Project 2 Written Report

Team 39

Ella Barnes, Fahim Hossain, John Kang, Heather Mello

Seymour Crystals, Inc.
Potter Engineering Center, Room 318
500 Central Drive
West Lafayette, IN 47906-2022

Dr. Glass,

Solar power is a very efficient way to generate energy, but a major problem associated with solar power is the storage of energy for use on cloudy days and at night. One popular way to store solar energy on a large scale is through the use of an elevated water reservoir. In this system, solar power is used to pump water up to a reservoir that sits on a hill. While the water is sitting in the reservoir, it has a large amount of potential energy that can be converted back into electricity by allowing the water to flow back down from the reservoir and spin a turbine that is connected to the power grid. The team was tasked with designing a model of such a system that, if implemented, would be capable of storing 120 MWh. During the design process, the team considered various constraints such as cost, efficiency, and even environmental and cultural factors. Ultimately, the team settled on a design that prioritizes efficiency and longevity through the use of high-quality materials while keeping costs to a minimum. The team attempted to make the model as simple and user-friendly as possible by making as many decisions as possible outside of the model, such as site selection and minimum overall efficiency. The team used a combination of empirical methods and cultural and environmental considerations in choosing a location for the reservoir before determining that site 1 was the best location for the reservoir. The team researched the efficiency of modern hydroelectric power plants to decide on a minimum acceptable efficiency for the model. After undertaking this research, the team decided that 80% efficiency was a reasonable, comparable target efficiency for the model, a decision that was supported by the model's computations later in the design process. In summary, the team designed a model that would cost the company approximately $670,000 and would have an overall efficiency of 0.805.

Sincerely,

Team 39

Executive Summary

The model utilizes values associated with site 1, including usable surface area, site preparation cost, access road cost, and physical characteristics of the site such as elevation, distance from the river, and the angle of elevation and accepts inputs for pump efficiency, turbine efficiency, pipe diameter, pipe friction, and reservoir wall height. The model calculates the necessary volume of water, optimal surface area of the reservoir, input energy required, time to fill and empty, and overall efficiency. The model outputs the area of the reservoir, required input energy, overall efficiency, and time to fill and empty. To find the most optimal solution that still meets the team's predetermined efficiency criteria, the model runs through all possible combinations of variable inputs and determines the combination that has the lowest relative cost. The overall cost was calculated by the team outside of the model by adding the set costs associated with site 1 to the relative cost determined by the model. The decision-making capabilities of the model are limited by the number of variables set by the design team before the creation of the model. The model suggests that a reservoir with a total surface area of 106,630 m^2 would be most efficient for storing solar power. This design would require an energy input of 149 MWh. The model uses 3m diameter pipes with a Darcy friction factor of 0.002 and pump and turbine efficiencies of 0.92. Though the model does not output a shape for the reservoir, the team decided that a square shape would be the best for the reservoir. The team made this decision based on the fact that the site was a square and the assumption that a square reservoir would be easier to build and maintain than a circular one. The time to fill and empty are 5.70 hours and 11.94 hours, respectively. The model's calculated overall efficiency is 0.8055. The team's model has a predicted total price of $669,331, not accounting for additional costs that may be incurred from necessary agricultural clean-up or future maintenance.

