Team 15:
ANGKOR WATerworks

Preliminary Proposal & Feasibility Study

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Executive Summary

Team 15: ANGKOR WATerworks has undertaken the task to devise an irrigation system in the province of Siem Reap, Cambodia. Water must be collected from Lake Tonle Sap and transferred to agricultural sites throughout the region. The design must take into consideration the original vision for this project, as created by SK Lee of Handong Global University.

The climate of Siem Reap, Cambodia has distinct wet and dry seasons. In the wet season, farming, such as rice production, can easily be accomplished due to the high availability of water resources. However, in the dry season, the low seasonal rainfall, and subsequent scarcity of water resources, greatly prohibits crop production. Additionally, Lake Tonle Sap, the large lake adjacent to the province of Siem Reap, has large lake level variations due to flooding of the Mekong delta. During the wet season, heavy rains throughout the region cause a large influx of water and a four fold expansion of the lake’s surface area.

A number of objectives must be considered for the design. First, the design must complement the Master Plan for Siem Reap, as designed by Professor Ezra Kim of Handong Global University in South Korea. Second, the design must be culturally appropriate to the Siem Reap region and considerate of current methodologies for irrigation systems elsewhere in Cambodia. Finally, the design should strive to stay within the estimated cost limit of US$ 3 million, as set out by SK Lee, for the possibility of implementation.

The preliminary design of the system has been separated into 5 distinct areas of interest: agricultural water needs, collecting, pumping, conveying, and storing. First, the agricultural water needs have been determined. Because rice has the highest water needs of the available crops, it has been chosen as the design crop. With this selection, the necessary flow rate of the system is 0.002555 cubic meters per second per hectare of field. Second, the methodology of water collection has been determined. A crib inlet structure will be placed in an area of Lake Tonle Sap that remains submerged even in the dry season. Water will travel through the crib via gravity and flow through a pipe to an inland pond drawn down by pumps. Third, a pumping station, which utilizes centrifugal pumps, will pump the water into another set of pipes which transports the water several kilometers. These pumps have the ability to be powered by solar or conventional power. The water is pumped to two intermediate pond and pump stations before it reaches the designated site of the agricultural college of Angkor Global University (AGU). Fourth, the route from the lake to the irrigation site at AGU was designed to follow current roads but stay outside of the developmental center of the Master Plan. Since the route is not within the area that will undergo drastic changes with the implementation of the Master Plan, it will not interfere with the execution of that plan. A 38.1 centimeter PVC pipeline is the conveyance method of choice. With that pipe diameter, a velocity that minimizes friction losses in the pipe, and the flow rate determined necessary for a hectare of rice, a 65 hectare field has been determined to be the design size. The fifth design stage is storage at the irrigation site. At each site, the water will reside in a storage pond until it is needed. As the water is taken from the pond for irrigation, the pond is supplemented with lake water from the pumping system.

Through data acquisition and preliminary analysis, the design as described is feasible in meeting the required considerations. Preliminary budget forecasts have this project coming in around US $6.1 million, based off of US mean price data. This cost is above the requested cost of US $3 million, but with continued research on and adjustments for Cambodian price data, the cost of the project has a great likelihood of changing.

The design analysis is proceeding on schedule, with a schedule in place for continued design. Already produced are preliminary designs for the intake structure, initial pumping pond, pumping stations, routing and storing pond. With continued design, these plans will be altered as necessary in order to deliver final technical and construction documents, along with supporting documentation and promotional material.
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1 Introduction

1.1 Background

Geographically located in Southeast Asia, the Kingdom of Cambodia is bordered by Thailand, Laos, Vietnam, and the gulf of Thailand, as shown in Figure 1.1.1. With an economy dominated by rice production, water management is essential to the prosperity of the country. However, decades of conflict have resulted in the one of the lowest per capita gross domestic products (US$290) in the world. Low production of goods and underutilization of resources within the country force many residents to import essential products, including potable water, from neighboring countries. Because this method is so expensive, efforts are being made to reduce foreign reliance and improve utilization of local resources.

In the early 1990’s, after the decades of conflict have ended, Cambodia has opened its borders to the international community. As a result, many international tourists have come to the Siem Reap region to see the Angkor Wat temples, described by UNESCO as one of the wonders of the world. Situated along Lake Tonlé Sap, the largest permanent freshwater lake in Southeast Asia, the Angkor Wat temples are situated within the former capital of the great Angkor Wat civilization. These temples are shown in Figure 1.1.2. With the influx of tourists to the region to visit the temples, considerable commercial development has occurred. However, much of this development benefits the foreign subsidiaries instead of the local community. In response, Handong Global University (HGU) has proposed Angkor Global University (AGU), a campus in Siem Reap that will aid the education and development of the local population. AGU complements an HGU vision for holistically developing the Siem Reap region. The proposed water conveyance system in this project will provide water to the area identified for AGU, among other possible Siem Reap regions.
1.2 Scope of Project

The goal of Team 15: ANKOR WATerworks is to provide a water distribution system to allow the residents of the province of Siem Reap, Cambodia, to grow crops during the dry season. Water should be collected and transported from Lake Tonle Sap to proposed irrigation sites throughout the region. As a proof-of-concept design, the proposed site of Angkor Global University has been selected for the initial irrigation site. Figure 1.2 shows a satellite image of the region with the AGU site highlighted. Approximately 40 kilometers from the lake, the site is located near the maximum distance that would be feasible for obtaining water from the lake. The design would include an intake system, pumping system, pumping station, conveyance system, and water storage facility at the proposed irrigation site. However, as the project team cannot visit the site in person, only a limited knowledge of current local conditions can be achieved. Therefore, a design that fully incorporates the existing hydraulic infrastructure, of which little is known, is not technically feasible. The design should remain independent of existing hydraulic infrastructure so as to be expandable, allowing future implementation throughout the region.
1.3 Description of Team

Team 15: ANGKOR WATerworks is composed of four civil engineering students. Team members include: Patti Brinks, Ben Kuiken, Tim Schrotenboer, and Eric Wildschut. As each team member comes from a different geographic location across North America, the team has multiple viewpoints from which to consider the design. Patti Brinks is from Hudsonville, MI with interests in geotechnical engineering. Ben Kuiken comes from Lynden, WA. Some of his interests are hydraulic and environmental engineering. Tim Schrotenboer is from Cupertino, CA. His interests include structural engineering. Eric Wildschut comes from Sarnia, Ontario with interests in hydraulic engineering.

