THE FRESNO LOW-HEAD HYDROPOWER PROJECT – A CASE STUDY

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ABSTRACT

The City of Fresno Water Division is planning to develop a low-head hydropower project on a new 60-inch diameter pipeline that delivers water to their surface water treatment plant. The hydropower plant will take advantage of excess pressure at the pipe terminus and generate electricity for use at the treatment plant. Flows through the pipeline will be a constant 46 cfs, with an excess head of 40 feet, from 2011 to 2020. The flow will increase instantaneously to 93 cfs, and the excess head will reduce to 18 feet, when the treatment plant is expanded in 2020. The City was challenged in finding a low-head turbine that can accommodate both flow and pressure conditions, while maintaining high efficiency. Seven turbine configurations were evaluated that considered variations in the number and type of turbines, operating during one or both of the two flow conditions, operating at low efficiencies during one flow condition, and modifying or replacing turbines when flow conditions change. The final configuration includes a 130-kw tubular unit with adjustable runner blades that can accommodate a range of flow and head conditions. Due to a wide range of possible economic, hydrologic and design conditions, two economic analyses were performed including a conservative and less conservative case. The benefit cost ratios ranged from 0.9 to 3.2. Other project challenges include finding a domestic turbine supplier, evaluating net metering opportunities, and seeking government grants for low-head hydropower. The project is still in the planning and design stage.

INTRODUCTION

In 2008, the City of Fresno, California evaluated several alignment corridors and performed a preliminary design for a 'Raw Water Pipeline' from the Friant-Kern Canal to the City of Fresno Surface Water Treatment Facility (SWTF). The study recommended a 60-inch diameter pipe to accommodate future anticipated flows of 60 MGD, and also to match the diameter of a limited section of the Raw Water Pipeline that had already been constructed under a new development. Flows are anticipated to be 30 MGD from 2011 to 2020, and then increase to 60 MGD. Under both flow scenarios, the water will have excess energy (head) at the pipeline terminus, providing an opportunity to generate hydropower.

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In 2009 the City of Fresno performed a study to evaluate the potential for installing a small hydroelectric powerplant at the terminus of the Raw Water Pipeline. The goal is for the powerplant to take advantage of excess head in the pipeline and generate power for use at the treatment plant.

This paper discusses the technical and economic challenges in developing a small in-line hydropower project. The primary challenge was finding a turbine and project configuration that could accommodate the instantaneous change in head and flowrate expected in 2020 when the treatment plant is expanded.

SITE DESCRIPTION

Fresno Surface Water Treatment Facility

In 2004, the City of Fresno completed construction of a Surface Water Treatment Facility (SWTF). The SWTF began treating surface water in June 2004 and currently delivers between 15 and 30 percent of the water supply to the City's water distribution system. The City had previously relied solely on groundwater for its potable water supply. The SWTF has a capacity of 30 MGD, and is expected to be expanded to accommodate 60 MGD by 2020. The proposed Raw Water Pipeline will terminate at the SWTF.

Proposed Raw Water Pipeline

The SWTF is currently supplied with Kings River and Central Valley Project (CVP) water conveyed by the Fresno Irrigation District's Enterprise Canal. Raw water from the canal is diverted under gravity flow to the SWTF raw water pump station and is then pumped to the water treatment headworks. Due to capacity limitations and water quality concerns in the Enterprise Canal, the City is proposing to construct a 60-inch diameter pipeline directly from the Friant-Kern Canal to the SWTF. The pipeline will be called the Raw Water Pipeline. The proposed Raw Water Pipeline will replace the Enterprise Canal as the primary conveyance facility to the SWTF. Several pipeline alignments from the Friant-Kern Canal to the SWTF were considered (see Figure 1). A short section of the pipeline has already been constructed under a recent school development. This was done early to avoid disturbing the new school facilities when the entire pipeline is constructed. A 60-inch diameter pipeline was selected for this section. Consequently, a 60-inch diameter pipeline was also selected for the entire pipeline. The size of the pipeline allows the water to have excess energy (head) when it reaches the SWTF. The proposed powerplant would be located at the treatment plant where the Raw Water Pipeline will terminate.

