market reliance: Dependence on a single supplier or the global market for critical components poses many risks. Specialized power systems, like hydroelectric, rely heavily on specific suppliers for mechanical and electrical components, and maintenance services.
Mitigation solutions: A good solution to this issue is to maintain a simple and well-adaptable design.

2.6.5 Photovoltaic Risk

While not the primary focus, it's important to consider the risks associated with operating photovoltaic (PV) systems. Unlike dams, PV farms are land-based and vulnerable to external factors.

Floods & Tornadoes: Kentucky's weather patterns, including flooding and tornadoes, pose significant risks to PV systems.
Mitigation solutions: Invest in durable mountings and structures to withstand tornadoes and adjust module height to prevent water damage during floods.

2.6.6 Cyber Security & Hardware Risk

Modernization introduces automation, reducing costs and labor requirements [14], but also exposes systems to cyber threats such as internet outages and cyber-attacks.

Geopolitical Tension: Geopolitical tensions present cybersecurity vulnerabilities in American power infrastructure, including supply chain issues, espionage, and cyber-attacks [10].
Mitigation solutions: Collaborate with other nations to establish updated cybersecurity protocols and protection services to safeguard power grids against geopolitical cyber threats.

AI & Quantum Computing: Breaking cryptography, data breaches and information disclosure, intellectual property theft, hardware tampering, algorithmic vulnerabilities, and much more.
Mitigation solutions: Train both human workforce and technology to be vigilant against phishing attacks, data leaks, and cybercrime. Continuous training and updating of security protocols are essential.

2.6.7 Potential Threat Actor Risk

When considering who possess the largest threat to the American power grid there are many threats to consider from disgruntled employees to threat of war.

Nation-State Threats: Nation-states pose a significant threat to national power systems through cyber-attacks, data collection, and service interruptions, motivated by opposition to American politics and culture.
Mitigation solutions: These issues are on a bigger scale but can be mitigated by electing leaders who don't promote war and provide the best solutions for America and the rest of the world.

Cybercriminals & Hackers: Cybercriminals pose a significant threat to the nation's power grid [14], exploiting vulnerabilities to access control equipment and disrupt services, potentially causing widespread damages.
Mitigation solutions: Addressing these threats requires hiring cybersecurity experts to identify and strengthen weak points within the system. Governments and companies must implement state-of-the-art protections and adopt healthy security practices to safeguard against cyber-attacks.

2.7 Environmental Impact

A preliminary disposition study of the Kentucky River Locks #1-4 [4] revealed significant data regarding the environment surrounding the proposed project location. The following section discusses potential impacts, mitigation strategies, and unavoidable consequences to the affected environment.

2.7.1 The Affected Environment

Climate: Kentucky's climate is influenced by several locational factors typically contributing to a wide seasonal temperature range, ample precipitation, and highly variable weather patterns [4].

Hydrology and Hydrography: Lying within the Bluegrass physiological region, the area is characterized by sinkholes, sinking streams, and springs created by weathered limestone. Elk silt loam reflects most dry soil at Lock #4 [4].

Species and Ecosystems: As a major tributary to the Ohio River, the USDA lists 47 aquatic plant species, 13 federally recognized threatened or endangered species, and 61 state recognized species that may be found within the area [4].

Aquatic Environment: The Kentucky Division of Water 303(d) List of Waters identifies the Kentucky River as impaired for one or more pollutants, as required under the Clean Water Act, including excessive sedimentation, eutrophication, and mercury in fish tissue [4].

Land Environment: No critical habitat has been identified within the study area [4].

Land Use: The proposed site plan is located at an existing flume and the Kentucky River Lock and Dam #4. The area includes recreational parking and fishing, as well as is used for commercial marine passage.

Visual Resources: The Kentucky River typically features a picturesque waterway, with woodland bordered banks and populus wildlife. The existing site features a weir dam and lock, its associated recreational facilities, a restaurant on the eastern bank, as well as a water treatment plant downstream.

Cultural Resources: Locks #1-4 are the oldest on the Kentucky River and are part of a historic district eligible for listing on the National Register of Historic Places. The district has significance in the areas of transportation and engineering; however, no archeological sites have been identified at Lock #4 [4].

2.7.2 Impacts of the Proposed Action, Subsequent Mitigative Measures Proposed, and Unavoidable Adverse Impacts

Air Quality: Total suspended particulate matter would have an unavoidable short-term local increase with the use of heavy equipment, potential blasting, fumes from chemicals and general construction activities. The resulting impact would be mitigated following Federal and state regulations governing air quality. Quality would revert to normal after construction.

Noise Levels: Operation of equipment during construction would create excessive or unwanted noise near a commercial restaurant and recreation area. The nearest residential area is less than one mile away and may be disturbed during construction hours. Noise Levels would revert to normal after construction.

Hydrology and Hydrography: During construction, water will be redirected from a section of the existing dam and the flume, increasing local velocity, however having a relatively insignificant impact on flow rate. The project uses an existing flume and therefore will not impact current river flow during operation.

Water Quality and Soils: Due to water velocity, soil pockets may be redeposited downstream, though the project will not cause additional siltation. Restorative measures may be taken to remove existing deposits from current structure.

Species and Ecosystems: Notable endangered species include seven species of mussels, three plant species, as well as three species of bat. The project anticipates no long-term impact on the plant or bat species and minimal short-term losses in the immediate area. The mussels have been identified as an invasive species to the location, and they do not rely on migration. Therefore, construction will incur local losses to population, however the project is expected to have minimal adverse long-term effects. Restorative measures may be taken to relocate the displaced mussels to their appropriate habitat.

Recreation and Resources: Construction would disrupt regular recreational activities and would slightly affect commercial operations due to an increased amount of local traffic. The addition of a solar farm would unavoidably remove other potential recreational capacities in the area, as well as from the location of the control station.

Visual Resources: Impacts of most structural hydropower features are negligible as they will either be underground or submerged. The new above ground structural features of the control station and co-developed photovoltaic plant will unavoidably reduce the degree of visual pleasure a visitor receives at any time by decreasing the variety of the environment and adding unnatural features to an otherwise undeveloped area.

Cultural Resources: As there were no historic or archeological sites found, though recognized in a historical district, care will be taken to ensure any remaining are identified and reported. Restorative measures will be taken to remodel existing structure prior to installation.

2.8 Conclusion

In conclusion, our comprehensive conceptual design, as part of Track 1 in the Hydropower Collegiate Competition, successfully addresses the challenge of transforming a non-powered dam into a source of sustainable energy for the community of Frankfort, Kentucky. Our proposed facility, through its hybrid design integrating both hydropower and solar energy, is poised to generate an estimated 5,000 MWh annually at a peak capacity of 1.346 MW. This projection aligns with the rising electricity demand and the global shift toward renewable energy sources. As we move forward, the implications of our project extend beyond the immediate benefits of clean energy; they represent a progressive step in reducing dependency on coal and encouraging the adoption of green technologies. Our work epitomizes the innovation and resilience required to navigate the energy transition, signaling a promising direction for renewable energy initiatives and community development. This project not only showcases the feasibility of small-scale renewable projects but also serves as a model for similar future projects aiming to harmonize environmental stewardship with community growth and technological advancement.