Figure 1.3 – Photo of team members
2 Problems

2.1 Dry Season Drought

In Siem Reap, Cambodia, a tropical monsoonal climate forms distinct wet and dry seasons. Figure 2.1 is a chart showing the average monthly rainfall in Siem Reap during a typical year. From May to October, large tropical storms can cause huge amounts of rainfall, capable of flooding areas in short times. This abundance of water softens the land, hardened from the previous dry season, and allows for the easy cultivation of a wide variety of crops, including the main Cambodian staple of rice. However, from about November to April, the dry season occurs when little rain falls, making cultivation much less productive. While it is possible to grow crops in some of the collected monsoonal rains, the yield is often below fifteen percent of the annual production.

![Figure 2.1 – Rainfall graph for Siem Reap, Cambodia](image)

Because of the limited rainfall occurring during the dry season, the possibility for a second growing season greatly diminishes as external water sources are needed to supply the necessary water. Farmers cannot rely on the rainfall to provide sufficient quantities of water to produce crops. Water must be stored from the wet season or collected from an external source, such as an underground aquifer or lake.

2.2 Lake Tonle Sap Variations

A possible source of water to suit the dry season growing needs of the Siem Reap region is Lake Tonle Sap. However, the tropical monsoonal climate drastically alters the lake throughout the year and presents challenges to collecting water from the lake. During the wet season, the water level of the Mekong River rises and water flows back into Lake Tonle Sap, with only a little water continuing along the normal path to the estuary. As the river becomes a source of water instead of a drain, the lake level and surface area experience a large increase from the dry season to the wet season. During the wet season, Lake Tonle Sap covers an area of approximately 10,500 square kilometers and rises an additional 3 to 9 meters. As the water level of the Mekong River falls, it returns to functioning as a drain. In the dry season, the lake area shrinks to roughly one-quarter in size, to approximately 2,600 square kilometers, and the depth...
decreases to less than 2 meters. Figure 2.2 shows the satellite images of Cambodia and Lake Tonle Sap during the dry and wet seasons.

**Figure 2.2** – Cambodia satellite photos showing water level differences during dry and wet season
3 Objectives

3.1 Integration with Master Plan

Professor Ezra Kim from Handong Global University has created a Master Plan for the province of Siem Reap, shown in Figure 3.1. This Master Plan calls for an area that not only benefits the hotels and other tourist attractions of the area, but more importantly, benefits the residents of Siem Reap. By creating a design harmonious with the Master Plan, the team will create a design that allows for economic justice for the residents of Siem Reap, helping to regain the prosperity the region once had.

![Figure 3.1 – Siem Reap after complete realization of Master Plan](image)

3.2 Culturally Appropriate Design

Another objective of the project is to create a design which is both culturally and technically appropriate. To accomplish this goal, the team will utilize resources readily available in the Siem Reap area. The design will use not only the material resources common to the region, but also the resources of labor and knowledge of the region. By doing this the team will create a design that complements the culture and technology of the local region. Additionally, when the system needs maintenance and repair, the tools, materials, and knowledge will already be available in the local region. By integrating with the culture and community of Siem Reap, this water system will be a statement of Cambodia promise.
3.3 Consideration of Past and Present Methodologies

Water transport systems have been widely used in Cambodia throughout its history. In ancient history, two primary methods of farming irrigation relied upon by Cambodians were floodplain and receding flood farming. In floodplain farming, rice was grown in areas watered by natural flooding that provided a year round availability of water. However, these locations were almost entirely abandoned by the tenth century, possibly due to a change in flood patterns. In receding flood farming, manmade land features, such as dykes, ditches, levees, and small dams, were constructed to delay and spread laterally the receding flood water as the dry season came. From the seventh to the thirteenth centuries, the great Angkor Wat civilization developed the Siem Reap region with a grand irrigation system of canals, moats, and reservoirs to drive its rice based economy. In recent history, during the Sihanouk period from 1953-1970, Prince Norodom Sihanouk wanted to replicate the success of the Angkor civilization. Under his authority, traditional structures were updated in larger scales using current construction techniques. Unfortunately, most of the large projects failed to reach the feasibility phase because of the outbreak of war in 1970. After the war, under the oppressive Khmer Rouge regime, rice again became the economic basis for the state. Almost the entire population was forced to grow rice during the wet season and to construct and implement water management and irrigation systems during the dry season. Unfortunately, due to the extensive execution and emigration of people with technical knowledge, the irrigation canals were not implemented properly. Instead of properly following contour lines, the canals were situated according to the coordinate lines drawn on most 1:50,000 scale topographical maps. This blunder created problems as canals often sloped in different directions in some sections than other sections. Due to these past developments, “today, more than 20 years after the Khmer Rouge regime, it is clear that only a small percentage of these structures can be incorporated in any future water management system, and they will require much additional investment. Most of the structures are useless or, even worse, disruptive to water management” (Sinath).

3.4 Cost Target

Previous project designs for the Siem Reap region, although complete and proper, have not been implemented for cost reasons. The governor of Siem Reap can approve and fund projects below the cost of three million dollars. Any cost above this must be approved by the monarchy of Cambodia. One of the objectives of Team 15 is to stay below the three million dollar limit, and thus stay within the realm of approval of the governor. Staying below this mark is important for the successful implementation of the design.
4 Preliminary Design Options

4.1 Agricultural Water Needs

When determining the amount of water supply needed for agricultural production, a number of factors are considered. The first of these considerations, site location, is critical because it determines the soil type. If the site has permeable soil, it will require more water because more water is lost to infiltration. A second and more critical consideration is the type of crop to be grown. Because each crop type has its own specific water needs, the amount of water to be delivered depends significantly on the crop type. Determining the crop type will set a basis for all subsequent calculations.

Calculations for the agricultural water needs are based off of the United Nations Food Aid Organization irrigation calculations handbook. Rice was chosen to be the design crop for several reasons. First, rice farming is already done in this region, and therefore the farmers are familiar with it. Second, a larger number of resources on rice farming in the developing world are available from the IRRI (International Rice Research Institute). Third, rice requires substantial ground infiltration and a constant layer of water on the surface in order for it to grow properly. This growing technique means that rice requires much more water than any other crop. If the design is able to meet the irrigation demands of rice, then it can meet the needs of any other type of crop. Figure 4.1 shows a rice field submerged for the growing season.

Thanks in part to investigations on soil type by the IRRI, Team 15 has been able to determine the exact soil characteristics in this region and its suitability for rice farming. These investigations have led to the understanding that the soil at the site is sandy, a very permeable medium. Unfortunately, this soil is not the most suitable for rice farming. However, many residents are currently farming rice in this region during the wet season, demonstrating its feasibility.

