IPRO 323
Low-Cost Water Pump Design/Testing to Serve Rural Villages
Final Report

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Sponsor: US Environmental Protection Agency, National Collegiate Inventors & Innovators Alliance (NCIIA) and Stuart Grants

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INTRODUCTION

Recent studies and analysis of water systems around the world indicate that most remote populations experience difficulty accessing safe drinking water. The most significant problems include contaminants such as bacteria, turbidity, and the lack of access to sources of water.

The proposed project is the continuation of IIT efforts to promote health and economic growth by identifying the most environmentally and economically feasible method(s) for pumping groundwater in rural areas around the world. The project focuses on providing clear definitions of project sustainability factors, at both local and global scales.

BACKGROUND

1. Sponsors

There is a great need for potable water supply systems in rural areas of Mexico. Our specific focus is on Monterrey, Mexico. Previous research has been conducted and supplied to IIT by Monterrey Institute of Technology. They determined the typical water needs of a community and the water resources available. In addition to this collaboration, this project is being sponsored by NCIIA and EPA p3 grants.

2. User Problems

The regions surrounding Monterrey face an intermittent water supply as a result of the inconsistent performance of windmills. The lack of a sufficient supply of wind, and the inability to reach a depth with uncontaminated water limits the reliability of the current water distribution system. The community does not have the resources to procure more common and reliable methods to obtain water.

3. Technological Implications

Many methods exist that require manual operation to retrieve water, such as hand pumps. More modern technologies utilize engines to provide a consistent supply of water, though these require additional resources such as gasoline or diesel fuel. The desire to increase efficiency and decrease the impact on the environment has caused alternative energy supplies, such as solar power, to be pursued. In addition, the use of solar power is attractive due to the low levels of maintenance required.

4. Historical Success and Failures

Previous attempts to solve the water crisis have been in the form of wind turbine technology. This technology relies upon wind movement to create enough electricity or generate enough mechanical motion to power the well pumps to extract water. However, due to the rapid change of wind directions in Mexico, the turbines have sustained consistent damage, making repairs costly and frequent.

5. Cultural and Scientific Issues

The location of the project site is in Mexico, which implies both language and cultural barriers that will have to be considered in designing the system. Because the Federal government owns all ground water in Mexico, caution must be exercised in following all local regulations.

6. Costs of the Problem

Without a consistent source of potable water, communities reach an economic standstill, losing the ability to sustain livestock and agriculture. This forces water to be imported, which is costly over time.

7. Details of a Proposed Implementation

Through research and consultation with professionals, a list of possible solutions will be considered. The best solution will then be tested in the form of a scaled down test model to understand and predict full-scale operation. The assembly of a full-scale prototype is the final goal of the IPRO.

PURPOSE

The students of IRPO 323 explored the possibility of using solar water pumps to access groundwater, particularly in areas that do not have easy access to water resources. The solar water pumps need to be cost effective, easy to install, and maintain; as well as fulfill the water requirements. However, in order to fully understand the system and its limitations, a small scale test model was constructed, and a larger scale test system is currently being implemented. The set objectives, therefore, were:

- Evaluate water sources and water demands of the target community
- Design and construct a small-scale test system to approximate the performance of a full-scale system
    - Use this system to test the performance of the design
- Design a full-scale solar powered water pumping system
    - Put this system to use at a test site (Black Oak Center)
- Define the pros and cons of a solar power pumping system
    - Research available components and perform cost-benefit analysis
    - Test the performance of the system
- Utilize data from test systems to optimize future use
    - Develop a plan to implement this pumping system in Monterrey, Mexico and/or other areas in need of such a system

The test models took place in the form of a small-scale model to perform tests on the roof of Farr Hall, and a large-scale model, which is a collaborative effort between IPRO 323 and Black Oak Center for renewable energy in Kankakee, IL.

Next semester IPRO 323 will need to take the data and information gained from this semester and use it to execute the pumping system in the selected communities in Mexico. Further research can and should always be done on photovoltaic cells because they are still an emerging technology and as they get better more options will be available at a cheaper cost.

RESEARCH METHODOLOGY

1. Problems

The existing problem is the final design of an efficient and effective well pumping system in Mexico. There is a great need for getting accessing potable groundwater in Mexico, supplying a sufficient amount of water to fulfill the needs of the community, and providing the power to extract that water.

2. Solving the Problem

The information needed to determine the water requirements and assistance in gaining access to the groundwater was gathered through consultation with Monterrey Institute of Technology and analyzing their research. The pumping system was then designed based on criteria such as ease of use, required maintenance, cost, and ability to supply enough water. The information was gathered and the needs for the pumping system and solar panel were calculated.

3. Testing of Solutions

We ended up deciding on two test systems; one smaller system constructed at IIT, as well as a large-scale system in Kankakee, IL. First, the performance of a particular model of solar panels was tested using a PC based oscilloscope. A concurrent test was run using the submersible pump powered with an inverter. When the solar panel was used to power the pump system, data was gathered to approximate expected performance relative to manufacturers ratings. This helped to determine the expected performance of the larger test system.

4. Documentation of Solutions

The data gathered is being presented as justification for the performance of the final pumping system design. A cost-benefit analysis is available as further justification of the cost. The final, large-scale design is documented with required system components, assembly method, and operating instructions. This design has a main focus on the initial retrieval of the water from the well and its storage.

5. Analyzing Solutions

We have delved into a few options for the operation of the pump, from diesel to wind and finally deciding upon solar power. Many forms of storage were analyzed from multiple smaller tanks to one large tank, which ended up being the best for Mexico. We have also looked at various types of submersible pumps.

6. IPRO Deliverable Generation

The final IPRO deliverables consist of the research done to determine the water needs of the community, test system performance data, expected full-scale system performance, documentation of the selected components, assembly method, designs of two phases of the final design, and suggestions for the next phase.

ASSIGNMENTS

The overall project divides into two subsections with respect to the different systems designed and/or tested as well as a full team collaborative effort. First, we designated part of the team (Ellen Rohde, Ryan Yarzak, Jaucinta Burt, Nicholas Bailey, Joshua Sullivan, Erick Leong, Leon Chen) to research small scale photo-voltaic panels, submersible pumps, and water storage devices to create a miniature system to run on the roof of Farr Hall. The system was run and data was analyzed in order to help the second sub-team (Brian Albee, William Pajak, Nicole Galbraith, Katty Davila, Jinting Liu) design a larger scale system for the farm in Kankakee, IL. Finally, our entire class instituted a cooperative campaign to obtain as much information with respect to the overall planning of a future implementation of a photo-voltaic water pumping and distribution system for rural Mexico.

The original project plan depicted a completely different organization of sub-teams due to our lack of proper direction with respect to how we were going to get from our mission statement to the actual effectuation of the system in Mexico. The group divided into four subsections:

1. Piping

William Pajak and Brian Albee were assigned the task of designing the piping materials, stability, and requirements for the test model and for the full scale model.

2. Pumping and Control System

Joshua Sullivan led this group along with help from Erick Leong and Katty Davila. The tasks at hand were to design and calculate pump functional requirements as well as corresponding control system requirements leading up to the purchase of the most fitting pump for our systems.

3. Photo-Voltaic Panels

Ryan Yarzak and Jaucinta Burt collaborated with sub-team leader Ellen Rohde to research and purchase an appropriate solar panel as well as design a method by which to test the voltage and power potentials and fluctuations in order to properly power the pump once the panel is integrated into the system.

4. Water Storage

Lead by Nicole Galbraith, the team consisting of Jinting Liu and Leon Chen was assigned the tasks of researching potential methods of storing the water in order to optimize the availability of potable water at all hours of the day for the smaller system as well as the final system in Mexico.

Once the entire team modified the course of action into a three phase project (Farr Hall, Kankakee Farm, and Mexico) from the original two part plan consisting of small and large scale systems, the sub-groups were then reevaluated and arranged into their current allocation. The office deliverables were delegated via volunteering or assignment based on the personal strengths and interests of specific team members.

OBSTACLES

- Obstacles:
    - Pipe: The pump purchased provided less head than the original pump specifications skewing the original piping dimensions.
    - Pump: The electrical converter's adjustment potentiometer was damaged while in use.
    - Solar Panels: The complexity of the first PC-based oscilloscope was beyond the time available to decipher.
    - Storage: The heating element did not provide enough warmth to the water in the storage tank to prevent freezing.
    - Team: Access to the Kankakee farm in order to study a larger scale solar powered pump.
    - Solar Panel: Ordering solar panels for the small-scale pump based on the performance of the initial solar panel.
- Resolution:
    - Pipe: The pipe system was changed to fit the recommended vendor pump.
    - Pump: Another DC converter has been ordered and more testing will commence once it arrives.
    - Solar Panel: Another PC-based oscilloscope with available software was purchased.
    - Storage: The lack of heat is no longer a problem as the spring weather is raising temperatures above freezing.
    - Team: Sustained contact with the owners of the Kankakee farm and set up visits to understand the conditions of the project in Kankakee
    - Solar Panel: A solar panel was purchased based on the data collected with the initial solar panel using an oscilloscope and software to monitor the total energy output of the solar panel
- Remaining Barriers:
    - Kankakee: Installing a system that is similar to that of the Mexico design, yet versatile enough that the owners of the Kankakee farm can adapt it to suit their needs for the system in the future.
    - Mexico: Convincing the Mexican government that the system designed is effective in providing safe water at a cost benefit, so that installation will be approved, as the Mexican government owns all ground water and access to it is enforced federally.
- Solutions:
    - Kankakee: Finalizing a design that will initially use one pump sending the water into a large storage tank on the ground. In the

future, when the funding is available, the tank will be lifted off of the ground to form a water tower, so that gravity will provide the pressure necessary for conveniences such as showers on the farm.

- Mexico: Write up a business proposal featuring the specifications of the system, expected lifespan of the system, potential maintenance needs, overall cost, and benefits of the system, demonstrating how the system would be much more efficient at providing villages with water than the current system.

RESULTS

The results of the test model showed many important observations about solar pumping systems. We found that the empirical data regarding insolation for Chicago geography matched well with our test data. This allowed for the proper selection of solar panels for the Kankakee, full-scale design. We also found that the location and angle of the solar panels played a crucial role in the operation of the pump system.

