Final Report

Illinois Institute of Technology

IPRO 343 – Technical and Market Integration of Small Hydroelectric Energy

November 30, 2006

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I. Introduction

Hydroelectric power is a type of renewable energy, in which converts the water kinetic and potential energy into electricity. Its power output is proportional to the height difference between the water level surface of upstream and downstream of a river or a dam, and also to the amount of water flow. A hydroelectric power plant consist mainly of a hydro turbine, in which converts the mechanical energy into rotational movement, the generator, in which converts the rotational movement into electricity, and the powerhouse, in which houses equipments that control the turbine and transfer energy to the grid.

It is most common in mountainous terrain where there are significant variations in height. The enormous amount of potential energy that can be obtained at no cost motivated the industry to build big dams and produce electricity in large scale. However, the idea that hydroelectric power plants could only be built in large scale, brought limited exploration of this kind renewable energy resource. Recently, the concern with the environment and with the increasing price of fossil fuels brought the attention of the industry to renewable energy sources. Technological advances in small hydro turbines have made it a feasible option. Numerous plants can be installed at low head dams across any river to supply clean and renewable energy with very low environmental impact.

II. Background

The main sponsor of this project is Dr. Alexander Tseng who is a pioneer on bringing hydro turbines, generators, switchgears and computer controls from China to America in order to develop highly-efficient and low-costing hydroelectric power plants. He believes that the low head hydroelectric industry has not yet been exploited as it should have in the United States. He compares 2,000 small low head hydroelectric plants operating in China with an approximated 100 in the United States to stress the point of how this kind of energy is not well explored in this country. Dr. Tseng is also highly convinced that small hydro industry is the answer to what USA, and other countries, have been looking for to prevent pollution and at the same time to keep up with the daily increasing demand of clean and renewable energy.

It is his goal to introduce IIT as a pioneer in building small hydroelectric plants in US, and the Fox River was pointed out as the starting point of this challenge. When planning a small hydroelectric plant, the economical, technical and environmental feasibility of the project is crucial. Basically, the revenues from energy selling must pay off the investment cost after a certain period, considering operational and maintenance costs. In addition, the power plant must observe the power connection standards and local grid limitations, and also the permitting process. Generally, investors look for projects that have a small pay-back period. In order to face this problem, this IPRO looks forward to design an efficient small hydro system. The siphon technique is explored, in which makes possible placing the penstock over the dam, improving the head and avoiding major dam modifications.

A small hydro system that has siphon intake can be found in the city of Kankakee, IL.

This small plant has 3 siphon turbines with a power capacity of 400 kW each, and a total output of 1.2 MW. This power plant delivers power to the water treatment plant situated two miles away. During certain times of the year the flow of the river is very large and more energy than the treatment plant requires is produced. This gives the opportunity to deliver the renewable power to the city of Kankakee and also to generate revenue.

There has been a history of attempts to build small hydroelectric plants on the Fox River, however they ended up failing. From IPRO 319, on spring 2006, we acknowledged that the American Hydro Company (AHC) made a feasibility study to build a low head hydro in the Elgin Dam, but their results showed a very high investment cost, almost 5.2 million dollars. The hydro turbine alone was quoted almost 1.3 million dollars. This led to the conclusion that the project was not economically feasible. This IPRO thinks that the reason of such high costs is because they approached the project with standard procedures of building large-scale hydroelectric plants.

III. Project Purpose & Objective

The main objectives of this IPRO are to design a two million dollars low-head hydroelectric power plant on an existing dam on Fox River and evaluate the technical, market and environmental impacts. From the IPRO 319 results we focus on two locations in Fox River, IL: Elgin Dam and Stolp Island East Dam.

IV. Research Methodology

After brainstorming in the beginning of this semester, we concluded that in order to approach these problems a research should be carried on four subjects: Site Evaluation; Economic Feasibility; Long-Term Assessment and Project Requirements. The results from researching these topics help to successfully organize and conduct the work throughout the semester.

A. Site Evaluation

This research focused on reviewing the suggested sites on the IPRO 319 Final Report. The reason for reviewing their work is because in their evaluation they considered the dam height as being the dam head, as Dr. Tseng pointed that out before this IPRO started. New calculations were then performed, dimensions were obtained from dam blueprints and mapping softwares, such as Google Earth, environment and other zoning requirements were investigated, among others. In addition, field trips were organized throughout the semester to obtain a more realistic evaluation, decide where the hydro system would be better located and also to experience from fact of just being at the site. Pictures and videos were taken during these field trips, in which provided good material for the deliverables. During this semester the results obtained from this research topic were very important for the overall performance of this project.

B. Economic Feasibility

In order to identify the best dam from the cost-benefit angle, our group pursued the following path. First, our IPRO team obtained technical and historical data from each dam by public documents and field trips to the most promising locations. Second, experts were invited to present their experiences in the area of hydropower. Inputs from relevant individuals involved with the Dayton facility were obtained. Third, actual the dam physical conditions, potential power production by dam, and feasibility of combining the existing dam with modern generators and turbines available in the market were collected. In order to calculate the accurate annual energy delivered by the small hydro unit, we firstly obtained the hydrology information. Then, the annual energy production and plant capacity was determined. Other parameters such as turbine type and penstock dimensions were also chosen at this point. Furthermore, in order to perform the economic feasibility, some parameters such as operational and maintenance costs, auxiliary equipment cost, installation costs of power transmission lines and a small power station had to be researched. Most parameters were calculated by RETScreen, in which is a software that deals with feasibility assessment for the development of renewable energy. It was designed by Natural Resources of Canada (CANMET) along with National Aeronautics and Space Administration (NASA) and United Nations Environment Program (UNEP). In addition, relevant financial indicators, including the net present value, year-to-positive cash flow and simple payback period, were investigated and a sensitivity and risk analysis was performed to measure the uncertainty of this project. All the results from this research were essential to this IPRO.

C. Long-Term Assessment

This research topic was to assess the long-term impacts of the proposed designs. In other words, this research was responsible for investigating all possible impacts that a small hydro system would bring to the environment, to the community and to the power market, among others. First, after the team decided the sites the members involved with this research visited the dams to observe the environment, to take photos and additional information about the fishes that inhabit the Fox River. These data became very important references in analyzing the environmental impact. Then, the general structure of the hydro system was studied carefully in order to evaluated and minimize the visual impacts, mortality of fishes caused by the turbine, and the release of unwanted substances in the river. Towards the end of the semester this research focused on the following: noise, wildlife, water quality and recreational effect, in which are the major effects that we found to be the most relevant. The results led to: an improved design, having a very low visual impact; use of biodegradable materials in the operation and maintenance of the turbine, such as using water to seal the turbine as in Kankakee Power Station; application of noise reduction materials on the interior of the power house, among others.

D. Project Requirements

This topic had the objective to manage the team, delegating and dividing various responsibilities among the team members, revising their work and giving important inputs, finding relevant research material, among other project requirements. For example, in order to properly design the hydro system several articles, books, brochures, reports were searched and the most important were shared with the team. In addition, some experts, professors and engineers contacted to help and to share experiences. For the research about Siphon turbines and its application, recently articles written in China, which utilize this kind of technology, were provided by Dr. Tseng and translated to English by Dr. Zuyi Li. These articles gave an insight of how the siphon structure must be calculated in order to have high efficiency. Based in that knowledge we proceeded to design the structure following specific parameters. In addition, knowing fluid mechanics was critical for the progress of the designing process. Several books about this matter were reviewed and discussed with Dietmar Rempfer, faculty of the Mechanical Engineering Department at IIT. The members involved with this research were then able to calculate theoretically the effective head losses in our designs. In addition, a visit to the city of Kankakee was necessary, in order to learn about the operation and maintenance of siphon units. During this visit on November 22, 2006 Engineer Peter A. Schiel (assistant Superintendent Utility of operations at the city of Kankakee) gave the team members valuable information about the type of equipment and the type of problems they have been confronting since 1991 when the construction begun. With this visit we had a better idea of the equipment sizes, the auxiliary structures and equipment that a small hydro requires. We decided to use AutoCAD software to draw the designs in scale. In order to have a professional presentation of our designs the members had to research and learn advanced AutoCAD drawing techniques. Two and three dimensional drawings were used to describe in a visual manner the preliminary and conceptual designs with real proportions.

V. Team Organization and Assignments

The organization of the project required one main structure that has three sub-teams and individual works were given based on the projects task needs. At the beginning of the semester, the team worked as one team to discuss and put the ideas together. Starting from the 8th week of class, our team composed with three sub-teams with managers. First, the list below displays the sub-teams and their members along with each sub-team's tasks.

A. Team Management

Members:

- Team Leader: Choe, Hyung
- Assistant: Abreu, Lisias

Assignments:

- Managed team schedule and tasks
- Provided research material and teaching classes

- Organized sponsor visit and technical tours
- Revised reports, minutes, slides, etc.
- Managing derivables
- Coordinating IPRO Day

B. Design Sub-Team

Members:

- Leader: Burgos-Lopez, Mauricio
- Assistant: Abreu, Lisias
- Assistant: Ha, Sooyoung
- Assistant: Lee, Chi Hwan

Assignments:

- Provided principles for the power plant structure design
- Analyzed and optimized the penstock to minimal losses
- Performed the preliminary 3D models and the complete 2D design
- Analyzed constraints of generator positioning, penstock shape
- Visited the Elgin Dam and Stolp Island Dam to collect more information
- Visited the Kankakee Power Station to know about their project and experience

C. Marketing Sub-Team

Members:

- Leader: Liu, Cong
- Assistant: Wu, Lei
- Assistant: Wang, Jianhui

Assignments:

- Simulated the ComEd power system including the small-hydro units
- Analyzed the impacts on the existing power system
- Analyzed the estimated energy production
- Researched on grants and tax credits.

D. Environment Sub-Team

Member:

- Leader: Song, Chang
- Assistant: Abreu, Lisias

Assignments:

- Researched on the permitting process
- Investigated the environmental impacts
- Provided solutions to reduce the negative impacts

E. Additional Tasks

Tasks:

- Time Keeper: Choe, Hyung
- Master Schedule Maker: Choe, Hyung

- Agenda Maker: Abreu, Lisias
- Minute Taker: Song, Chang
- Weekly Report: Ha, Sooyoung

VI. Obstacles

The greatest obstacle of our IPRO was time management. The time spent by our team was not enough to perform all the tasks and to obtain the desired results. Most members were not able to manage their agenda as the time required to perform each task increased throughout the semester. Firstly, we think that some IPRO's have potential to be an EnPRO, for example this IPRO. More accurate results would be obtained if we had members working on this project as interns. Secondly, the objectives and desired results were not very clear in the beginning. Our team has the impression that the sponsor had a very clear and straight objective for this project. However that objective was not presented fully to our team and relevant research material provided by the sponsor previously was not properly made available. Hence, we did a significant amount of work, which at the end did not affect the final results. For a future IPRO, a meeting with the sponsor at the very beginning would be more useful, making the time and task management very efficient, than a meeting at the end.

A. Marketing Team

Some obstacles were encountered while completing the planned tasks for the marketing team. There was lack of solid data, such as equipment cost, daily flow rate, required residual flow over dams on Fox River, to assess the financial feasibility with more accuracy. Other obstacle faced was the difficulty to evaluate the reliability and accuracy of data found on the internet or other sources. This sub-team resolved these obstacles through seeking for more sources the data and discussing with experts. For instance, there is not a gauge station at Elgin Dam and we had to interpolate data from two gauge stations. In additional we met with our sponsor Dr. Tseng, who has abundant experience on building small hydroelectric facilities all over the world, only at the end of the semester. His experience would give our sub-team very good suggestion in the beginning of this IPRO. Finding all the required permits was another obstacle. Some of them are well know, but there are some local permitting process that will only be known during the implementation phase.

B. Design Team

Several obstacles were encountered while completing the planned summary tasks for the design team project. Firstly, the members of our team were not familiar with small hydro concepts and technical aspects of a real design. There are many unknown dimensions on the chosen dams and hydro systems. The last was very complicated to determine since the penstock sections have to comply with the site dimensions. In order to resolving these obstacles the following solutions were taken: related information about the dams and small hydro systems were studied; the turbine data and geometry of the turbines were obtained from our sponsor, Dr. Tseng; softwares such as Mat-lab, C++, and Excel were used to optimize the design of the siphon. Our team should have spent more time in the beginning learning about the fluid mechanics in small hydro systems.

C. Environment Team

Mainly two obstacles were encountered while completing the planned summary tasks for the environment team. In the beginning of this IPRO, we were unable to find information of impacts of installing a hydro system at low-head dams that are already built. Most documents about the environmental impacts are meant for large hydro systems and finding relevant material was not easy. After discussing with the team about these obstacles, we received important inputs that helped us focusing on the problems more than trying to find out a resource that would provide all the needed information.

VII. Results

This IPRO studies the technical design and market integration of small hydroelectric energy, which is renewable and emission free. Large-scale hydroelectric plants require large dams, high civil cost, and huge investment. The IPRO approach to utilizing hydroelectric energy is through small-scale plants, which require small investment and have minimum adverse environmental impacts. The objective of this IPRO is to demonstrate the advantages of small hydro application via the design of small hydro plants at the existing dams on the Fox River. Two candidate sites (the Elgin Dam and the Stolp Island East Dam) are selected based on a previous study. Three sub-teams including marketing team, design team, and environment team approach the same objective from market integration, mechanical design, and environmental assessment perspectives. For more detailed information see the attached technical report.

The marketing team performed feasibility studies using RETScreen, a software developed by the Canadian government. The studies are based on various factors including dam gross head (7.2 feet for Elgin and 7 feet for Stolp Island East), flow duration curves, electricity price (5.1 cents per kilowatt-hour), equipment and construction costs (approximately 2 million dollars), and applicable government grants (1 million dollars) and tax credits (0.9 cents per kilowatt-hour). Studies show that small hydro projects on both candidate sites are profitable. The Elgin project will have a design flow of 1237 cubic feet per seconds, a maximum plant output of 566 kilowatts, and annual energy production of 3,071,000 kilowatt-hours. The Elgin project will have a net present value of $274,234 with simple payback year of 12.5 years and year-to-positive-cash-flow of 6.5 years. The Stolp Island East project will have a design flow of 992 cubic feet per seconds, a maximum plant output of 630 kilowatts, and annual energy production of 3,502,000 kilowatt-hours. The Stolp Island East project will have a net present value of $518,807 with simple payback year of 9.9 years and year-to-positive-cash-flow of 4.1 years. The marketing team also performed sensitivity analysis to study the impact of various uncertainties including electricity price, design flow, and government grants. The results show that the profitability of both projects is guaranteed considering those uncertainties. The impact of the small hydro projects on power market is also studied by the marketing team using a security-constrained unit commitment software developed by the power group at IIT. The results show that with a capacity less than 1,000 kilowatts, both projects will have negligible impacts. However, massive application of similar projects will have detectable impacts.

The design team studied the available information of both sites, including blueprints (for Elgin only), dam configurations, and dam dimensions. To minimize the dam modifications and also to reduce the civil work costs, the design team proposed the application of siphon technique for the Elgin project. Applying the theory in fluid mechanics, the design team investigated different cross-section shapes and dimensions in order to firstly ensure the operation of the siphon and furthermore to reduce the weight on the top of the dam, to minimize head losses, and to trim down the required civil work. Two options were applied to reduce the water head loss and improve the efficiency. The first option is to use a vacuum pump connected to the highest point of the siphon. The second option is to apply rubber dam technique (spillway gates controlled by air bladders) to improve the net head and to control the river flow. The siphon technique was initially also proposed for the Stolp Island project. However, after discussing with engineers from the City of Aurora, the design team concluded that the siphon design would be practically infeasible due to visual impact and instead proposed the use of compact bulb turbine technique. The design team completed the preliminary designs for both projects using AutoCAD. Three views are available for each site including section view, top view, and site view.

The environment team evaluated both positive and negative impacts of the small hydro projects on local environment. On the positive side, with the implementation of the proposed small hydro projects, we could reduce 1,690,000 lbs of carbon dioxide emissions, 3,330 lbs of sulfur dioxide emissions, 1,030 lbs of nitrogen oxide emissions, and 36,000 MBTU of fossil fuel usage. On the negative side, the projects will have temporary impact on water quality, recreational activities, and traffic. The temporary noise impact during the construction is expected to have a direct effect to the surrounding environment within a radius up to 300 feet, including strollers, wildlife, library (Elgin), casino (Stolp Island East), and nearby residents. Low revolution of small hydro turbine would minimize the harm to the fishes inhabiting the area. Mortality of the fishes can be further reduced by installing a fish screen in addition to the trash rack.

VIII. Conclusion

This IPRO has achieved the goal of designing low-head small hydro projects at Elgin and Stolp Island East that are economically profitable, technically efficient and feasible, and environment friendly. This IPRO could be a starting point of a massive application of small hydro in the state of Illinois and around the country. Possible future work include communicating this project to the general public and seeking political support, learning the permitting process and applying for grants, contacting manufacturers and contractors to obtain more accurate price quotation, and obtaining more detailed site dimensions and fine-tuning the technical designs. We envision the continuation of this IPRO with an EnPRO for actual implementation.

IX. Acknowledgements

IPRO 343 would like to thank the following individuals for their contribution to our work:

- Dr. Alexander Tseng” Sponsor of this IPRO
- Dr. Mohammad Shahidehpour: Chairman of the ECE department
- Dr. Zuyi Li: Assistant Professor of the ECE department
- Peter Schiel: City Engineer, Kankakee IL
- Dan Feltman: New Development Coordinator, Aurora IL

Technical Report

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I. Abstract

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The design team studied the available information of both sites, including blueprints (for Elgin only), dam configurations, and dam dimensions. To minimize the dam modifications and also to reduce the civil work costs, the design team proposed the application of siphon technique for the Elgin project. Applying the theory in fluid mechanics, the design team investigated different cross-section shapes and dimensions in order to firstly ensure the operation of the siphon and furthermore

to reduce the weight on the top of the dam, to minimize head losses, and to trim down the required civil work. Two options were applied to reduce the water head loss and improve the efficiency. The first option is to use a vacuum pump connected to the highest point of the siphon. The second option is to apply rubber dam technique (spillway gates controlled by air bladders) to improve the net head and to control the river flow. The siphon technique was initially also proposed for the Stolp Island project. However, after discussing with engineers from the City of Aurora, the design team concluded that the siphon design would be practically infeasible due to visual impact and instead proposed the use of compact bulb turbine technique. The design team completed the preliminary designs for both projects using AutoCAD. Three views are available for each site including section view, top view, and site view.

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II. Mechanical Design

Most existing dams on Fox River have several decades and their current structural condition is relatively hard to evaluate. In addition, the blueprints that show the dam construction type can hardly be found. With this in mind, the design proposed here uses the siphon technique in order to minimize the dam modifications and also to reduce the civil work costs. Different cross sections shapes and dimensions were designed in order to firstly ensure the operation of the siphon and furthermore to reduce the weight on the top of the dam, to minimize head losses, and to trim down the required civil work, among others. Rivers with low slope, like the ones in Illinois, make the difference of upstream and downstream elevations not very significant. One other attribute of the siphon is that for it can improve the net head. In addition, the net head can also be improved with a rubber dam, in which can be inflated controlling the river flow over the dam.