Initial calculations have already determined the amount of water that will be needed for rice production. Per hectare, the field requires 2000 cubic meters of water in order to allow for the 200 millimeters of infiltration that is needed for the soil. This must be done approximately one week before planting. After
planting, an additional 1000 cubic meters of water is needed to provide for the 100 millimeter water surface. This water requirement takes into account all evapotranspiration, infiltration and the needs of the plants. For this surface to be maintained, a constant supply of water is needed. Based on a rice field size of 65 hectares, a water supply of 0.166 cubic meters per second is necessary. This field size has been chosen in accordance with pipe diameter specifications, discussed in Section 4.5.1. Table 4.1 details some of the design factors that have been used to determine agricultural needs.

<table>
<thead>
<tr>
<th>Climate</th>
<th>Evaporation</th>
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<tr>
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<td>Temperature during dry season</td>
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<tr>
<td></td>
<td>Precipitation during dry season</td>
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<td></td>
<td>Effective Precipitation</td>
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<td>Wind Speed</td>
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<td>Humidity</td>
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<td>Growing hours</td>
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<tr>
<td></td>
<td>Sunshine intensity</td>
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<td>Seasons</td>
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<table>
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<th>Crop type</th>
<th>Initial soil saturation (Root Saturation)</th>
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<td>Maintained water layer</td>
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<td>Transpiration</td>
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<tr>
<td></td>
<td>Length of growing season (seedling to harvest)</td>
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<td></td>
<td>Water needs for 3 different growth cycles (beginning, middle, end)</td>
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<tr>
<td></td>
<td>Length of each growth cycle</td>
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<td>Cultural appropriateness</td>
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<table>
<thead>
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<th>Soil type</th>
<th>Dictates permeability</th>
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<tbody>
<tr>
<td></td>
<td>Percolation and seepage losses</td>
</tr>
</tbody>
</table>

| Crop size        | Determines a scaling of how much water will be needed overall |

4.2 Collecting

4.2.1 Source

In order to transport water to the proposed irrigation sites throughout the Siem Reap province, an appropriate water source must be located. However, the chosen water source must be able to meet the necessary water requirements during the dry season, when water is the scarcest. In Siem Reap, four sources are available for water collecting during the dry season. First, as was done centuries ago in the region, large barays, or reservoirs, could be filled with water diverted from the Siem Reap River during the wet season. Storing this excess water from the wet season provides sufficient quantities to be used during the dry season. Second, water can be pumped directly from the Siem Reap River during the dry season. Once the water is elevated from the river, it may flow via gravity to the proposed irrigation sites. Third, water can be pumped onsite from wells accessing the groundwater aquifers. This would eliminate
the need to transport the water from the source to the proposed irrigation sites. Fourth, water could be pumped from Lake Tonle Sap. This large freshwater lake retains a large capacity of water even during the dry season.

To determine the water source that is the most appropriate solution, several factors that must be considered are capacity, energy needs, footprint, political preference, proximity to site, and scalability. Table 4.2.1 shows the decision matrix for selecting the water source.

<table>
<thead>
<tr>
<th>Water Source</th>
<th>Capacity</th>
<th>Energy Needs</th>
<th>Footprint</th>
<th>Political Preference</th>
<th>Proximity to Site</th>
<th>Scalability</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
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<td>Barays</td>
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<td>6</td>
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<td>202</td>
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<tr>
<td>Siem Reap River</td>
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<td>8</td>
<td>7</td>
<td>2</td>
<td>8</td>
<td>2</td>
<td>180</td>
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<td>2</td>
<td>9</td>
<td>1</td>
<td>167</td>
</tr>
<tr>
<td>Lake Tonle Sap</td>
<td>8</td>
<td>4</td>
<td>5</td>
<td>9</td>
<td>2</td>
<td>8</td>
<td>259</td>
</tr>
</tbody>
</table>

The use of barays is a proven concept in the province of Siem Reap. Two large barays were constructed centuries ago to provide water for the region. However, only one baray partially remains in use today, while the other has been drained due to increased development in the area. The barays provide a large capacity with low energy needs because the water can flow by gravity from the barays to the proposed irrigations sites. Unfortunately, the reservoirs require a large footprint to hold the necessary capacity. This would prevent the land from being utilized for other uses and so is not preferred by the political authorities of the region. The large footprint would also prevent the baray from being located near the proposed irrigation sites and would prevent easy scalability.

The Siem Reap River provides another source of freshwater. The footprint and energy needs would be low for utilizing this water source as the water would only need to be pumped out of the river to be transported to the site by gravity. However, the river’s capacity is greatly reduced in the dry season due to lack of rainfall. This does not allow for easy scalability of the system.

Water for the system could also be supplied from onsite wells. Onsite wells reduce the distance water must be transported and ensure a water supply with reduced contaminant levels due to aquifer filtration. However, of the almost 7600 wells in Cambodia for which UNICEF has records, less than three percent have yields greater than 10 cubic meters per hour. With yields typically around 0.72 cubic meters per hour, no groundwater sources containing sufficient capacity for large-scale irrigation have been identified. Groundwater use must be limited to small fruit and vegetable gardens, especially dry season crops with low water needs.

Utilizing Lake Tonle Sap as the water supply allows enough capacity to provide a seemingly unlimited supply for the residents of Siem Reap. This would allow for scalability, as there would be no water supply limit. For this reason, the government of Siem Reap prefers a system that utilizes Lake Tonle Sap as the water source. Unfortunately, the proposed irrigation sites may not be located in close proximity to the lake. Consequently, energy must be provided to pump the water from the lake to the sites.

### 4.2.2 Intake Method

In order to collect water from Lake Tonle Sap, the appropriate intake method must be designed. The intake method must be reliable and should be culturally appropriate for the region. Three categories of intake can be utilized: infiltration intake, direct intake, and gravity intake. Through the infiltration
method, water is pumped through soil before it reaches the pumps. This process provides preliminary filtration of the water, delivering cleaner water through the system. Through the direct intake method, infiltration is omitted and water is pumped directly from the lake. Finally, through the gravity intake method, water flows by gravity from the lake to the pumping station with no external power source. For each of the three methods of intake, two forms are evaluated in order to select the preliminary design. Table 4.2.2 shows the decision matrix for selecting the intake method.

As mentioned earlier, the infiltration intake method provides for preliminary filtration of the water. Beyond providing cleaner water, filtration has the possibility of preserving the life of the pumps by reducing solids in the influent stream. However, the filtration media may be pulled through the intake pipes and damage the pumps. Two methods of infiltration are possible if the lakeshore soil that the water is being pulled through is suitably permeable. The first method involves locating large caissons near the shoreline of Lake Tonle Sap. Slotted laterals are placed at the bottom of the caisson, radiating horizontally outward. Placing a submersible pump into the caisson draws down the water level, creating a head difference between the lake surface level and the water surface level in the caisson. This difference causes water to flow into the slotted laterals and into the caisson via gravity. The second infiltration intake method involves extending a large trunk main from the pumping station into the lake. The end of the trunk main is fitted with an infiltration bed: an array of slotted laterals. The pumps would pull water through the soil, slotted laterals, and trunk main to the pumping station.