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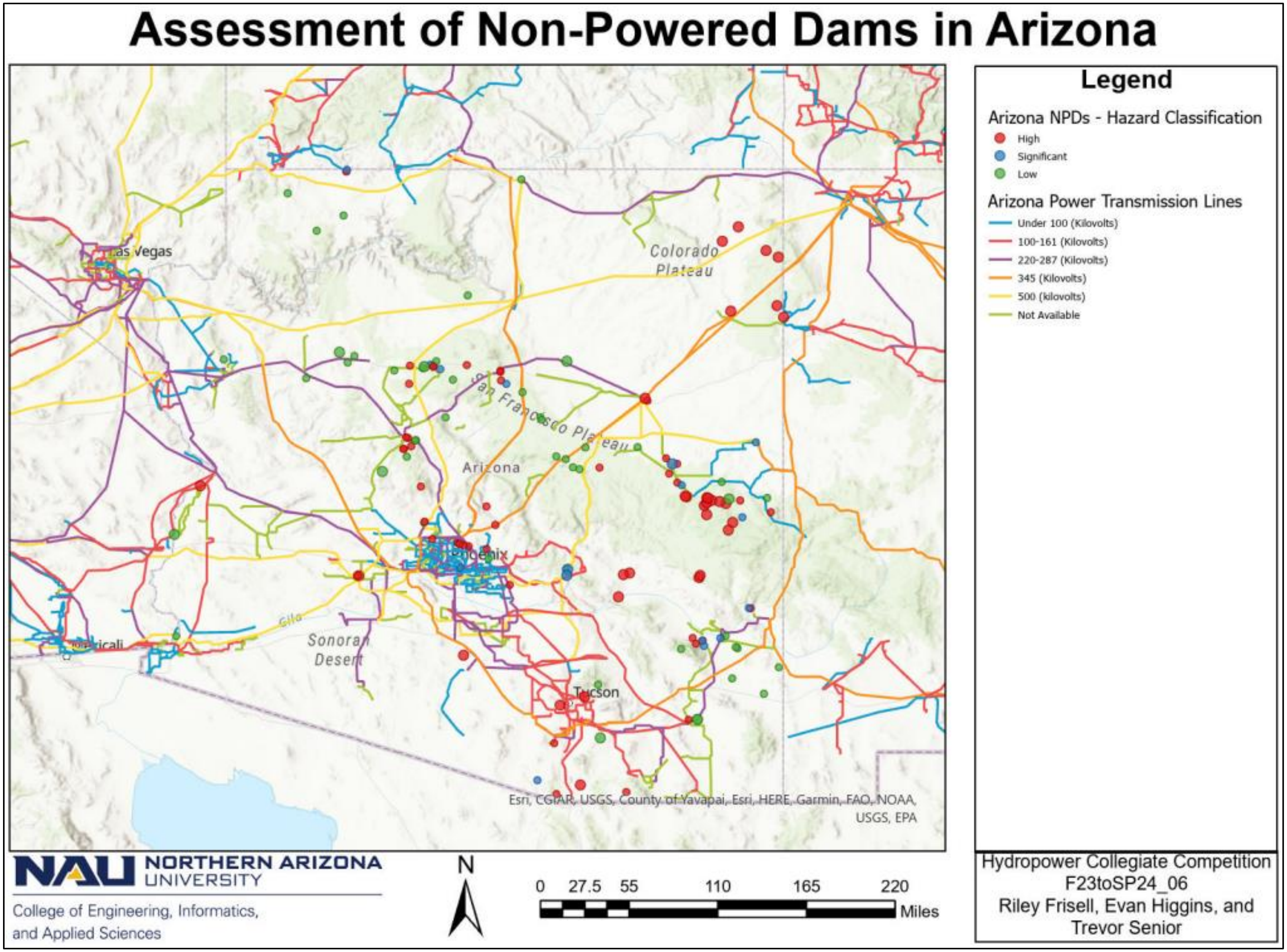
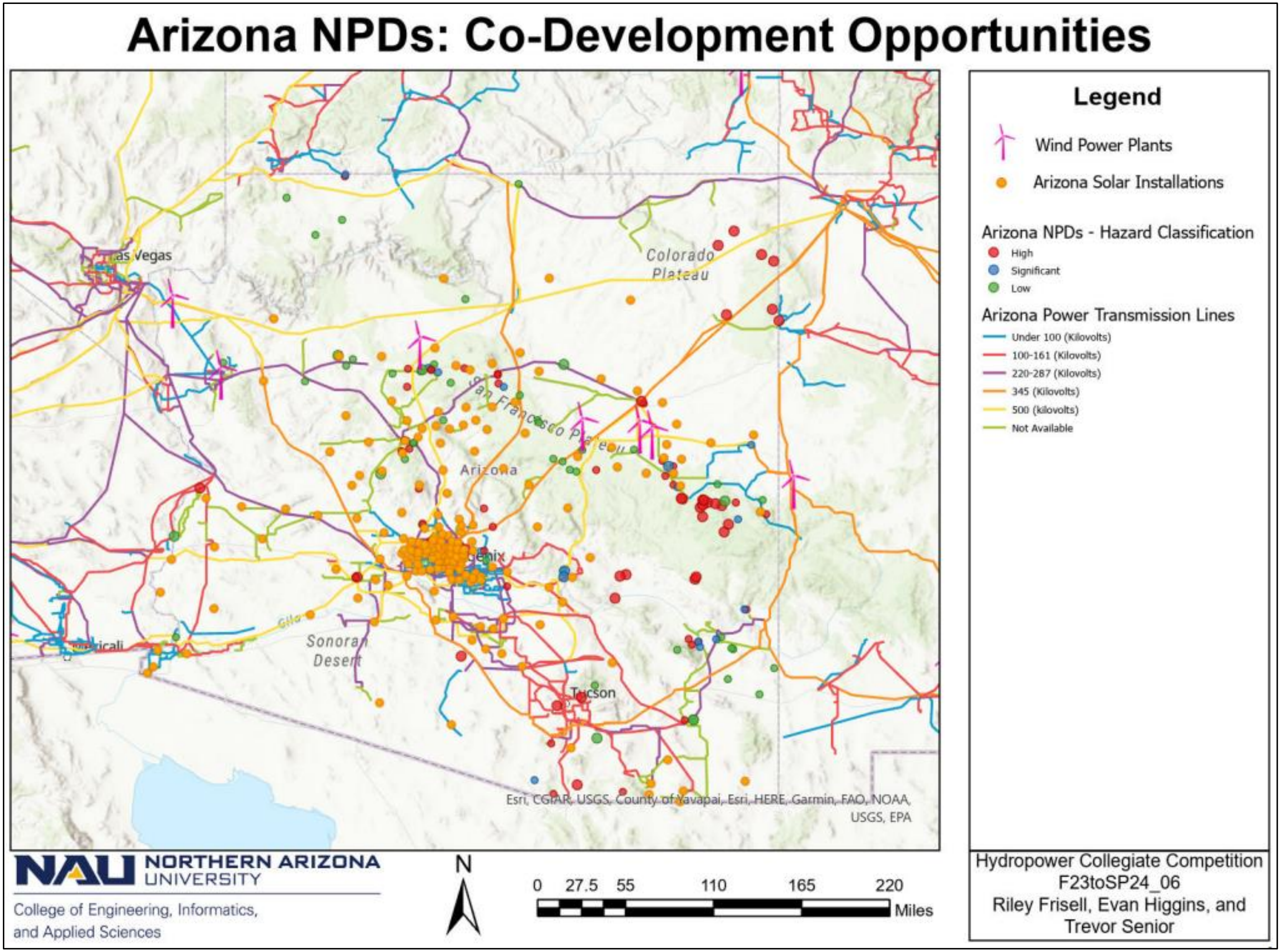
Appendix A1 – Arizona ArcGIS Pro Layouts