Using the data received from the small-scale test system, we implemented a final design consisting of an elevated storage system, a submersible water pump, four 50W solar panels as well as the necessary piping to supply water to the cabins. This design was the second design, the first being one with storage tanks in the attics of the cabins. This initial design was found to be potentially unsafe with high load factors on the cabin beams. The final design was officially proposed and approved by Architect Daniel Hatch. This design will be implemented in a two phase process, the first phase being the construction of the well and concrete foundation as well as the pump, solar panel, storage tank, and pipe installation. The second phase consists of raising the storage tank 15ft for the gravity fed system.

RECOMMENDATIONS

For future semesters of IPRO 323, we hope to continue work with the renewable energy farm in Kankakee, IL through the completion of the two-phase solar panel pumping system. We hope to have this site as an educational resource for IIT for testing and cooperation with possible future projects. We hope to gain approval from the Government of Mexico and implement our design in Monterrey, Mexico. Our final goal is to have a solar pumping system installed and running for the rural communities surrounding Monterrey, Mexico.

REFERENCES

Hatch, Daniel. Personal Interview. 14 April. 2008.

Lizarraga, Ingrid, et al. Solar Powered Pump PPQ Chemical Plant Project. Monterrey, Mexico: Tecnologico De Monterrey, 2007.

Mexico, Photovoltaic Energy. Consulting Library. 1 Jan, 2005. 15 Mar 2008

<http://www.re.sandia.gov/wp/wpGuia/home.html>.

PS200 HR/C. Hamburg, Germany: Lorentz, 2007.

Ramirez, Jose Alberto, et al. Chemical Plants Project. Monterrey, Mexico: Tecnologico De Monterrey, 2007.

Solar Water Pumping: Applications Guide. Scottsdale, AZ: Kyocera, Inc, 2002.

United States, Department of Energy. Renewable Energy for Water Pumping Applications in Rural Villages. New Mexico, 2001.

ACKNOWLEDGEMENTS

Our team would like to extend our deepest gratitude to the owners of the Kankakee site, Dr. Jifunza Wright and Mr. Fred Carter. We are very thankful for the ability to utilize their site to help us properly evaluate a larger scale system as well as aide in the advancement of learning for future projects.

We would also like to acknowledge Monterey Institute of Technology and their exchange student Katty Davila for providing priceless background information as well as dedicated assistance toward the advancement of our project.

For helping us modify our Kankakee design to make it feasible and realistic, we really appreciate the effort and input from Architect Daniel Hatch.

Finally, we are grateful for the ongoing support throughout the semester from our supervising faculty member, Dr. Nasrin Khalili.

Appendix A – Test System Designs

The project for IPRO 323 was broken down into three phases. The first of these phases consisted of a small test system. The prototype was designed to acquire hands on experience with solar panels, water pumps, and the integration of the two. The criteria imposed on the small test system included small size, easy accessibility, low cost, and a simple setup. Based on these features, each member of the team came up with a concept. The ideas and their pros and cons were discussed during class. One proposal was finally chosen and modified to become our current solar water pump test system.

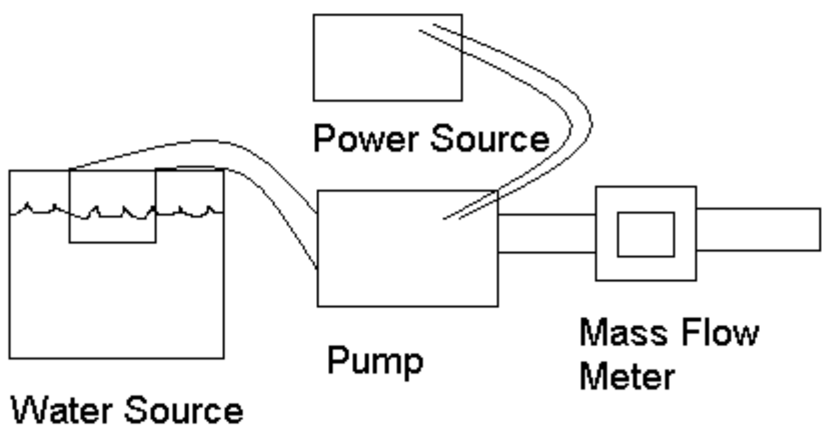


Figure 1: Erick's Pump Design

Advantages	Disadvantages
Measures Flow Rate	Vague description of parts
Portable System	Needs constant input of water

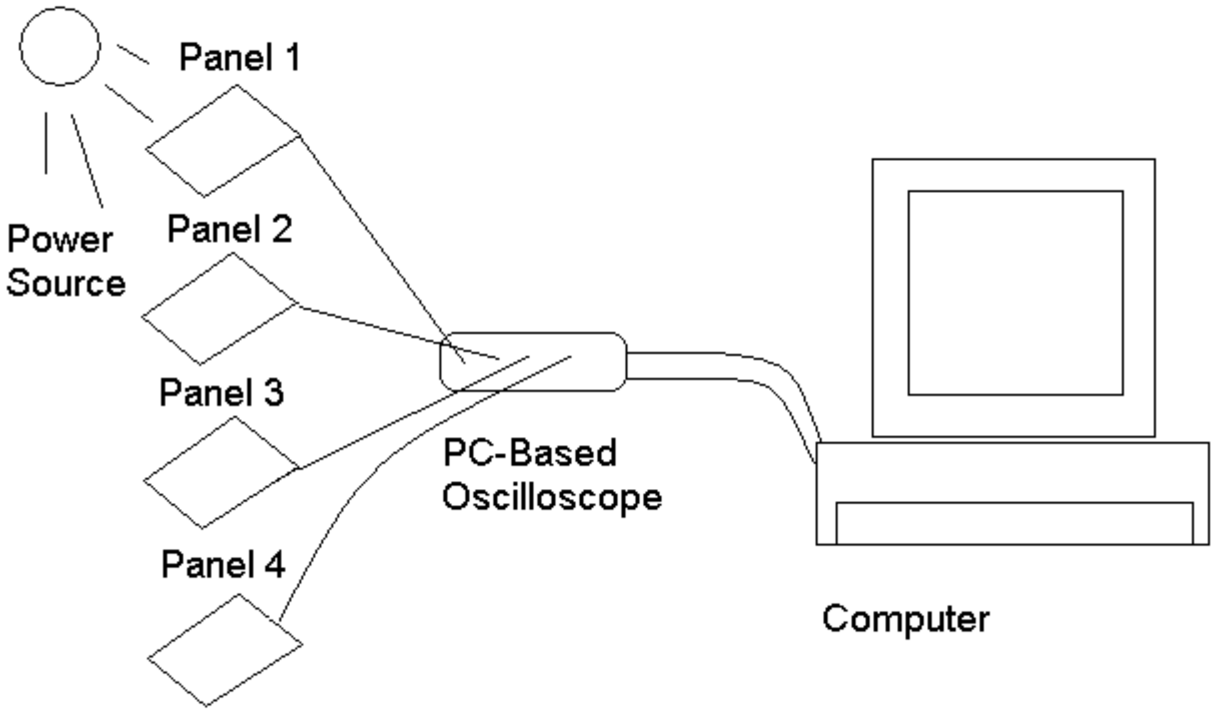
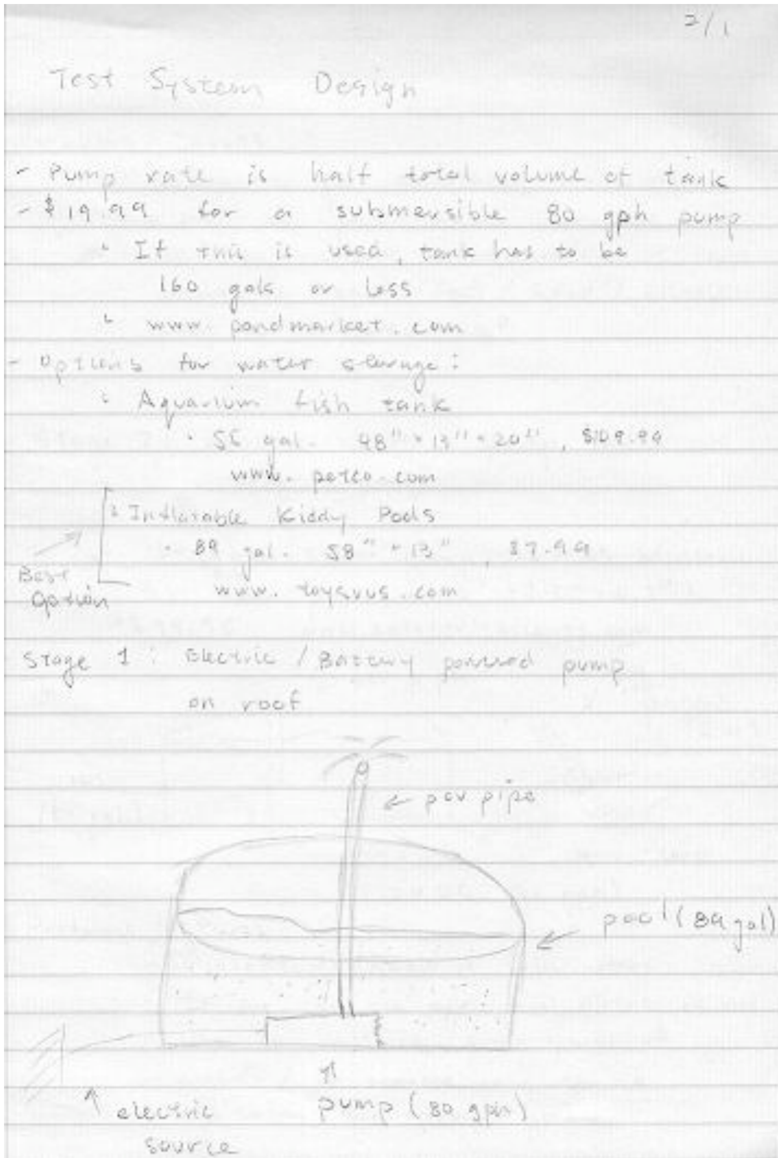