The main condition for use of infiltration intake methods is the permeability of the soil. If the soil is too dense and lacks sufficient pore space, the resistance becomes too great to achieve the necessary flow rates. The head loss of the water through the soil is too high, exceeding the net positive suction head for the pumps. This causes cavitations and drastically reduces the life of the pumps. Unfortunately, in the province of Siem Reap, the soil in and near Lake Tonle Sap is not sand, the desired media. Figure 4.2.2 shows the area to have the ‘Great Lake’ soil type, a soil with high clay content and therefore low permeability. Therefore, it is not technically feasible to implement an infiltration intake method.
Other intake methods use direct intake and omit the step of infiltration. Similar to the infiltration bed method, the direct intake methods extend a trunk main from the pumping station out into the lake. Using a floating intake, the entire main and intake structure would be suspended from buoyant structures on the lake. The pipeline and intake would then be accessible, as they would rise and fall with the lake level. However, because of the unsecured nature of the pipeline and intake, monsoonal forces can easily damage the structure. This method is not desirable, as a design is needed that is dependable and reliable. For the other direct intake method, the trunk main would not float on the surface, but rather, be buried .5 meters under the lake bottom to provide protection from environmental forces. At the end of the trunk main, a crib structure would be constructed from wood and wire meshing and weighted down with rocks. The crib would be located on the lake bottom with the inlet located at the center. The rocks and structure would provide large-solids filtration. Unfortunately, direct intake methods cannot be used because of the location of the pumping station out of the seasonal floodplain, as further explained in Section 4.3.3. This location causes an intake pipe length of over 8 kilometers and a suction head greater than can be attained by conventional pumps.

The final intake method utilizes gravity to transport the water from the lake to the pumping station. For the first form, a channel is dredged to a level lower than the dry season lake level. Despite the distance that the lake recedes in the dry season, water can still flow to the pumping station. The channel could be constructed using the relatively inexpensive labor in the area, but the large lake level variations present a problem. Because the lake level varies so much from wet season to dry season, the channel would be too deep near the pumping station to safely construct. In order to mitigate this problem, the second form utilizes a pipeline instead of a channel. This avoids the problem of steep channel side slopes. In order to pull the water through the pipeline, a deep retention pond must be constructed with a water surface elevation at or below the level of the lake. The pumps pull water from the pond and draw the water surface level below the lake level. The ensuing head difference causes water to drain from the lake into the retention pond. The intake of the gravity pipeline is fitted with a crib structure similar to that of the direct intake method. Subsequently, this method has been selected for the preliminary design.

<table>
<thead>
<tr>
<th>Table 4.2.2 – Decision matrix for intake method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Filtration</strong></td>
</tr>
<tr>
<td><strong>Weighting</strong></td>
</tr>
<tr>
<td>Caisson w/ Laterals</td>
</tr>
<tr>
<td>Infiltration Bed</td>
</tr>
<tr>
<td>Floating Structure</td>
</tr>
<tr>
<td>Suction Crib Structure</td>
</tr>
<tr>
<td>Dredged Channel</td>
</tr>
<tr>
<td>Gravity Crib Structure</td>
</tr>
</tbody>
</table>

4.3 Pumping

In order to transport water from Lake Tonle Sap to the proposed site of Angkor Global University, the water must rise in elevation approximately 40 meters over the course of 40 kilometers. Therefore, gravity cannot be the only driving source. Pumps must be utilized to meet the necessary elevation requirement, while providing the adequate flow necessary for agricultural production. Specific pumps need to be chosen to operate under these conditions. However, certain challenges and constraints exist that must be overcome while selecting the appropriate pumps.

4.3.1 Pump Type
The selected pumps must be culturally appropriate to the region. Local residents must be able to operate and maintain the pumps. The project falls short if the pumps malfunction and the people do not have the ability (e.g. tools or knowledge) to repair them. When the pumps are not running, the water is not being transported to the agricultural sites, possibly compromising crop production. To minimize the occurrences of failure, the pump that is selected must be durable and efficient. This prevents unnecessary shutdowns and increases the life of the equipment by having it run fewer hours.

One possible option for pumping is off-the-shelf solar pumps. These pumps are individually powered by their own solar panel. This allows the pump to run without the need of an outside energy source. No continual energy costs must be paid to keep the pump operating. Unfortunately, in order to transport the necessary capacity of water per hectare to the proposed irrigation sites, too many pumps are required. Individual solar pumps that provide enough head to reach the proposed site from the lake only provide roughly 0.0005-0.0006 cubic meters per second. Additionally, because only 8 of the 12 daylight hours in Cambodia during the dry season have enough intensity for solar power production, the necessary pump flow rate must be increased to over 0.166 cubic meters per second for the 65-hectare irrigation site. Therefore, an unreasonable number of 330 pumps is needed to provide sufficient flow. If individual solar pumps are used that provide less head but more flow, the number of pumps reduces to 160, still an unreasonable number. Therefore it is not feasible to use individually powered solar pumps. Centrifugal pumps provide greater flows, allowing a more reasonable number of pumps per hectare. Cornell provides multiple centrifugal pumps that can be used for pumping the water flows the necessary distance. Submersible pumps could be used to pump water from the retention ponds. However, the ease of maintenance and motor connectivity as well as greater reliability, make centrifugal pumps a better choice for the preliminary design.

### Table 4.3.1 – Decision matrix for pump type selection

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<th>Ease of Maintenance</th>
<th>Flow Capacity</th>
<th>Reliability</th>
<th>Implementation Feasibility</th>
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4.3.2 Power Source

Although off-the-shelf centrifugal pumps will be used, it is still possible to power them by solar power. This allows the project to maintain its minimal operating costs, while ensuring that the number of pumps remains feasible. Evaluating the solar panel area necessary to meet the power needs of individual solar pumps, it is possible to estimate the amount of space that must be set aside near the pumping stations for the solar grids. From the calculations, approximately 40 - 50 square meters must be allocated per hectare of the proposed irrigation site. A spreadsheet used to perform these calculations is included in Appendix A4.1. However, as an alternative to solar power, the pumping station may be connected to the Siem Reap power grid. Both of these alternatives are viable options that can be considered by the government of Siem Reap, according to their available upfront and operating funding.