Arizona NPDs: Co-Development Opportunities
Legend
Wind Power Plants
Arizona Solar Installations
Arizona NPDs - Hazard Classification
High
Significant
Low
Arizona Power Transmission Lines
Under 100 (Kilovolts)
100-161 (Kilovolts)
220-287 (Kilovolts)
345 (Kilovolts)
500 (kilovolts)
Not Available
Colorado Plateau
Sonoran Desert
Tucson
Esri, CGIAR, USGS, County of Yavapai, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA
NORTHERN ARIZONA UNIVERSITY
College of Engineering, Informatics, and Applied Sciences
N
0 27.5 55 110 165 220 Miles
Hydropower Collegiate Competition
F23toSP24_06
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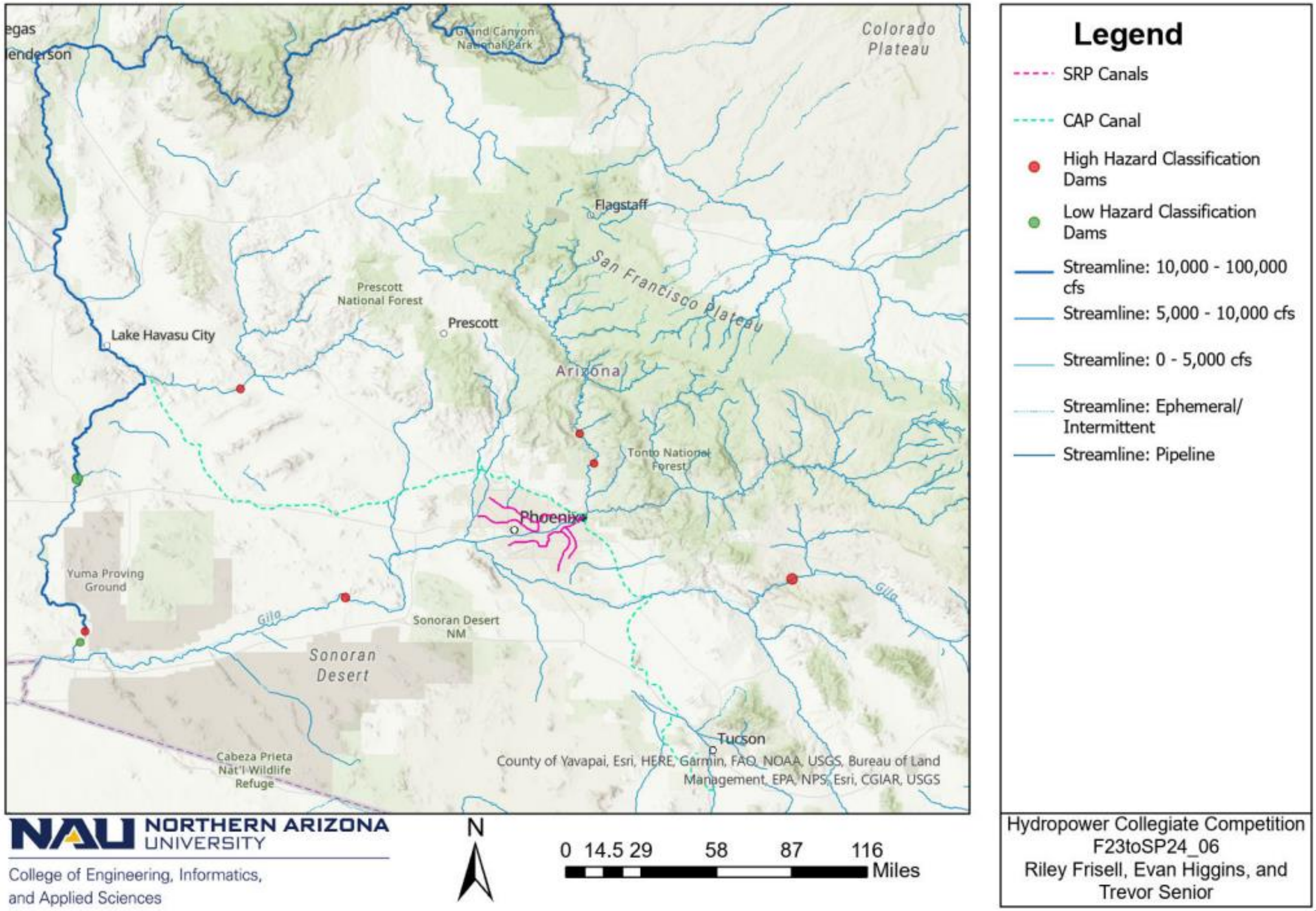
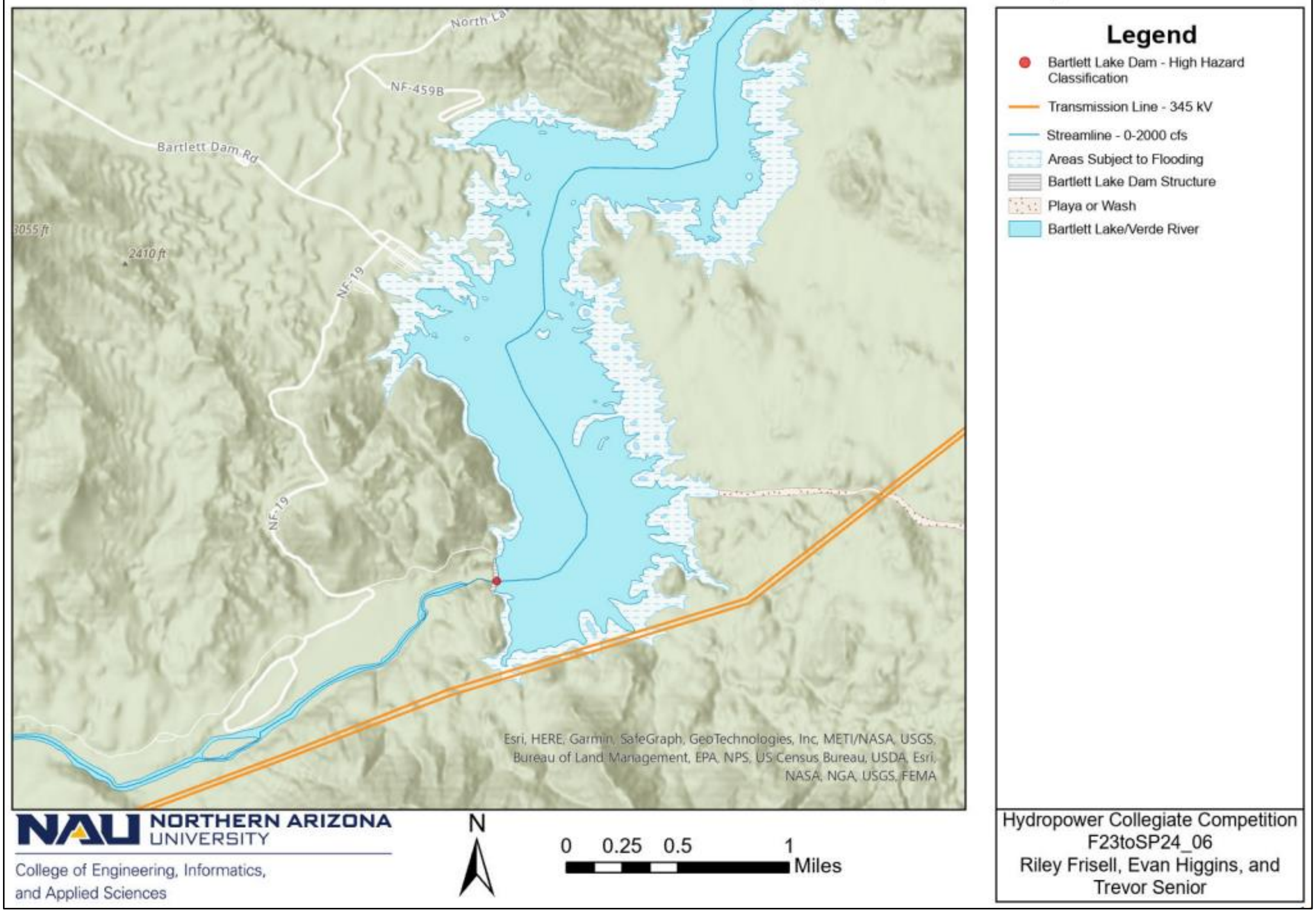
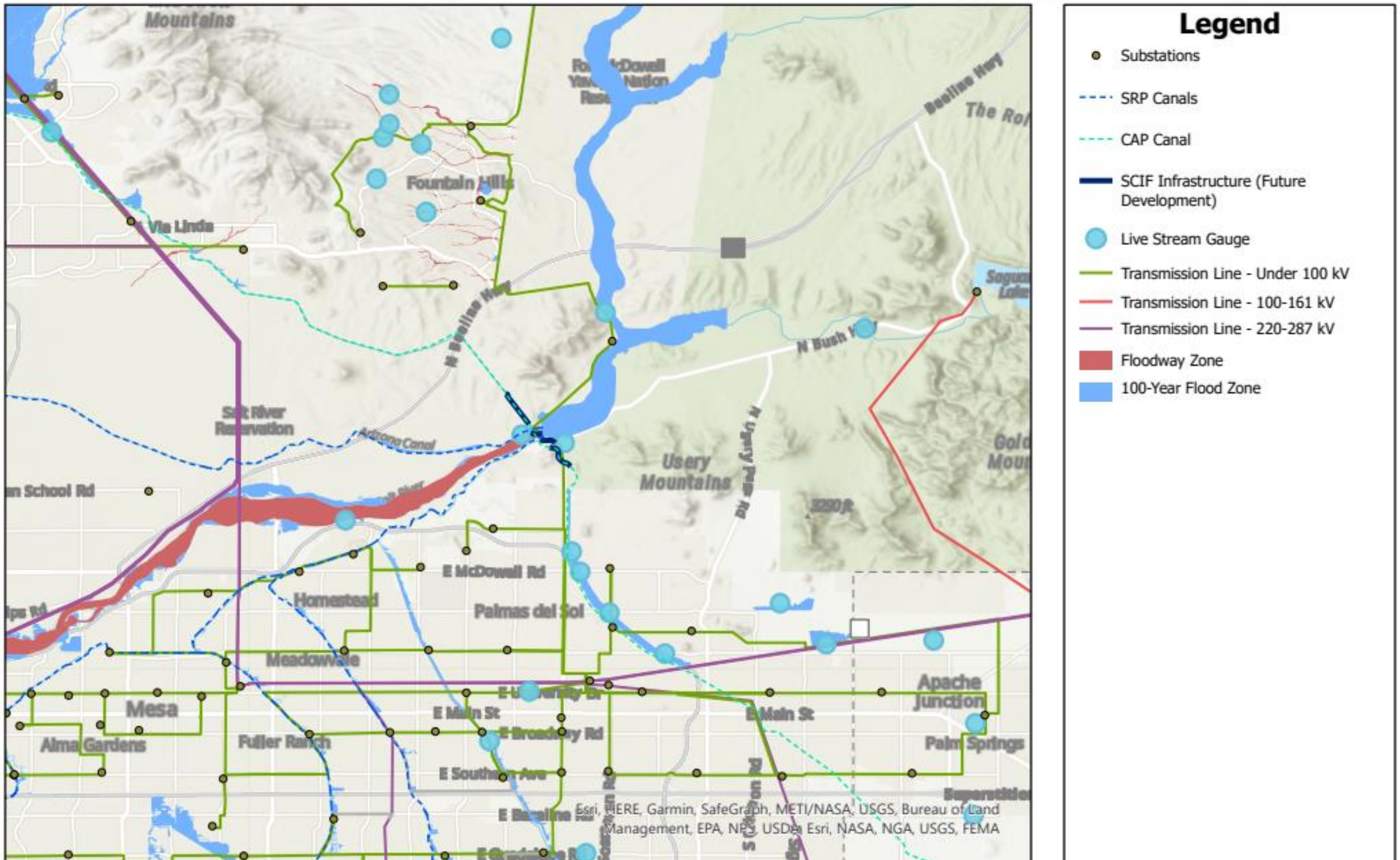
Final Selection of Arizona Non-Powered Dams