1. *Siphon*

A. Basic Principles

A siphon is a continuous tube that allows liquid to be drained from an upper reservoir through an intermediate point that is higher than both reservoirs. Theoretically, the flow is driven only by hydrostatic pressure without any need for pumping. In practical systems, a vacuum pump in the highest intermediate point is required to remove the unwanted gas formations and maintain the siphon operation. It is also necessary that the final end of the tube be lower than the liquid surface in the upper reservoir as shown in figure 1.

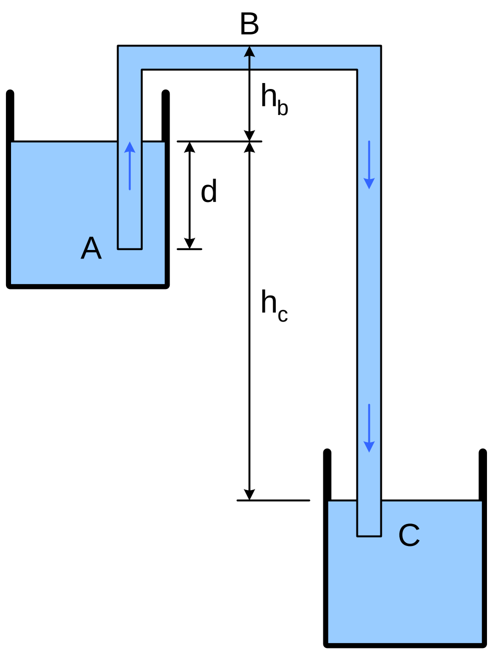

Fig. 1. The siphon principle

A siphon turbine has certain physical and geometrical characteristics, in which determine its proper working conditions. Hence, the preliminary stage of designing the siphon intake has to be considered carefully and be well calculated. We present here a design that complies with the minimum criteria shown and explained in [1]. The results shown here are considering ideal conditions, and the implementation of such design is not advisable without physical small scale model and further mathematical calculations assuming different scenarios.

B. Theory

Once started, a siphon requires no additional energy to keep the liquid flowing up and out of the reservoir. The siphon works because the ultimate drain point is lower than the reservoir and the flow of liquid out the drain point creates a partial vacuum in the tube such that liquid is drawn up out of the reservoir.

The maximum height of the intermediate point (the crest) is limited by atmospheric pressure and the density of the liquid. At the high point of the siphon, gravity tends to draw the liquid down in both directions, creating a partial vacuum. Atmospheric pressure on the top surface of the higher reservoir is transmitted through the liquid in the reservoir and up the siphon tube and prevents a vacuum from forming. When the pressure exerted by the weight of the height of the column of liquid equals that of atmospheric pressure, a partial vacuum will form at the high point and the siphon effect is ended. For water at standard pressure, the maximum height is approximately 10 m (33 feet); for mercury it is 76 cm (30 inches).

C. Body optimization

First of all, we have to list some common aspects that have to be taken into account for a reasonable design:

- The transitions from different geometries must be as smooth as possible.
- The cross sectional area should be circular in order to optimize the fluid mechanics.
- The cross sectional area in the main elbow at the siphon intake should have the same diameter
- The ratio between the curvature radius and the pipe diameter should be greater than 2.

One of the critical parts of the design is the siphon intake. Following the parameters one of the biggest losses in the design comes from bends. If the fluid mechanical losses are greater than the head available at the existing dam, the siphon will not work. Hence, we optimize its shape.

For the loss coefficient at the bends we have the following equation.

$$\zeta_b = \zeta_{10^6}\left(\theta, R/D_n\right) \times \beta_{\mathrm{Re}} \times \beta_f \times \beta_{L2} \tag{1}$$

where, θ is the curvature angle, R is the curvature radius and D_n is the pipe diameter. ζ_{10^6} is the loss coefficient when the Reynolds number $\mathrm{Re} = 10^6$, or basic loss coefficient. β_f is the ratio of the rough pipe friction coefficient f_r to the smooth pipe friction f_s coefficient considering that all tests are performed for smooth pipes (using Moody chart). In general, $\beta_f = 1.4$. $\beta_{\mathrm{Re}} = 1.0$ when $Re \neq 10^6$. The ratio between the curvature radius and the pipe diameter should be greater than 2. A reasonable design should have $R/D > 1.5$. With this relationship, we are able to find the optimal body of the siphon intake.

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Fig. 2. $\zeta_{10^6}\left(\theta, R/D_n\right)$ curves

In figure 3 we can see a preliminary design, which was thought taken into account the basic design criteria and the relation described in fig 2.

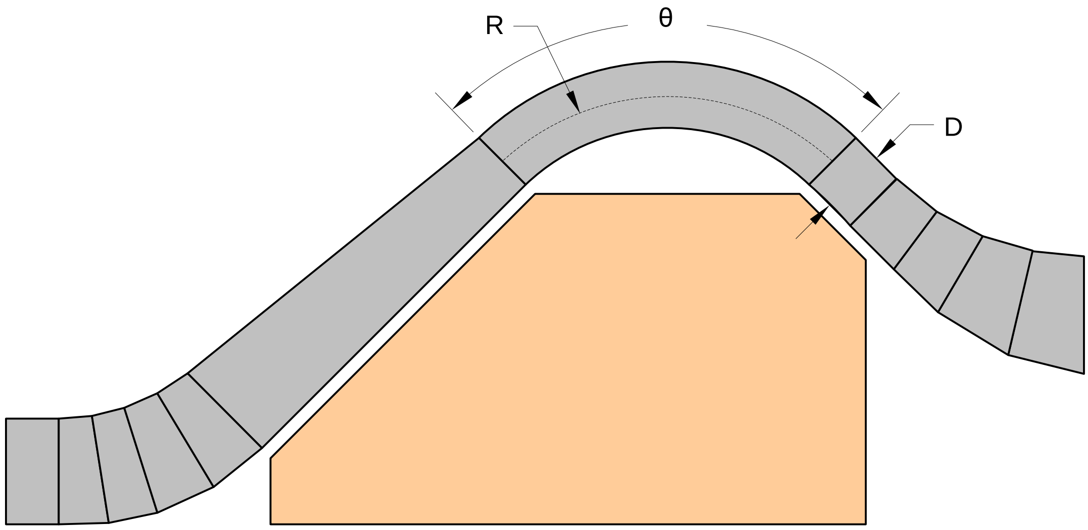


Fig. 3. Preliminary siphon design

When obtaining the values of the curvature radius, curvature angle and diameter of each part of the siphon design we must look for the lowest loss coefficient in figure 2 in order to minimize the losses.

2. Theory of fluid mechanics

Fluid mechanics is the science that studies the static and the dynamics of compressible and incompressible fluids. One of the principles of fluid mechanics for is that they have better mechanical behavior when they flow throw circular cross-area pipe. That is the reason our design has circular cross sectional area in order to avoid unnecessary losses. Here some of the basic equations that were applied to study the head loss which is the major concern in the design of the siphon body are briefly explain and used to estimate it.

First of all the head lost is the loss in potential energy. One way to understand that 1 ft head loss means is to imagine that the potential energy that the fluid had in the beginning is decreased by the head loss because the high has been decreased by friction effects.

A. Bernoulli Equation

A non-turbulent, perfect, compressible, and barotropic fluid undergoing steady motion is governed by the Bernoulli Equation:

$$V^2 2g + z + \tilde{P}g = C \text{ (streamline)} \quad (2)$$

where, g is the gravity acceleration constant (9.81 m/s ^{2} ; 32.2 ft/s ^{2}). V is the velocity of the fluid, z is the height above an arbitrary datum, C remains constant along any streamline in the flow, but varies from streamline to streamline.

If the flow is "irrotational" (fluid flow has no rotational component), then C has the same value for all streamlines. The function is the "pressure per density" in the fluid, and follows from the barotropic equation of state. For an incompressible fluid, the function simplifies to p/ρ , and the incompressible Bernoulli Equation becomes:

$$V^2 2g + z + p\rho g = C \quad (3)$$

B. Reynolds Number

In fluid mechanics, the Reynolds Number (Re) is the ratio of inertial forces ($v_s \rho$) to viscous forces (μ/L) and is used to determine whether a flow will be laminar or turbulent. It is the most important dimensionless number in fluid dynamics and provides a criterion for determining dynamic similitude. When two similar objects in perhaps different fluids with possibly different flow rates have similar fluid flow around them, they are said to be dynamically similar

C. Roughness

The roughness is a measurement of small-scale variations in the height of a physical surface of pipe, and it varies for each type of material. However, even if the smoothest type of material is used in for the pipes, it will be worn away during several years. Therefore we choose a mean value of roughness $\varepsilon = 0.000158$.

D. Viscosity

Viscosity is the resistance of a material to change its form. This property can be thought of as an internal friction. We assumed viscosity of pure water, therefore we neglect the dirt in the water, where $\nu = 1.58 * 10^{-9}$ ft ^{2}/s .

E. Other variables

The other terminology used in this design is introduced here.

D = diameter of pipe
L = total pipe length
V = velocity of flow given
P_1, P_2 = pressure at water surface and outlet
$z_1 - z_2$ = Difference of height between water surface and outlet
f = friction factor given by the Moody chart
H_{major} = major loss, head loss or pressure loss due to friction in ducts, pipes and tubes

F. Equations

Solving the equations we have:

$$\frac{P_1}{\rho}+\frac{V_1^2}{2}+g\times z_1=\frac{P_2}{\rho}+\frac{V_2^2}{2}+g\times z_2+g\times H_{\mathrm{major}} \tag{4}$$

where,

$$H_{major}=f\times\left(\frac{L}{D}\right)\times\left(\frac{V^2}{2g}\right) \tag{5}$$

$$\frac{V^2}{2}=g\times(z_1-z_2)-f\times\left(\frac{L}{D}\right)\times\left(\frac{V^2}{2g}\right) \tag{6}$$

$$\frac{1}{\sqrt{f}}=-2.0\times\log\left(\frac{\varepsilon}{D\times 3.7}+\frac{2.51}{\mathrm{Re}\times\sqrt{f}}\right) \tag{7}$$

where,

$$\mathrm{Re}=\frac{VD}{\upsilon} \tag{8}$$

$$\frac{1}{\sqrt{f}}=-2.0\times\log\left(\frac{\varepsilon}{D\times 3.7}+\frac{2.51\times\upsilon}{V\times D\times\sqrt{f}}\right) \tag{9}$$

3. Design results

Firstly we divided the siphon design in different sections. For each section the fluid velocity and the friction factor were obtained using the EES software, ME Dept, IIT. The preliminary designs tested had the total head loss varying from more than 100% to 20%. There are two options that can reduce the total head loss to standard values, varying from 7% to 5%.

The first option is to use a vacuum pump connected to the highest point of the siphon. This system is able to remove all unwanted gas formations that get trapped in the top of the upper elbow, reducing the efficiency of the siphon. This improved pressure in the siphon result in an extra head, from the upstream water surface to the top of the siphon. In the Kankakee Power Station, the vacuum pump improves the head in about 3 ft. The other option is to introduce a system to control the river flow. This second option is described in the next section.

The final siphon intake is applied at Elgin Dam but not at Stolp Island East Dam. During this semester, we met with the engineers from Aurora City to discuss the possibility of installing a hydro system with a siphon intake at Stolp Island East Dam. We concluded that a siphon intake at Stolp Island East is not feasible due to the visual impact, but they are still very interested in having a hydro system and they look forward for an alternative design. Therefore, we performed the head loss calculations, considering the penstock without a siphon and contouring the dam on the east side.

After considering the two options for improving the net head in our calculations and the total head loss could then be reduced to approximately 5%. The final designs for both locations are show in the next figures, and also in the Appendix.

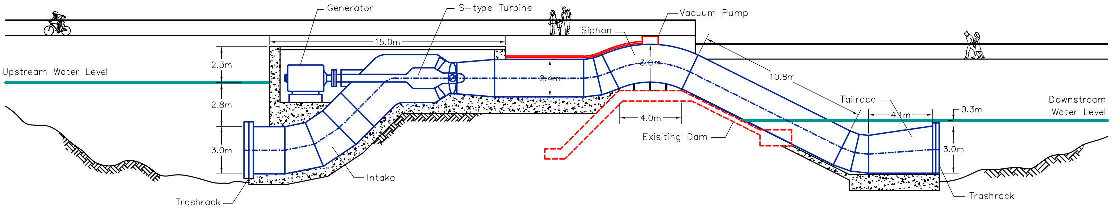


Fig. 4. Small Hydro Design at Elgin Dam: Section View

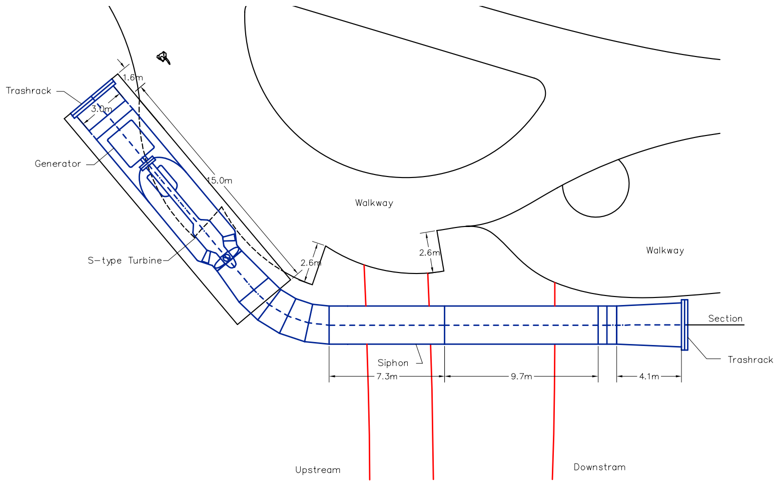


Fig. 5. Small Hydro Design at Elgin Dam: Top View

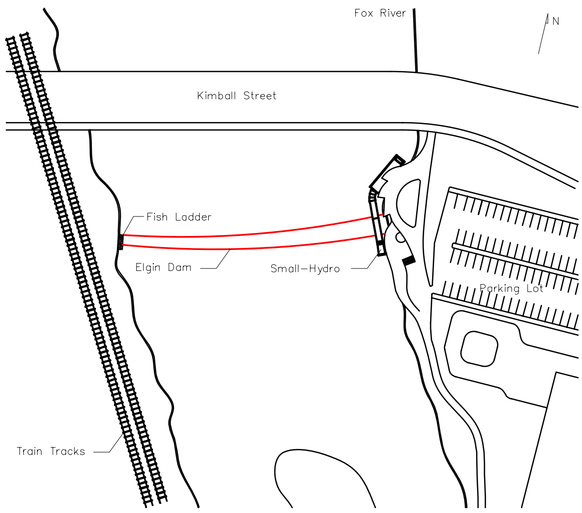


Fig. 6. Small Hydro Design at Elgin Dam: Site View

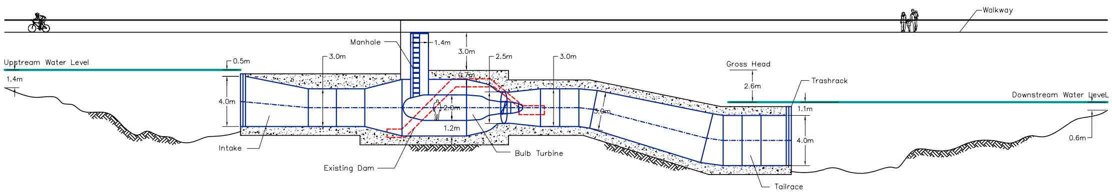


Fig. 7. Small Hydro Design at Stolp Island East Dam: Section View

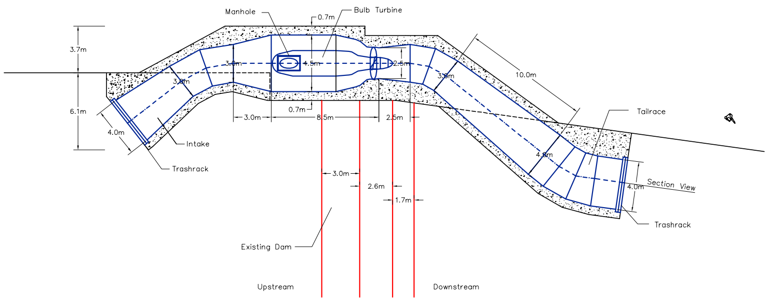


Fig. 8. Small Hydro Design at Stolp Island East Dam: Top View

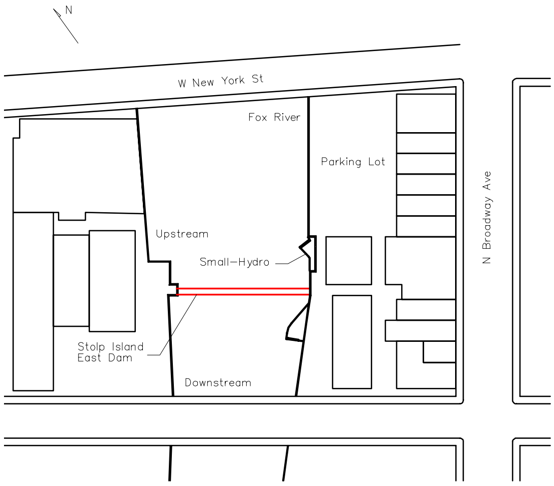


Fig. 9. Small Hydro Design at Stolp Island East Dam: Site View

4. River flow control

A minimal flow over the dam, or residual flow, is required by FERC for most small hydro projects on existing dams. The ability to control the river flow, allowing the all the possible flow to pass through the turbine, represents the maximum energy production by the hydro system. There are several ways to control a river flow, but we look for the ones that have low environmental impact, low maintenance, good aesthetics, and a simple and low cost construction. Two technologies meet these requirements: Rubber dams and spillway gates controlled by air bladders.

Rubber dams are long tubular-shaped fabrics placed across channels, streams and weir crest to raise the upstream water level when inflated. They are used to divert water for irrigation, for raising existing dams and for flood controls. Inflatable dams can be filled with water, air or both.

Rubber dams or spillway gates controlled by air bladders should be considered in order to improve the net head of any small hydro projects, and also to control the river flow.

A. Examples

In figures 5 and 6 the construction and operation of a rubber dam is shown. Water and/or air can be used to fill the rubber dam. The inflation and deflation can be manual or automatically controlled. The automatic control system can monitor the upstream water level and adjust the air pressure in the dam to maintain a prescribed water level in the upstream pool. Although, the engineers from Kankakee Power Station preferred to use spillway gates controlled by air bladders. They said that in practice rubber dams are not recommended to operate on intermediate air pressure levels.