4.3.3 Intake Pump Location

The location of the pumps along Lake Tonle Sap must be considered. Because the area of Lake Tonle Sap increases four-fold during the wet season compared to the dry season, the seasonal shorelines can be over 8 kilometers apart. This presents a challenge as water needs to be pumped from the lake during the
dry season but the pump station needs electricity and cannot become submerged during the wet season. One possible solution involves constructing a pumping station at the dry season shoreline level. At this location, the pumps would easily be able to pull water from the lake during the dry season. However, this presents additional challenges as the water level rises during the wet season. A secure line that houses the electrical lines must stay dry to ensure proper operation. The station must also endure the forces of storm surges in the lake during the monsoon season. Additionally, maintenance would be very difficult during the wet season, as the lake would surround the pumping station.

Another possible location for the pumps would be along the wet season shoreline. This would ensure that the pumps stay dry and easily maintainable during the wet season. However, this location does present other challenges. Because the pumps would be located over 8 kilometers from the water intake, a large net positive suction head would result if a pump was used to draw the water uphill. Net positive suction head can cause cavitation and ruin pumps. To mitigate this problem, a gravity-fed structure, as previously described in Section 4.2.2, will be used.

4.3.4 Pumping Stations

In order for the system to continually operate properly and efficiently, the pumps must be secured from environmental and social dangers. Because Cambodia has a monsoonal climate, it is important to construct a pumping station that shelters the pumps from water and wind damage. The pumps may not be submerged from wet season rain and flood waters or they will become inoperable. Additionally, the pumps must be secured from vandalism. Only authorized entry should be permitted near the pumps. For construction of the pumping station, common regional practices must be incorporated. Concrete columns are placed at the corners of the building and at a spacing of 2 meters between the corners. Clay bricks adhered with mortar provide stability between the columns.

To allow for future expansion of the system, additional pumping stations and retention ponds will be located along the route to the proposed irrigation site. Similar to the intake pumping station, the pumping stations along the route will be scaled to the appropriate size for the necessary water flows. With two additional pumping stations 10 and 20 kilometers from the intake pumping station, water can be diverted from the main line to other future proposed irrigation sites.

4.5 Conveying

4.5.1 Method

A system of pipes or a system of canals can be used in order to convey water from the lake to the proposed irrigation sites. As both are already employed within Cambodia, both systems are culturally appropriate. The Siem Reap region currently utilizes a system of canals, but, as previously stated, the existing canal system is less than ideal. Many of the canals have fallen into disrepair, and others have
proven useless or disruptive to water management. Because of their condition, the use of existing canals is not possible without first investing a great deal to repair them.

Another option to consider is the construction of a new canal system. Since canals are gravity driven, the new canal system would entail building up the end of the canal near the lake to the point that water flows downhill to the site. This can be accomplished in one large step at the lake or in several steps during the 40 kilometer span. Since the AGU site is at an elevation approximately 40 meters above the lake during the dry season, one large step at the lake is not a feasible option. A better option would be to construct a series of twenty canals increasing in elevation two meters at each step. A small pump would be required at each of the twenty steps.

Another option is a system of pipes beginning at the lake and following a direct course to AGU. Again, the route could be done as one step or in a series of multiple stages. In this system, the pipes would be buried 45-60 cm below ground to provide for proper protection from the monsoonal climate and harmful UV rays.

In the proposed system, security is a factor that must play into the design. Although future plans for the system include the possibility of drawing water at intermediate points, the original design calls for water discharge only at the university site. The design is for a specific amount of water necessary for irrigation, and does not originally consider the excess necessary if residents are to draw water before it gets to the site. Therefore, the water line must be secured from illegal water discharges. Securing a system of pipes is easier to accomplish than securing a system of canals, as a tap into a pipeline would be more obvious.

Another factor that must be considered is water loss in transit. Infiltration and evaporation are two of the main water losses in a canal. The canals are lined with clay, a medium with low permeability, helping to keep infiltration at a minimum. However, the surface water in the canal would be exposed to evaporation throughout the entirety of the dry season. Another, smaller area of water loss is through plant uptake. Plant growth on the sides of the canals draws an additional amount of water to that already lost by infiltration and evaporation. The water lost by these three factors must be compensated for by additional water intake at the lake and additional flow rate though each of the pumps. The water loss in a piping system is minimal, with only minor water losses at pipe connections.

The surface area necessary for each system must also be considered. While nothing can be built above the pipeline, it requires a relatively small amount of right of way. A canal needs a larger area of right of way than a pipe because of the additional volume required to achieve the same flow rate at the outlet.

Related to the additional area needed, a canal requires additional infrastructure in order to travel over it. Since the pipe would be buried below ground, roads can be built over it with little consideration. However, with a canal, a bridge or culvert must be built to get from one side to the other. Since our conveyance system spans a length of 40 kilometers, many such bridges or culverts would be necessary to maintain the present ease of travel.

The cost of each system must also be considered. The cost of a canal must account for digging and lining the canal and the labor and materials associated with that work. Another cost in the use of canals are the pumps necessary at each step up in the system. In a pipeline, the cost of the pipe must be considered as well as the labor and materials to dig the trench for the pipe and fill it back in. The cost of the pumps for the piping system is also included. Relative to pipes, a system of canals is a less expensive alternative because most of the cost is associated with labor. According to the Kingdom of Cambodia website, labor in Cambodia is relatively inexpensive when compared to the cost of labor in North America.
Table 4.5.1 displays the decision matrix used to determine the conveyance system of choice. As seen in the table, a system pipes is a much better alternative for the design. Therefore, pipes will be the conveyance system of choice for the design.

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When considering a pipeline, there are five main types of pipe that can be used: PVC, reinforced concrete, steel, cast iron, and ductile iron. According to the Cambodia Yellow Pages, PVC is readily available in the Siem Reap region. PVC is lightweight and corrosion resistant. Disadvantages to PVC are the vulnerability to ultraviolet light and high thermal expansion coefficient. However, the pipeline would be buried and therefore not exposed to ultraviolet light once installed. Also, given the geographic location of Siem Reap and relatively small seasonal variations in temperature, thermal expansion is not a significant factor. Reinforced concrete pipe is not recommended because S.K. Lee, the project visionary, dismissed concrete for several areas of the design. He cited the fact that PVC is more cost effective and easier to work with than concrete. Preliminary budget calculations prevent the use of the three remaining alternatives. Therefore, it is expected that PVC piping will serve as our basis for pipeline design. PVC pipe is available in a variety of sizes. This design uses a pipe with diameter of 38.1 cm because it maximizes the amount of water the pipe can transfer. This amount of water, combined with the necessary flow rate for rice production and a velocity that minimizes head losses, is what has determined our design field size of 65 hectares.