Bartlett Lake Dam - Topographic Map



East Mesa/Apache Junction Topographic Map



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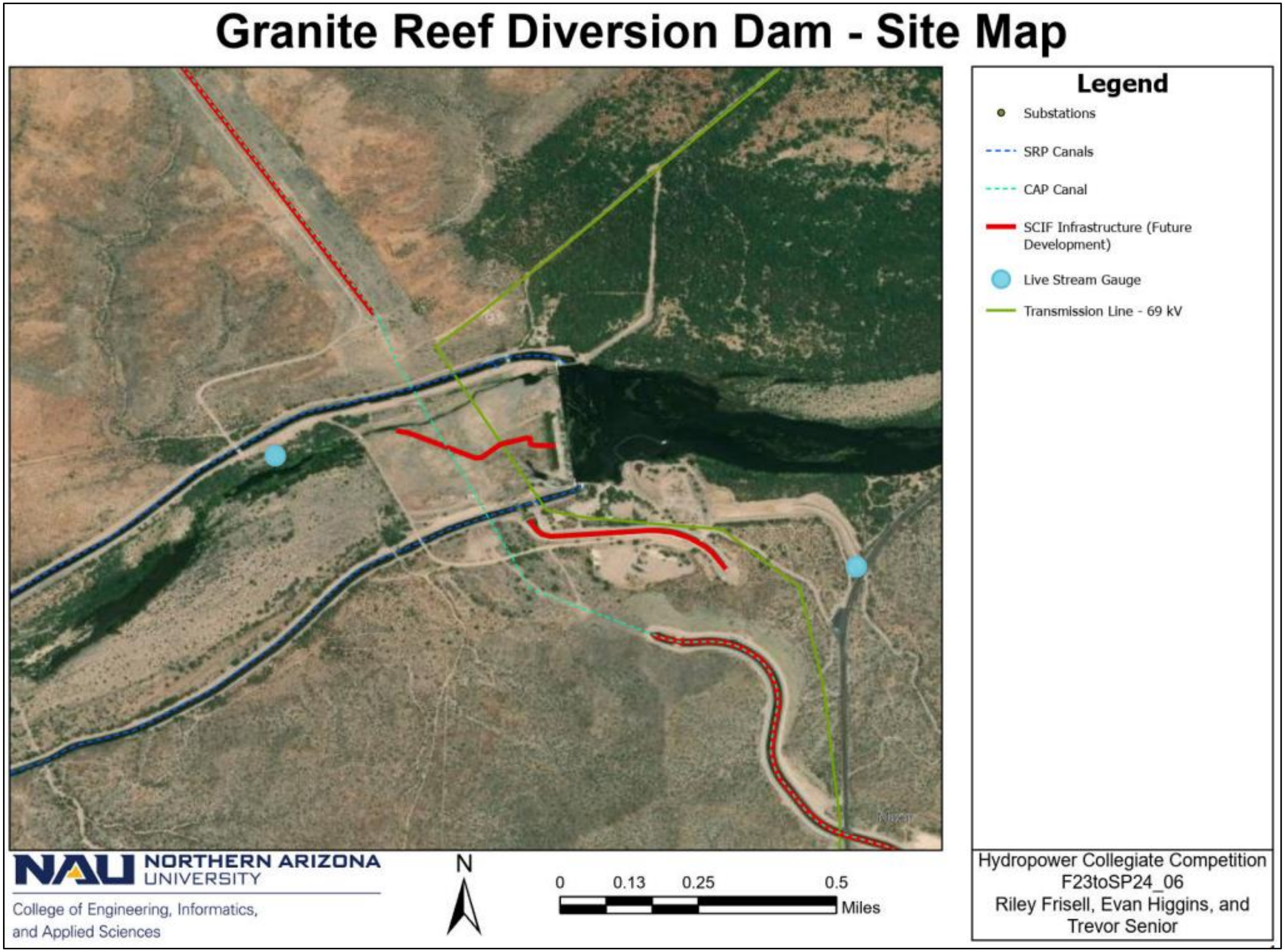
Granite Reef Diversion Dam - Site Map
Legend
Substations
SRP Canals
CAP Canal
SCIF Infrastructure (Future Development)
Live Stream Gauge
Transmission Line - 69 kV
NAU NORTHERN ARIZONA UNIVERSITY
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N
0
0.13
0.25
0.5
Miles
Hydropower Collegiate Competition
F23toSP24_06
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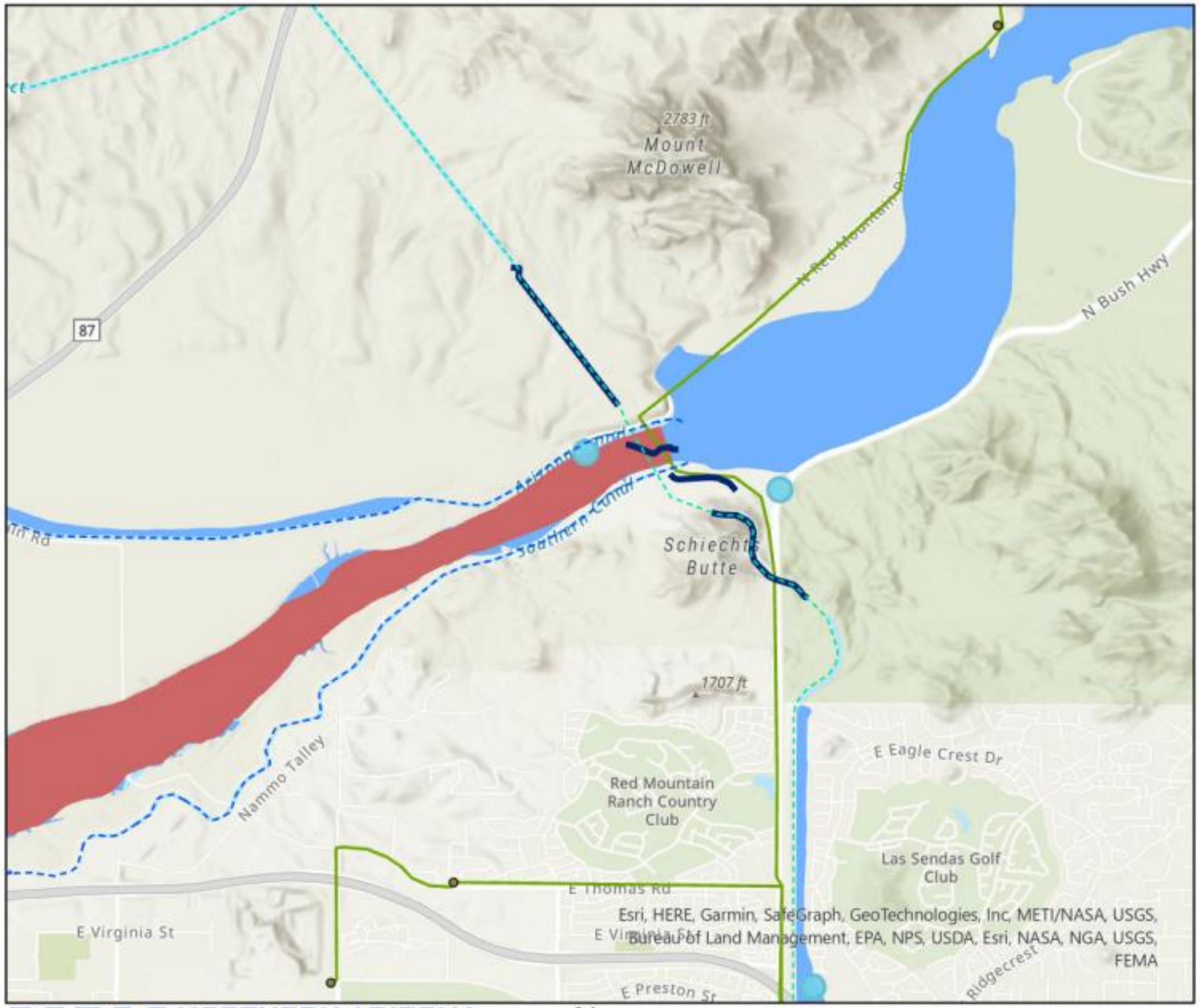
Granite Reef Diversion Dam - Site Topographic Map