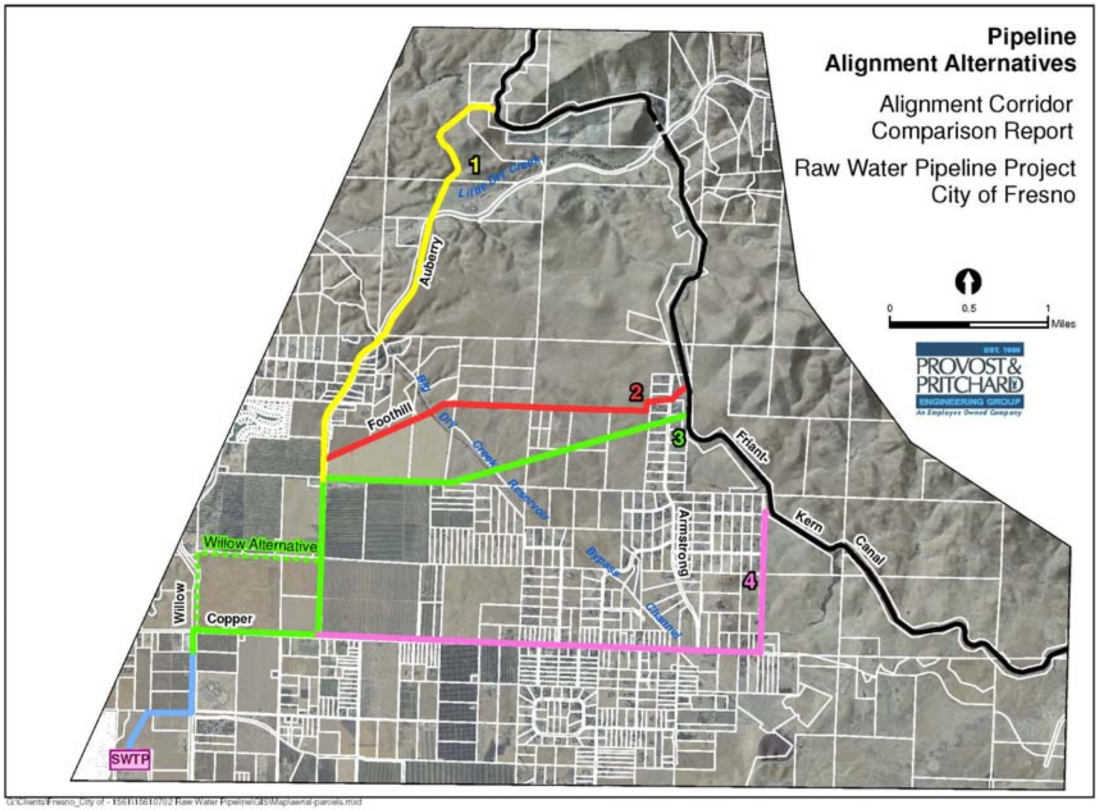

Figure 2. Pipeline Alignment Alternatives

ENERGY USAGE AND DEMANDS

The proposed powerplant will provide approximately 80,000 to 90,000 kwh/month. In comparison, monthly energy demands at the SWTF varied from 326,500 kwh to 843,000 kwh in months when water was treated. Future energy demands will approximately double when the volume of water treated is increased from 30 MGD to 60 MGD in 2020. Therefore, the hydropower plant could only provide a portion of the SWTF's energy demands, but it could offset a significant portion of the electricity bill for the SWTF.