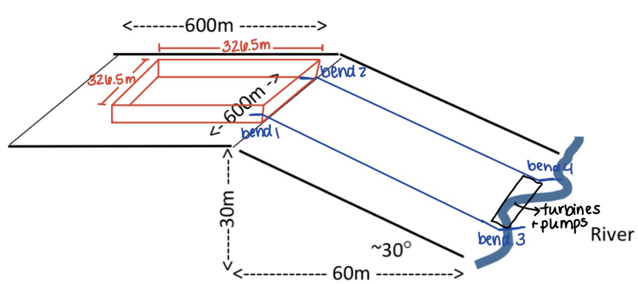


Figure 1: Zone 1 layout

Cost Impact Analysis

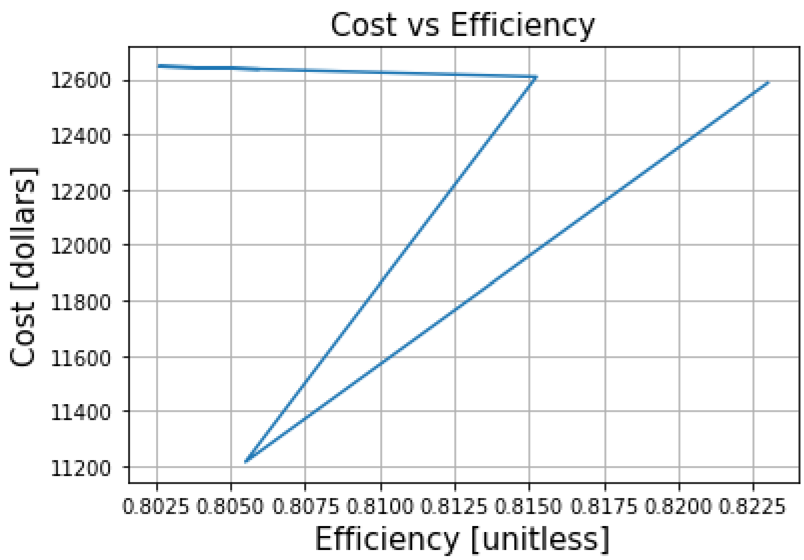
The team began by using the universal accounting equation to derive intermediate equations for energy loss from pipe bends, pipe friction, pump inefficiency, and turbine inefficiency as well as equations for the velocity of water going up to and down from the reservoir, mass of water, and required input energy.

$$V_{down} = \frac{Q_{turbine}}{Area_{pipe}} \qquad V_{up} = \frac{Q_{pump}}{Area_{pump}}$$

$$M = \frac{\left(E_{out} + E_{in}\left(\frac{1}{\eta_{turbine}}\right) - 1\right)}{g(H + d/2) - f(L/D)(V_{down}^2/2) - \varepsilon_1 V_{down}^2/2 - \varepsilon_2 V_{down}^2/2}$$

$$\begin{aligned} E_{in} = {} & m(f(L/D)V_{up}^2/2) + m(\varepsilon_1 V_{up}^2/2) + m(\varepsilon_2 V_{up}^2/2) + E_{out} \\ & + E_{out}\left(\left(\frac{1}{\eta_{turbine}}\right) - 1\right) + m(f(L/D)V_{up}^2/2 + m(\varepsilon_1 V_{down}^2/2) \\ & + m(\varepsilon_2 V_{down}^2/2) \end{aligned}$$

The model was developed specifically using site 1, so all costs that are unique to site 1 are present in the model. Another assumption that was key in the team's design process was that higher quality, more expensive materials would have a greater lifespan and require less future maintenance, therefore justifying an additional upfront cost. For any variable inputs, the model runs through all possible combinations to get an output with the lowest cost that is still associated with an efficiency above the team's predetermined minimum efficiency of 0.8. The minimum efficiency was determined by the team through research into modern hydroelectric power plants and findings that modern plants can reach an efficiency of up to 0.9. The team decided to set a minimum efficiency that was comparable to the maximum but still left room for lower costs. With inputs of pump efficiency, pipe diameter, pipe friction, and turbine efficiency, the model outputs area, required input energy, efficiency, fill time, and empty time. Additionally, the model outputs a graph that compares the efficiencies and relative costs of all the possible combinations of values.