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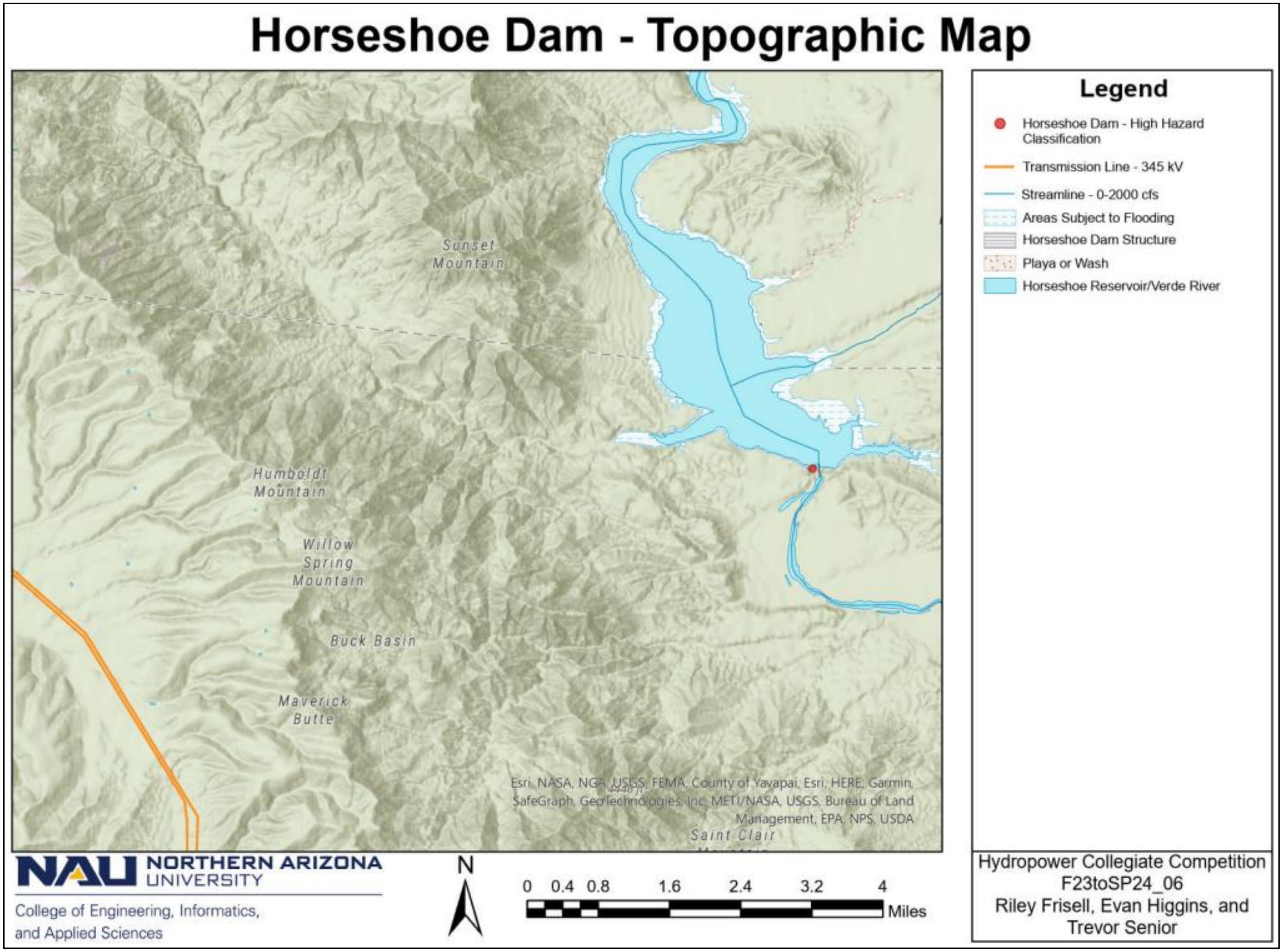
Horseshoe Dam - Topographic Map
Legend
Horseshoe Dam - High Hazard Classification
Transmission Line - 345 kV
Streamline - 0-2000 cfs
Areas Subject to Flooding
Horseshoe Dam Structure
Playa or Wash
Horseshoe Reservoir/Verde River
Sunset Mountain
Humboldt Mountain
Willow Spring Mountain
Buck Basin
Maverick Butte
Saint Clair
Esri, NASA, NGA, USGS, FEMA, County of Yavapai, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA
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N
0 0.4 0.8 1.6 2.4 3.2 4
Miles
Hydropower Collegiate Competition
F23toSP24_06
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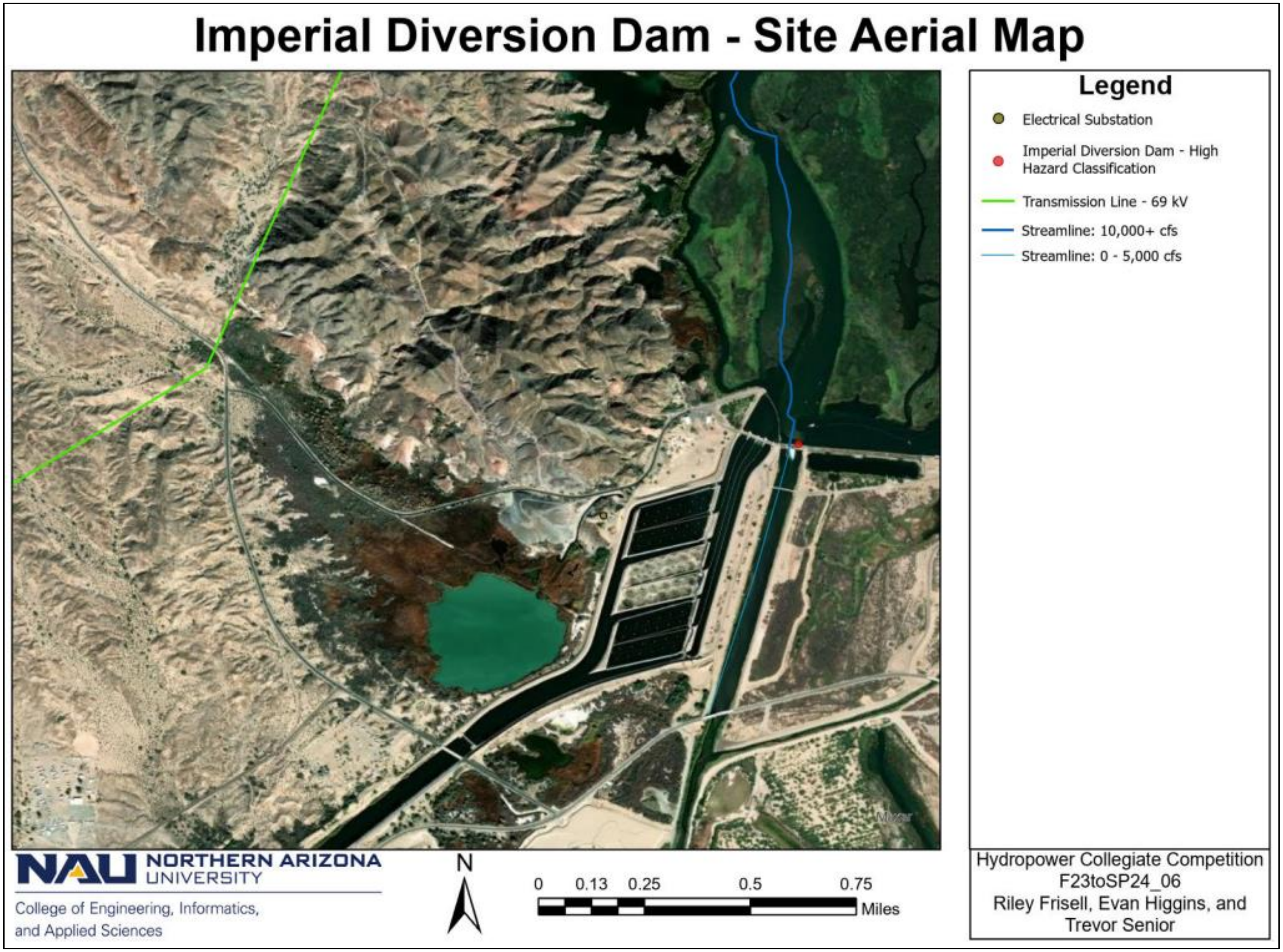
Imperial Diversion Dam - Site Aerial Map
Legend
Electrical Substation
Imperial Diversion Dam - High Hazard Classification
Transmission Line - 69 kV
Streamline: 10,000+ cfs
Streamline: 0 - 5,000 cfs
NORTHERN ARIZONA UNIVERSITY
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N
0 0.13 0.25 0.5 0.75
Miles
Hydropower Collegiate Competition
F23toSP24_06
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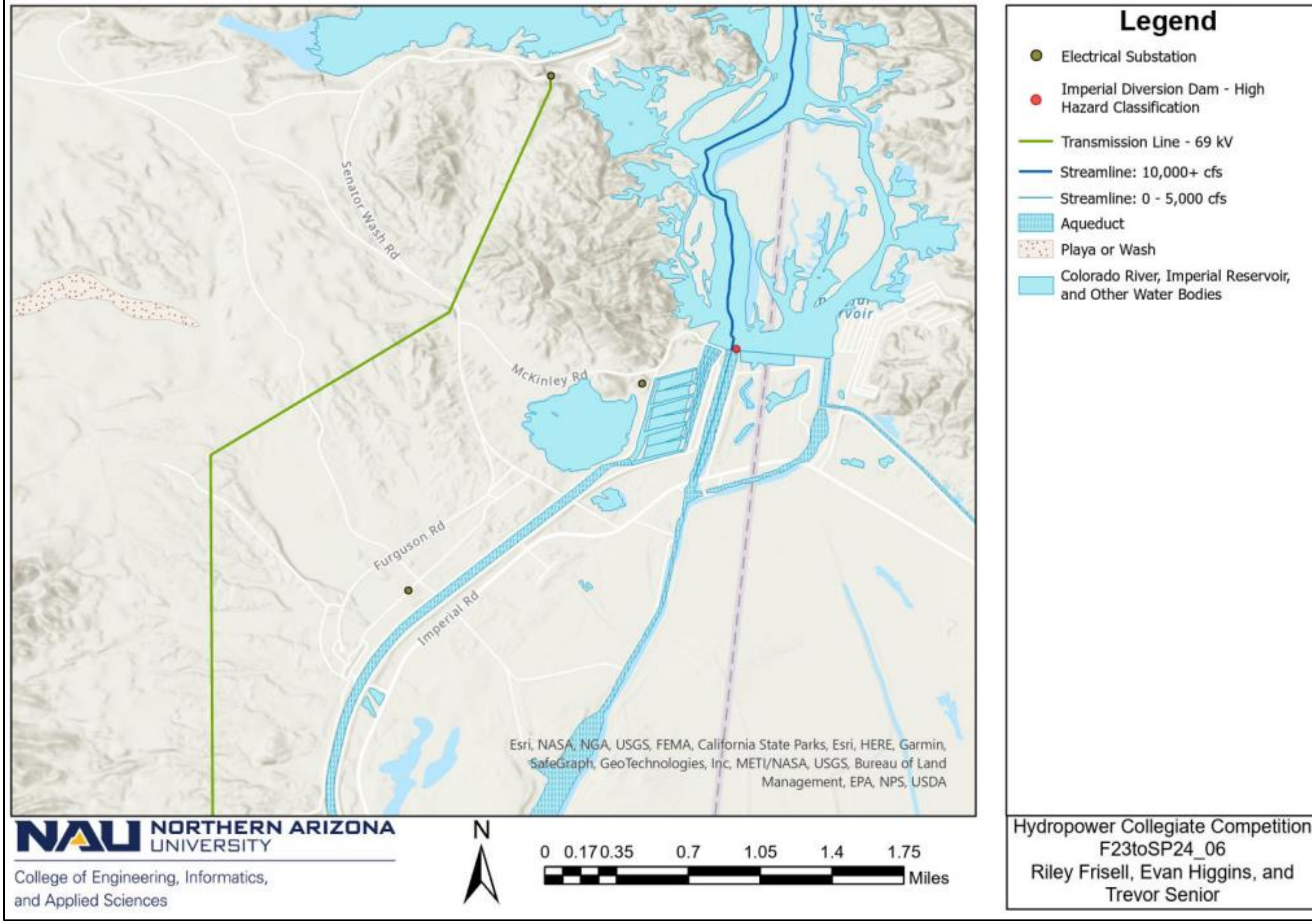
Imperial Diversion Dam - Topographic Map