DESCRIPTION OF ALTERNATIVES

Flows to the treatment facility are expected to increase from 46 cfs to 93 cfs in 2020. At the same time the excess head will decrease from 40 to 18 feet. This will require that the initial turbines installed in 2011 be replaced or modified in 2020. A variety of turbine installation alternatives were considered to accommodate these changes and are listed in Table 1**.**

Table 1. Turbine Installation Alternatives

Option	Description	0-10 Years	After 10 Years
1	Operate 46 cfs Turbine for 10 Years	Install 46 cfs turbine	Remove and salvage powerplant
2	Install 46 cfs Turbine and Divert Excess Flows through Bypass	Install 46 cfs turbine	Keep in place and operate at lower efficiency, divert new 46 cfs through bypass line
3	Install 46 cfs Turbine and Modify in 2020	Install 46 cfs turbine	Modify turbine to accommodate higher flow and lower head
4	Install 46 cfs Turbine in 2011 and Second 46 cfs Turbine in 2020	Install 46 cfs turbine	Install second 46 cfs turbine
5	Install 93 cfs Turbine in 2011	Install 93 cfs turbine and operate at low efficiency	Continue operating 93 cfs turbine now at higher efficiency
6	Install Turbine that Can Accommodate Range in Conditions	Install single turbine that can accommodate full range of flows and heads	Continue using turbine that can accommodate full range of flows and heads
7	Install 93 cfs Turbine in 2020	Nothing	Install 93 cfs turbine

Option 6, Install Turbine that Can Accommodate Range in Conditions, was identified as the most practical and economical alternative. A discussion on each of these alternatives is provided below.

Option 1 – Operate 46 cfs Turbine for 10 Years

This option includes installing a turbine that can accommodate the low flow, high head conditions (46 cfs and 40 feet). When the flowrate changes in 2020, the system would be removed and salvaged. No attempt would be made to generate electricity after 2020. The economic analysis shows that the project cannot be paid off in less than 10 years, even under the most optimistic assumptions presented. Furthermore, the salvage value of the turbine would probably be low, and it could be difficult to find someone looking for a used turbine of the same size. As a result, this option was eliminated from consideration.

Option 2 – Install 46 cfs Turbine and Divert Excess Flows through Bypass

This option would only generate power using 46 cfs under both flow conditions. After 2020, the new 46 cfs of flow would be diverted, thus missing the opportunity to generate some potential hydropower. This option would not be economical because the revenue would be too low after 2020, and therefore was eliminated from consideration.

Option 3 – Install 46 cfs Turbine and Modify in 2020

This alternative is similar to Option 6, but this alternative would involve major modifications in 2020, while Option 6 would require minor or no modifications in 2020. This alternative was eliminated from consideration because a turbine was found that could accommodate the range in flows and heads with only minor modifications (Option 6).

Option 4 – Install 46 cfs Turbine in 2011 and Second 46 cfs Turbine in 2020

This option would require the installation of two separate turbines. This would incur higher capital costs than installing a single turbine (Option 6) and therefore was eliminated from consideration.

Option 5 – Install 93 cfs Turbine in 2011

Under this option the turbine would be designed for 93 cfs, operate at a low efficiency from 2011-2020, then operated at a high efficiency after 2020. This option was also eliminated from consideration because no turbine was found that can operate under both flow conditions without modifications.

Option 6 – Install Turbine that Can Accommodate Range in Conditions

This option would be the most economical because it would minimize change-over costs in 2020 when flow conditions change, and the turbine would operate at fairly high efficiencies under the two different flow conditions with only minor modifications. A turbine that can accommodate both flow conditions was found and was used in the economic analyses.

Option 7 – Install 93 cfs Turbine in 2020

Waiting until 2020 to install a turbine is not necessary because a turbine was found that can accommodate the range in flow conditions (Option 6). In addition, it would probably be more difficult to connect a hydropower plant to the Raw Water Pipeline in the future, when it is operating, than in 2011, while it is being constructed. Therefore, this option was dropped from consideration.

POTENTIAL ENERGY GENERATION

Energy generation at the proposed powerplant was calculated using flow data, excess hydraulic head values, and equipment performance data. The energy generation was estimated under both conservative and less conservative assumptions for comparison purposes. The assumptions used in each analysis are show in Table 2. Both scenarios are considered to include reasonable assumptions.