The model was validated by inputting given values and confirming that the outputs matched. Limitations to the model include difficulty in adaptation to other scenarios and the team's decision to prioritize cultural and environmental considerations over the potential for greater efficiency or lower cost. To keep the model efficient and easy to use, the team opted to specify many inputs in the code rather than have the program run through every possible combination of every possible variable. This makes the model too rigid to be used without major overhauls for other scenarios and different sites. Additionally, the team felt it had a moral obligation to consider the cultural and environmental limitations of sites 2 and 3, which led the team to favor site 1 in initial discussions. Once the team created an evidence-based decision matrix, the team's decision to use site 1 was further validated.

Sites					
Customer Needs	**Technical Needs**	**Weight**	**Zone 1**	**Zone 2**	**Zone 3**
Water capacity	Surface Area (m^2)	2	360,000	25,620	39,760
Energy storage	Height (m)	2	30	100	65
Pipe cost	Distance from River (m)	1	60	130	91.2
Road Cost	Access Road Cost ($)	1	40,000	100,000	150,000
Cost (misc)	Additional Costs ($)	1	10,000	8,000	63,600
Terrain Preparation	Prep Cost ($)	0.5	90,000	12,810	2,386
Sum of Scores			4.715	3.779	2.306

Strengths of the model include that it cuts down on required surface area for the reservoir and keeps drain time to just under 12 hours. By minimizing the required surface area, the model reduces the overall cost of construction by limiting the amount of land that needs to be prepared. Though the cost of site preparation at site 1 is only $0.25/m^2$, site 1 has a total surface area of 360,000 m^2. Preparing the entire site would cost $90,000. By only requiring approximately ⅓ of the site's usable surface area, 106,630m^2 to be specific, the model reduces site preparation cost to just $26,657.50. The model keeps drain time to approximately 12 hours, which means the reservoir would be able to provide 10MW per hour to a nearby community for 12 hours, enough time to power the community overnight or over the course of a cloudy or rainy day.

```
Inputs:
Pump efficiency =  0.92
Pump FLow volume =  65  m^3/s
Pipe diameter =  3.0  m
Pipe length =  67.08  m
Pipe friction =  0.002
Depth =  12.5  m
pipe reservoir elevation =  30  m
K1 =  0.15
K2 =  0.15
Turbine Efficiency =  0.92
Turbine Flow volume =  31  m^3/s
Mass =  1304507128.88  kg

Outputs:
Area of Reservoir =  106629.28  m^2
Ein =  148.98
Efficiency =  0.81
Fill Time =  5.7  hrs
Empty Time =  11.94  hrs
```

Discussion

Although site 1 was selected as the best choice for building the reservoir using a decision matrix, it was also chosen due to cultural considerations and environmental concerns. Practically, the team eliminated site 2 because of the chance that it would be impossible to build on this site. Some regions prevent building on top of burial sites, which would prevent the reservoir from being built altogether. In addition to this, the team felt morally conflicted about building over a burial site even if proper permits and permission were granted. Therefore, the team eliminated site 2 due to both practical and moral concerns.

Site 3 was eliminated because of environmental concerns from the threat of erosion and collapse. Soil erosion was an obvious concern, with physical factors such as potential collapse and requirements for ongoing maintenance, as well as cost from higher maintenance requirements also impacting the team's decision. Additionally, environmental concerns associated with removing so many trees made site 3 less desirable. Finally, the requirement for at least one extra bend due to the site's physical layout made site 3 more difficult to work with. It is also important to note that site 3 scored the lowest on the decision matrix due to its extensive site preparation costs, and both the physical and environmental concerns further confirmed the fact that the team would eliminate site 3.

A height of 12.5 meters for the reservoir was chosen in an attempt to minimize cost while maximizing efficiency. At first, the possibility of using 15 meter walls was considered, but it was quickly determined that the extra $45 per meter was not a justifiable cost based on calculations using 12.5 meter walls and a higher turbine flow rate. Though both combinations resulted in a drain time lower than 12 hours, the team concluded that it was much more cost-efficient to use 12.5 meter walls rather than 15 meter walls.