Hydropower Collegiate Competition
F23toSP24_06
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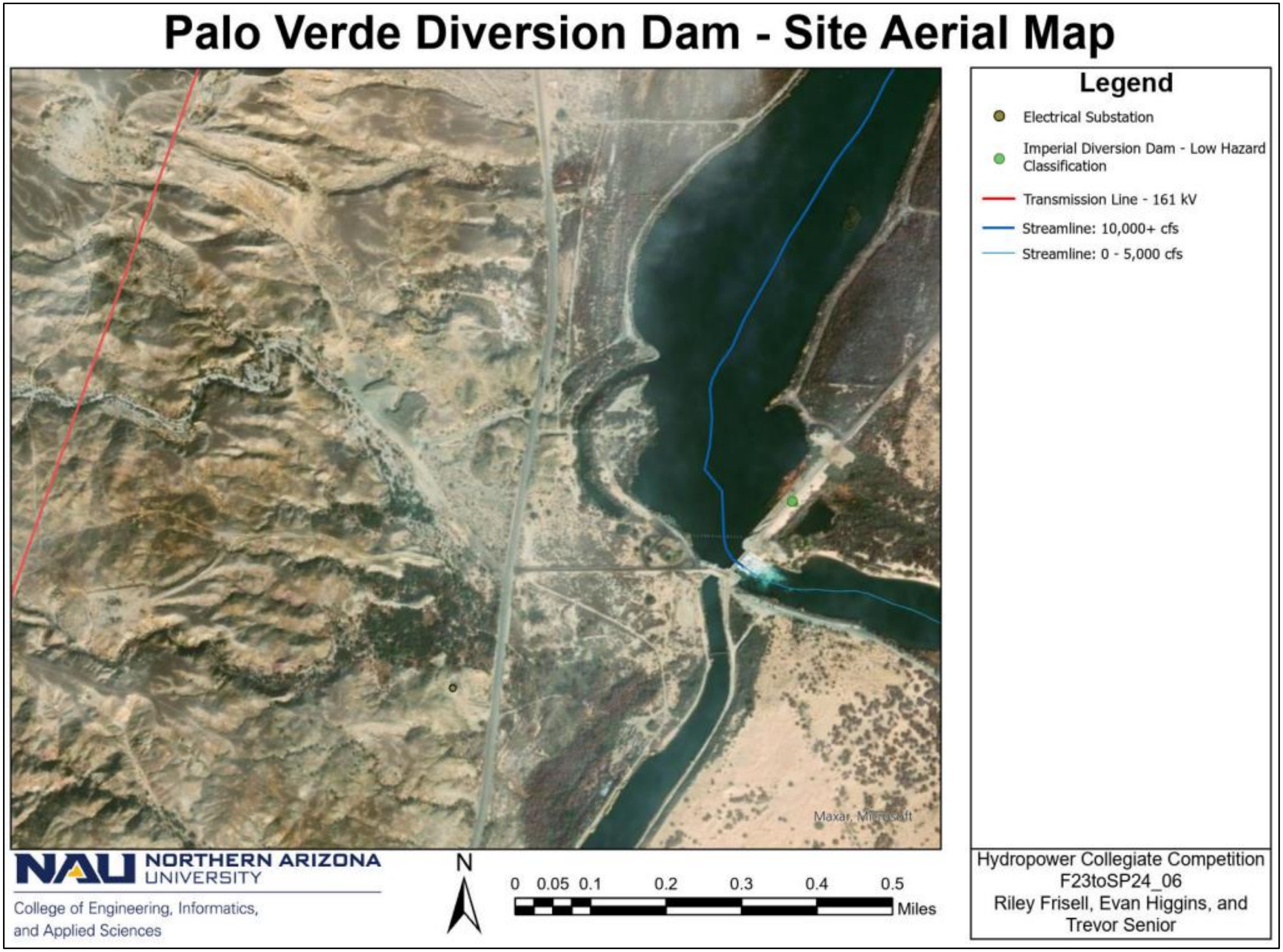
Palo Verde Diversion Dam - Site Aerial Map
Legend
Electrical Substation
Imperial Diversion Dam - Low Hazard Classification
Transmission Line - 161 kV
Streamline: 10,000+ cfs
Streamline: 0 - 5,000 cfs
Maxar, Microsoft
NAU NORTHERN ARIZONA UNIVERSITY
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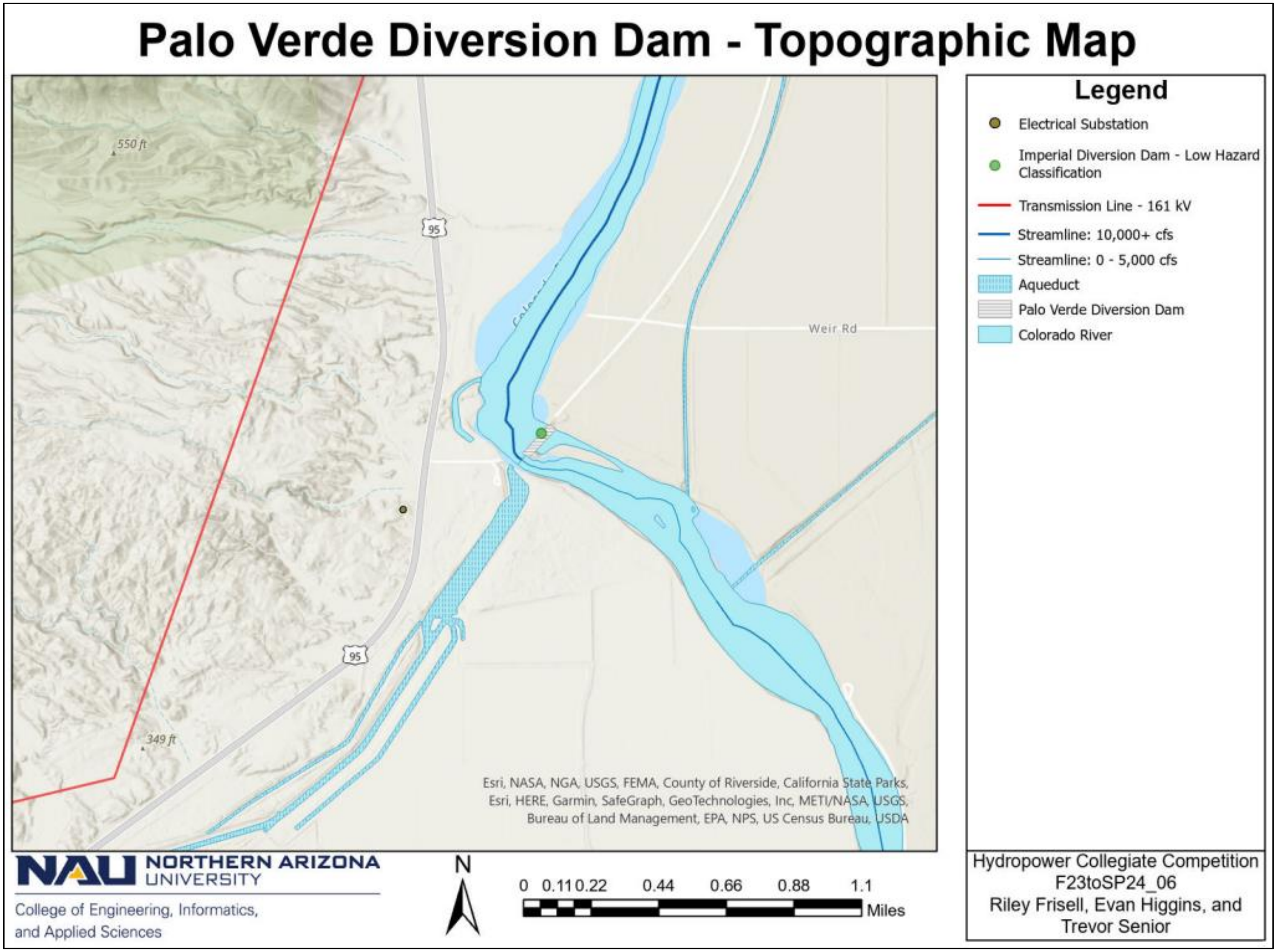
N
0 0.05 0.1 0.2 0.3 0.4 0.5
Miles
Hydropower Collegiate Competition
F23toSP24_06
Riley Frisell, Evan Higgins, and Trevor Senior


Palo Verde Diversion Dam - Topographic Map
Legend
Electrical Substation
Imperial Diversion Dam - Low Hazard Classification
Transmission Line - 161 kV
Streamline: 10,000+ cfs
Streamline: 0 - 5,000 cfs
Aqueduct
Palo Verde Diversion Dam
Colorado River
550 ft
349 ft
95
Weir Rd
Esri, NASA, NGA, USGS, FEMA, County of Riverside, California State Parks, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA
NAU NORTHERN ARIZONA UNIVERSITY
College of Engineering, Informatics, and Applied Sciences
N
0 0.11 0.22 0.44 0.66 0.88 1.1 Miles
Hydropower Collegiate Competition
F23toSP24_06
Riley Frisell, Evan Higgins, and Trevor Senior

Appendix A2 – Dam Selection Decision Matrices and Risk Matrices

Table A2.1: Initial dam selection for Arizona. Matrix was modified during further investigation into other dams.