4.5.2 Routing

Another main consideration for conveyance is routing. Three main alternatives are available here: follow a route in accordance with the future plans for the area, follow a route in accordance with what exists in the area currently, and a combination of the first two alternatives.

The first alternative considers the vision of the Master Plan for Siem Reap. In this alternative, the future region plan would be the basis for routing, and the water line would follow a route non-intrusive to future building and expansion in Siem Reap. Because the current and future structure of the region may not align, this alternative may involve relocation of current residents in preference to the future plan.

The second alternative is to follow current drainage lines or roads. In this alternative, structures that the design must work around are already in place and therefore easier to consider. The advantage to following drainage lines it that there will be a higher probability of a steady uphill grade. Burial of the system would be at a more constant depth, with the high chance of less digging to install. At further investigation of this alternative, it has been discovered that the drainage lines follow a route with many twists and turns, as seen in Figure 4.5.2.1. Because of the additional pipe necessary to follow this route, it has been discarded as an alternative. A route which follows current roads seems a more viable alternative. There are several roads that follow a relatively straight line from the lake toward the AGU site. By following one of these roads, much less pipe will be necessary to get water from the lake to the irrigation sites.

The third alternative combines the previous two alternatives by finding a route that will not alter much during the implementation of the Master Plan. To accomplish this, the route must be outside of the major...
developmental center of Siem Reap, where the Master Plan is focused. The areas outside of this center are relatively unaffected by the re-structuring of the area. Since this alternative combines the advantages of both of the previous alternatives, it was chosen for this design. The route the proposed pipeline follows, as well as previously discussed routes, is shown in Figure 4.5.2.2.
4.6 Storing

On-site storage is important to the design for the reason of redundancy. If water is stored on-site, that water can be used for irrigation in the case of a pipe break, pump failure, or power outage. The design will allow for the proper amount of storage to provide for a reasonable amount of contingency.

The storage of water for the site is based off of a number of variable factors. It is connected to the site’s available space, the pumping capabilities and operating policy and the soil type in the area. The two possible storage types that are being considered are a detention pond and a large storage tank. Figure 4.6 shows a possible storage tank.

First, the site’s available space is a major factor, as a smaller site permits less water storage. It is quite likely that a detention pond would take up more space than a storage tank. A safe detention pond is less than 3 meters deep, and holding tanks can hold water up to 25 meters deep. Therefore the same volume of water can be stored in a tank and a detention pond, with the tank having a smaller footprint.
The pumping capabilities and operating policy have the greatest effect on the storage needs. If the pumps are going to be designed small and run less often, a much larger storage area would be required than if the pumps are larger and run more. Storing all of the water needed for the crop is infeasible due to the large amount of water required for the crop. For the 65 hectare rice field, a three-meter deep retention pond with dimensions of 200 meters by 325 meters is needed for the initial infiltration and initial water layer. The storage capacity of the design will be optimized with the pump operating policy to ensure that the water needs are being met while minimizing the need to store excessive amounts of water.

The soil type also plays a role in the determination of the storage type. If the soil in the proposed area is sandy, then a detention pond is not feasible unless it is lined. The pond either has to be inlayed with a synthetic lining or lined with a layer of clay, which can be found near the shores of Lake Tonle Sap. The cost of lining the pond, whether with a synthetic liner or with clay transferred from the lake, has a direct impact on the price of the detention pond. Storage tanks need proper footings depending on the soil type, adding an additional cost to an already more expensive option.
5 Preliminary Design

The intake chosen for the design incorporates a crib structure on the end of a gravity-fed pipe. A preliminary design for the profile of the intake pipe from the lake to the pumping station retention pond is shown in Figure 5.1. A preliminary design for the intake crib is shown in Figure 5.2. Larger versions of all the diagrams for the preliminary design are available within Appendix A2.

![Figure 5.1 – Intake Pipe Profile](image1)

![Figure 5.2 – Preliminary Design for the Intake Crib](image2)

For the pumping aspect of the design, the pumping station will be located at the site shown in Figure 5.5. The pumping station is designed with a levee around it to minimize the chance of flooding that will damage the pumps and possible solar panels. The pumping station incorporates an underground level to house the pumps. This allows a lesser net positive suction head for the pumps to operate. From the intake structure to the pumping station, a large gravity-fed pipe is used to reduce friction losses. This pipe feeds into a retention pond located next to the pump house. From there, the water from the retention
pond is pumped into the pump house and into the connected pipeline. Located on the site and within the surrounding levees is an area whose size is allowable for solar panels to power the centrifugal pumps. The station must be secure to prevent unauthorized access, while still allowing space for maintenance. Figure 5.3 shows a preliminary design for the pumping station layout. All dimensions shown are in meters.

![Pumping Station Diagram](image)

**Figure 5.3 – Pumping Station Diagram**

The chosen route follows the path mentioned earlier, a route following existing roads outside of the main developmental center of the Master Plan for Siem Reap. This route is shown in blue on Figure 5.5.

For storage on the irrigation site, a detention pond is the chosen design. A preliminary schematic of the irrigation site detention pond is shown in Figure 5.4.
All of these components will be combined to create the preliminary design for our overall system. Figure 5.5 shows a schematic of the entire system.
6 Costs

The following cost estimate come from RSMeans’ *Building Construction Cost Data 2002* referencing all United States cost for materials. RSMeans’ guide also provides the estimated cost for labor and time spent on labor. For the cost estimate it is assumed that Siem Reap contractors can work for the same cost and with equal efficiency as US contractors. Appendix A5 shows a preliminary construction cost estimate for the Siem Reap water conveyance system in U.S. Dollars. Material, labor, and equipment costs are eligible to change for the final report.

The following is a summary of each major aspect of the project. A contingency of 15% is applied to each category and subsequently to the total cost. This contingency allows for small adjustments in costs of materials, labor, and equipment.

- Intake $1.01 million
- Three Pump Houses $1.47 million
- Six Pumps $0.04 million
- Routing $3.51 million
- Storage $0.07 million
- Total $6.10 million

The primary expense for the water conveyance project lies within routing. Based on the rough estimate, the entire project budget would be spent purely routing. The total project cost is currently estimated at $6.1 million. This number is $3.1 million over the proposed $3 million budget, but calculations using local Cambodian pricing may adjust the calculated costs.
7 Project Feasibility

The feasibility of this project is based on a number of factors. The first set of factors is dependent on the project scope and the second set is based on team functionality and ability. Project factors include cultural appropriateness, integration into the master plan, cost and project scope. Team factors include project scope, scheduling, and team ability.

The cultural appropriateness of this project will be achieved through a number of ways. First, by using local labor and materials, this will ensure that what is implemented will be fixable by local craftsmen should it ever break down. Although a dependable system will be designed, real world conditions dictate that maintenance is an issue that will arise.