Figure 2: Erick's Solar Panel Design

Advantages	Disadvantages
Portable System	Cost (4 panels)
Permits long test durations	Requires a computer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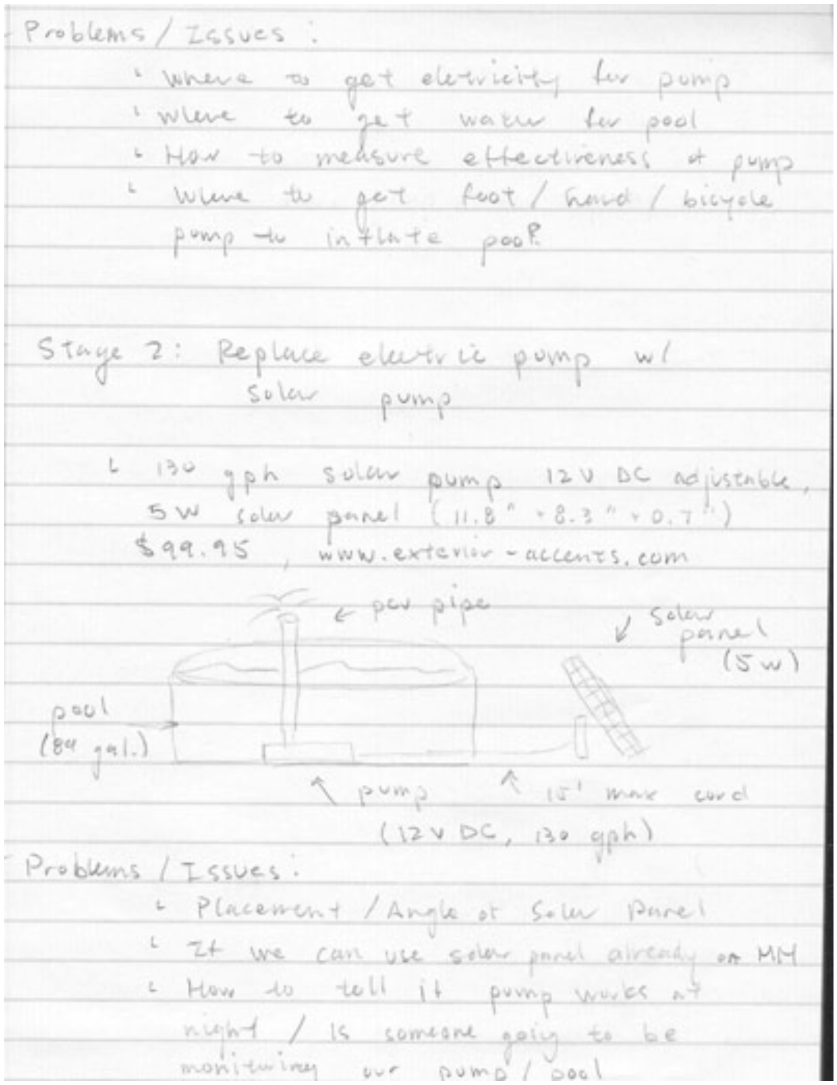
Test System Design

- Pump rate is half total volume of tank
- $19.99 for a submersible 80 gph pump
  - If this is used, tank has to be 160 gals or less
  - www.pondmarket.com
- Options for water storage:
  - Aquarium fish tank
    - 55 gal. 48" × 13" × 20", $109.99
      www.petco.com
  - Inflatable Kiddy Pools
    - 89 gal. 58" × 13", $7.99
      www.toysrus.com

Best Option

Stage 1: Electric / Battery powered pump on roof

Figure 3: Leon's design (page 1)



Problems / Issues:
- where to get electricity for pump
- where to get water for pool
- How to measure effectiveness of pump
- where to get foot / hand / bicycle pump to inflate pool

Stage 2: Replace electric pump w/ solar pump

- 130 gph solar pump 12V DC adjustable, 5W solar panel (11.8" × 8.3" × 0.7") $99.95, www.exterior-accents.com

Problems / Issues:
- Placement / Angle of Solar Panel
- If we can use solar panel already on MH
- How to tell if pump works at night / is someone going to be monitoring our pump / pool

Figure 4: Leon's design (page 2)

Advantages	Disadvantages
Maintains a water cycle	Storage will not support pump
Materials are easy to obtain	System seems unstable
Inexpensive	

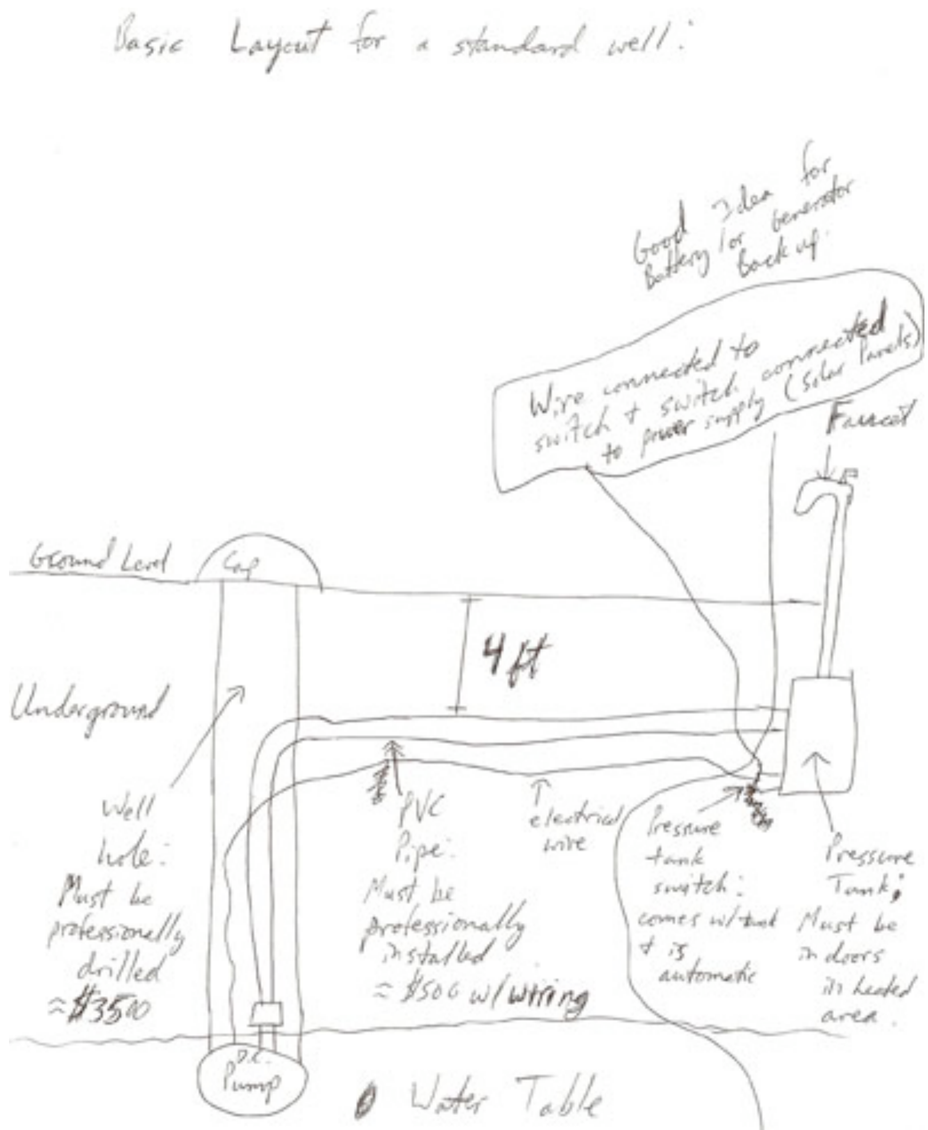


Figure 5: Brian's Design

Advantages	Disadvantages
Future Applications	Requires pre-drilled well

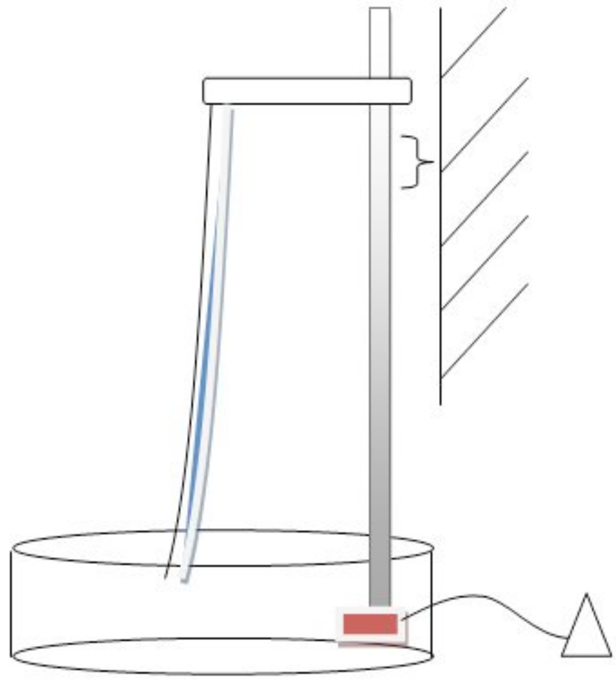


Figure 6: Bill's Design

Advantages	Disadvantages
Maintains a water cycle	Needs further details on components
Secured to wall	