Table 2. Energy Generation Assumptions

Description	Conservative Case	Less Conservative Case
Flowrate (2011- 2019)	30 MGD (46 cfs)	30 MGD (46 cfs)
Flowrate (2020+)	60 MGD (93 cfs)	60 MGD (93 cfs)
Available Head (2011-2019)	40 feet	40 feet
Available Head (2020+)	17 ft to 14 ft[1]	18 feet
Turbine Efficiency	90%	90%
Generator Efficiency	90%	95%
Powerplant Downtime	3%	2%
Water Supply Availability	94%	100%
Inflation of Energy Costs above Overall Inflation	0%	0.5%/year

1 – The available head is assumed to decline 1 foot every decade

For the purpose of this analysis, a project life of 50 years was used. However, with proper maintenance, the power plant should perform well beyond a 50-year period.

The potential energy generated for the conservative scenario is about 1,000,000 kwh/year in 2011 tapering down to about 710,000 kwh/year after 50 years, due to an increase in pipe roughness. For the less conservative case, the generation is about 1,100,000 kwh/year the first ten years, and then a steady 1,040,000 kwh/year for the remaining 40 years. A summary of the estimated revenue is provided in Table 3. The revenue is based on 2009 electricity and demand rates for Pacific Gas & Electric utility.

Table 3. Estimated Annual Revenue

Years	Conservative Case	Less Conservative
2011-2020	$102,000	$118,000
2020 -2030	$88,000	$112,000
2030-2040	$82,000	$118,000
2040-2050	$77,000	$123,000
2050-2060	$72,000	$128,000
Average	$84,000	$120,000

PROJECT DESIGN

Following is a discussion on the project's civil, mechanical and electrical facilities. A schematic drawing of the design can be found in Figure 2.