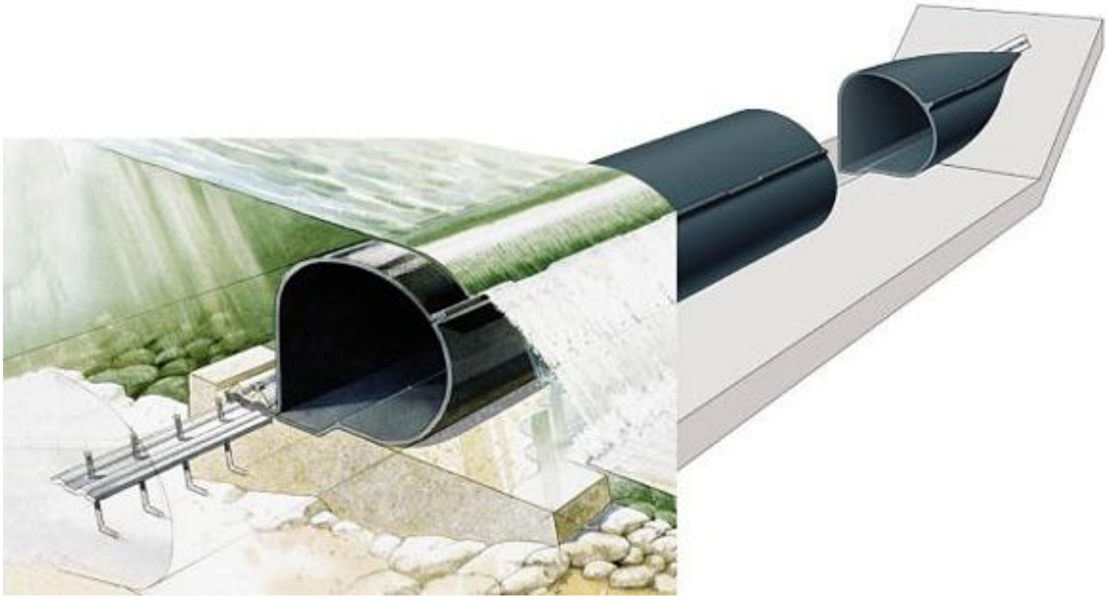


Fig. 10. Construction of rubber dam (Source: Bridgestone, 2003)

(a) deflated (b) inflated

Fig. 11. Operation of a rubber dam (Source: Bridgestone, 2003)

(a) deflated (b) inflated

Fig. 12. Spillway gates controlled by air bladders (Source: Obermeyer, 2005)

In figure 6 spillway gates controlled by air bladders are shown. These differs from a rubber them because it has a more accurate control, modular design, and the steel gate panels overhang the air bladder in all positions, protecting the bladder from floating logs, debris, ice, etc.

B. Rubber Dam Manufacturers:

Qingdao Clear Sea Environmental Technologies Co., Ltd.
601 Qing Shan Road, Qingdao, Shandong, China, 266100
Mr Wang An, Tel : 86 532 7623210, Fax: 86 532 762321, Cel: 13864853051
http://www.rubberdam.net/

Bridgestone Industrial Products America, Inc.
155 West 72nd Street, Ste 407, New York, NY 10023, U.S.A.
Tel: +1-212-496-1487, Fax: +1-212-496-1542, E-mail: racbepy@bway.net
http://www.bridgestone.co.jp/english/diversified/rubberdam/

Mason Bilafer Partnership
30/6 Grimston Gardens. Folkestone, Kent CT20 2PX, United Kingdom
Tel: (44) 1303 254241, Fax: (44) 1303 220664,
E-mail: enquiries@masonbilafer.com
http://www.masonbilafer.com/

Dyrhoff
Industrigaten 14, 2406 Elverum
Tel: 62 42 84 44, Fax: 62 42 84 45, Org. nr: 986 377 735 MVA
Bjørn Lunner, Project Engineer, bjorn.lunner@dyrhoff.no
http://www.dyrhoff.no/en-vannkraft.html/, http://www.sumigate.com/

Obermeyer
P.O. Box 668, Fort Collins, CO, 80522
Email: hydro@obermeyerhydro.com
Tel: 970-568-9844 Fax: 970-568-9845
http://www.obermeyerhydro.com/

III. Power Market Impact

1. SCUC Model

All modern power systems are managed by an Independent System Operator (ISO). The state of Illinois is operated by two ISO's: Midwest and PJM. The northeast portion of Illinois is served by ComEd, in which is under the PJM administration. In order to maintain the reliable operation of the power system, PJM evaluates all the power market transactions and determines a secure state of operation. In the day-ahead market, the commitment of generating units, their power dispatch and the electricity prices throughout the system are settled one before of the real operation. We use Security-Constraint Unit Commitment model [2-18] to analysis the impacts of small hydro in the existing power system, in which the same methodology is used by PJM. Here, the objective function of SCUC is to minimize total operation cost, as shows equation 1. The first part refers to the system energy production cost and the last two refer to startup and shutdown costs of generating units.

$$Min \quad \sum_{i=1}^{NG}\sum_{t=1}^{NT}\left[F_{ci}(P_{it})*I_{it}+SU_{it}+SD_{it}\right] \tag{1}$$

The set of constraints are: the system power balance,

$$\sum_{i=1}^{NG}P_{it}*I_{it}=P_{D,t}+P_{L,t} \qquad (t=1,\cdots,NT) \tag{2}$$

the system spinning reserve and operating reserve requirements,

$$\begin{aligned}&\sum_{i=1}^{NG}R_{S,it}*I_{it}\ge R_{S,t}\\&\sum_{i=1}^{NG}R_{O,it}*I_{it}\ge R_{O,t} \qquad (t=1,\cdots,NT)\end{aligned} \tag{3}$$

ramping up and down constraints,

$$\begin{aligned}&P_{it}-P_{i(t-1)}\le[1-I_{it}(1-I_{i(t-1)})]UR_i+I_{it}(1-I_{i(t-1)})P_{i,\min}\\&P_{i(t-1)}-P_{it}\le[1-I_{i(t-1)}(1-I_{it})]DR_i+I_{i(t-1)}(1-I_{it})P_{i,\min}\\&(i=1,\cdots,NG)\ (t=1,\cdots,NT)\end{aligned} \tag{4}$$

minimum up and down time constraints,

$$\begin{aligned}&\left[X_{i(t-1)}^{on}-T_i^{on}\right]*\left[I_{i(t-1)}-I_{it}\right]\ge 0\\&\left[X_{i(t-1)}^{off}-T_i^{off}\right]*\left[I_{it}-I_{i(t-1)}\right]\ge 0\\&(i=1,\cdots,NG)\ (t=1,\cdots,NT)\end{aligned} \tag{5}$$

real power generation limits,

$$P_{i,\min} I_{it} \leq P_{it} \leq P_{i,\max} I_{it} \quad (i = 1, \cdots, NG)\ (t = 1, \cdots, NT) \tag{6}$$

and fuel consumption and emission allowance constraints,

$$F_{FT}^{\min} \leq \sum_{t=1}^{NT} \sum_{i \in FT} \left[F_{fi}(P_{it}) * I_{it} + SU_{f,it} + SD_{f,it} \right] \leq F_{FT}^{\max} \tag{7}$$

$$\sum_{t=1}^{NT} \sum_{i=1}^{NG} \left[F_{ei}(P_{it}) * I_{it} + SU_{e,it} + SD_{e,it} \right] \leq E_S^{\max} \tag{8}$$

In addition, network security constraints include transmission flow constraint (9), phase shifter angles limits (10), tap changing (11) and phase shifting transformer setting (12):

$$-PL_{l.\max} \leq PL_{l,tp}^{s}(\mathbf{P_t}, \boldsymbol{\gamma_t}) \leq PL_{l,\max} \quad \forall l, \forall t \tag{9}$$

$$V_{b,\min}^{t} \leq V_{b}^{t} \leq V_{b,\max}^{t}\ (b = 1, \cdots, NB)\ (t = 1, \cdots, NT) \tag{10}$$

$$\mathbf{T_{min}} \leq \mathbf{T}^{t} \leq \mathbf{T_{max}} \quad (t = 1, \cdots, NT) \tag{11}$$

$$\boldsymbol{\gamma_{min}} \leq \boldsymbol{\gamma_t} \leq \boldsymbol{\gamma_{max}} \qquad \forall t \tag{12}$$

The electricity prices at all buses are obtained from the cost of the marginal generating unit when there is no power flow congestion in the transmission lines. This global electricity price is also called Market Clearing Price (MCP). In case where the capacity of transmission lines are not enough to transfer the energy from one location to another, different electricity prices will happen throughout the system. Basically, the locations who cannot receive power from the lowest cost generating unit due to transmission congestions will have a higher electricity price. In PJM, in which includes ComEd's power system, the electricity prices when there is congestion are calculated based on the Locational Marginal Prices (LMP). The LMP's can be calculated as Lagrangian multipliers of constraint (2), and MCP's can be got with results of Unit Commitment (UC) and Economical Dispatch (ED).

We suppose 1 MW small hydro is built at Elgin Dam, and this amount of energy is connected to TDC-570 ELGIN bus, as shows in the following figure. We model this unit as being a negative load of 1 MW connected at TDC-570 ELGIN. We performed the same procedure connecting a unit with the same capacity at a bus close to Aurora city, but the results were the same. For that reason we only show the results for Elgin Dam.

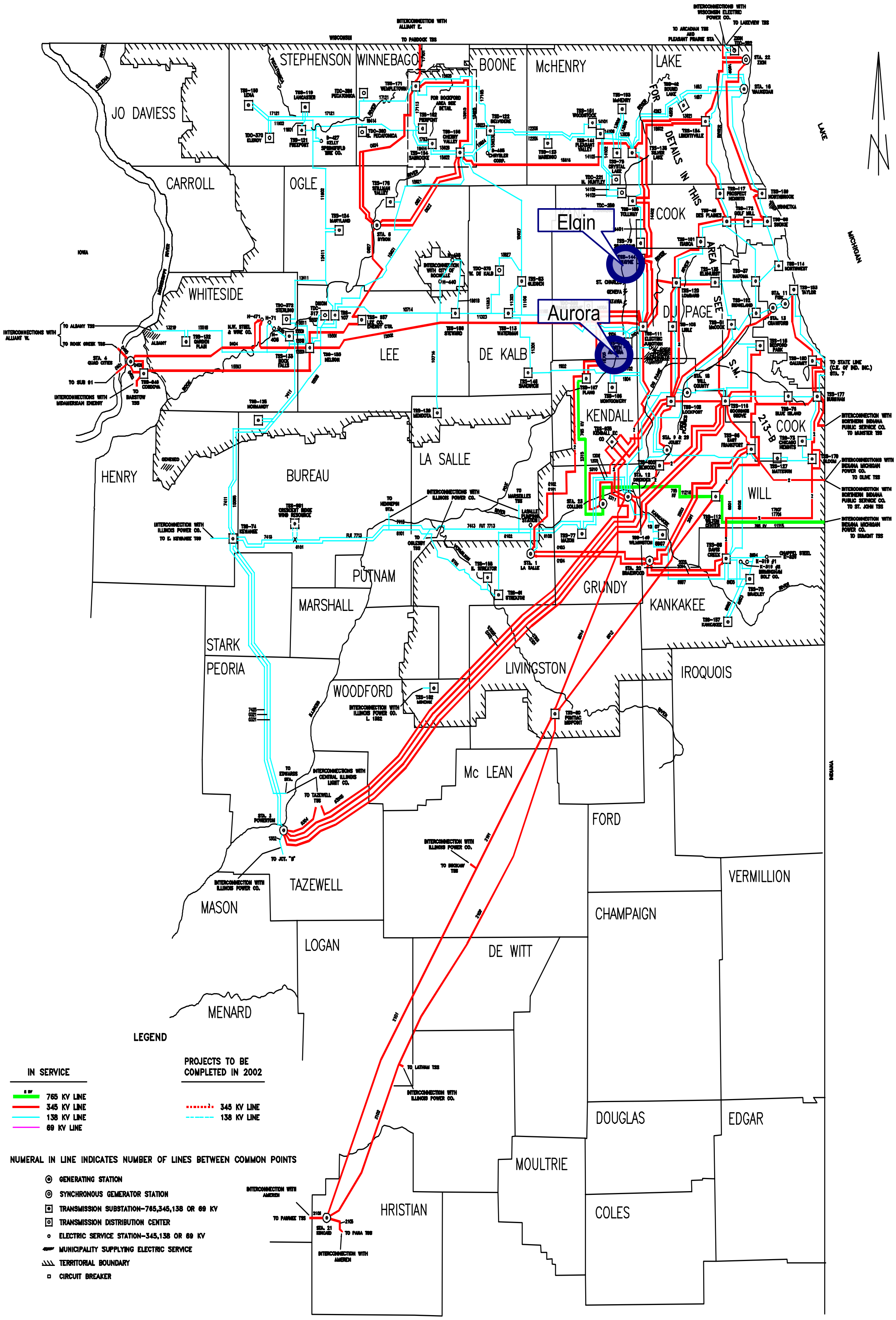


Fig. 13. Power system network structure

2. Impact of Small Hydro on Existing Power Systems

We use COMED network data to analysis the impact of small hydro on existing power systems. Compared corresponding loads of 2005 and 2006, we can see that loads increase about 20 percent. Thus, load data we used are those in July 2006 with 20% increase.

With load data and existing network, we calculate two sets of LMP's at the certain bus corresponding to with and without the small hydro energy to see the impact of small hydro on existing power system. Results are shown in figures 17 and 18. We also calculate LMP's at the certain bus when we drop the load by 10MW and 96.68 MW. We can not expect a significant impact of small hydro on existing power system, because the small hydro (1 MW) is too small compared with existing power system (25,000 MW).

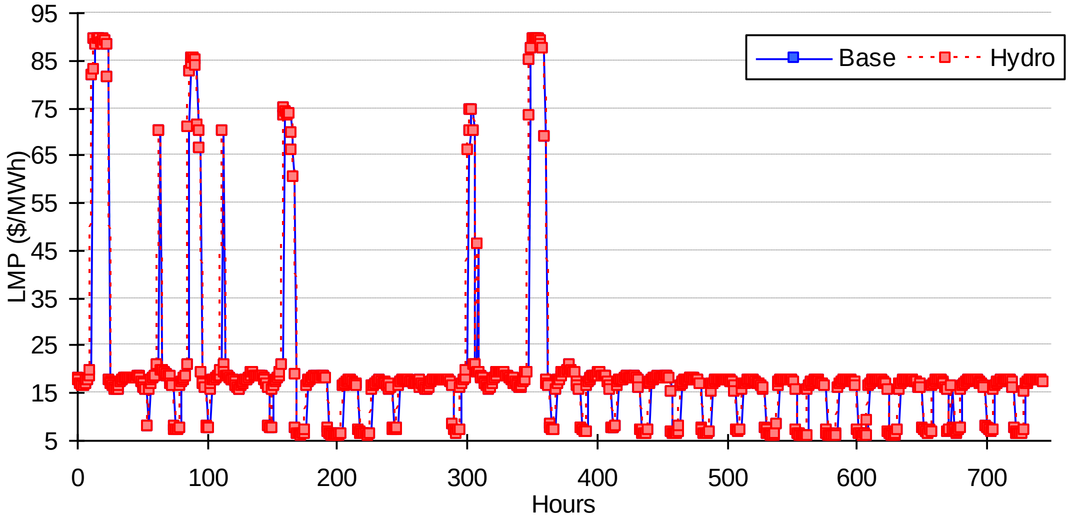


Fig. 14. LMP of Base case and Hydro Energy Injected

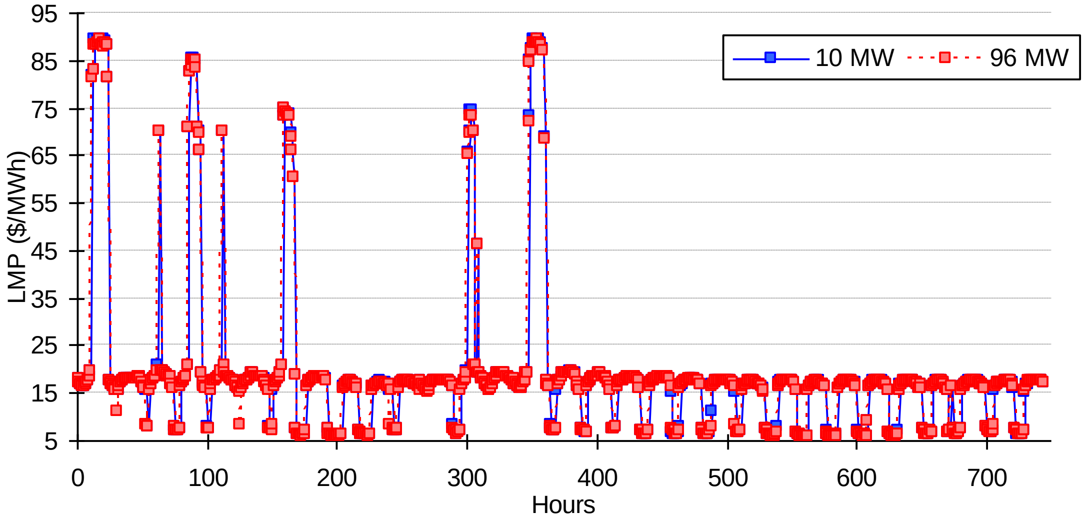


Fig. 15. LMP of dropping 10MW and 96.68 MW at certain bus

In the figure 19 we can see the trend of peak hour LMP with the raising of injected hydro power. We can see that when the total load at certain bus is dropped, the peak LMP is dropped about 0.5 $/MWh. Again we can not expect significant impact of small hydro on existing power system, but the small hydro do can decrease the total operation cost, as shown in table II, the total operation cost for one month could be reduced by $ 15,905.10.

Table 1. Influence of Power Dropped at Certain Bus on Peak Hour LMP

Rated Power (MW)	**LMP ($/MWh)**
0	87.22692
1	87.22692
10	87.19692
96	86.86538

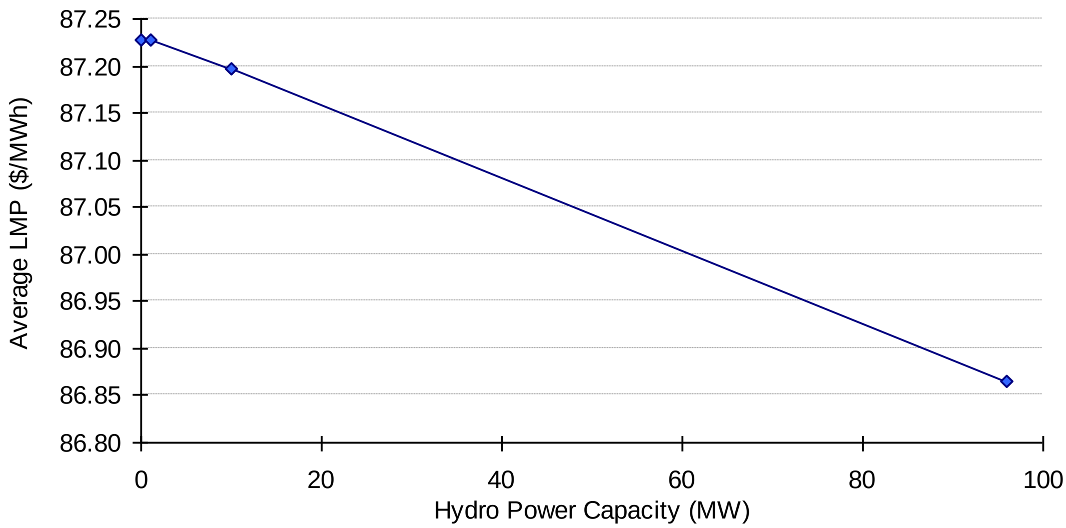


Fig. 16. Relationship between peak hour LMP and Power Dropped at Certain Bus

Table 2. Generation Cost for one month

Scenario	**Total Operating Cost ($)**
Without Hydro	103,483,592.71
With Hydro	103,467,687.61

IV. Environmental Issues

The impact of the Hydro Power on the local environment is evaluated. The main purpose of this analysis is to make the design as environmentally friendly as possible.