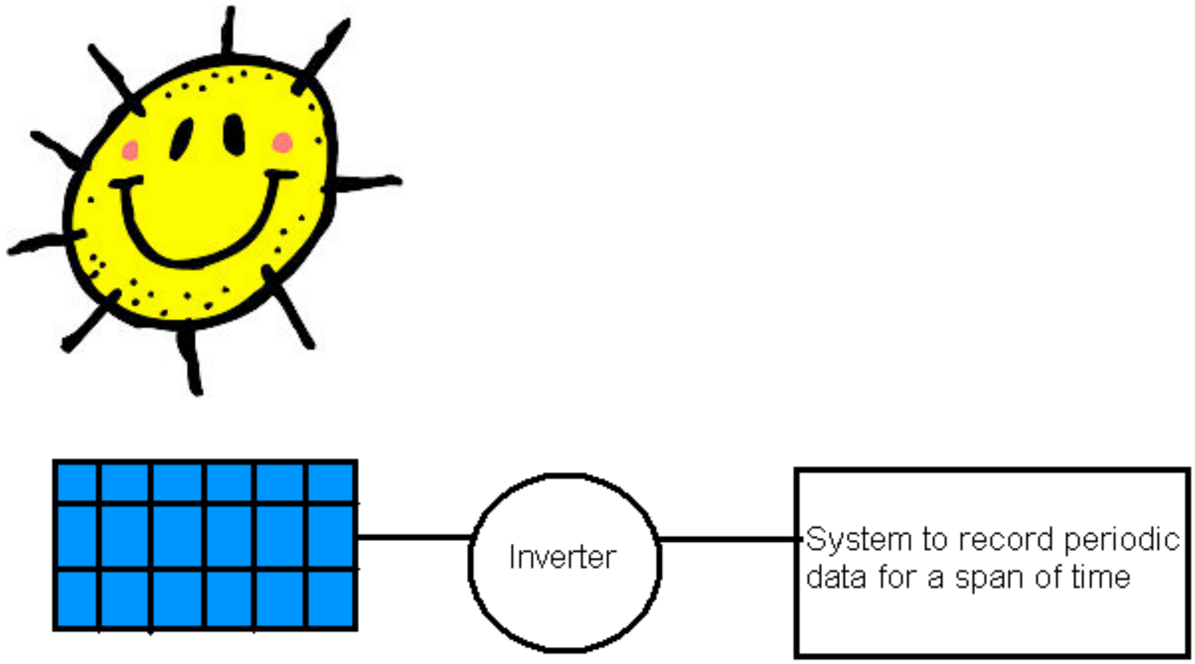


Figure 7: Ellen's Design

Advantages	Disadvantages
Portable System	Requires a computer
Ability to record data	Complicated array of electrical parts

Appendix B – Kankakee Design Proposals

The second phase of our IPRO was to design and install a solar water pumping system at a rural farm site in Kankakee, Illinois. A survey of the premises was conducted by half of the team members. Measurements, pictures, and requirements were procured and shared with the resf of the IPRO. Each person was then assigned to come up with an efficeint and reliable system. The ideas (shown below) were presented and the advantages were taken and combined together to form our proposed design.

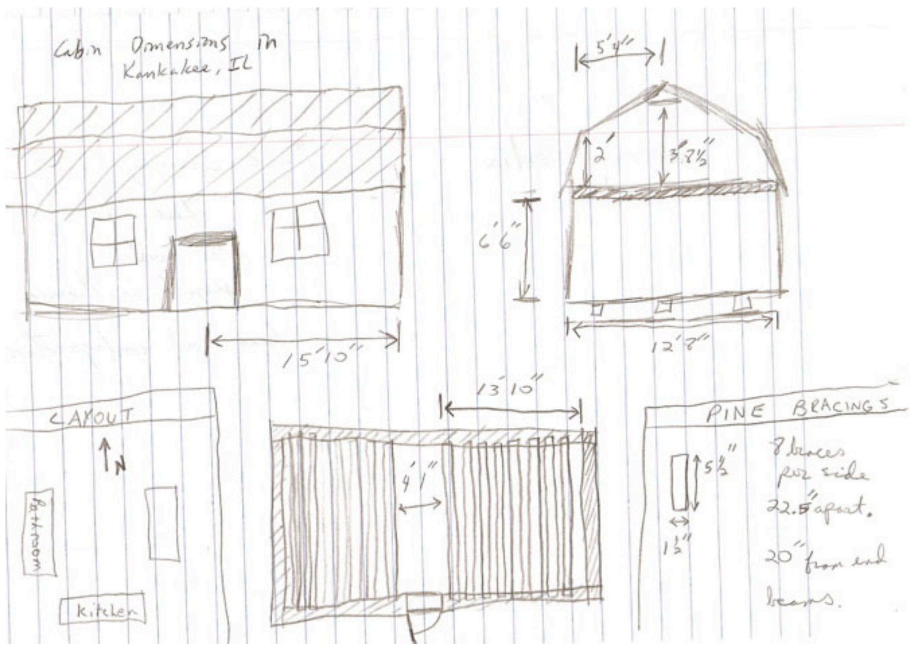


Figure 1: Cabin Dimensions (By: Brian)

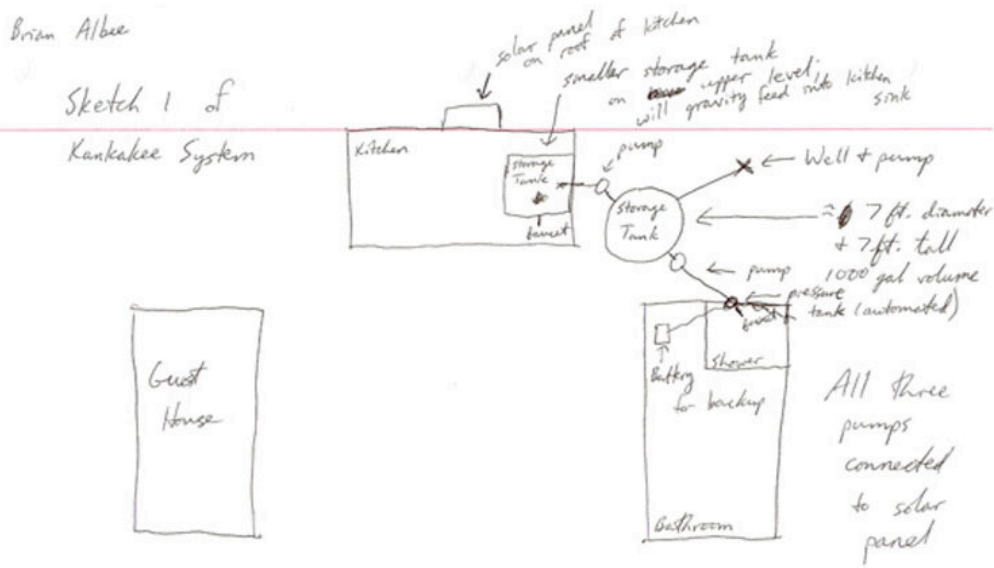


Figure 2: Brian's 1st design

Advantages	Disadvantages
Provides Water Pressure	Price
Separates the system for the two cabins	Complicated Electrical System
Water can be pumped at anytime (Power Generator)	

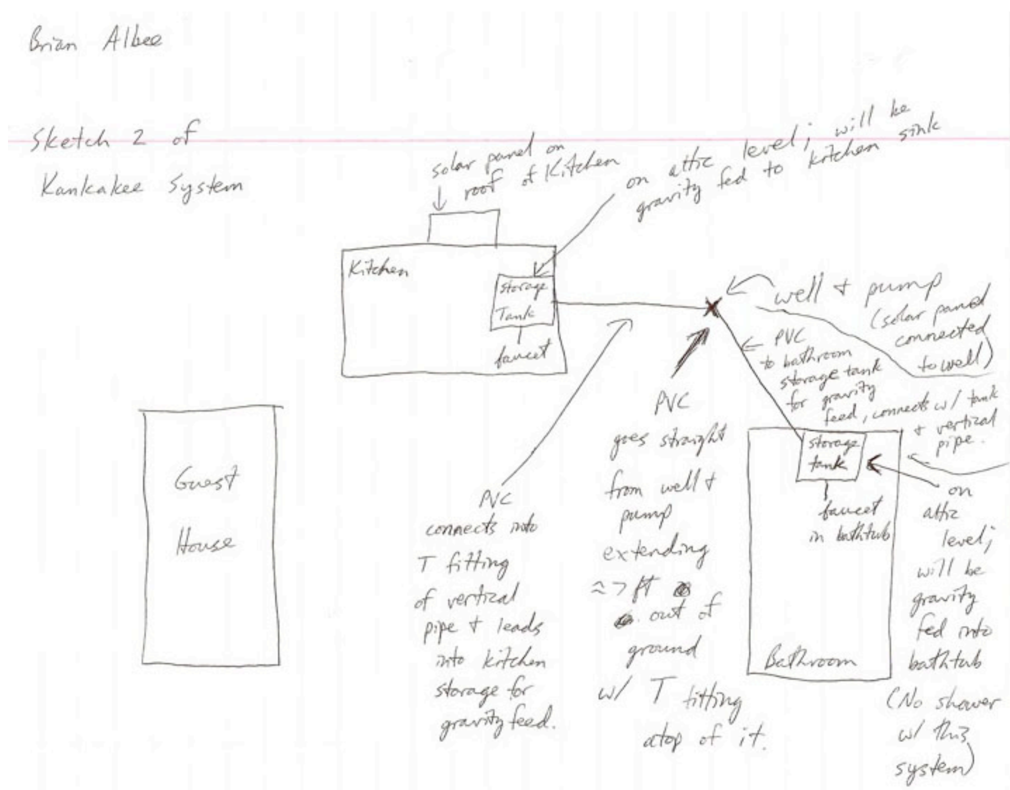


Figure 3: Brian's 2nd design

Advantages	Disadvantages
Simple System	Safety Issues
Cost Efficient	Storage Design