Integration into the Master Plan is being considered. The proposed route follows an area that is outside of the boundaries of the master plan for the region. Thus, it will be viable for implementation now and also fit well within the region after the plan is enacted. This effectively solves both problems of how to route the system, as it works with both present conditions and future construction.

Cost analysis determines that initial calculations have placed the project at twice the goal price. However, cost estimates are based on U.S. prices and have a great possibility of changing to reflect local costs in Siem Reap.

The scope of the project is such that design of the complete system as described in this report is feasible. It integrates with the overall idea of a system to transport water for irrigation, yet it details one possible solution of many. This makes the system feasible to be designed, as the scope is not beyond the breadth of the project.

Project scope is also important in terms of team factors. With the current scope that is in place, the team is properly prepared to complete the project. Through division of work, each area will be broken up and dealt with separately, and then tied into the rest of the system.

Scheduling also factors into feasibility. Scheduling of this previous semester has provided a model from which the schedule of work yet to be completed has been derived. Lessons learned with time allotments from last semester have been applied to second semester’s schedule. Scheduling has placed the project ready for completion with the target of May 2006.

Team ability also has to be factored into the project feasibility. With a number of interests in the different facets, along with a wide perspective, the team believes that they will be able to complete this project, as scheduled, for its completion in May 2006.


8 Schedule

Located in Appendix A1.1 is a schedule for previously completed work. This schedule was produced in early October and resulted in a congested workweek during mid-November. The schedule in Appendix A1.2 is for work yet to be completed. Team 15 scheduled the work so that only one major aspect of the project is tackled at any given time. This reduces the work load and distributes the work evenly throughout the semester. The schedule for future work is planned so that a majority of the work is complete seven weeks before the final report. This amount of time provides contingency to allow a portion of the project to take longer than originally planned and still be able to reach completion on time. This schedule for future work, with its built in contingency time, communicates that the design will be completed in good time for the projected end date of May, 2006.
9 Deliverables

Upon the completion of the design, Team 15: ANGKOR WATerworks will present two sets of deliverables.

The first set will contain technical and construction documents along with supporting documentation for implementation of the project, including a comprehensive cost analysis. This set of documents will be delivered to the Handong Global University representatives who will present this idea to the Governor of the region for approval and funding purposes. As this is a politically motivated project, promotional materials highlighting the main areas of the design and its benefit to the region will also be included. These materials can be used in conjunction with other presentations and can be delivered to the Governor he when arrives at Calvin for his possible visit in early May.

The second set of deliverables will include all supporting documentation, combining calculations, alternative designs, implemented designs, cost analysis, team budget and schedule. These deliverables will be presented to the Calvin faculty for their review and assessment of the team’s final grade. This documentation will also be available to the Cambodians, as per their request.
10 Conclusion

Due to the limited knowledge available about this area, information for design has been hard to acquire, but steady progress is still being made. Research to this point has provided a solid footing for current and future design work. Communication with the team in Cambodia will also fill in some unknowns and will help provide concrete data.

The design thus far includes plans for the areas of collecting, pumping, conveying, and storing water to be used for irrigation at various locations in the Siem Reap area. The first site proposed for implementation is the agricultural college of Angkor Global University. With further analysis and more concrete design, this system will be ready for implementation in Siem Reap. Realization of this design will provide the people of Angkor Global University, as well as the local population, with a system that will work well and be reliable for years to come.
References


Suregaurd Fencing. Hours of Sunlight Sunshine Cloudiness. 


Appendices

A1: Schedules
   A1.1 Schedule of work completed to date
   A1.2 Schedule of work yet to be completed

A2: Details
   A2.1 ST-101 Intake Detail
   A2.2 ST-102 Pump House Detail
   A2.3 ST-103 Pump House Detail
   A2.4 ST-104 Storage Pond Detail
   A2.5 ST-105 Storage Pond Inlet
   A2.6 ST-106 Pumping Area with Pond
   A2.7 ST-107 Lake to Pond Profile

A3: Agricultural Calculations
   A3.1 Evapotranspiration Calculation
   A3.2 Rice Evapotranspiration Calculation
   A3.3 Irrigation Needs For Rice

A4: Pump Calculations
   A4.1 Pump Spreadsheet

A5: Cost Analysis
   A5.1 Preliminary Cost Estimate
   A5.2 Estimated Work Crew Wages
A1: Schedules

A1.1 Schedule of First Semester Work
A1.2 Schedule for Second Semester
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<td>Determine depth of pipe</td>
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PROPOSED INLET STRUCTURE

CROSS SECTION

PROPOSED INLET STRUCTURE

PLAN VIEW

SEPARATED BY WIRE MESH

EACH COMPARTMENT

LARGE ROCKS

SMALL ROCKS

OPEN AREA

LARGE ROCKS

SMALL ROCKS

LARGE ROCKS

SMALL ROCKS

LARGE ROCKS

SMALL ROCKS

LARGE ROCKS

SMALL ROCKS

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SMALL ROCKS

LARGE ROCKS

SMALL ROCKS
A3.1
Evapotranspiration Calculation

Food and Agriculture Organization of the United Nations

IRRIGATION WATER MANAGEMENT
Training manual no. 3     Chapter 2: Climate and Crop Growth

BLANEY-CRIDDLE FORMULA:

\[
ETo = \rho \left(0.46 T_{\text{mean}} + 8\right)
\]

*\(ETo\) = Evapotranspiration \(\text{mm/day}\)
*\(\rho\) = Mean Daytime Hours
*\(T_{\text{mean}}\) = Mean Temperature \(\text{°C}\)

Mean Temp Calculation for November through April:

\[
T_{\text{mean}} = \frac{T_{\text{max}} + T_{\text{min}}}{2} = \frac{T_{\text{AprHigh}} + T_{\text{JanLow}}}{2} = \frac{32.8 + 22.4}{2} = 27.6\text{°C}
\]

Mean Daytime Hours Calculation for November through April:

Google Earth Latitude for Angkor \(\approx 13\text{°N}\)
Table 4 of FAO packet for November through April gives:

\(\rho \approx 0.27\)

\(ETo\) Calculation for November through April

\[
ETo = \rho \left(0.46 T_{\text{mean}} + 8\right) = 0.27 \left(0.46 \cdot 27.6 + 8\right) = 5.59
\]

\(ETo = 5.6 \text{ mm/day}\)
A3.2
Water Need for Rice

Food and Agriculture Organization of the United Nations

IRRIGATION WATER MANAGEMENT
Training manual no. 3 Chapter 3: Crop Water Needs

\[ ETo \times Kc = ET \text{ Crop} \]

\[ ETo = \text{Evapotranspiration} \]
\[ Kc = \text{CropFactor} \]
\[ ET \text{ Crop} = \text{Crop Water Need (crop evapotranspiration)} \]

\[ Kc \text{ and } ET \text{ Crop Calculation:} \]