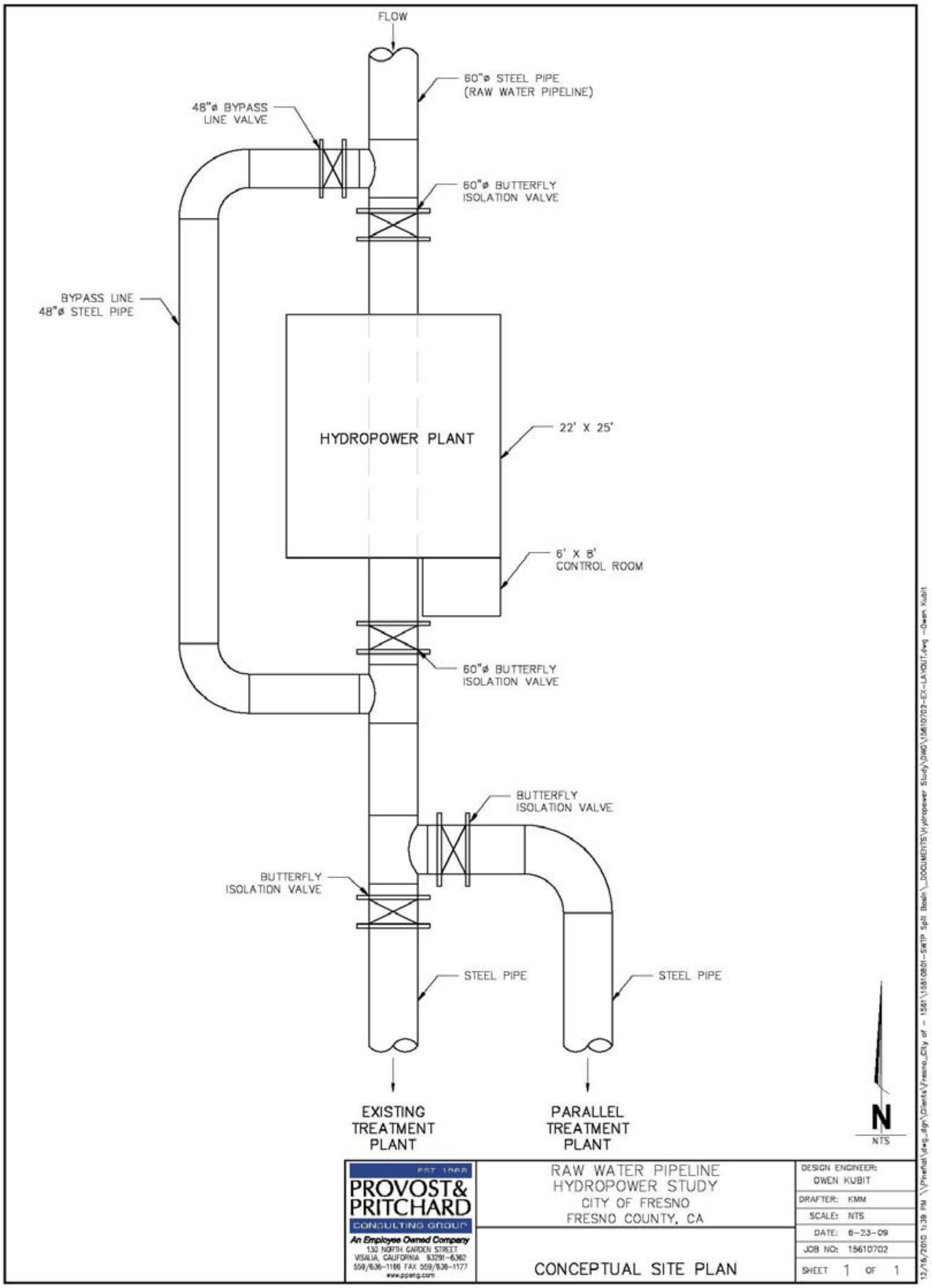

Figure 1. Conceptual Site Plan of Hydropower Plant

Turbine

Turbines are normally selected based on very specific characteristics of the site for optimum performance. The initial and final flow/head conditions for this site fit two different categories from the manufacturer's perspective. The initial condition (40 feet of head) falls in a low-head category while the final condition (18 feet of head) is in the very low-head category. Significant research was performed to find a domestic turbine manufacturer. Nine companies were contacted for equipment and cost information. The City found that turbine sales engineers often have little or no interest in customers seeking their smaller units, and are more focused on selling large turbines. In addition, most companies did not make or supply equipment that would meet the site conditions of this project, or could only meet the initial flow/head conditions. Turbines meeting the head and flow requirements therefore must be found from foreign suppliers. The lack of a domestic manufacturer is probably attributed to the minimal development of small scale hydropower in the United States, and lack of government incentives to develop small hydropower during the last 20 years. France, England, Japan and China are a few countries that have worked extensively with low-head hydropower, particularly due to government promotion, and are more likely to manufacture smaller turbines. International bidding will therefore be required for the equipment. Bidding, design, manufacturing and shipping will require at least 16 months.

Voith Hydro of Japan, a joint venture of Voith Siemens Hydro Equipment makes a turbine that will operate under both the initial and final flow/head conditions with only minor modifications when conditions change in 2020. That appears to be the most economic equipment to use for this site and, therefore, was used to establish the economics for this feasibility study.

The turbine manufactured by Voith Hydro is a tubular unit (L-type) with adjustable propeller blade runner. The turbine drives the generator with a timing belt rather than a gear assembly, which makes it easier to change speed ratios necessary for the two flow/head conditions. Maintenance of the turbine includes replacement of the timing belt every six months and pulleys, bearing, and water seals every five years. At the 10-year maintenance period, the pulley size would change to meet the speed ratio necessary for the final flow/head operating condition. This would require adjusting the runners, changing the pulley ratio, and possibly installing different belts.