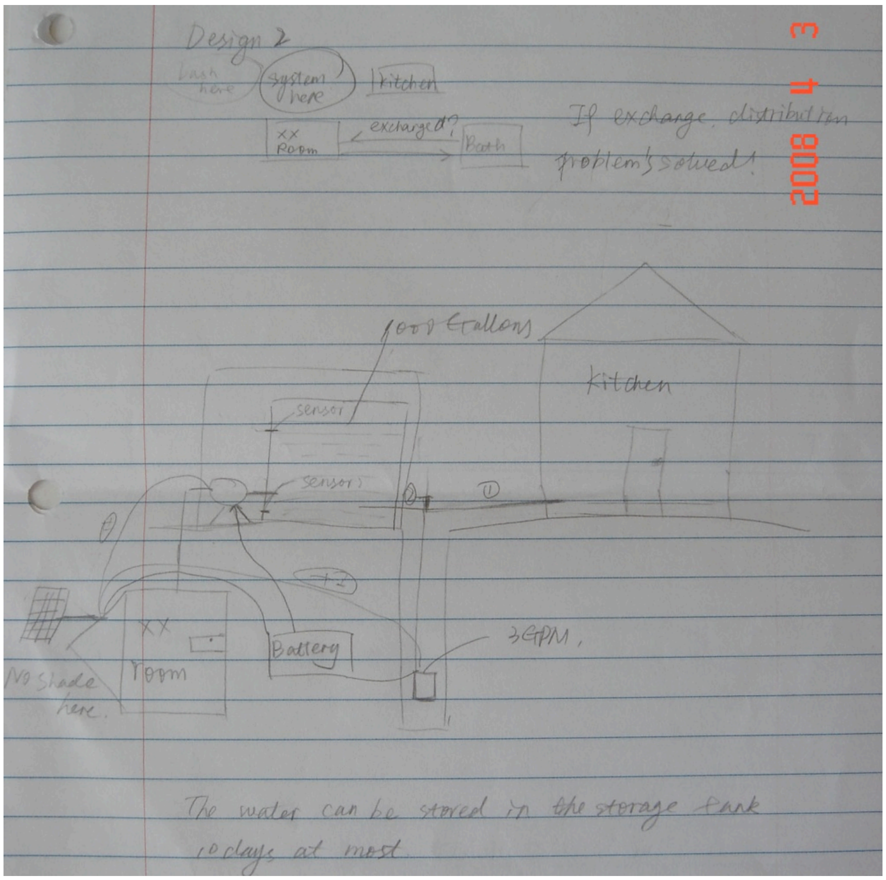


Figure 4: Jinting's 1st design

Advantages	Disadvantages
Pressurized Bathroom (two pumps)	Price
	Complicated Electrical System

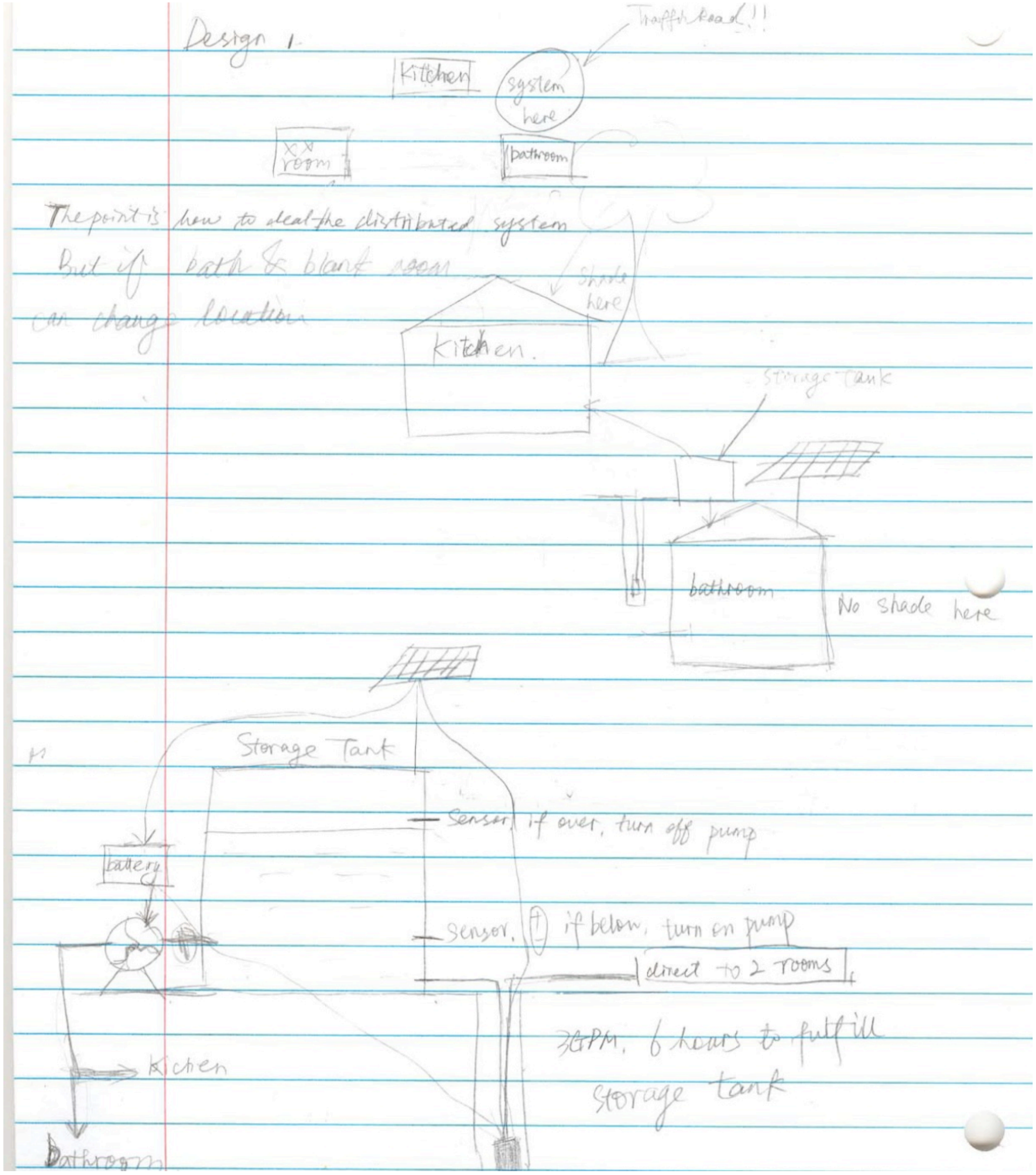


Figure 5: Jinting's 2nd design

Advantages	Disadvantages
Relocation of the Storage Tanks	Change in layout
Designed with future implications	
Accounts for natural surroundings	
Straightforward Design	
Maintains high traffic region	

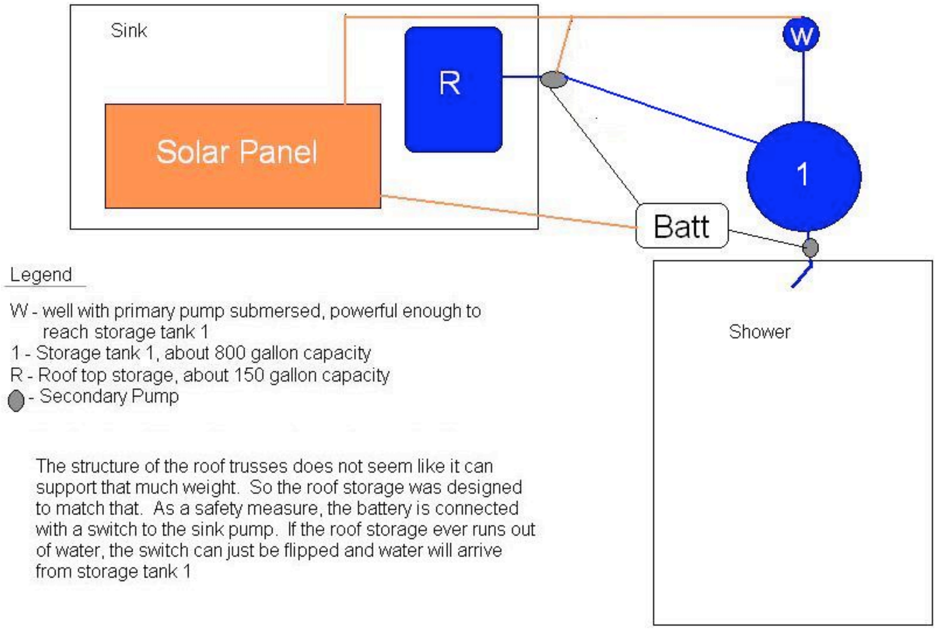


Figure 6: Leon's 1st design

Advantages	Disadvantages
No Primary Storage	Cost associated w/ Battery Use
Provides Water Pressure	Price
Divides the system for the two cabins	Complicated Electrical Wiring
Use of Power Generator	

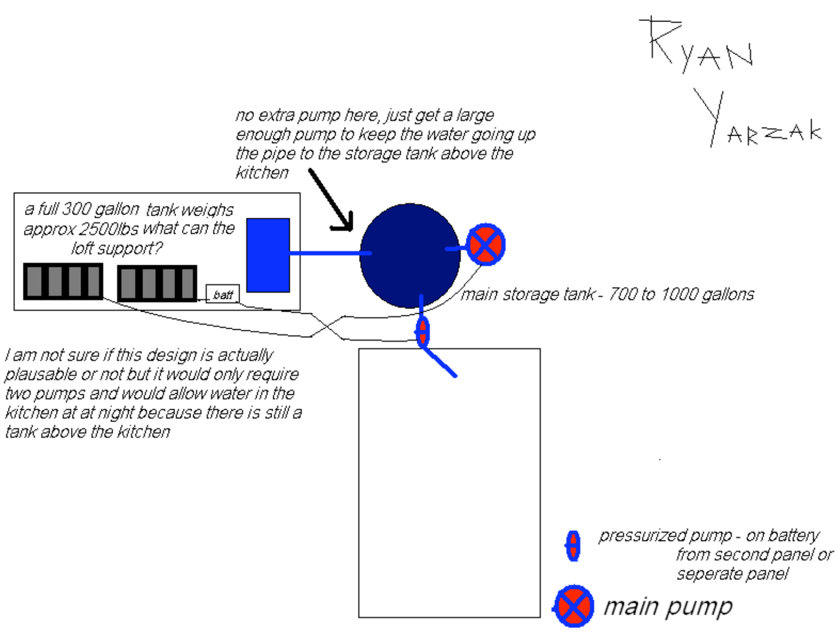


Figure 7: Ryan's degisn

Advantages	Disadvantages
Two Pumps	Price
Storage in Kitchen	Complicated Electrical System
Battery Use	
Large Water Storage (Accounts for Water Shortages)	