1. Water Quality

Water turbidity in the immediate area of the construction site would be temporarily increased. All construction in the river will occur after dewatering and salvage activities. Contaminants such as gasoline or oil, concrete could be accidentally released into the river but will have a temporary effect on the environment. Caution must be taken during construction to minimize the release of these contaminants.

2. Riparian Areas

Removal of small vegetation area will be necessary prior to construction. The removal of vegetation area will be around 3 acres in Elgin Dam and 1 acre in Aurora Dam. Generally impacts on wildlife are directly related to removal of vegetation. Any disturbance of previously undeveloped areas in riparian zone affects wildlife. In addition, construction noise and activities and human intrusion after development can cause some animals to avoid otherwise suitable habitat. However, although the removal of vegetation is required, it is expected to have a short term wildlife impacts. Visitors of Aurora and Elgin often fish and also use the park nearby the dam. Some of the effects that can be caused by the construction will be direct.

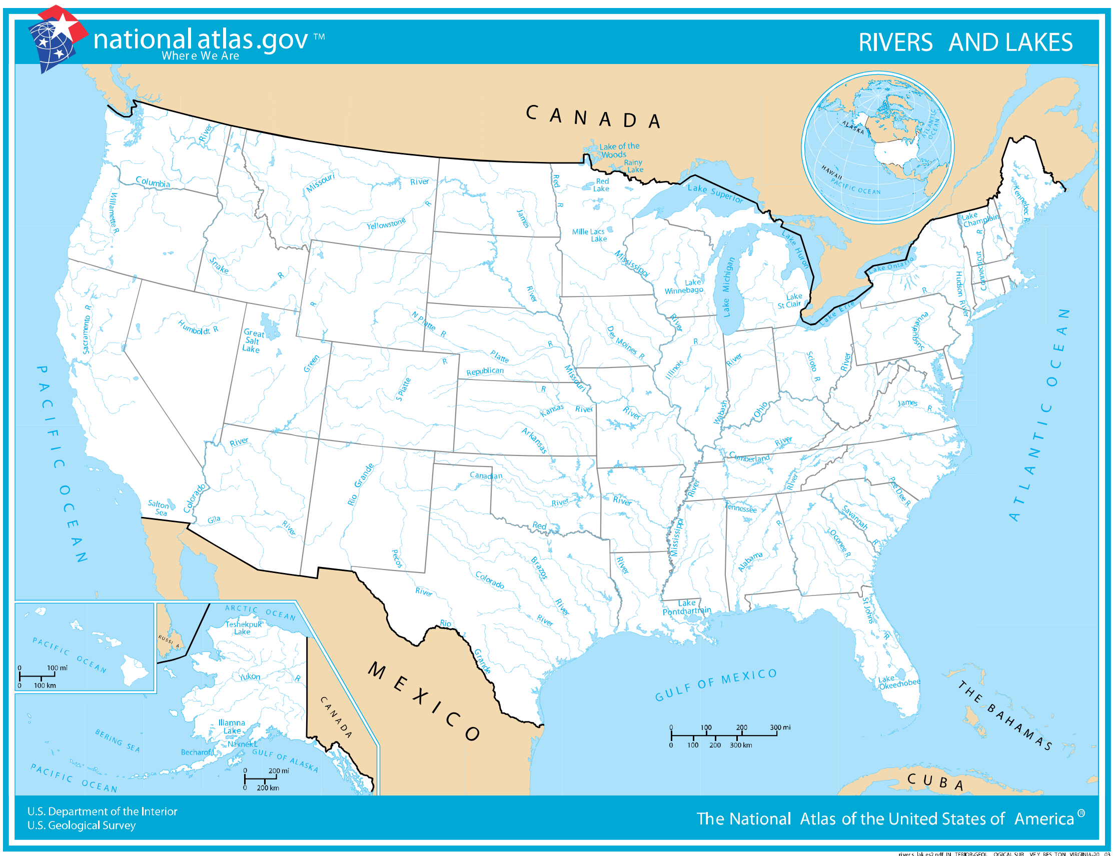


Fig. 17. Major Rivers in the United States (Source: NationalAtlas.gov)

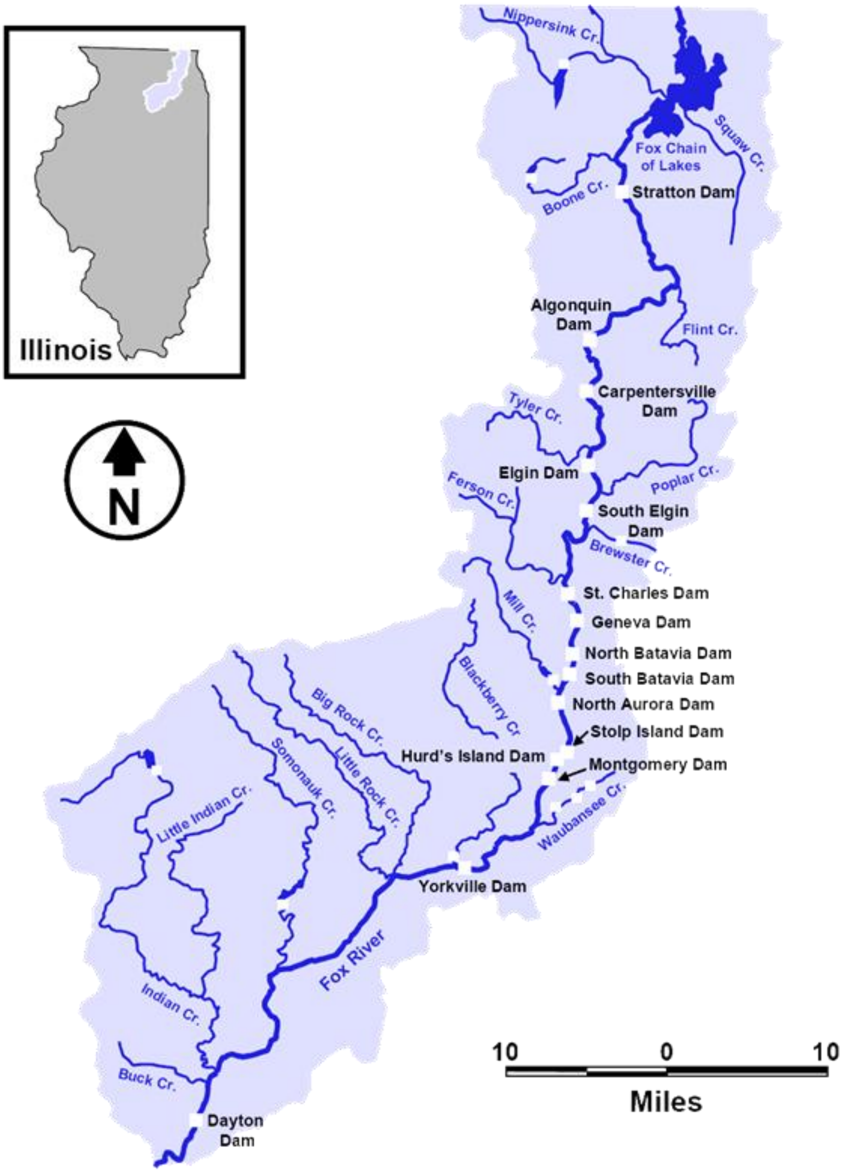


Fig. 18. Fox River, IL (Source: Wikipedia, 2006)

3. Recreation

The construction of the hydro-system and the pipelines will be able to be seen from the neighborhood and it is expected to have a long term effect by making an unpleasant scene for some of the visitors and also the residents in the neighborhood. The construction is also expected to limit fishing in the immediate area due to the reduction of fishes near the contaminants area. However solutions can be made for the visual Impact by making the hydro-system an attraction for the visitors. It can be made into a small observatory for the people to go on top of the hydro-system and observe the structure of the system and also to experience the view of the river from a different perspective. The hydro-system can be turned into a feature of Elgin and Aurora cities so that the people can became proud of having a renewable energy facility in their city. For the fishing issue, the impact of the construction that will bring is expected to be short-termed and eventually will bring benefit to the fishers from the abundant oxygen the hydro-system will produce that would attract the fishes

4. Noise

The temporary effect caused by noise during the construction is expected to have a direct effect to the surrounding environment that includes strollers, wildlife, library (Elgin), casino (Aurora), nearby residents and any other elements that can be affected up to 300 feet radius. Although this noise issue is expected to be temporary, it will be inevitable for locations such as the library (Elgin) and casinos (Aurora) to be directly effected from the impact the construction noise will have. Because construction noise is a matter of course for the hydro-system, minimization of the noise is necessary to protect the living environment of the people of Elgin and Aurora. One solution for minimizing the noise effect will be picking the right time for heavy construction and alerting the neighborhood previous to a large-scale construction.

Fig. 19. Surroundings of Elgin Dam

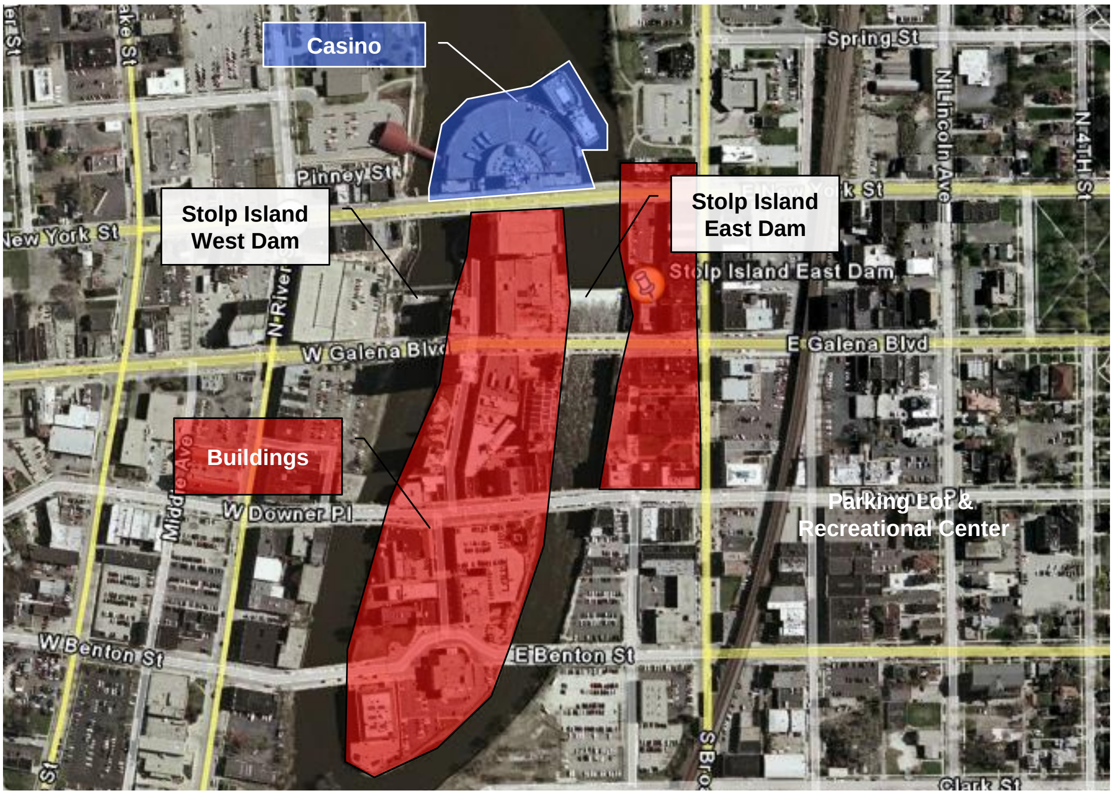


Fig. 20. Surroundings of Stolp Island Dams

5. *Traffic*

Seen from the map, the construction site is likely to take place nearby the bridge and thus expected to have certain effect on the traffic on that road. During the construction the bridge is expected to be crowded several of times.

6. *Wildlife*

The main focus on the aspect of this effect is on fishes. As it is known, Hydro System has a significant effect on fishes. Generally the biggest effects of the Hydro System is the mortality of the fishes caused by the turbines. However, we can construct a fish screen addition to the trash rack at the intake to reduce the mortality. Also due to the fact that for the turbines having properly spaced blades with proper revolution are not a threat to fish, it is expected our Hydro System's low revolution would not be harmful to the fishes inhabiting the area.

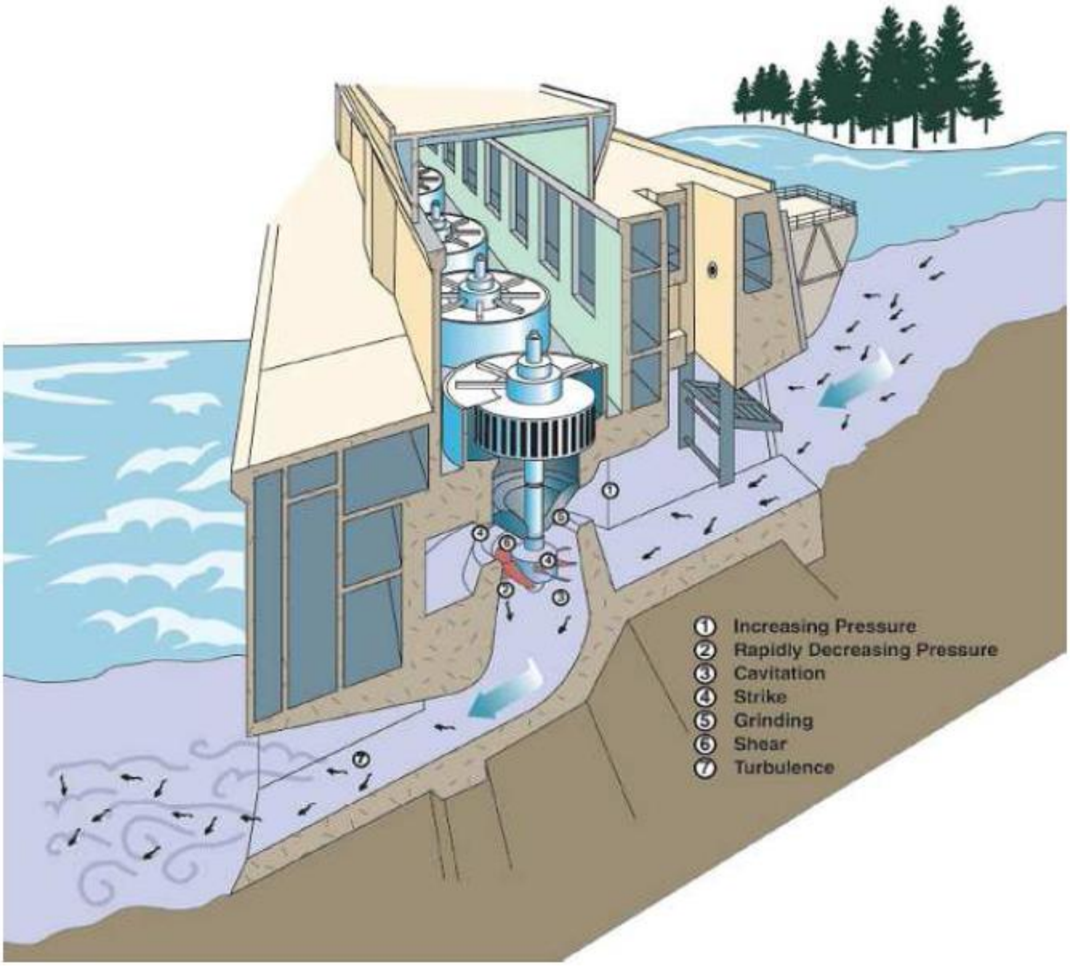


Fig. 21. Example of the fishes adapting with the turbine by swimming through it

Fig. 22. Fish ladder at Elgin Dam.

Fig. 23. Fish passage and canoe shoot at Stolp Island Dams.

Fig. 24. Fishes that inhabit the Fox River

7. Fuel and Emissions Reductions

According to the U.S. Environmental Protection Agency (EPA), "fossil fuel-fired power plants are responsible for 67 percent of the nation's sulfur dioxide emissions, 23 percent of nitrogen oxide emissions, and 40 percent of man-made carbon dioxide emissions". For this reason we evaluate the fuel and emissions reductions due to the addition of our designs at Elgin Dam and at Stolp Island East Dam. The same simulation software used to perform the power market analysis was used here. We simulated four scenarios: No small-hydro; 1 MW; 10 MW; and 100 MW. From the results obtained we were able to evaluate the amount of fuel consumed and emissions emitted by the fossil fuel-fired power plants at each scenario. The following figures shows the results.

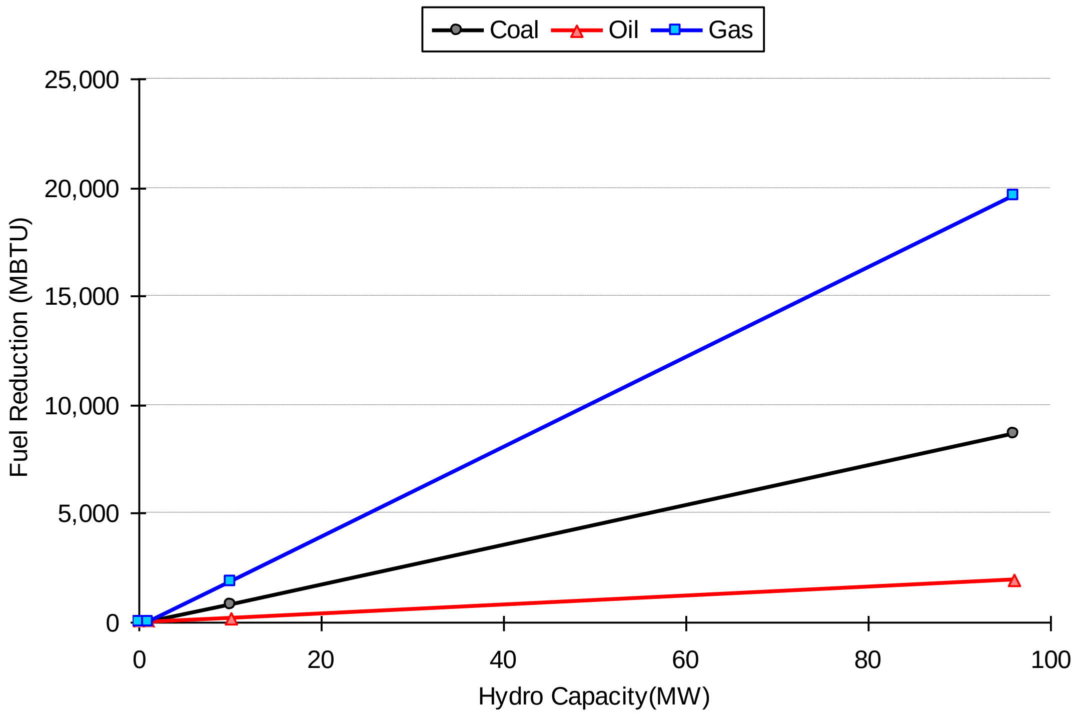


Fig. 25. Fuel reduction in Illinois due to addition of small hydro.