Other Facilities

Additional facilities in the project design include the following:

- Induction type generator
- Reinforced concrete pit
- 48-inch diameter bypass pipeline with flow control valves
- 60-inch diameter butterfly isolation valves

- Hydraulic power units to operate the valves
- Cinder block powerhouse building
- SCADA system

Connection to Electrical System

The generated electricity could either be used on-site or delivered to the electrical grid for sale. Using the electricity on site is recommended because a grid connection would have no economic advantage at this time and would be time consuming to implement. A detailed list of reasons for using the power on site is provided below:

1. FERC Approval. Connecting to the electric grid would require a permit from the Federal Energy Regulatory Commission (FERC). This would be a time consuming and costly process.
2. Power Purchase Agreement. The City would need to prepare a power purchase agreement with the local electric utility (Pacific Gas and Electric) or another power provider. This too would require additional costs, could be time consuming, and may commit the City to a long-term agreement and performance requirements. In addition, some power purchasers may have little interest in the project due to its low power generation (150 kW).
3. Contract Management. The City would have on-going administrative costs for dealing with the power purchase agreement.
4. Capital Facilities. Connecting to the grid would require additional capital facilities, including a distribution line, step-up transformer, and additional switchgear for line/utility protection.
5. Transmission Losses. Some of the power would be lost as it is conveyed from the powerplant to the grid, which is several hundred feet away.

Based on their current electric rate schedule, the City pays a blended rate of about 10 cents per kwh. The price the local utility pays for wholesale power is negotiated, but, on average, it is about 3.5 to 4 cents per kwh. Higher prices of 5 to 6 cents per kwh can be found on the spot market. The local utility does offer some special rate schedules for renewable energy that offer about $0.10/kwh for a 10-year contract and $0.11/kwh for a 20 year contract. While these rates were competitive in 2009, there is no provision for escalation or inflation, and during the term of the agreement the rates will not increase. As a result, when inflation is considered, these rate schedules will probably be a poor option compared to displacing the electricity on site.

Electrical Facilities

The facility was evaluated on the basis that it will use all power on-site and not feed the grid. The electrical facilities required will include a feeder to the nearest load center which has the capacity and voltage corresponding to the capacity of the generator. A protection relay scheme is needed to prevent reverse power flow into the grid, ground fault protection to protect the utility from generator grounds and standard generator protection. No step-up transformer will be needed. An existing motor control center has the ability to receive the 130 kW of generated power.

ECONOMIC ANALYSIS

An financial analysis was performed that considered capital costs, operation and maintenance costs, benefit to cost ratios, various interest rates, and other factors that may impact the project economics in the future. Total capital costs were estimated to be $1.3 million, and operation and maintenance costs were estimated at $16,400/year.

A financial analysis was performed with loan periods of 10, 20 and 30 years and interest rates of 0%, 3% and 5%. Project benefits were estimated based on a 30-year and 50-year project life span. Using these variables, and the conservative and less conservative energy generation assumptions (see Table 2), benefit cost ratios were estimated to range from 0.9 to 3.20. Both the conservative and less conservative case are considered to have reasonable assumptions, suggesting that more detailed investigations are needed to refine the economics. Some important unknowns are foreign exchange rates when the turbine will be purchased, and the future market value of renewable energy.

No viable grant funding was identified for hydropower projects, with renewable energy funding focusing on wind solar and biomass. Grant funding could significantly improve the project economics and reduce uncertainty regarding the benefit cost ratio.

CONCLUSIONS

The following conclusions and lessons can be learned from the investigation:

- No domestic suppliers were found that manufacture turbines that can accommodate the range in flows and head. This probably reflects the low level of small hydropower development in the United States.
- Some turbine sales engineers showed little interest in assisting the design team with a small hydropower project.
- Grant funding for small hydropower is currently lacking, with renewable energy funding focused on other areas.
- The benefit cost ratio varied from 0.9 to 3.2, even though the range in assumptions was considered reasonable. This suggests that more detailed investigations are needed to refine the benefit cost ratio.
- For this project, using the electricity on site is a far superior alternative to net metering due to the low fees paid by the local utility for electricity generated, and the permitting and infrastructure requirements needed to establish a system interconnection
- A variety of alternatives are available for a project that has a range of flow and head conditions. In this case the best alternative was a tubular unit with adjustable propeller blade runner. The turbine drives the generator with a timing belt rather than a gear assembly, which makes it easier to change speed ratios necessary for the two flow/head conditions.

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