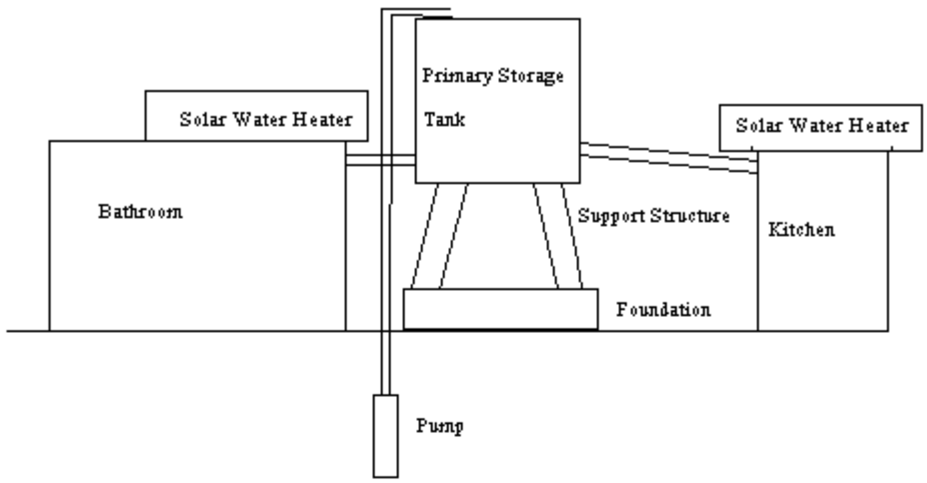


Figure 8: Erick's design

Advantages	Disadvantages
Gravity fed	Water tower construction is expensive
Solar Heating	

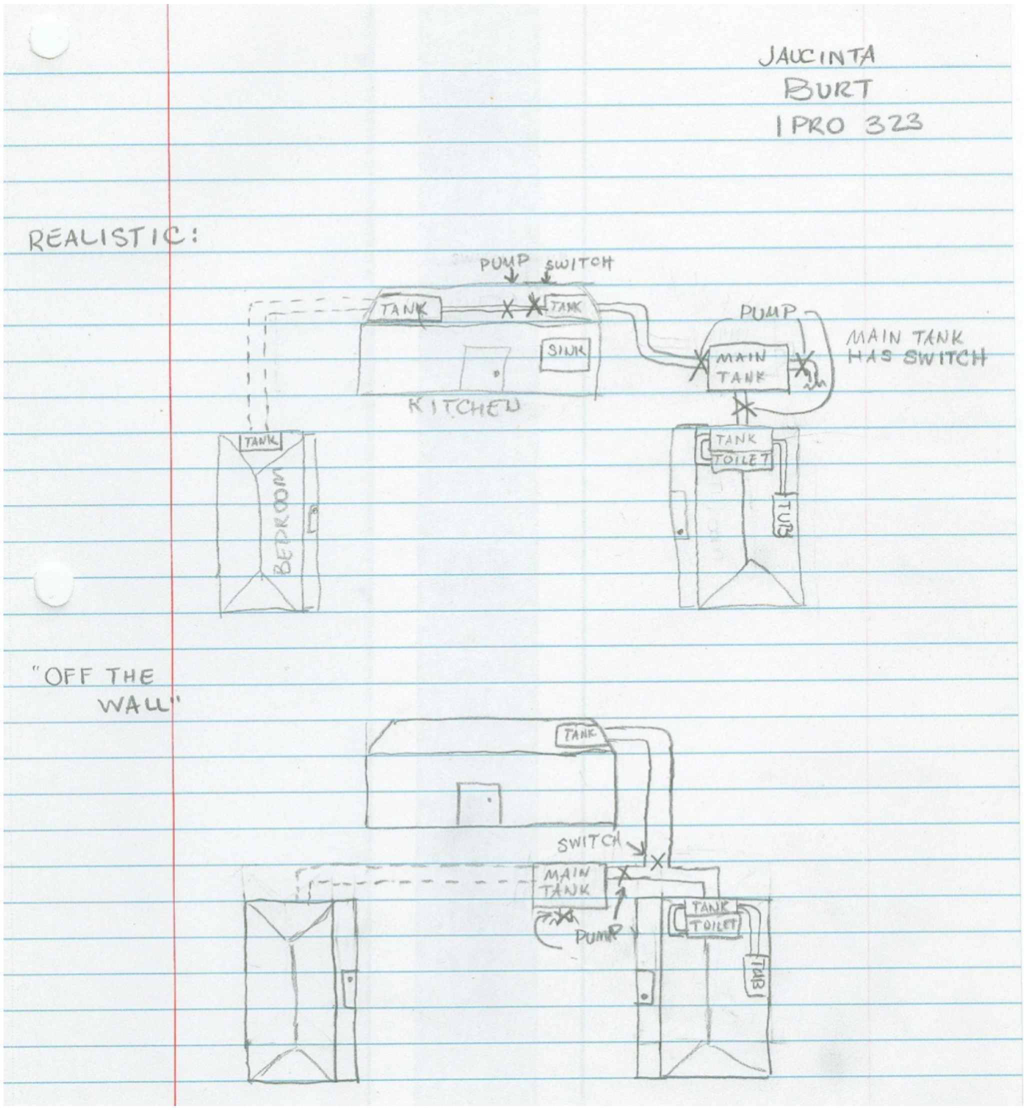


Figure 9: Jaucinta's design

Advantages	Disadvantages
Takes the third cabin into consideration	Weight in Kitchen (Safety Concern)

Niki Ideas for Kankakee

* actual sketches not shown *

Design 1:

Pump between south and west cabins with 1000gal storage tank. Have small storage tanks in attic of south cabin, one on each side. The water will be pumped from the large storage tank to the closest tank, then pump to second storage tank. The second tank will be available for providing water to east cabin. There will not be a pump controlling the pressure of the water distribution within the south cabin, simply gravity. The west cabin will have no storage tank of it's own, simply pump directly from the large storage tank. The showerhead will provide the pressure (pressurized).

Design 2:

Same location for large storage tank and small tanks in south cabin, but adding a small heated storage tank in west cabin.

Advantages	Disadvantages
Expansion Possible with Piping only	Price
Main & Sub Storage Tank	Two storage tanks in attic (Safety Concern)
Pressurized Shower Head	
Float Valve	

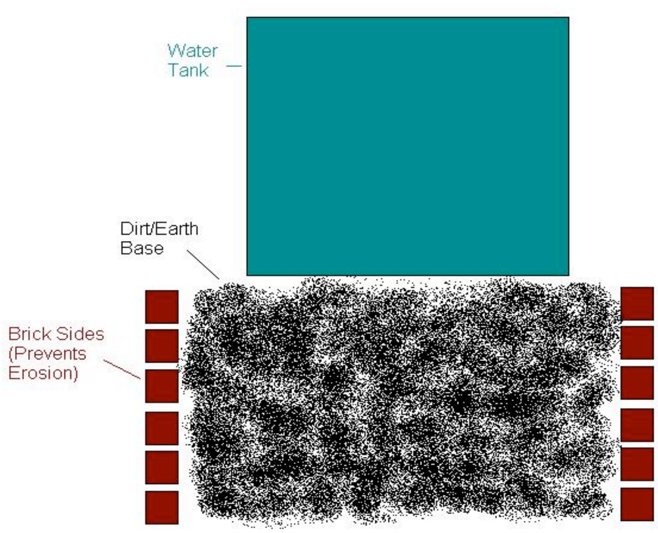


Figure 11 : Josh's Design

Advantages	Disadvantages
Simplistic Design	Legal Regulations

Appendix C – Kankakee Initial Design Proposal

Design of Solar Water Pump System For Black Oak Center, Kankakee, IL

Project Description:

Recent studies and analysis of water systems around the world indicate that most remote populations experience difficulty accessing safe drinking water. The most significant problems include contaminants such as bacteria, turbidity, and the lack of access to sources of water.

The proposed project is the continuation of IIT efforts to promote health and economic growth by identifying the most environmentally and economically feasible method(s) for pumping groundwater in rural areas around the world. The project focuses on providing clear definitions of project sustainability factors, at both local and global scales.

The specific goals and objectives of this study are to:

1. Design and manufacture a prototype for an environmentally and economically sustainable water pump system for accessing ground water in remote areas.
2. Install and test the performance of the designed prototype pump at IIT.
3. Utilize solar water pump system to provide access to ground water at a pilot site. The pilot site selected in this study is a farm located 70 miles south of Chicago, in Kankakee Illinois (Mr. Carter and Dr. Carter Wright Farm: Black Oak Center).
4. Test the performance of the system.
5. Define pros and cons associated with such a pumping systems.
6. Optimize the design, and provide suggestions to optimize the benefits.
7. Utilize information gathered from the site and develop a business plans and associated implementation strategies for such a pumping systems in Mexico and/or other areas in need of such systems.

Design

1. Schematic:

Pictured below are schematic drawings of the proposed design for the Kankakee farm. Figure 1 illustrates the side view of the cabins where piping from the pump will carry the water up the side of the building into a trapdoor where the water will be deposited into a storage tank placed into the attic framework. All of the piping will be 1 inch in diameter NFT. This layout will be used for both of the buildings that the pump will be connected to, both within 6 feet of each other.