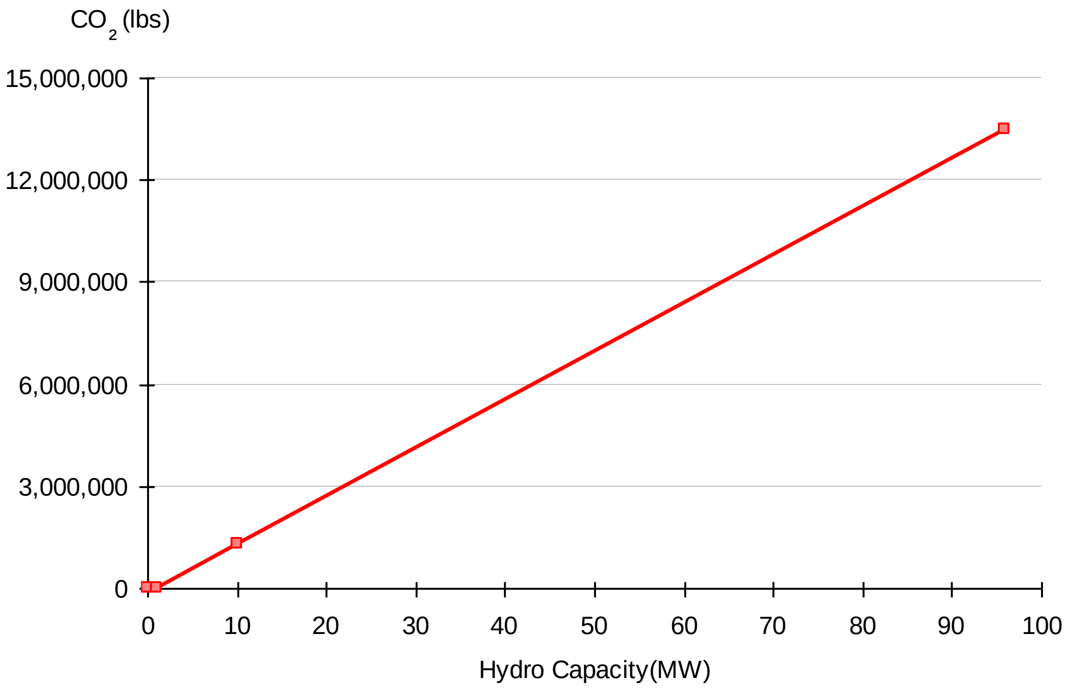


Fig. 26. CO_2 reduction in Illinois due to addition of small hydro.

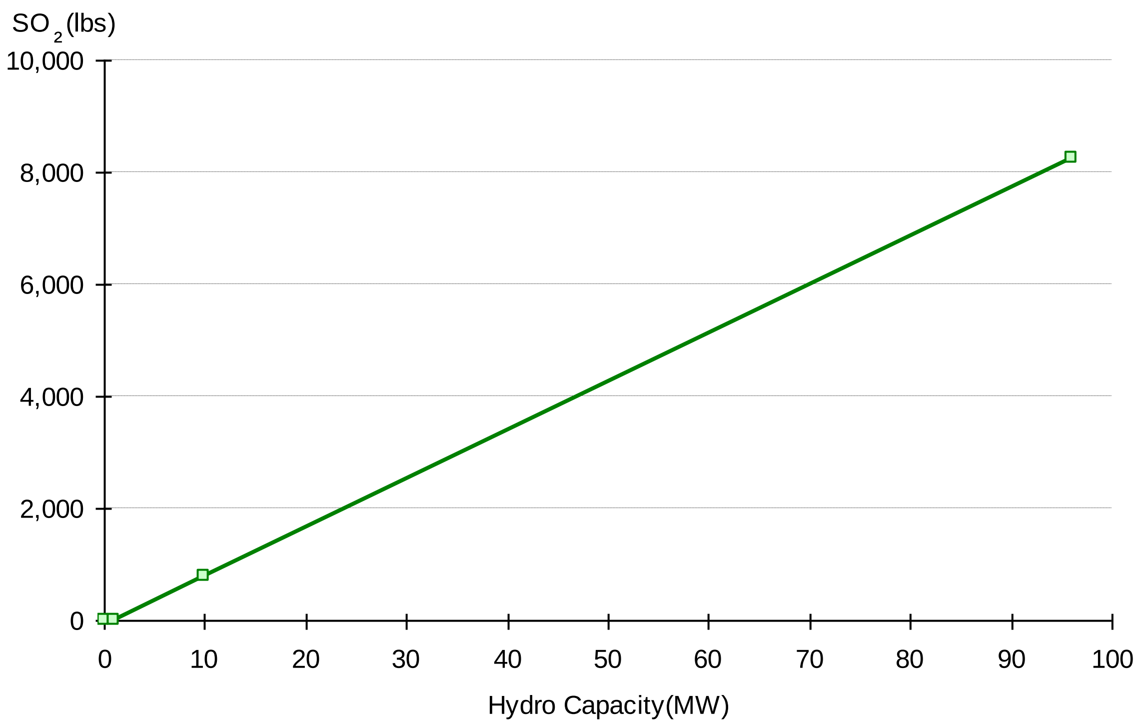


Fig. 27. SO_2 reduction in Illinois due to addition of small hydro.

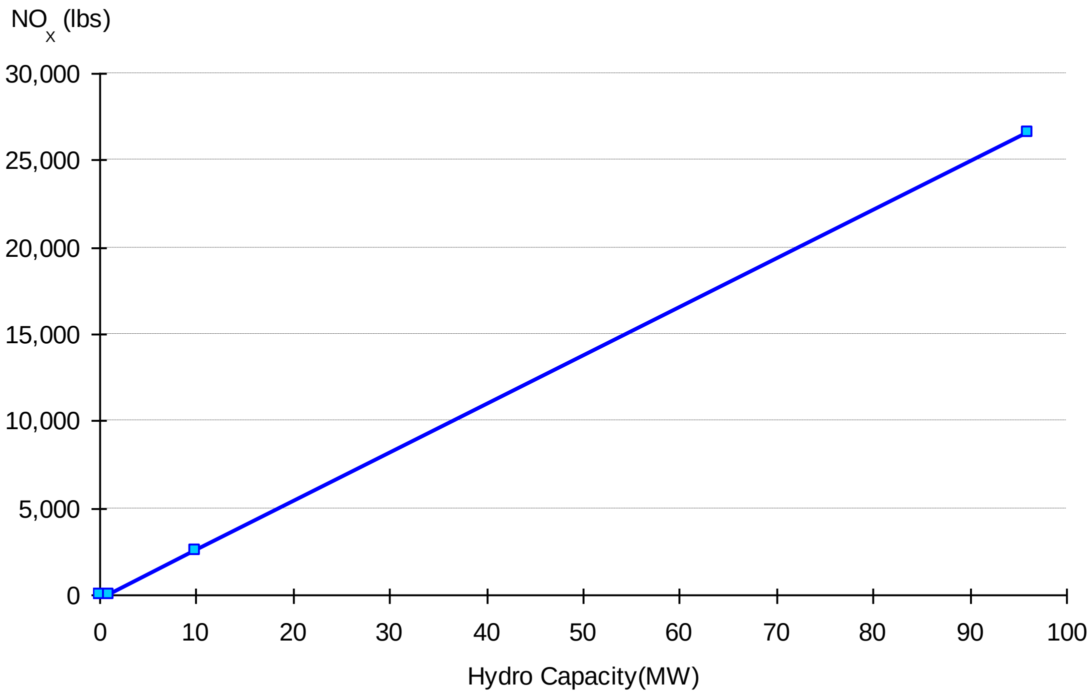


Fig. 28. NO_X reduction in Illinois due to addition of small hydro.

We can see that with the implementation of our designs, we would reduce 1,690,000 lbs of carbon dioxide emissions, 3,330 lbs of sulfur dioxide emissions, 1,030 lbs of nitrogen oxide emissions and 36,000 MBTU of fossil fuel. These results show one of the positive environmental impacts of small hydro.

V. Economic Assessment

1. Objective and Tool

The objective of this section is mainly to assess the financial feasibility of small hydroelectric facilities on the Fox River. The IPRO 319 last semester and North American Hydro Company have already done some preliminary assessment. According to their reports [19–21] and to the hydrology data obtained from the internet [22, 23], Elgin Dam and Stolp Island East Dam are the best two dams eligible to have a hydroelectric facility built. Therefore, our assessment will focus on these sites.

We used RETScreen International Clean Energy Project Analysis Software to deal with the data and calculate the relevant financial results. RETScreen is a professional software that deal with feasibility assessment for the development of renewable energy, designed by the Natural Resources Ministry in Canada and supported by agencies such as NASA and UNEP [24–26]. In RETScreen Small Hydro Project, several worksheets are provided (Energy Model, Hydrology Analysis and Load Calculation, Equipment Data, Cost Analysis, Greenhouse Gas Emission Reduction Analysis, Financial Summary and Sensitivity and Risk Analysis). Generally, the Energy Model, Hydrology & Load and Equipment Data worksheets are completed first. The Cost Analysis worksheet should then be completed, followed by the Financial Summary worksheet. The Gas Emission Reduction Analysis and Sensitivity worksheets are optional.

Therefore, in this report we firstly estimate how much renewable energy can be produced based on the hydrology data and equipment data. Then, we discuss the investment cost, annual cost and renewable production credit. Thirdly, we evaluate the impact of different electricity selling prices ($/kWh) and Grant Awards at some financial indicators such as the Net Present Value (NPV) and Year-to-Positive Cash Flow.

2. Power Production Estimates

A. Hydrology Analysis

The potential energy at each site is proportional to the flow and the difference of the upstream and downstream water level, or gross head. The gross head is different from the dam height. This was a mistake found in IPRO 319 report, because the hydro potential at each dam was calculated using the dam height and not the gross head. There are no long-term data of the change in gross head across the dams, in a sense that if there is a river flow increase, the upstream and downstream will both be raised. Therefore, in this study we assume a constant gross head, in which is lower than the height of the dam. The data used by this IPRO are shown in the following tables.

Table 3. Information of Elgin Dam

Description	Data
Dam Name	Elgin
Dam Height	13 ft
Gross Head	7.2 ft
Residual Flow	100 ft3/s
Length	325 ft
River Mile	71.9 mi
Drainage area	1540 (estimate)

Table 4. Information of Stolp Island East Dam

Description	Data
Dam Name	Stolp Island East
Dam Height	8.5 ft
Gross Head	7.0 ft
Residual Flow	100 ft3/s
Length	177 ft
River Mile	48.9 mi
Drainage area	1720 (estimate)

Based on the investigations on our field trip and the information on the United States Geological Survey (USGS) website [23], the two candidate dams (Elgin and Stolp Island East) on the Fox River should be run-of-the-river dams. As a result they have no significant storage and flow over each dam varies according to short-term (storm) and long-term (seasonal) events. Flow can be characterized using a flow duration curve.

Daily mean flow data used to develop flow duration curves can be obtained from the USGS website. The USGS maintains several gauge stations respectively on the Fox River including Algonquin, South Elgin, and Dayton as shown in table 3. However, the problem is there isn't any gauge station at Elgin and Stolp Island East, so we couldn't calculate the flow duration curve of the candidate dams directly.

Table 5. Stream gauge stations on the Fox River, IL

USGS ID	Name	Area (mi2)	Record
5550000	Algonquin	1403	1915-present
5551000	South Elgin	1556	1989-1998
5552500	Dayton	2642	1925-present

Table 6. Flow duration data at Elgin Dam

Time (%)	Flow (ft3/s)	Time (%)	Flow (ft3/s)	Time (%)	Flow (ft3/s)
0%	5034	35%	1207	70%	602
5%	3449	40%	1091	75%	545
10%	2476	45%	999	80%	477
15%	2044	50%	912	85%	416
20%	1799	55%	838	90%	356
25%	1554	60%	748	95%	297
30%	1337	65%	675	100%	185

Table 7. Flow duration data at Stolp Island East Dam

Time (%)	Flow (ft3/s)	Time (%)	Flow (ft3/s)	Time (%)	Flow (ft3/s)
0%	3875	35%	896	70%	447
5%	2573	40%	811	75%	402
10%	1854	45%	746	80%	351
15%	1530	50%	678	85%	306
20%	1333	55%	621	90%	263
25%	1156	60%	553	95%	223
30%	992	65%	500	100%	135

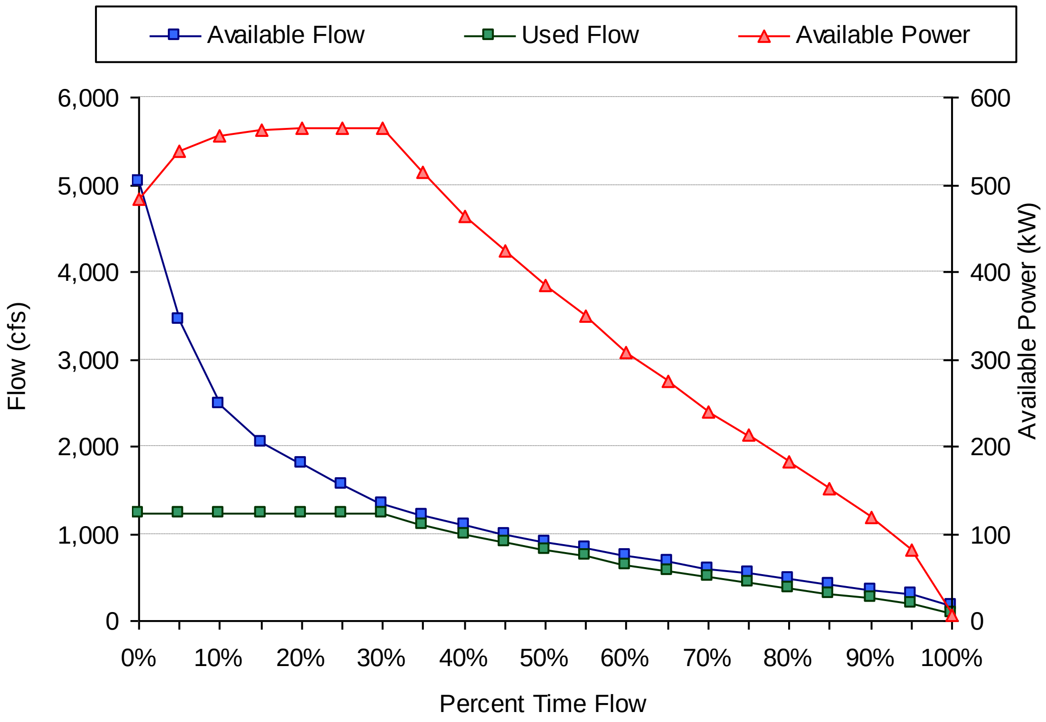


Fig. 29. Flow duration curve at Elgin Dam

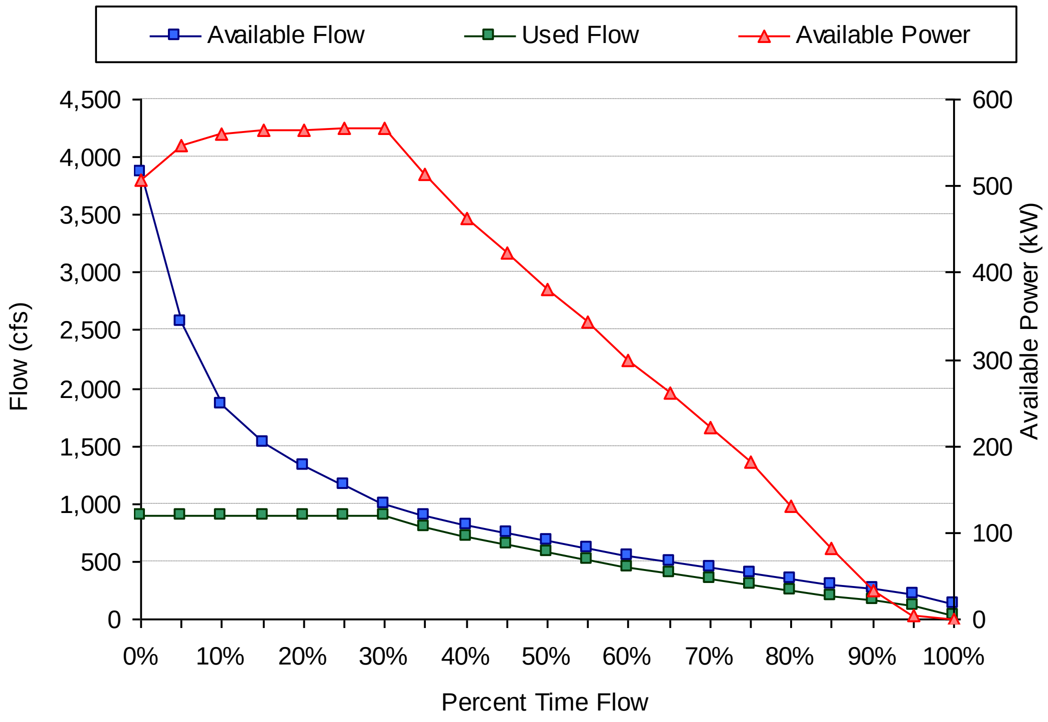


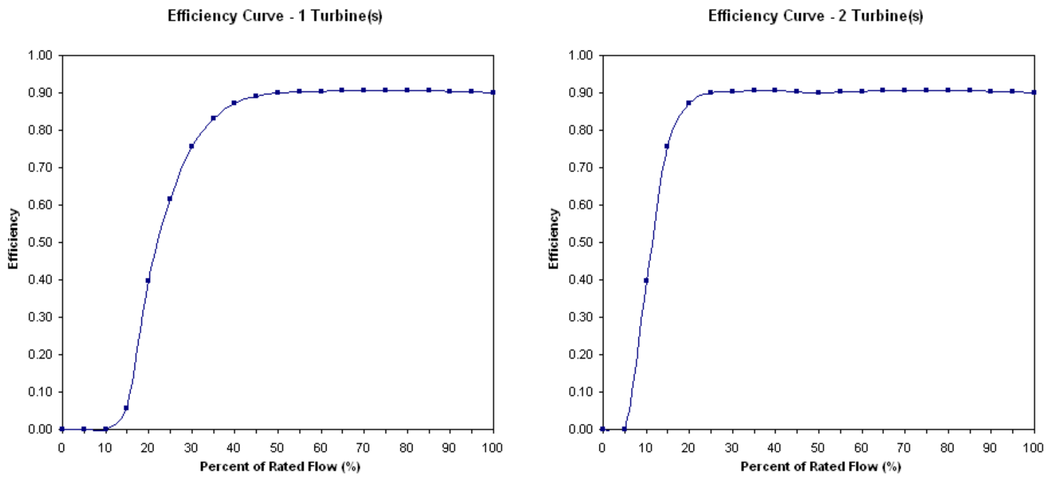
Fig. 30. Flow duration curve at Stolp Island East Dam

The report from Mahdi and Anderson [19] proposed an interpolation method to estimate the flow duration curve on other sites that does not have gauge stations. They assumed that the flow at any point in the river is proportional to the drainage area in between two points. For Elgin dam, the watershed area is supposed to be little less than that on South Elgin (Figure 20 and Table 6) because of the short distance between these two sites (3.7 miles). And then, we can interpolate the flow duration curve on this site as below

As to the Stolp Island East Dam, it runs parallel with Stolp Island West Dam so that the river flow in city of Aurora is divided into two streams, as shown in Figure 16. By assuming that the 65% of water stream flow across the East Dam, we can obtain the estimative flow duration data in Table 7.