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

Table A2.2: Point scoring legend for revised matrices for remaining states.

Criterion	Weight	Soring Legend (0-100 point)	
		given score	Key
1. Potential Energy	25%	0-100	1 MW =10 pts
2. Flow Rate	10%	0-100	1000-2500+ cfs (5 pts per 1000 cfs
3. Distance to Existing Power Infrastructure	10%	0-100	20+ -> 0 miles away (-5pts per mile away)
4. Dam Ownership Type	5%	0-100	Hydropower developers = 100, private companies = 90, army corps = 80, Federal = 70, state = 60, municiplaities = 50, join ventures = 40, coops = 30, beuro of reclemation = 20 , other =10
5. Potential Environmental Impact (risk)	10%	0-100	risk level 1 = 100, 2 = 70, 3 = 40, else = 10
6. Dam Integrity (age)	12%	0-100	for each year old it is -1 pt
7. dam type	13%	0-100	concrete = 100, gravity or arch = 50, rock = 70, earth =30
8. Accessibility (access for construction and maintenance)	5%	0-100	for every mile away -5 pts
9. Local Community Need	10%	0-100	determine from research; include economic indices and local tribes/communities nearby
Total	**100%**		
Relative Rank			

Table A2.3: Top 3 selection of final dams assessed.

Criterion	Weight	KR Lock & Dam #4 KY03016		Mishawaka Fish Ladder IN00806		Fish Barrier Dam WA00769	
		Score out of 100	Weighted Score	Score out of 100	Weighted Score	Score out of 100	Weighted Score
1. Potential Energy	25%	32	8	16	4	40	10
2. Flow Rate	10%	90	9	75	7.5	32.9	3.29
3. Distance to Existing Power Infrastructure	10%	90	9	60	6	96	9.6
4. Dam Ownership Type	5%	80	4	60	3	50	2.5
5. Potential Environmental Impact (risk)	10%	80	8	60	6	50	5
6. Dam Integrity (age)	12%	45	5.4	80	9.6	46	5.52
7. Dam Structure	13%	90	11.7	70	9.1	100	13
8. Accessibility Access	5%	85	4.25	60	3	100	5
9. Local Community Need	10%	80	8	90	9	50	5
Total	**100%**		**67.35**		**57.2**		**58.91**
Relative Rank		**1**		**2**		**3**	

Table A2.4: Kentucky and Indiana dam selection matrix.

Criterion	Weight	KR Lock & Dam #4 KY03016		Williams Dam IN00805		Mishawaka Fish Ladder IN00806	
		Score out of 100	Weighted Score	Score out of 100	Weighted Score	Score out of 100	Weighted Score
1. Potential Energy	25%	32	8	15	3.75	16	4
2. Flow Rate	10%	90	9	80	8	75	7.5
3. Distance to Existing Power Infrastructure	10%	90	9	20	2	60	6
4. Dam Ownership Type	5%	80	4	30	1.5	60	3
5. Potential Environmental Impact (risk)	10%	80	8	0	0	60	6
6. Dam Integrity (age)	12%	45	5.4	40	4.8	80	9.6
7. Dam Structure	13%	90	11.7	100	13	70	9.1
8. Accessibility Access	5%	85	4.25	35	1.75	60	3
9. Local Community Need	10%	80	8	5	0.5	90	9
Total	**100%**		**67.35**		**35.3**		**57.2**
Relative Rank		**1**		**3**		**2**	

Table A2.5: Colorado dam selection matrix.

Criterion	Weight	Ritschard Dam		Windy Gap Dam		Trinidad Dam	
		Score out of 100	Weighted Score	Score out of 100	Weighted Score	Score out of 100	Weighted Score
1. Potential Energy	20%	57	11.4	15	3	54	10.8
2. Flow Rate	10%	1.2	0.12	4	0.4	1.3	0.13
3. Distance to Existing Power Infrastructure	10%	100	10	100	10	97	9.7
4. Dam Ownership Type	5%	60	3	60	3	70	3.5
5. Potential Environmental Impact (risk)	10%	40	4	70	7	40	4
6. Dam Integrity (age)	12%	10	1.2	44	5.28	36	4.32
7. Dam Structure	13%	30	3.9	30	3.9	30	3.9
8. Accessibility Access	10%	95	9.5	95	9.5	100	10
9. Local Community Need	10%	25	2.5	35	3.5	40	4
Total	**100%**		**45.62**		**45.58**		**50.35**
Relative Rank		**3**		**2**		**1**	

Table A2.6: California dam selection matrix.

Criterion	Weight	New Woodbridge Diversion ID CA01461		Anderson Cottonwood CA00226		Healdsburg Recreation CA00791		Russian River No. 1 CA00849	
		Score out of 100	Weighted Score	Score out of 100	Weighted Score	Score out of 100	Weighted Score	Score out of 100	Weighted Score
1. Potential Energy	20%	30	6	90	18	40	8	45	9
2. Flow Rate	10%	6	0.6	43	4.3	13	1.3	13	1.3
3. Distance to Existing Power Infrastructure	10%	100	10	60	6	45	4.5	70	7
4. Dam Ownership Type	5%	80	4	80	4	60	3	60	3
5. Potential Environmental Impact (risk)	10%	70	7	60	6	100	10	60	6
6. Dam Integrity (age)	12%	82	9.84	0	0	29	3.48	39	4.68
7. Dam Structure	13%	20	2.6	40	5.2	100	13	50	6.5
8. Accessibility Access	10%	100	10	60	6	45	4.5	90	9
9. Local Community Need	10%	40	4	25	2.5	50	5	40	4
Total	**1**		**54.04**		**52**		**52.78**		**50.48**
Relative Rank		**1**		**3**		**2**		**4**	

Table A2.7: Washington dam selection matrix.

Criterion	Weight	Fish Barrier Dam WA00769		Barrier Dam WA00555		Howard A. Hanson Dam WA00298	
		Score out of 100	Weighted Score	Score out of 100	Weighted Score	Score out of 100	Weighted Score
1. Potential Energy	25%	40	10	25.8	6.45	100	25
2. Flow Rate	10%	32.9	3.29	13.5	1.35	5.5	0.55
3. Distance to Existing Power Infrastructure	10%	96	9.6	100	10	80	8
4. Dam Ownership Type	5%	50	2.5	50	2.5	70	3.5
5. Potential Environmental Impact (risk)	10%	50	5	50	5	50	5
6. Dam Integrity (age)	12%	46	5.52	37	4.44	39	4.68
7. Dam Structure	13%	100	13	100	13	30	3.9
8. Accessibility Access	5%	100	5	100	5	40	2
9. Local Community Need	10%	50	5	25	2.5	30	3
Total	**100%**		**58.91**		**50.24**		**55.63**
Relative Rank		**1**		**3**		**2**	

Table A2.8: Idaho dam selection matrix.

Criterion	Weight	Payette Lake ID00244		Boise Diversion Dam ID00281		Murtaugh Lake Dam ID00156	
		Score out of 100	Weighted Score	Score out of 100	Weighted Score	Score out of 100	Weighted Score
1. Potential Energy	25%	70	17.5	82	20.5	94	23.5
2. Flow Rate	10%	43	4.3	15	1.5	38	3.8
3. Distance to Existing Power Infrastructure	10%	94	9.4	91	9.1	92	9.2
4. Dam Ownership Type	5%	40	2	70	3.5	90	4.5
5. Potential Environmental Impact (risk)	10%	20	2	35	3.5	30	3
6. Dam Integrity (age)	12%	30	3.6	20	2.4	15	1.8
7. Dam Structure	13%	25	3.25	40	5.2	30	3.9
8. Accessibility Access	5%	55	2.75	60	3	70	3.5
9. Local Community Need	10%	75	7.5	55	5.5	25	2.5
Total	**100%**		**52.3**		**54.2**		**55.70**
Relative Rank		**3**		**2**		**1**	

Table A2.9: Oregon dam selection matrix.