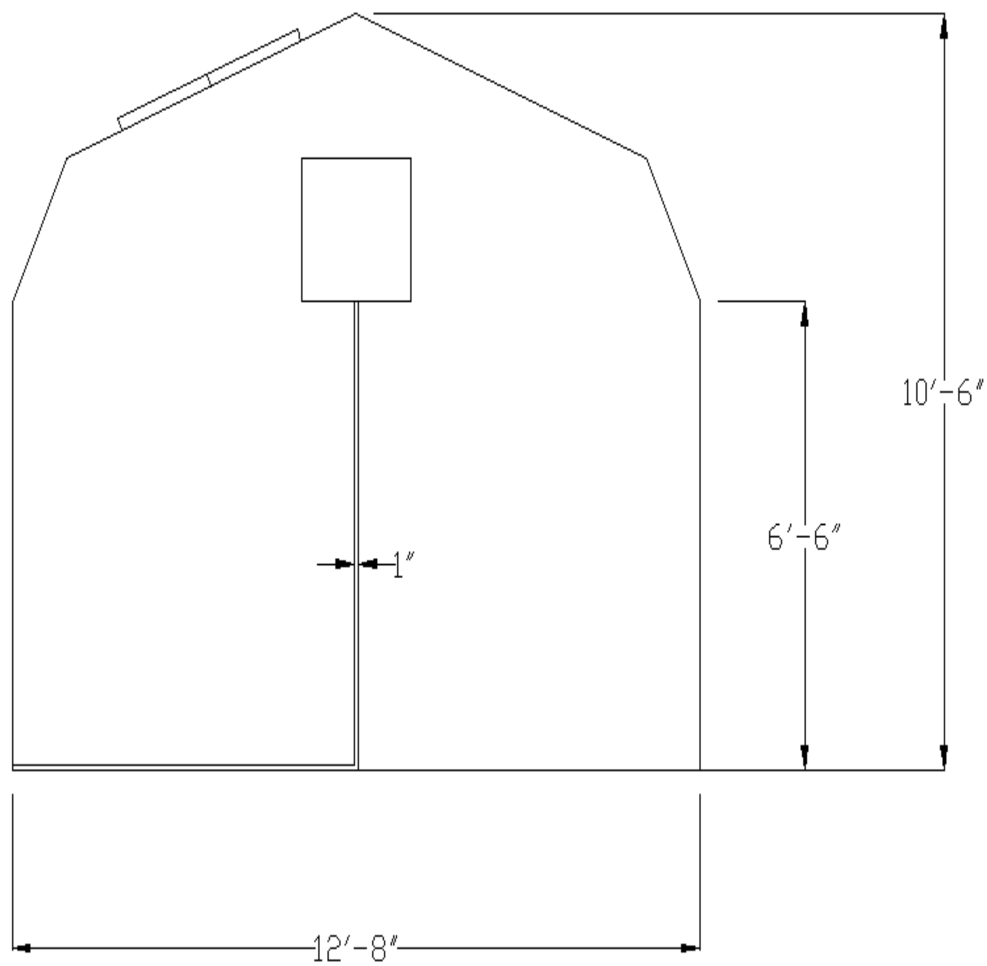


Figure 1: Side view of cabin

The next figure shows the proposed drilling depth and complete layout of piping. (Figure 2) The proposed well will run 100 feet underground and will enclose the solar pump, the water will split off in a T-junction underground and carry through the piping into the storage tanks of both buildings. Four solar panels will be placed upon the roof of the cabin facing south.

Figure 2: Pump, well, and pipe layout

2. Calculations:

a. Flow Rate:

The water requirements are assumed to be 200 gallons per person. For a family of three people, this gives a daily requirement of 600 gallons for the farm in Kankakee. Based on this as well as the solar insolation data for the city of Chicago, the following calculations were made to determine the required flow rate during peak insolation times.

Month	Water Requirement (L/day)	Insolation (Peak hr /day)	Peak Flowrate (L/ Peak Hour)
January	2271	2	1135.5
February	2271	3	757
March	2271	4	567.75
April	2271	4	567.75
May	2271	5	454.2
Jun	2271	6	378.5
July	2271	6	378.5
August	2271	6	378.5
September	2271	5	454.2
October	2271	4	567.75
November	2271	3	757
December	2271	2	1135.5

This shows that the maximum flow rate required is 1135.5 L/hr, which correlates to a necessary pump flow rate of 5 GPM.

The system will need approximately 121 ft. of SCH 40 PVC piping for the well piping and the bathroom. This has a dynamic value of 2.178 ft (0.664 m) when the coefficient of friction of the material and fluid is taken into account.

The static duty required is 39 ft. (11.9 m), which includes standing water level, drawdown, and elevation. The total head requirement including static and dynamic calculations is 41.2 ft. (12.55 m). Further calculations are required for the static level based on water table analysis made by the well drilling company.

The pump selected to meet these requirements is the Lorentz PS200 HR-14. This provides up to 20 m of lift and requires 24-48 V DC with a maximum flow rate of 11.8 GPM. In order to ensure operation on less than clear days, we will use a nominal 48 V solar panel array with a peak of 70 V to power the pump. The controller that comes with the pump will aid in regulating the power output by the panels and is designed for this specific pump model.

The solar panels needed to properly power the pump will be four BP 350J panels. These are rated at 50W each with a nominal voltage of 12V and a max voltage of 17.5 V. Solar panel mountings were selected in order to maximize the tilt of the panels based on location. In addition, the mounting will help protect and stabilize the panels against external weather conditions.

The pipe selection of SCH 40 PVC pipe was selected based on the lightweight of the material, the resistance to elemental stress, water flow resistance, and cost.

b. Stress Analysis:

Multiple tests were run to determine a proper size tank that would fit safely in the attic. An initial concern was the ability to fit the tank into the house. Taking into account these considerations, the storage tank selected will hold 260 gallons of water with dimensions of 61"x59"x18" has been selected. In order to determine the safety factor on stress for the cross beams, a few static calculations were made to determine the stress placed on the beams. These calculations required a few assumptions:

- Weight of the cross beams was negligible with respect to the weight of the water.
- Load was assumed to be a distributive load over the width of the tank (59"). This was done by dividing the weight over the 3 cross beams it will be placed over.
- Load per beam was divided by the distance it would be distributed along the cross beam.
- Tank was placed in the center of the attic, it would cause the most stress on the cross beams, with the location of max stress being at the midpoint of the beam.
- It was assumed to be a plane stress equation for beam loading.
- Assumed that the cross beams were made out of a pine wood with a Young's modulus of 11 GPa and a yield stress of 40 MPa.

With the use of the assumptions above, along with moment and force equations, the following equation was determined for the maximum stress within the beams (Equation 1).

$$\sigma_{max} = \frac{6w\,L_2\,L - 3\,w\,L_2^{\,2}}{4\,b\,h^2} \qquad \text{Eq. 1}$$

Where,

- w = Distributive load (N/m)
- L_2 = Length of distributive load (m)
- L = Length of beam (m)
- b = Cross beam width (m)
- h = Cross beam height (m)

After running the calculations, it was determined that the maximum stress obtained was 21789.5 kPa. This gives a yield stress safety factor of 1.84. This value does not take into account the weight of the wood cross beams, however, it should be noted that the stress would also be reduced if the load was placed closer to one end of the cross beams.

Visual FEA was also used to determine the maximum stress within the beam including the mass of the wood beams. With an estimated wood density of 700kg/m^3, it the following stress analysis was obtained.

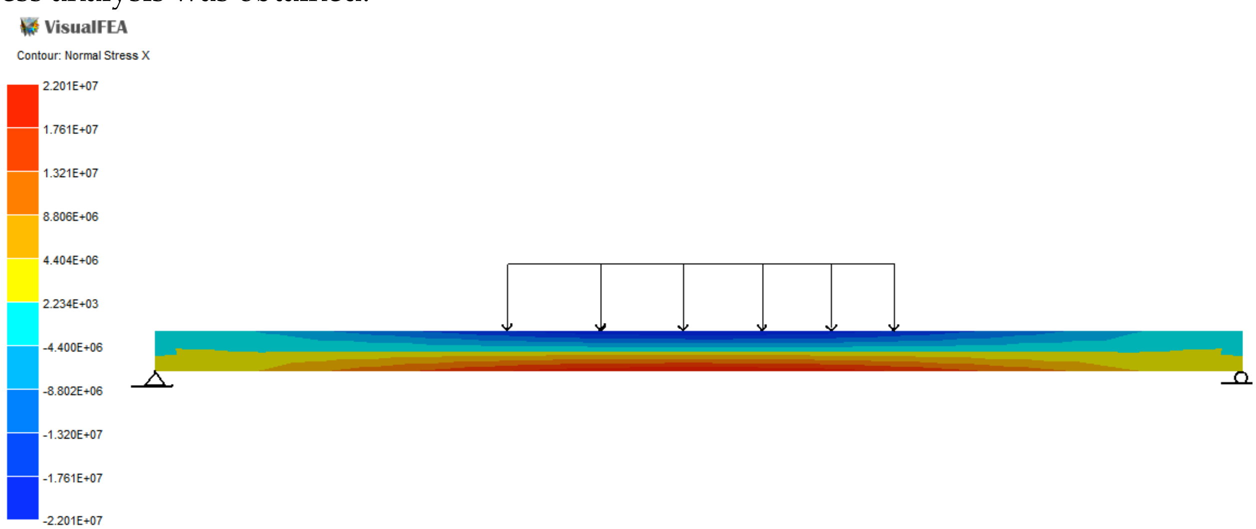


Figure 3: Stress analysis of pine cross beam under distributive load.

Using Visual FEA, it was also determined that the maximum stress including mass of the wood beam would be about 22000 kPa. This is almost identical to the value obtained through hand calculations including assumptions. The stress obtained using Visual FEA was used to calculate a second stress safety factor of 1.82. Additional calculations and considerations will need to be made before determining if extra support will be required.

3. Costs

For the components selected with research through available online retailers the following is the estimated system cost.

Tanks: \$628.54 x 2 = \$1257.08

Solar Panels: $329.95 x 4 = $1319.80 + $86.57 (shipping) = $1407.36
Solar Panel Mounting Brackets: $91.80 x 2 = $183.60 + $15.60 (shipping) = $199.20
Pump and Controller: $1150
Estimated Piping Cost: $200

Total System Cost: $4213.67

4. Benefits:

Based on the analysis of overall cost, performance, efficiency and sustainability, it was concluded that using photovoltaic power generation would be the superior system compared to wind and diesel power for the Kankakee site.

Wind power generation lacks appeal due to the long-term mechanical problems caused by fatigue and friction. Though it is no more environmentally friendly than solar power, the maintenance costs over a long period of time becomes so great it negates the benefit of the initial low cost. From these aspects, wind power is omitted from being the preferred method to produce the power required to run the pump.

Diesel power was considered for its ability to withstand greater total dynamic head, flow rates, and times of operation; but was detrimental in the cost of operation and routine maintenance. Diesel engines run the risk of contaminating the nearby water sources resulting in a hazard to the environment and thereby are a less desirable power generating system.

Solar power is proven to be the most beneficial means to produce the power required for the pump because of its low cost, less frequent maintenance requirements, and reliability.