3. Turbine and Generator

Figure 27 (a) and (b) indicate that the efficiency of 2-turbine at the relatively small flow is higher than that of 1- turbine if their design efficiency of the rated flow are same [25–26]. That is because the operation of two turbines could be more flexible than a single turbine. Certainly, the number of turbine we plan to install on the candidate dams lies on many factors, not only turbine efficiency curve, rated flow but also the equipment cost.



(a) One turbine (b) Two turbines

Fig. 31. Turbine efficiency curve

Plant capacity P_{des} can be calculated at the design flow Q_{des}. The equation simplifies to:

$$P_{des} = \rho g Q_{des} [H_g - (h_{hydr} + h_{tail})] e_{t,des} e_g (1 - l_{trans})(1 - l_{para}) \quad (13)$$

Where P_{des} *is* the capacity of the plant, ρ is the density of water (1,000 kg/m^3), g the acceleration of gravity (9.81 m/s^2), H_g the gross head, h_{hydr} and h_{tail} are respectively the hydraulic losses and tailrace effect associated with the flow; and $e_{t,,des}$ is the turbine efficiency at design flow Q_{des}, calculated as explained in last section. Finally, e_g is the generator efficiency, l_{trans} the transformer losses, and l_{para} the parasitic electricity losses.

Table 8. Input parameters in RETScreen

Parameters	**Elgin**	**Stolp Island East**
Maximum hydraulic losses	5 %	5 %
Transformer losses	1 %	1 %
Parasitic electricity losses	2 %	2 %
Annual downtime losses	4 %	4 %
Maximum tailwater effect	1.0 ft	1.0 ft
Design Flow	30 %	30 %

Table 9 and 10 list the parameters we choose for the two candidates if the design flow is exceeded 30% of the time. Alternatively, we also can use 1 unit instead of 2 units, which would result in the reduction of the equipment cost per kWh and renewable energy production at the same time.

Table 9. Turbine Parameters

Location	**Units**	**Type**	**Rated Head**	**Rated Flow**
Elgin	1	S-Type	7.2 ft	1237 cfs
Stolp Island East	2	Bulb	7.0 ft	992 cfs

Table 10. Plant Parameters

Location	Design Flow	Annual Energy	Plant Capacity
Elgin	1,237 cfs	3,071 MWh	566 kW
Stolp Island East	992 cfs	3,502 MWh	630 kW

4. Renewable Energy delivered

Actual power P available from the small hydro plant at any given flow value Q is given by the following equation,

$$P = \rho g\, Q[H_g - (h_{hydr} + h_{tail})] e_t e_g (1 - l_{trans})(1 - l_{para}) \quad (2)$$

this formulation (2) is similar with (1), and in formulation (2), e_g is the generator efficiency.Hydraulic losses are adjusted over the range of available flows based on the following relationship:

$$h_{hydr} = H_g l_{hydr,max} \frac{Q^2}{Q_{des}^2} \quad (3)$$

where $l_{hydr,\max}$ is the maximum hydraulic losses specified by the user, and Q_{des} the design flow. Similarly the maximum tailrace effect is adjusted over the range of available flows with the following relationship:

$$h_{tail} = h_{tail,max} \frac{(Q - Q_{des})^2}{(Q_{max} - Q_{des})} \quad (4)$$

where $h_{tail,max}$ is the maximum tailwater effect, i.e. the maximum reduction in available gross head that will occur during times of high flows in the river. Q_{max} is the maximum river flow, and equation (4) is applied only to river flows that are greater than the plant design flow (i.e. when $Q > Q_{des}$).

Calculation of power available as a function of flow using equation (2) for all 21 values of the available flow $Q_1' \ Q_5', \ldots\ldots, Q_{100}'$ used to define the flow-duration curve, leads to 21 values of available power $P_1 \ P_2, \ldots\ldots, P_{100}$ defining a power-duration curve. The flow values used in equations (2) and (3) are actually $Q_{n,des}$ used defined as:

$$Q_{n,des} = min(Q_n', Q_{des}) \quad (5)$$

Renewable energy available is determined by calculating the area under the power curve assuming a straight-line between adjacent calculated power output values. Given that the flow-duration curve represents an annual cycle, each 5% interval on the curve is equivalent to 5% of 8,760 hours (number of hours per year). The annual available energy E_{avail} (in *kWh/yr*) is therefore calculated from the values P (in *kW*) by:

$$E_{avail} = \sum_{k=1}^{20} \left(\frac{P_{5(k-1)} + P_{5(k)}}{2} \right) \frac{5}{100} 8760(1 - l_{dt}) \tag{6}$$

where l_{dt} is the annual downtime losses as specified by the user.

For central-grid applications, it is assumed that the grid is able to absorb all the energy produced by the small hydro power plant. Therefore, all the renewable energy available will be delivered to the central-grid and the renewable energy delivered, E_{dlvd}, is simply:

$$E_{dlvd} = E_{avail} \tag{7}$$

Since the design flow is defined as the maximum flow that can be used by the turbine, and this value should be specified by user. The selection of the design flow depends, primarily, on the available flow (hydrology) at the site. For central-grid connected run-of-river projects the optimum design flow is usually close to the flow that is equaled or exceeded about 30% of the time. In this studies, when the design flow is exceeded 30% of the time, the curve of Available Flow, Flow Used and Available Power at the Elgin dam and Stolp Island East dam are shown in the figures 25 and 26. When the Annual down time losses is 4%, the Annual Renewable Energy delivered are 3026MWh and 7825MWh at the Stolp Island East dam and Elgin dam respectively.

Alternatively, we can change the design flow within a reasonable range as shown in table 8. Regulated by the formulation (1) and (2), the small Hydro plant capacity and Renewable energy delivered would vary with the design flow.

Table 11. Design Flow and Annual Energy Production at Elgin Dam

Design Flow (ft3/s)	**Plant Capacity (kW)**	**Energy Production (MWh)**
800	366	2397
900	412	2583
1000	457	2749
1100	503	2896
1200	549	3026
1300	594	3143
1400	640	3248
1500	686	3343
1600	732	3430
1700	777	3509
1800	823	3579
1900	869	3641
2000	915	3694

Table 12. Design Flow and Annual Energy Production at Stolp Island Dam

Design Flow (ft3/s)	Plant Capacity (kW)	Energy Production (MWh)
678	431	2885
746	474	3054
811	515	3193
896	569	3352
992	630	3587
1060	673	3591
1156	734	3700
1220	775	3762
1333	847	3852
1430	908	3910
1530	972	3955

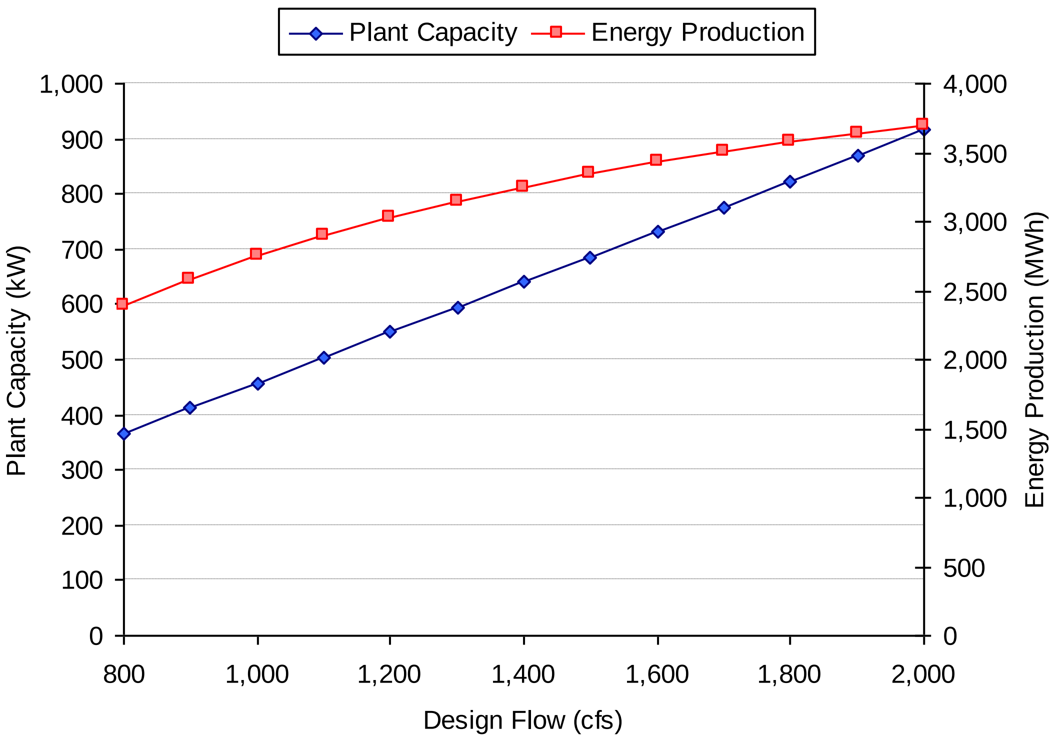


Fig. 32. Design Flow and Annual Energy Production at Elgin Dam

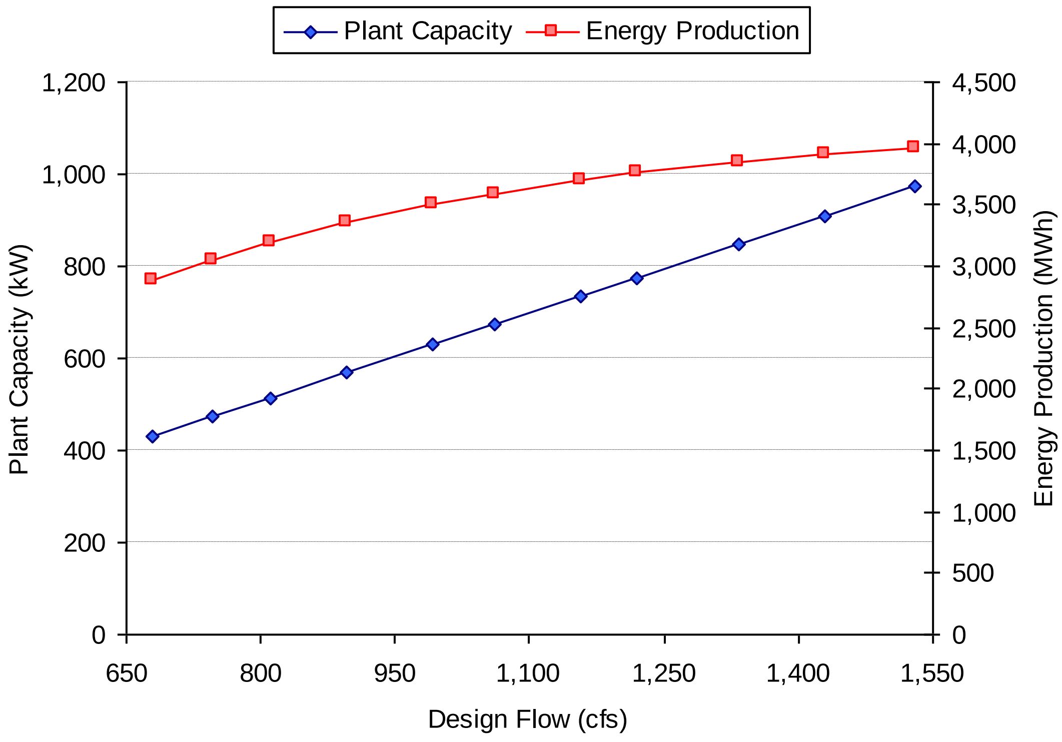


Fig. 33. Design Flow and Annual Energy Production at Stolp Island East Dam

5. Cost and Credit Analysis

A. Initial Cost

North American Hydro Company estimated that the initial cost of the small hydro at the Elgin dam should be more than 5 million dollars [20], which results in the project unprofitable. The same conclusion would happen in Stolp Island East dam if we adopt the conventional construction because its investment cost is so expensive. Dr. Tseng suggested that we can use siphon turbine and needn't do much civil engineering on both candidate site. He offered an alternative cost estimate which could be found in the report by Mahdi and Anderson [19]. We adjust some data slightly from the report and list them below.

Table 13. Cost Estimate

Description	**Elgin Dam**	**Stolp Island East Dam**
License and Development	$ 130,000.00	$ 130,000.00
Energy Equipment	$ 800,000.00	$ 900,000.00
Administration	$ 80,000.00	$ 80,000.00
Transmission Line and Substation	$ 100,000.00	$ 100,000.00
Engineering and Design	$ 80,000.00	$ 80,000.00
Civil Engineering Work	$ 600,000.00	$ 550,000.00
Contingencies	$ 250,000.00	$ 250,000.00
Total	$ 2,040,000.00	$ 2,090,000.00

The total cost of developing hydroelectric generating facilities was estimated to be approximately $2,090,000 at Stolp Island East Dam and $2,040,000 at Elgin Dam respectively.

B. Annual O&M Cost

The Annual operation and maintenance cost was estimated to be approximately $100,000.00 at both dams [27–29].

C. RE Production Credit

Renewable Energy Production Credits are most common for electricity generation from renewable energy projects. The value typically represents the amount that can be credited to the project in exchange of the production credit generated by the renewable energy delivered by the system.

For example, it is possible to receive a tax credit of 1.5 /kWh in the USA for electricity produced from wind, biomass or chicken manure. Whether or not the small hydroelectric project would qualify to receive such payments depends on the rules of the specific programs in the jurisdiction in which the system is installed.

On the Energy Information Administration website [30], we found that Payment of 0.9/kWh for 10 years for hydro power generation after July 1, 1994, if dam in existence by March 31, 1994 or substantially refurbished after July 1, 2001 (Statute 216C.41). With the EPACT 05 amendments, the production 0.9/kWh tax credit is available for electricity produced from certain small-scale hydroelectric [30]. Consequently, in this assessment, the RE Production Credit is 0.9/kWh for 10 years.

D. Grant Award from Illinois State Government

In order to foster investment in and the development and use of renewable energy resources with in the state of Illinois, the Renewable Energy Resources Program (RERP), which has been administrated by Illinois department of Commerce and Economic Opportunity, provide a fund to the projects that demonstrate potential to increase the utilization of renewable energy technologies in Illinois. The focus of the RERP includes wind, solar thermal energy, photovoltaic systems, dedicated crops grown for energy production, organic waste biomass, hydropower that does not involve new construction or significant expansion of hydropower dams [31–33].

From 2000, two new small hydropower on the existing dam in Illinois received grant award from the program, respectively 3MW and 1.2MW capacity hydro power received 1 million $ and 0.352 million $ [34, 35].

The grant amount available from this program may vary depending on the capacity of the plants, environment assessment and other application documents. It appears that the development of run-of-river hydroelectric generating facilities at the Elgin Dam and Stolp Island East Dam qualify for the 1 million dollars award. Therefore, in this study we considered a grant of 1 million dollars for each project, and in the sensitivity analysis section, the grants award varies from 0 to 1 million dollars.

6. Electricity Price and Financial Summary

A. Avoided Cost of Energy

Avoided cost of energy represents either the "average" or the "marginal" unit cost of energy for the base case electricity system. It is important to determine this value in the financial assessment because it directly relate to the payback period of our project. By our case study in the Part 1 of this report, we have already calculated the location marginal price with SCUS program on the certain bus in which hydroelectric power injected. It appear that the marginal price fluctuates in the range from 0.006$/ kWh to 0.09$/kWh and the average value is approximately 0.02$/kWh, relatively too small to prove that building hydroelectric facilities is economically feasible. However, we quickly found that this competing electricity price is not absolutely reasonable for our project. The main reason is that in our model we didn't consider much congestion existing in the real power system, which will even bring about the remarkable increase of the LMP in a certain zone.

Professor Shahidehpour suggested that we can adopt the zone load-weighted LMP as the electricity price in our assessment. Here, we need to illuminate that the original information downloaded from the PJM website Error! Reference source not found. is the Zone LMP based on each hour. In order to obtain zone load-weighted LMP at least of one year, we use the hourly load to weight the hourly LMP, and then accumulated each weighted value, the third step is to be divided by the summation of hourly load, as shown in the following formulation.

$$\text{Zone Load-Weighted LMP} = \frac{\sum \text{Hourly Integrated Real Time LMP} \times \text{Hourly Load}}{\sum \text{Hourly Load}} \quad (8)$$

Considering the data of ComEd network from 10.2005 to 09.2006, the Zone Load-Weighted LMP is 0.05094 $/kWh.

B. Financial Summary

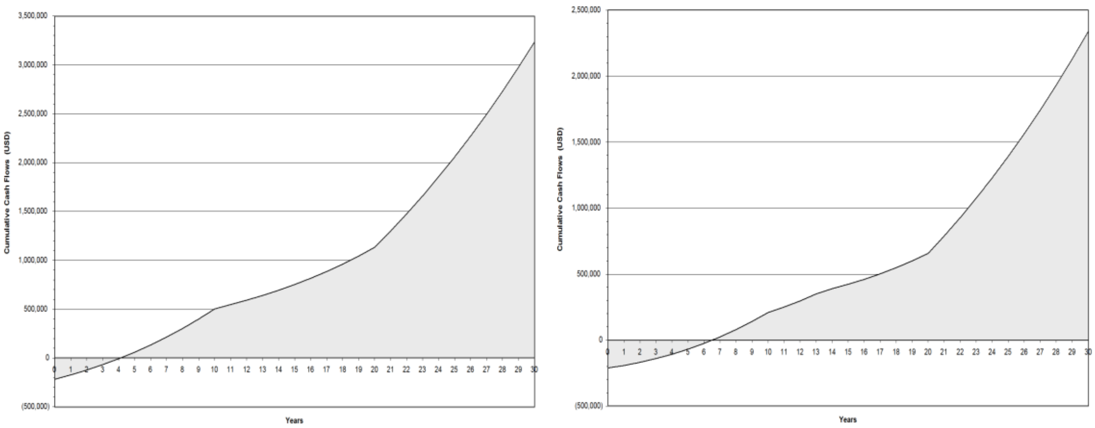
Typical financial figures for the analysis are provided by us. If the Stakeholders were to receive a grant for each project from IL renewable energy program, the maximum grant available from this program is $1,000,000. The rest part of our investment cost except 1M$ would come from debt and private capitals. Assuming that the City of Elgin or Aurora would provide this project debt with revenue from municipal bonds with a 20-year maturity term and a yearly interest of 5.3%, the prorated annual cost of repaying these bonds would be approximately $69507 and $71,430 respectively.