The team also explored the possibility of people/animals/objects falling into the reservoir impacting the efficiency of the reservoir. Using grizzly bears as a rough approximation of the largest likely thing to fall into the reservoir, it was determined that over 1,000 bears would have to fall into the reservoir simultaneously to have an impact on efficiency. Although the team confirmed that people, animals, or objects falling into the reservoir would not have an impact on efficiency due to the displacement of water, the fact that these items could fall into the reservoir and get stuck in a pipe was considered. However, it was assumed that the 12.5 meter walls would prevent any animals or people from falling into the reservoir. Even if any of these items fell into the reservoir, it was also assumed that the pipes would not be blocked by these items, as they are 3.0 meters in diameter.

Other factors that were explored, such as the effect of evaporation and rainfall on the mass of the water in the reservoir, were also determined to be insignificant. The only factors that were determined to be significant were energy loss from the pump, energy loss from the turbine, pipe friction, and bend friction. Factors other than those discussed were not included in the model.

Conclusions and Recommendations

Using the model, it was determined that the efficiency for both the pump and the turbine should be 92% to maximize efficiency for the entire reservoir. In addition to this, a pipe diameter of 3.0 m was found to be the best fit, with the friction coefficient of the pipe being .002.

In addition to finding the most efficient materials for the reservoir, the model also computed certain values using these materials. The mass of the water in the reservoir was calculated to be about 1,300,000,000 kg. The surface area of the reservoir was determined to be 106630 square meters. The length of each reservoir wall was not determined in the model, but since the reservoir shape was established to be a square, each side of the reservoir was calculated to be 326.5 meters long. Energy input was found to be 149 MWh, which appears to be a valid result based on the fact that it is greater than energy output, as some energy was lost to the pump and turbine efficiencies, friction in the pipes, and pipe bends. The overall efficiency was calculated to be .8055, with a fill time of 5.70 hours and an empty time of 11.94 hours.

One major assumption of the model was that higher quality materials are also longer lasting. This assisted the team in making the decision to value efficiency over cost, as a reservoir with the best, most durable materials would have the least future cost in repairs.

Given a larger time frame, the team would have preferred to make a more comprehensive model that could be used in many different situations rather than requiring manual predetermined inputs. To make the model simpler so it could be completed in one week, the team determined that they would have the code read files rather than hard coding all of the data into the model. If the team had more time to work on the model, the data would have been hardcoded into the model so that cost could be factored in when deciding on the most efficient materials. The team decided not to factor cost into the decision to keep the model as simple as possible given a short time frame.

References

Bradford, A. (2016, April 18). *Grizzly Bear Facts*. LiveScience. Retrieved October 31, 2021, from https://www.livescience.com/54453-grizzly-bear.html

Encyclopædia Britannica, inc. (n.d.). *Reservoir*. Encyclopædia Britannica. Retrieved November 1, 2021, from https://www.britannica.com/technology/reservoir.

Hydroelectric Power. Hydroelectric Power Generation. (n.d.). Retrieved November 2, 2021, from https://www.mpoweruk.com/hydro_power.htm.

Landslides, Slope Failure, and Erosion. Exponent. (n.d.). Retrieved November 2, 2021, from https://www.exponent.com/services/practices/engineering/civil-engineering/capabilities/geotechnical/landslides-slope-failures--erosion/?serviceId=8a0e4c07-38ac-40f9-9430-7973ed926ebd&loadAllByPageSize=true&knowledgePageSize=7&knowledgePageNum=0&newseventPageSize=7&newseventPageNum=0&professionalsPageNum=1.

PHMC federal laws and acts protecting burial sites. PHMC > Cemetery Preservation and Recordation. (n.d.). Retrieved November 2, 2021, from http://www.phmc.state.pa.us/portal/communities/cemetery-preservation/laws/federal-laws.html.

Pump wear - labourtaber.com. (n.d.). Retrieved November 2, 2021, from https://www.labourtaber.com/Pump%20Wear.pdf.