5. Cost Benefit Analysis

In order to estimate the present value of the project, it is necessary to calculate the capital cost and the cash flows. The capital cost included the price of the pump, the panels, the storage tanks and piping required to set up the system and was estimated around $4,213.67.

The cash flows for this project are the cost of the water provided by the pump per year. Some assumptions were made in order to simplify the estimates:

- The cost of 1000 gals of water is $2 (Chicago)
- The pump can supply 220,000 gals of water per year
- At the end of the 10 year period the system has a resale value of $1000.00

The estimated cash flow is $438.00 per year.

Assuming a 10 year life and an interest rate of 10% the present value of the cash flows is $2691.3348, what gives a Net Present Value of ($1,137.34)

Assuming a 10 year life and an interest rate of 15% the present value of the cash flows is $2198.2344, what gives a Net Present Value of ($1,768.24)

It is important to mention that even though the NPV is negative, the life of the system will probably be longer than 10 years. Other factors are not taken into account such as: the cost of obtaining water by other means (i.e. generator, fossil fuel pump, tap water, etc.), the benefits from having accessible water at any time (from drinking and showering to irrigation), the amount of gasoline saved by not having to go to the city to get water, among others.

6. Legal:

a. Expected Outcome:

1. The Kankakee site and installed solar system will be fully supported by IIT, and EPA, NCIIA grants,

2. The Kankakee site and installed solar system will be designated as an "IIT educational site"

3. The site will be used for a wide range of educational activities identified by IIT upon completion for the XXXXX years

4. IIT will have full access to the solar system and the site, and will have option to expand the existing system in order to support other related Environmental projects, which could benefit farming, business development, and ecological development in that area, etc.

-

b. Maintenance (THIS PART NEEDS TO BE CORRECTED BY IIT LAWYERS)

Farm owners are responsible for operation and maintenance of the system. IIT will, however, provide technical assistance to the farm owners per their request in the case of defects, mishaps, malfunctions, etc.

c. Liabilities (THIS PART NEEDS TO BE CORRECTED BY IIT LAWYERS)

- IIT will not be responsible in any form or shape for accidents that are caused by modifications or additions to the system done by the farm owner or by any other party not associated to IIT.

- IIT will not be responsible in any form or shape for accidents or damage caused by a water pumping system that was produced from our designs.

- IIT will not be held responsible for any damage that may occur to the furniture, carpet, flooring, etc. that may occur due to leakage of the tank.

- IIT will not be held responsible for damage to the structure or framework caused by the weight of the water storage tank.

- IIT will not be responsible for any damage to the piping on the side of the cabins caused by any outside party.

- ♦ IIT will not be responsible in any form or shape for accidents involving the site, system components, use of pumped water, and any consequence of using ground water obtained by this system.
- ♦ IIT will not be held liable for illness that might occur due to bacteria build up in still water.
- ♦ IIT will not be responsible in any form or shape for the contamination of ground water due to negligence of the water pumping system, or failure of parts in the system.
- ♦ IIT will provide insurance in the case of the pump or other components of the system failing due to negligence in construction for up to but no later than one year of the completion of construction.
- ♦ IIT will not be responsible for any maintenance on the system components after the insurance allowance has expired.
- ♦ IIT will not be responsible for any maintenance on the system components after the insurance allowance has expired.
- ♦ IIT will not be held responsible damage that might occur to the solar panels caused by inclement weather or animals.

7. Economic Growth:

Based on the analysis of photovoltaic, wind and diesel power generation, it is concluded that solar power is the most efficient method of power generation for the Kankakee site.

Generating power utilizing wind lacks appeal due to the long-term mechanical problems caused by fatigue and friction. It is no more Eco-friendly than solar power. From these aspects, wind power is omitted from being the preferred method to produce the power required to run the pump. As an alternate means of power generation diesel power was considered which is beneficial in its ability to withstand greater total dynamic head and flow rates but is detrimental to the cost of operation and routine maintenance. Diesel engines run the risk of contaminating the nearby water sources resulting in a hazard to the environment and thereby is a less desirable power generating system.

Solar power is proven to be the most beneficial means to produce the power required for the pump because of its low cost, less frequent maintenance requirements, and reliability.

One of the economic benefits of this project is to save energy and set up a self-supply system with renewable energy. If the project runs successfully in Kankakee farm, it is will be a good example of solar water pumping systems in rural areas and developing countries in both energy saving and financing ways. At the moment, there is only one family living there, and the farm is still under development. However in the future, more cabins will be built; leading to an increased demand for water and the system can be upgraded with comparative low costs to provide enough water for several families.

Another potential for economic growth by implementing this project is the educational value in organizing visits to the solar water pumping system. The implication is a real scale sustainable system in action. The educational value to the community is the increased attention to sustainable systems increasing the desirability of such systems in rural communities. The incentives for using a solar well are tax reductions from the federal government and economic incentives from local governments and other agencies. The ramifications of an increased spread of solar pumps would be a net increase in reliance on green technology and the ecological savings from the reduced fuel use and green house emissions.

Proposed Solar System Financing Structure

The system consists of:

1. Installing a well
2. Designing water pumping system
3. Purchase of the pump, distribution system, solar system,
4. Construction,
5. Liability/insurance

Itemized Elements of Solar Water Pump System and Responsible Parties (pay structure)

Responsible/Item	**Design**	**Solar Panels**	**Pump**	**Piping**	**Storage**	**Well**
IIT (Grants)	**X**	**X**	**X**	**X**		**-**
Black Oak Center	**X**				**X**	**TBD**
IIT (Other resources)						**TBD**
Liability/insurance	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**

TBD= To Be Determined

Appendix D – Cost Benefit Analysis

Kankakee Proposed Design CBA

Design I

The first system design utilizes the cabin crawl space for water storage tanks. This cuts down on construction costs, but limits the amount of water that can be stored and also provides less water pressure for use in taps and showers.

System storage & water distribution components:
- Storage tanks
- Well construction
- System piping

Solar Power Option:
- Lorentz solar pump & controller
- Solar panels & mounting brackets

(No maintenance anticipated)

Gas Power Option:
- Grainger gas generator pump
- Gas powered generator

(This option estimates at least one full replacement for both power components within ten years)

Design II

The second system design intends to construct a single elevated external water tank. This system provides a clean and consistent water pressure so long as there is water in the tank. It also simplifies joint connections and monitoring systems.

System storage & water distribution components:
- Single storage tank
- Elevation structure cost
- Well construction
- System piping

Solar Power Option:
- Lorentz solar pump & controller
- Solar panels & mounting brackets

(No maintenance anticipated)

Gas Power Option:
- Grainger gas generator pump
- Gas powered generator
(This option estimates at least one full replacement for both power components within ten years)

CBA Analysis

General Benefits to All Designs:

The use of an on-site well system frees the owners from the necessity of tying into a utility water supply. This provides the benefit of eliminating the cost both of laying pipes as well as paying for water usage. These benefits are outlined below.

Water Costs $2 per gallon. Estimated usage is 600 gallons/day. = $438/year
Laying water pipes cost $100/meter. Estimated 20 miles to utility hook up. = $3,200,000

The table below outlines the 10% and 15% estimations for combined 10 year present value considering equal payments in each subsequent year to cover the pipe laying cost.

	10%	15%
10 years	$1,968,963.33	$1,608,214.23

The above also corresponds to a benefit cash flow of $320,438 per year for a 10 year period.

Various System Design Costs:

Design I – Solar:

The table below summarizes the present costs of the intended design.

Design I w/ Solar	Cost
Pump	$1,150.00
Panels & Brackets	$1,606.59
Storage	$1,257.08
Well Construction	$5,000.00
Piping	$200.00
Total	$9,213.67

Design I – Gas:

Gas costs are calculated based on a fixed cost of $3.50 per gallon. The average generator size considered (~1000 watt) will require 61 gallons per year to provide 600 gallons per day. Both the generator and pump are considered to be replaced after 10 years. The table below summarizes these and other particular design costs.

Design I w/ Gas	Cost
Pump	$400.00
future pump	$154.22
generator	$350.00
future generator	$134.94
Gas	$1,102.06
Storage	$1,257.08
Well Construction	$5,000.00
Piping	$200.00
Total	$8,598.29

Design II – Solar:

The table below summarizes the present costs of the intended design.

Design II w/ Solar	Cost
Pump	$1,150.00
Panels & Brackets	$1,606.59
Storage	$516.25
Well Construction	$5,000.00
Piping	$200.00
Elevation Cost	$1,500.00
Total	$9,972.84

Design II – Gas

For the following cost summary, the same general assumptions are applied to the gas, pump, and generator components as were used in evaluation of the gas powered option of Design I.

Design II w/ Gas	Cost
Pump	$400.00
future pump	$154.22
generator	$350.00
future generator	$134.94
Gas	$1,102.06
Storage	$516.25
Well Construction	$5,000.00
Piping	$200.00
Elevation Cost	$1,500.00
Total	$9,357.46

Cost-Benefit Summary:

Taking into account all the previous data for cost and benefit, the following table provides a summary of significant values as well as calculated NPV and the estimated payback period.

Design	Cost	Benefit	NPV	Payback Period (years)
Design I w/ Solar	$9,213.67	$1,968,963.33	$1,959,749.66	0.028753363
Design II w/ Solar	$9,972.84	$1,968,963.33	$1,958,990.49	0.031122526
Design I w/ Gas	$8,598.29	$1,968,963.33	$1,959,019.61	0.026850827
Design II w/ Gas	$9,357.46	$1,968,963.33	$1,958,260.44	0.029182656

Overall Conclusions:

From the general analysis, one can see that the benefits of instituting any system design are immense while the costs almost insignificant in comparison. The gas powered option of Design I appears the most economical. However, there are notable qualitative benefits in both having no expected system maintenance of a Solar system as well as the guaranteed consistent water pressure and simplicity of an elevated external water tank. Further, Design II does allow for the attic space of the cabins to be reclaimed for any original storage purposes. Nonetheless, these qualitative benefits are less easily negotiated in a straightforward cost-benefit analysis. Therefore, it seems fair to reduce this discussion to noting that all the design options seem at least approximately equivalent, and it is thereafter to be left a question of convenience and aesthetics as to which design option is chosen apart from this survey.