From the analysis in the former section and economic knowledge, it was determined that other parameter input items are set as follow:

- Income tax rate of 30%;
- Inflation at 2.5%;
- Discount rate of 10%;
- Electricity price 0.051$/kWh;
- RE production credit of 0.009 $/kWh with 2% escalation rate;

- Design flow is equaled to 30% time;
- Project life of 30 years;

Through calculation of the cash flows of each project on candidate sites by RETScreen, the average Annual savings in electrical energy consumption at the water treatment plant would be $184,270 for Elgin and $210,097 for Stolp Island East. The year to cash flow would be 6.5 years and 4.1 years; the simple payback year would be 12.5 years and 9.9 years respectively. There are some other financial indicators results from our assessment in the Table 11.



(a) Elgin Dam (b) Stolp Island East Dam

Fig. 34. Cash Flow Curves

Table 14. Economic Indicators

Economic Indicator	Elgin Dam	Stolp Island East Dam
Pre-tax IRR and ROI	20.00%	29.10%
After-tax IRR and ROI	18.60%	27.80%
Simple Payback	12.5 yr	9.9 yr
Year-to-positive cash flow	6.5 yr	4.1 yr
Net Present Value - NPV	$ 274,234.00	$ 518,807.00

Assuming that the stakeholders' expecting simple payback period would be less than 15 years and After-tax IRR (Internal Rate of Return) and ROI (Return on Investment) would be more than 10%, it would be economically feasible to proceed with building both two candidate hydroelectric facilities.

7. Sensitivity and Risk Analysis

A. Sensitivity Analysis

Whatever ways and means we have made used to assess the financial feasibility, some parameters can not be taken as granted, such as investment costs, electricity price, among others. Therefore, stakeholders would be rather concerned about that the impact on our assessment results by variations of parameters in certain ranges.

In the following figures, the design flow and electricity price are varied by the indicated offsets and financial indicators, such as year-to-positive cash flow and net present value behave differently for each project. A decision-maker for hydro projects could refer to these figures and check the corresponding financial indicators in a certain area. For instance, if grant award from Illinois state would be 0.4–0.6, and the electricity price fluctuates between 0.05–0.06$/kWh, the year to positive cash flow could vary from 6 to 13 years at Stolp Island East Dam.

From these three-dimensional figures below, we can also find the optimal design value in order for the best economic indicators. For example, according to curved face in the first figure below, in case of 0.04 $/kWh as the electricity price for Stolp Island East Dam, the optimal design flow should be 900–1000 cft so as to ensure the economic indicator, Year to positive cash flow, to be minimum value.

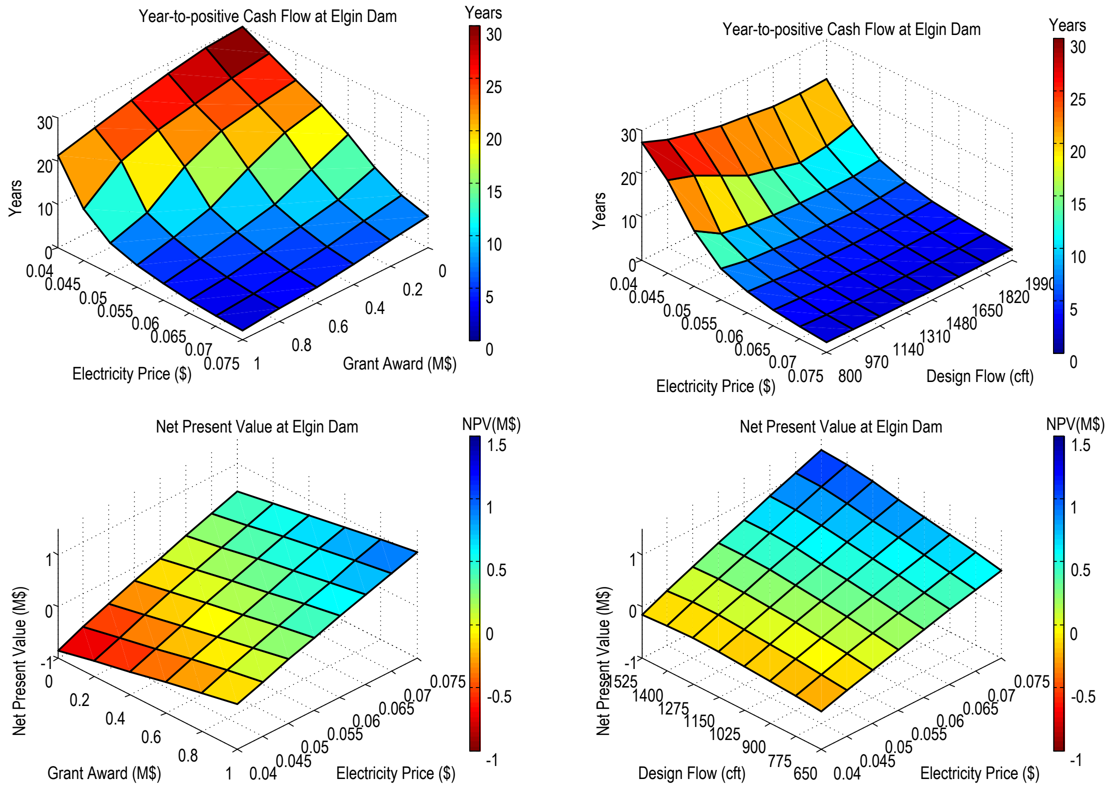


Fig. 35. Sensitivity Analysis at Elgin Dam

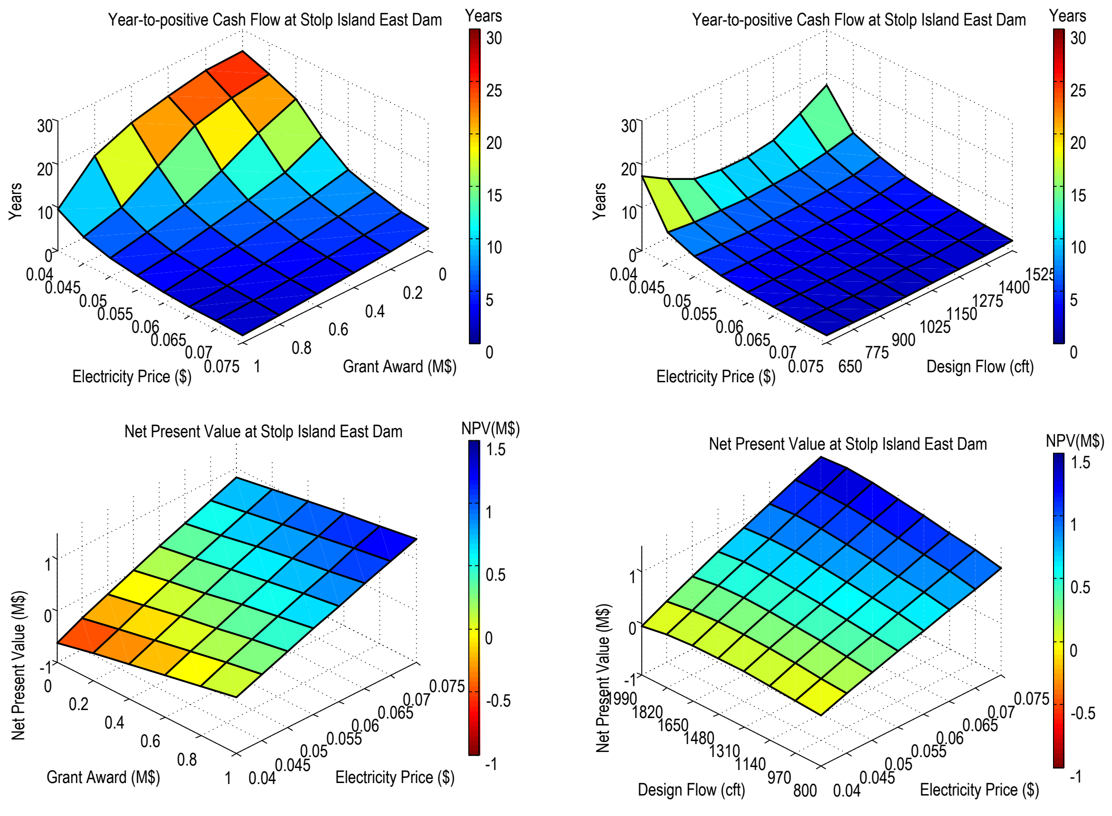


Fig. 36. Sensitivity Analysis at Stolp Island East Dam

B. Risk Analysis

The risk analysis is performed using a Monte Carlo simulation that includes 500 possible combinations of input variables resulting in 500 values of year-to-positive cash flow or other economic indicators. Through our calculation, results indicate that if the variability of the financial indicator is acceptable, or not, by looking at the distribution of the possible outcomes. An unacceptable variability will be an indication of a need to put more effort into reducing the uncertainty associated with the input parameters that were identified as having the greatest impact on the financial indicator.

Table 15. Parameters Range at Elgin Dam

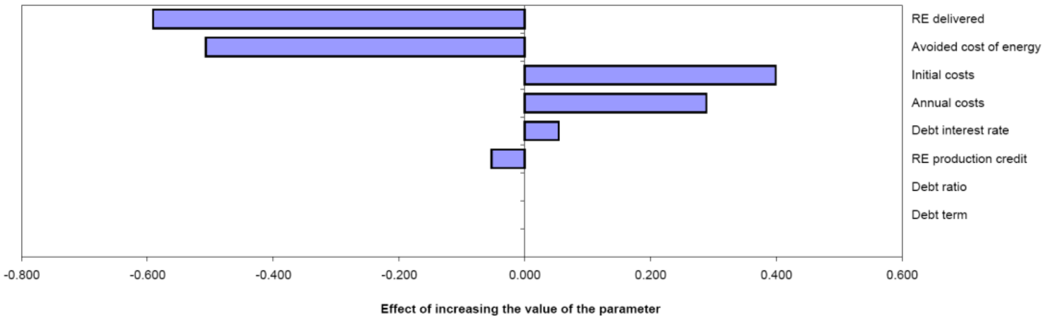
Parameter	Unit	Value	Range	Minimum	Maximum
Avoided cost of energy	USD/kWh	0.0510	+/– 15%	0.0434	0.0587
RE delivered	MWh	3,502	+/– 15%	2,976	4,027
R&D costs – Grant award	USD	1,090,000	+/– 20%	872,000	1,308,000
Annual costs	USD	100,000	+/– 15%	85,000	115,000
Debt ratio	%	80.0%	+/– 0%	80.0%	80.0%
Debt interest rate	%	5.3%	+/– 10%	4.8%	5.8%
Debt term	yr	20	+/– 0%	20	20
RE production credit	USD/kWh	0.009	+/– 10%	0.008	0.010

For Stolp Island East Dam, assuming that the level of risk is 10%, the basic input parameters here are identical with those in IV, if the avoided cost of energy (electricity price) are varied by 15%, RE delivered are varied by 15% and ects (see

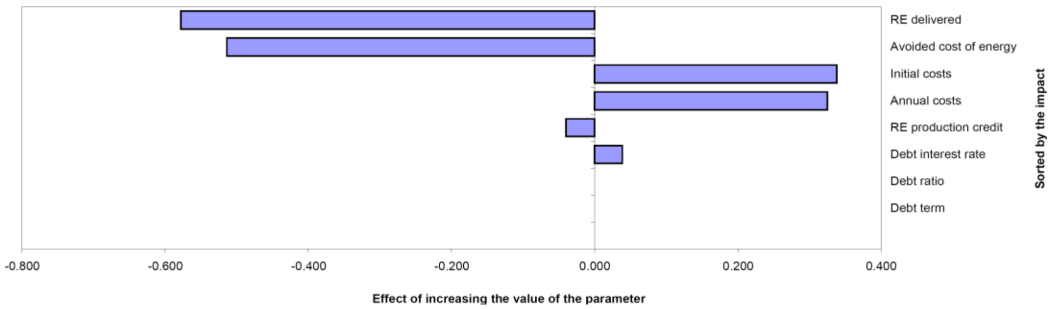
Table 12) , the year to positive cash flow would lie in the range from 2.9yr to 7.2yr with 90% level of confident. On the condition that the stakeholders' expecting year to positive cash flow would be less than 15 years, this small hydro facility would be economically feasible to build and the variability of input parameters would be acceptable.

Table 16. Parameters Variability Range at Stolp Island Dam

Parameter	Unit	Value	Range	Minimum	Maximum
Avoided cost of energy	$/kWh	0.0510	+/– 15%	0.0434	0.0587
RE delivered	MWh	3,071	+/– 15%	2,610	3,532
R&D costs – Grant award	$	1,040,000	+/– 20%	832,000	1,248,000
Annual costs	$	100,000	+/– 15%	85,000	115,000
Debt ratio	%	80.0%	+/– 0%	80.0%	80.0%
Debt interest rate	%	5.3%	+/– 10%	4.8%	5.8%
Debt term	yr	20	+/– 0%	20	20
RE production credit	USD/kWh	0.009	+/– 10%	0.008	0.010



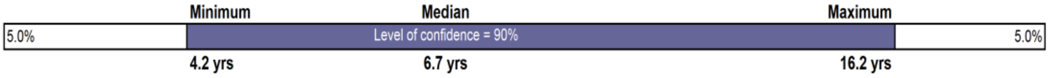
(a) Elgin Dam



(b) Stolp Island East Dam

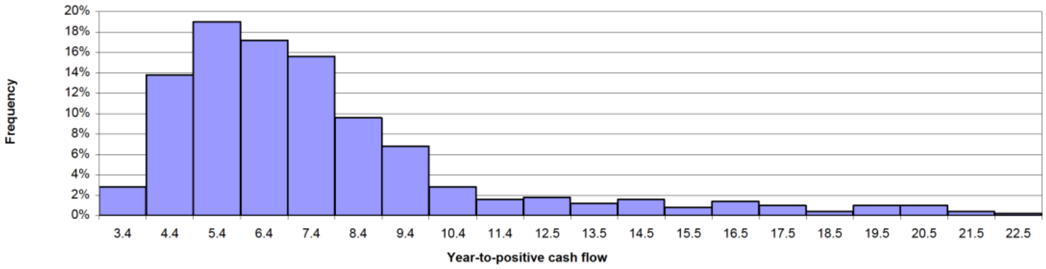
Fig. 37. Impact on Year-to-Positive Cash flow

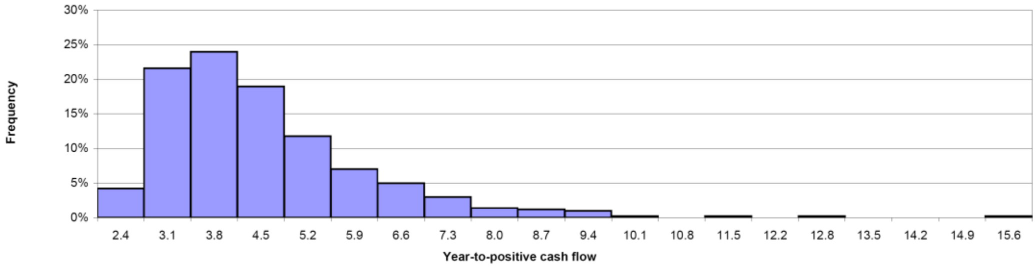
(a) Elgin Dam



(b) Stolp Island East Dam

Fig. 38. Confidence Interval





(b) Stolp Island East Dam

Fig. 39. Distribution of year-to-positive cash flow

VI. Conclusion

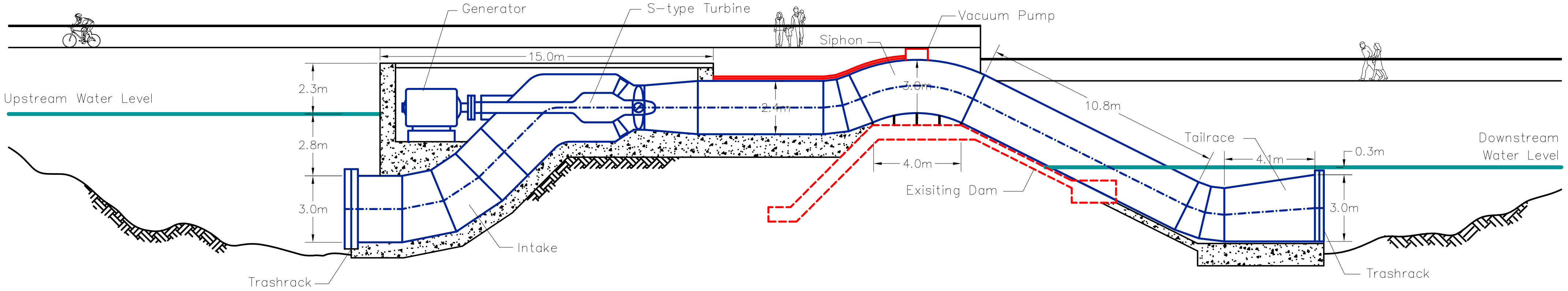
This IPRO has achieved the goal of designing low-head small hydro projects at Elgin and Stolp Island East that are economically profitable, technically efficient and feasible, and environment friendly. This IPRO could be a starting point of a massive application of small hydro in the state of Illinois and around the country. Possible future work include communicating this project to the general public and seeking political support, learning the permitting process and applying for grants, contacting manufacturers and contractors to obtain more accurate price quotation, and obtaining more detailed site dimensions and fine-tuning the technical designs. We envision the continuation of this IPRO with an EnPRO for actual implementation.

VII. References

[1] X.Wang, “Body style design on the flow path of the siphon intake,” Small Hydro Power, 1999. National Research Institute for Rural Electrification, Ministry of Water Resource, Hangzhou.
[2] M. Shahidehpour, H. Yamin, and Z. Li, Market Operations in Electric Power Systems. New York, NY: John Wiley & Sons, Mar 2002.
[3] M. Shahidehpour and M. Marwali, Maintenance Scheduling in Restructured Power Systems. Norwell, MA: Kluwer Academic Publishers, June 2000.
[4] N. Deeb and M. Shahidehpour, “A decomposition approach for minimizing real power losses in power systems,” in Proc. of IEE Generation, Transmission and Distribution, vol. 138, Part C, pp. 27–38, IEEE, Jan 1991.
[5] J. K. Delson and M. Shahidehpour, “Linear programming applications to power system economics,” IEEE Transactions on Power Systems, vol. 7, pp. 1155–1163, Aug 1992.
[6] N. Deeb and M. Shahidehpour, “Cross decomposition for multi-area optimal reactive power planning,” IEEE Transactions on Power Systems, vol. 8, pp. 1539–1544, Nov 1993.
[7] C.Wang and M. Shahidehpour, “Ramp-rate limits in unit commitment and economic dispatch incorporating rotor fatigue effect,” IEEE Transactions on Power Systems, vol. 9, pp. 1539–1545, Aug 1994.
[8] S. Wang, M. Shahidehpour, D. Kirschen, S. Mokhtari, and G. Irisarri, “Short-term generation scheduling with transmission and environmental constraints using an augmented lagrangian relaxation,” IEEE Transactions on Power Systems, vol. 10, pp. 1294–1301, Aug 1995.
[9] K. Abdul-Rahman, M. Shahidehpour, M. Aganagic, and S. Mokhtari, “A practical resource scheduling with opf constraints,” IEEE Transactions on Power Systems, vol. 11, pp. 254–259, Feb 1996.
[10] M. Shahidehpour and V. Ramesh, Nonlinear Programming Algorithms and Decomposition Strategies for OPF. IEEE, 1996.
[11] H. Ma and M. Shahidehpour, “Transmission constrained unit commitment based on benders decomposition,” International Journal of Electrical Power & Energy Systems, vol. 20, pp. 287–294, Apr 1998.
[12] H. Ma and M. Shahidehpour, “Unit commitment with transmission security and voltage constraints,” IEEE Transactions on Power Systems, vol. 14, pp. 39–44, May 1999.
[13] M. K. C. Marwali and M. Shahidehpour, “Coordination between long-term and short-term generation scheduling with network constraints,” IEEE Transactions on Power Systems, vol. 15, pp. 1161–1167, Aug 2000.
[14] Z. Li and M. Shahidehpour, “Generation scheduling with thermal stress constraints,” IEEE Transactions on Power Systems, vol. 18, pp. 1402–1409, Nov 2003.
[15] M. Shahidehpour, Y. Fu, and T. Wiedman, “Impact of natural gas infrastructure on electric power systems,” Proceedings of the IEEE, vol. 93, pp. 1042–1056, May 2005.
[16] Y. Fu, M. Shahidehpour, and Z. Li, “Long-term security constrained unit commitment: Hybrid dantzig-wolfe decomposition and subgradient approach,” IEEE Transactions on Power Systems, vol. 20, pp. 2093–2106, Nov 2005.