Criterion	Weight	Winchester OR00263		Blue River Dam OR00013		Fern Ridge Dam OR00016	
		Score out of 100	Weighted Score	Score out of 100	Weighted Score	Score out of 100	Weighted Score
1. Potential Energy	25%	70	17.5	64	16	11.7	2.925
2. Flow Rate	10%	21.885	2.1885	2.5	0.25	2.5	0.25
3. Distance to Existing Power Infrastructure	10%	65	6.5	45	4.5	75	7.5
4. Dam Ownership Type	5%	30	1.5	70	3.5	70	3.5
5. Potential Environmental Impact (risk)	10%	70	7	65	6.5	75	7.5
6. Dam Integrity (age)	12%	0	0	45	5.4	16	1.92
7. Dam Structure	13%	30	3.9	30	3.9	30	3.9
8. Accessibility Access	5%	100	5	80	4	100	5
9. Local Community Need	10%	50	5	75	7.5	75	7.5
Total	**100%**		**48.5885**		**51.55**		**39.995**
Relative Rank		**2**		**1**		**3**	

Table A2.10: Siting Risk Matrix for feasibility and decision matrix considerations

Siting Project Risk Mitigation Matrix's (1 = low impact, 5 = extreme impact)																						
Feasibility Risk	**Construction and Civil Impact**	Time	Cost	Risk	**Energy and Grid Impact**	Time	Cost	Risk	**Technichal/other Impact**	Time	Cost	Risk	**Mechanical Impact**	Time	Cost	Risk	**Enviromental Impact**	Time	Cost	Risk	**RISK SCORE** Max individual	Total Score
Potential Energy (20 MW max)	Large civil impact, the larger the more time to impliment	5	5	3	The larger the system the more we can add to the grid and earn $	1	1	1	While larger, it will likely require more upkeep	3	3	3	More size more impact	3	4	4	Again the larger our system the larger the possible fallout	4	4	4	60	48
Flow Rate (20,000 cfs max)	Higher flow rate means more complex civil techniques	5	5	5	Higher flow results more possibility for implementation and production	1	1	1	Will require more complex solutions	5	5	5	More stress on systems.	5	5	3	Less impact if constat run of river	2	3	2	60	53
Distance to existing power infrastructure	Makes contruction and operation difficult and expensive	3	5	2	Loss in transmission and effeciencies	3	4	2	Further from power the more difficult to repair/operate	3	3	3	Longer shut off/on time further away, harder O&M	4	3	3	Further is harder for emergency midigation in case of disaster	3	4	4	60	49
Ownership Type	Makes construction feasable	5	4	2	may have to pay/rent the land	2	3	3	Not much	1	1	1	Type of operation, noise and when power is generated	2	2	2	Impose or don't risk	2	2	1	60	33
Community Need	Community must need/see impact to allow	3	3	3	Most places need renewbale power with government initiatives	1	1	1	Community may complicate construction methods	3	2	2	Not much impact on mechanichal	1	1	1	Can decide if a dam is built or not; attend to community needs	4	4	5	60	35
Environmental	Largly decides operations	4	4	4	Green energy yay!	1	1	1	May increase difficulty of technichal solutions	3	3	2	Solutions have to be considered for enviromental sustainability	3	4	2	Obviously!	5	5	5	60	47
Dam Integrity (time since last refurbishment	The older the more upgrades required	3	3	3	Not much impact besides powerhouse	1	2	1	Technichal solutions may be required	3	3	1	Not much impact on mechanichal	1	1	1	Large consqeunces for improper upgrades the older the dam	2	3	2	60	30
Dam Type	Huge impact on cost and time	5	5	4	Not Applicable	1	1	1	May require technical solutions	3	3	2	Not much impact on mechanichal	2	2	1	Earth dams require more development and more risk	3	3	4	60	40
Accessability	Will increase cost and effecincy	5	4	2	Expensive infastructure	3	4	2	Not much	2	2	1	Not much impact on mechanichal	2	2	2	More driving and less acess	2	2	4	60	39

Tables A1-A3 assess the risks associated with each site and rank the risk for each category out of 100, with the lower the number being the best.

Table A2.11: 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 A2.12: 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 A2.13: 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**

Appendix B

Table B12: Initial estimated energy generation with interpolated flow values at 5% of the year (18.25 days) and estimated output based on Voith's SteamDiver hydraulic curves.

Days	Flow	Gross Head	Gross Head	Net Head	16.95 Unit Output and Production		10.15 Unit Output and Production		Total Output and Production	
[d]	[cfs]	[ft]	[m]	[m]	[kW]	[MWh]	[kW]	[MWh]	[kW]	[MWh]
0.365	2720.2	12.55	3.83	3.67	0	0	0	0	0	0
3.285	2034.3	12.77	3.89	3.73	0	0	0	0	0	0
5.475	1656.5	12.87	3.92	3.76	0	0	0	0	0	0
9.125	1319.6	12.96	3.95	3.79	0	0	0	0	0	0
18.25	846.7	13.07	3.98	3.82	0	0	0	0	0	0
18.25	625.8	13.12	4.00	3.84	600	262.8	211	92.61	811	355
18.25	498.4	13.14	4.01	3.84	601	263.4	212	92.84	813	356
18.25	419.1	13.16	4.01	3.85	602	263.8	212	92.97	815	357
18.25	368.1	13.17	4.01	3.85	603	264.1	212	93.05	815	357
18.25	322.8	13.17	4.02	3.85	603	264.3	213	93.13	816	357
18.25	282	13.18	4.02	3.86	604	264.5	213	93.19	817	358
18.25	236.2	13.19	4.02	3.86	604	264.7	213	93.26	817	358
18.25	194.8	13.19	4.02	3.86	605	264.8	213	93.31	818	358
18.25	162.8	13.20	4.02	3.86	605	265.0	213	93.36	818	358
18.25	128.6	13.20	4.02	3.86	605	265.1	213	93.40	818	358
18.25	95.4	13.21	4.03	3.86	605	265.2	213	93.44	819	359
18.25	78.7	13.21	4.03	3.86	606	265.3	213	93.46	819	359
18.25	61.7	13.21	4.03	3.87	606	265.3	213	93.48	819	359
18.25	50.1	13.21	4.03	3.87	606	265.4	213	93.50	819	359
18.25	38.8	13.22	4.03	3.87	606	265.4	213	93.51	819	359
18.25	27.3	13.22	4.03	3.87	606	265.4	214	93.52	820	359
18.25	12.9	13.22	4.03	3.87	0	0	214	93.54	214	94
9.125	7.3	13.22	4.03	3.87	0	0	214	46.77	214	47
5.475	3.4	13.22	4.03	3.87	0	0	214	28.06	214	28
3.285	2.6	13.22	4.03	3.87	0	0	214	16.84	214	17
									Total Annual Generation (MWh)	5912
									Average Output (kW)	674.8
									Capacity Factor	82.34%

Table B2: All compiled capital costs for the entire project development.

Project Development Costs:	Current Prices	Adjusted Inflation Prices
Obtain FERC License	$ 200,000	$ 240,000
Project cost incurred before closing	$ 100,000	$ 120,000
Cost of Additional FERC Work?	$ 120,000	$ 144,000
Final Design Engineering Work?	$ 250,000	$ 300,000
Development Fee	$ 250,000	$ 300,000
Land and Water Rights	$ 32,000	$ 38,400
Equipment (No Warranty)	$ 78,624.00	$ 94,349
Solar Inverter (10-25 Year Warranty)	$ 19,656.00	$ 23,587
Solar Modules (25 Year Warranty)	$ 229,320.00	$ 275,184
Transmission Line Right of Way	$ 25,052	$ 30,062

Plant Procurement & Construction Costs:	Current Prices	Adjusted Inflation Prices
Site Preparation	$ 150,000	$ 180,000
Draft Tubes	$ 600,000	$ 720,000
Excavate Bedrock	$ 200,000	$ 240,000
Dewater Area of Development (Cofferdam)	$ 500,000	$ 600,000
Concrete Work (Including Rebar and Other Material)	$ 900,000	$ 1,080,000
Trash Rack and Frame	$ 375,000	$ 450,000
Turbines/Generators and Shutoff Gates	$ 2,000,000	$ 2,400,000
Switchgear	$ 300,000	$ 360,000
Log Boom	$ 50,000	$ 60,000

Control Building	$ 425,000	$ 510,000
Transformer/Station Main Breaker	$ 120,000	$ 144,000
Low Voltage Transformers	$ 900,000	$ 1,080,000
Electrical Cables (Included with Voith)	$ -	$ -
Electrical Wiring	$ 500,000	$ 600,000
Backup Power System	$ 120,000	$ 144,000
Solar Panels and Wiring	$ 1,200,000	$ 1,440,000
Solar Modules	$ 281,736.00	$ 338,083
Solar Inverter	$ 32,760.00	$ 39,312
Balance of System Equipment	$ 229,320.00	$ 275,184
Transmission Line	$ -	$ -
Grid Interconnect	$ 32,760.00	$ 39,312
Project Cost Subtotal	**$ 8,916,576**	**$ 10,699,891**

Engineer & Construction Management Costs:	Current Prices	Adjusted Inflation Prices
Engineer and Other Professional Services	$ 600,000	$ 720,000
Contingency Budget	$ 33,022.08	$ 39,626
Solar Installation Labor and Equipment	$ 117,936.00	$ 141,523
Installer Margin/Overhead	$ 163,800.00	$ 196,560
Engineering and Enviromental Studies	$ 19,656.00	$ 23,587
Engineering/Developer Overhead	$ 196,560.00	$ 235,872
Rental or purchase of cranes, pumps, and other equipment	$ 300,000	$ 360,000

Total Project Cost	**$ 11,652,202**	**$ 13,982,642**