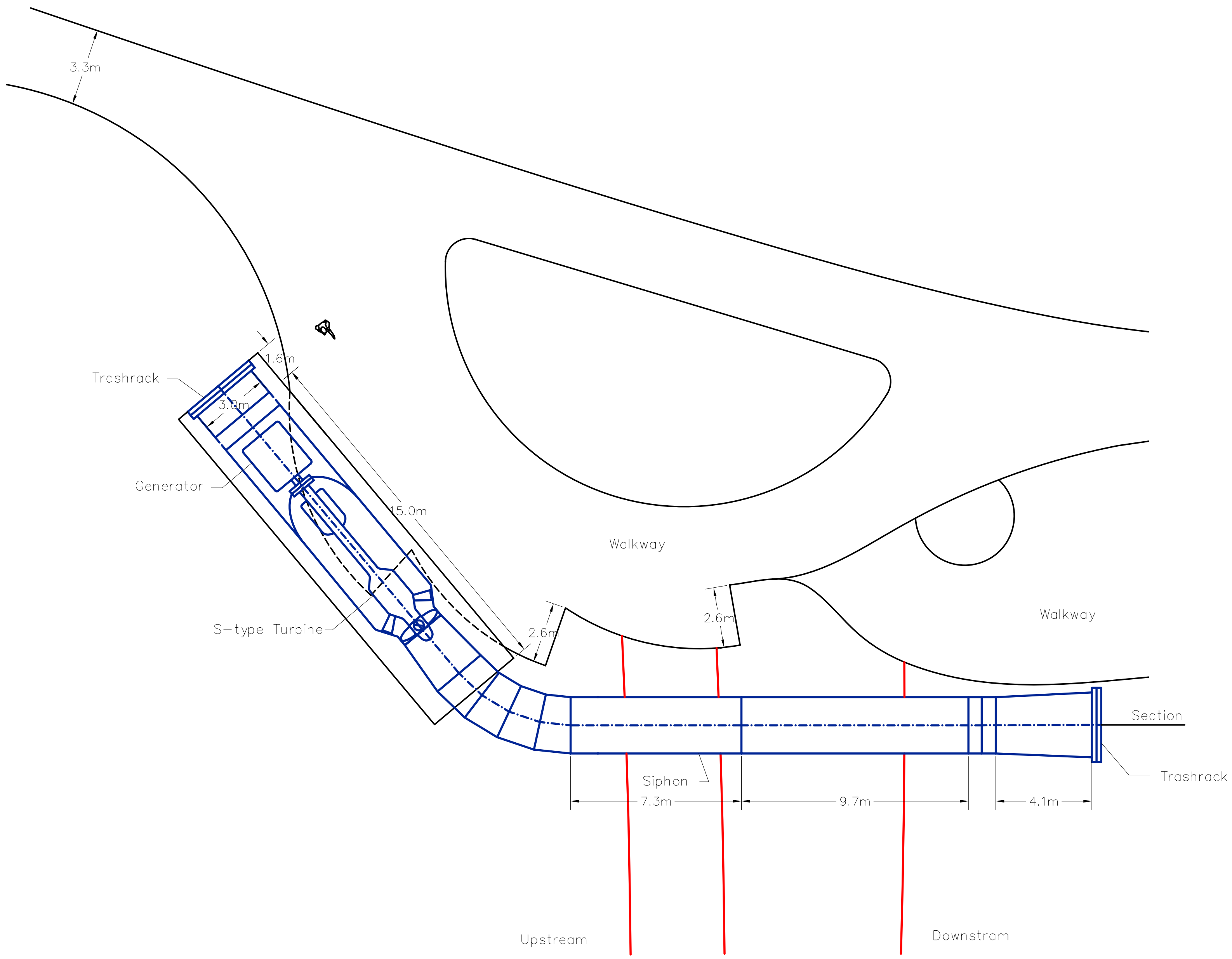
[17] M. Shahidehpour, W. F. Tinney, and Y. Fu, "Generation scheduling with thermal stress constraints," IEEE Transactions on Power Systems, vol. 93, pp. 2013–2025, Nov 2005.
[18] Y. Fu, M. Shahidehpour, and Z. Li, "Security-constrained unit commitment with ac constraints," IEEE Transactions on Power Systems, vol. 20, pp. 1001–1013, May 2005.
[19] N. Mahdi and P. Anderson, "Feasibility assessment for low hydroelectric facilities on the Fox River in northeast Illinois," Dec 2005.
[20] NAH, "Feasibility study for the development of a hydroelectric generating station at the kimball street dam." [On-line] Available at: http://www.nahydro.com/, Feb 2005.
[21] IPRO–319, "Final report." IIT Interprofessional Projects Program (IPRO), Illinois Institute of Technology [On-line] Available at: http://iknow.iit.edu/, Dec 2005.
[22] Chicago Area Paddling & Fishing Guide, "Dams and obstructions in the Chicago area." [On-line] Available at: http://www.chicagofishing.org/, 1995.
[23] USGS, "National Water Information System: Web Interface." Department of the Interior, U.S. Geological Survey, [On-line] Available at: http://nwis.waterdata.usgs.gov/nwis/, Nov 2002.
[24] RETScreen, "RETScreen International Clean Energy Project Analysis Software: Small Hydro Project Model." [On-line] Available at: http://www.retscreen.net/, Jan 2005.
[25] RETScreen, "RETScreen Software Online User Manual: Small Hydro Project Model." RETScreen International Clean Energy Decision Support Centre, [On-line] Available at: http://www.retscreen.net/, Jan 2005.
[26] RETScreen, "Clean Energy Project Analysis: RETScreen Engineering & Cases Textbook." RETScreen International Clean Energy Decision Support Centre, [On-line] Available at: http://www.retscreen.net/, Jan 2005.
[27] J. L. Gordon and A. C. Penman, "Quick estimating techniques for small hydro potential," Water power and dam construction, vol. 29, no. 11, 1979.
[28] D. G. Hall, R. T. Huntand, K. S. Reeves, and G. R. Carroll, "Estimation of economic parameters of U.S. hydropower resources," Dec 2003.
[29] J. S. Gulliver and R. E. Arndt, Hydropower Engineering Handbook. McGraw Hill Inc., 1 ed., Oct 1990.
[30] FERC, "Renewable Energy Production Tax Credit: Instructions for requesting certification of incremental hydropower production pursuant to the Energy Policy Act of 2005." Federal Energy Regulatory Commission (FERC), [On-line] Available at: http://www.ferc.gov/industries/hydropower/gen-info/comp-admin/credit-cert.pdf, Dec 2005.
[31] ICC, "Response to Governor's Sustainable Energy Plan for the State of Illinois: Resolution 05–0437." Illinois Commerce Commission, [On-line] Available at: http://www.dsireusa.org/documents/Incentives/IL04R.pdf, Jul 2005.
[32] DCEO, "Renewable Energy Resources Program Report: January through December 2005." Illinois Department of Commerce and Economic Opportunity, [On-line] Available at: http://www2.illinoisbiz.biz/StatutoryMandatedReports/07252006-2005RERPREPORTfinal.pdf, 2005.
[33] DCEO, "Renewable Energy Resources Program: Solar Thermal, Photovoltaic, Biomass, Wind and Hydropower Request for Proposals Guidelines and Application." Illinois Department of Commerce and Economic Opportunity,

[On-line] Available at: http://www.dsireusa.org/documents/Incentives/IL04R.pdf, 2003.
[34] DCEO, "Renewable Energy Resources Program Report: December 1997 through December 2004." Illinois Department of Commerce and Economic Opportunity, [On-line] Available at: http://www.commerce.state.il.us/NR/rdonlyres/DA007C62-32BC-4A03-AA53-8F42D20EB628/0/AnnualReport2004 RERPREPORT.pdf, 2005.
[35] M. Bolinger, R. Wiser, L. Milford, M. Stoddard, and K. Porter, "Clean Energy Funds: An overview of state support for renewable energy." Environmental Energy Technologies Division at Ernest Orlando Lawrence Berkeley National Laboratory, Clean Energy Funds Network, and National Renewable Energy Laboratory, [On-line] Available at: http://eetd.lbl.gov/ea/EMP/reports/47705.pdf, Apr 2001.
[36] PJM, "PJM website." Pennsylvania–NewJersey–Maryland (PJM) Interconnection, [On-line] Available at: http://www.pjm.org/, 2006.



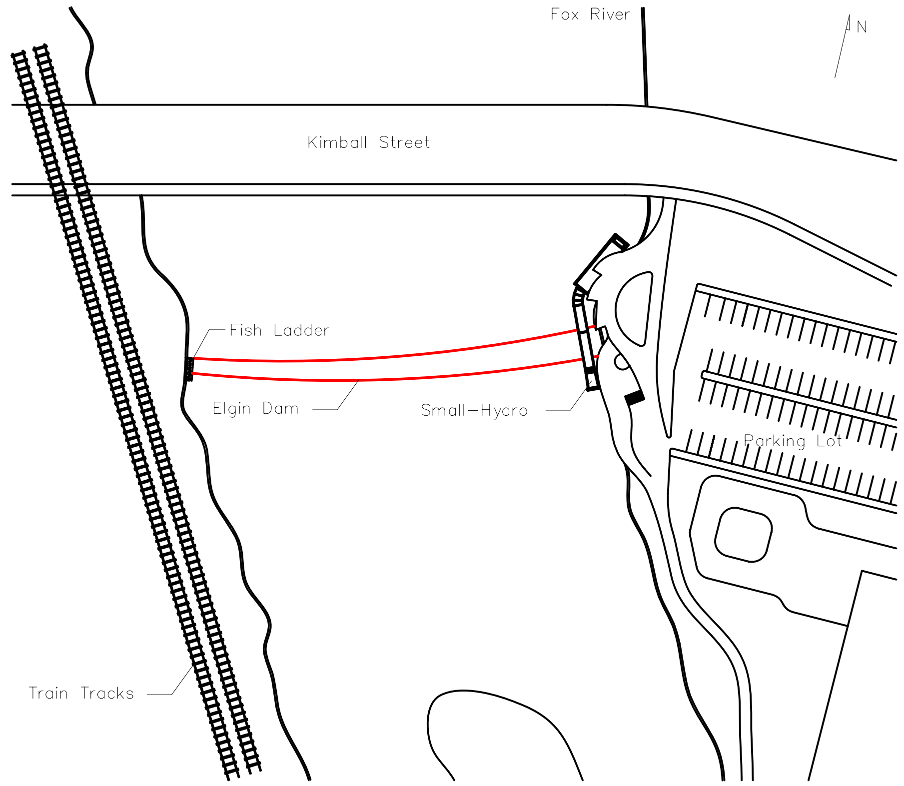
Section View

Scale 1:250



Top View

Scale 1:250



Site Plan

Scale 1:2000

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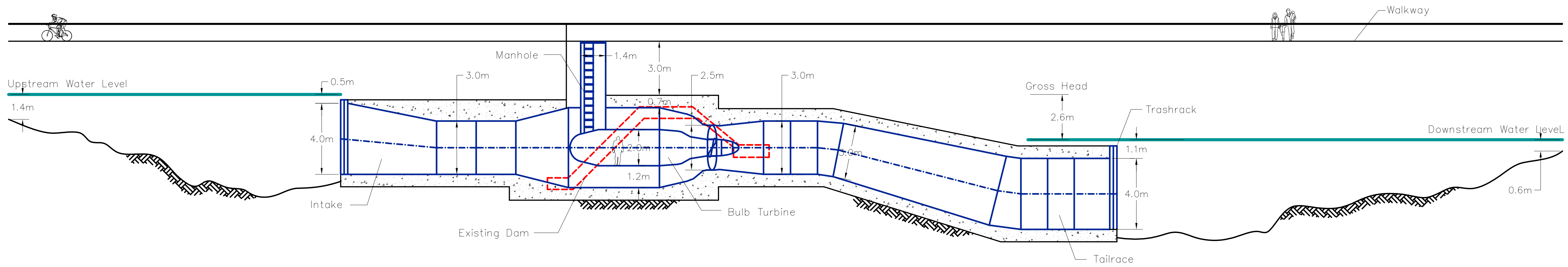
SMALL HYDRO DESIGN AT ELGIN DAM	
S-TYPE TURBINE	2/2



Section View
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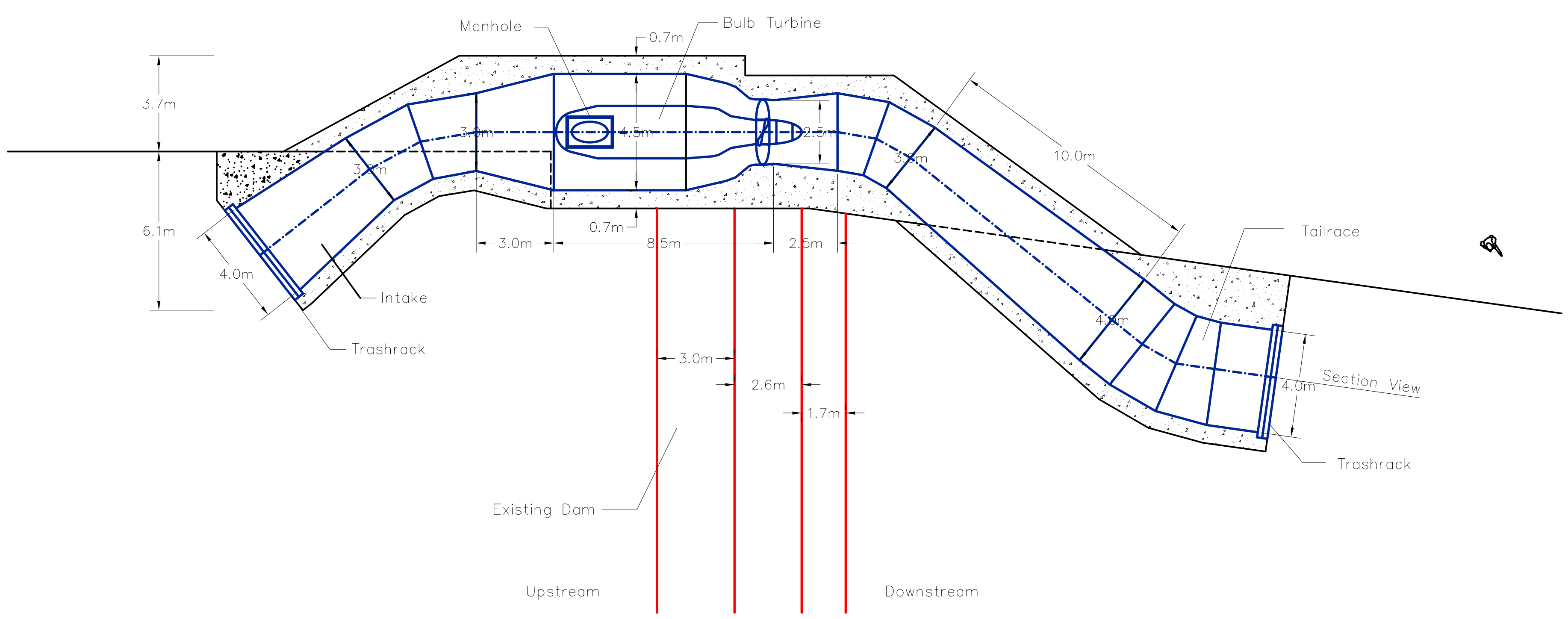

Top View
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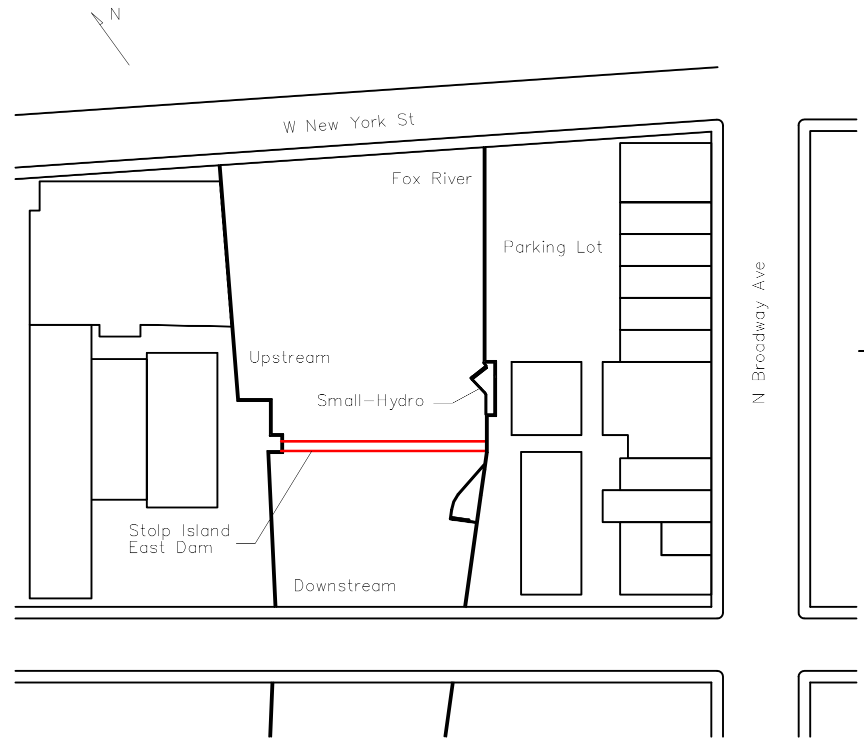

Site Plan
Scale 1:2000

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IPRO 343 - TECHNICAL & MARKET INTEGRATION OF SMALL-HYDRO ENERGY

SMALL HYDRO DESIGN AT STOLP ISLAND EAST DAM

BULB TURBINE 1/2