Pg 29, Little Wind, Dry Season gives Rice \( Kc \) values

<table>
<thead>
<tr>
<th>ET Crop Table: Rice</th>
<th>Growth Stages</th>
<th>( Kc )</th>
<th>( ETo \text{ (mm/day)} )</th>
<th>( ET \text{ Crop (mm/day)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Growth</td>
<td>0-60 Day</td>
<td>1.1</td>
<td>5.6</td>
<td>6.16</td>
</tr>
<tr>
<td>Mid Season</td>
<td>60-120 Day</td>
<td>1.2</td>
<td>5.6</td>
<td>6.72</td>
</tr>
<tr>
<td>Final Stage</td>
<td>120-150 Day</td>
<td>1.0</td>
<td>5.6</td>
<td>5.6</td>
</tr>
</tbody>
</table>

Total water needed to grow rice during the dry season in Siem Reap:

\[
\text{Water Need} = 6.16 \frac{\text{mm}}{\text{day}} \cdot 60 \text{ days} + 6.72 \frac{\text{mm}}{\text{day}} \cdot 60 \text{ days} + 5.6 \frac{\text{mm}}{\text{day}} \cdot 30 \text{ days} = 940.8 \text{ mm}
\]

Water Need for Rice = 940.8 mm

\[ \text{NOTE: The water need for rice during the dry season is about } 241 \text{ mm more than if the rice was grown during the wet season} \]
A3.3
Irrigation Water Needed for Rice

Food and Agriculture Organization of the United Nations

IRRIGATION WATER MANAGEMENT
Training manual no. 3 Chapter 4: Irrigation Water Needs

\[ \text{IN} = \text{ET Crop} + \text{SAT} + \text{PERC} + \text{WL} - \text{Pe} \]

\( \text{IN} \) = Irrigation Needed (mm/day)
\( \text{ET Crop} \) = Crop Water Need
\( \text{SAT} \) = Saturation level
\( \text{PERC} \) = Percolation rate
\( \text{WL} \) = Water Level to be Maintained
\( \text{Pe} \) = Effective Precipitation

\( \text{ET Crop} \) As found in “WATER NEED FOR RICE”
Worst case is Mid Season:

\[ \text{ETCrop} = 6.72 \frac{\text{mm}}{\text{day}} \]

\( \text{SAT} \) is given to be 200 mm:

\[ \text{SAT} = 200 \text{mm} \]

\( \text{PERC} \) for sandy soils is given:

\[ \text{PERC} = 8 \frac{\text{mm}}{\text{day}} \]

\( \text{WL} \) is given to be 100 mm:

\[ \text{WL} = 100 \text{mm} \]

\( \text{Pe} \) Calculation is as follows:
Average Precipitation (P) for the 6-month dry season = 30.8 mm/month
P<75 mm/month Therefore use the following equation

\[ \text{Pe} = .6P - 10 = .6 \left( 30.8 \frac{\text{mm}}{\text{month}} \right) - 10 = 8.5 \frac{\text{mm}}{\text{day}} \]

\[ \text{Pe} = 8.5 \frac{\text{mm}}{\text{day}} \]

STORAGE NEEDED FOR INITIAL FIELD FLOOD:
Initial Saturation = \( \text{SAT} + \text{WL} = 200\text{mm} + 100\text{mm} = 300\text{mm} \)

\[ \text{Initial Saturation} = \text{SAT} + \text{WL} = 200\text{mm} + 100\text{mm} = 300\text{mm} \]

PUMPING NEEDS TO WATER FIELDS

\[ \text{PumpNeeds} = \text{ETCrop} + \text{PERC} - \text{Pe} = 6.72 \frac{\text{mm}}{\text{day}} + 8 \frac{\text{mm}}{\text{day}} + 8.5 \frac{\text{mm}}{\text{day}} = 6.22 \frac{\text{mm}}{\text{day}} \]

\[ \text{NOTE: This is about equal to 11.23 GPM/Ha if the pump ran for 24 hours a day} \]
### Appendix A4.1

**Conergy SunCentric**

<table>
<thead>
<tr>
<th></th>
<th>ha</th>
<th>1</th>
<th>10</th>
<th>65</th>
<th>1000</th>
<th>10000</th>
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</thead>
<tbody>
<tr>
<td><strong>Hectares for Agriculture</strong></td>
<td>gpm/ha</td>
<td>13.5</td>
<td>13.5</td>
<td>13.5</td>
<td>13.5</td>
<td>13.5</td>
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<tr>
<td><strong>Flow Rate per Hectare</strong></td>
<td>gpm</td>
<td>13.5</td>
<td>135</td>
<td>877.5</td>
<td>13500</td>
<td>135000</td>
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<tr>
<td><strong>24hr Flow Rate</strong></td>
<td>m³/sec</td>
<td>0.0009</td>
<td>0.008517</td>
<td>0.055362</td>
<td>0.851718</td>
<td>8.517177</td>
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<td><strong>Sunlight Available</strong></td>
<td>hr</td>
<td>8</td>
<td>8</td>
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<tr>
<td><strong>Adj. Flow Rate</strong></td>
<td>gpm</td>
<td>40.5</td>
<td>405</td>
<td>2632.5</td>
<td>40500</td>
<td>405000</td>
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<tr>
<td><strong>Wanted Flow Velocity</strong></td>
<td>m³/sec</td>
<td>0.0026</td>
<td>0.025552</td>
<td>0.166085</td>
<td>2.55153</td>
<td>25.55153</td>
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<td><strong>Necessary Pipe Area</strong></td>
<td>in²</td>
<td>2.60</td>
<td>25.99</td>
<td>168.93</td>
<td>2598.93</td>
<td>2598.93</td>
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<td><strong>Necessary Pipe Diameter</strong></td>
<td>in.</td>
<td>1.82</td>
<td>5.75</td>
<td>14.67</td>
<td>57.52</td>
<td>181.91</td>
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<td><strong>Watts per Pump</strong></td>
<td>W</td>
<td>1100</td>
<td>1100</td>
<td>1100</td>
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<td><strong>Pump Voltage</strong></td>
<td>V</td>
<td>36</td>
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<td><strong>Pump Spacing</strong></td>
<td>km</td>
<td>10</td>
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<td><strong># of Pump Stations</strong></td>
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<tr>
<td><strong># of Pumps @ Each Station</strong></td>
<td>#</td>
<td>1</td>
<td>9</td>
<td>53</td>
<td>811</td>
<td>8101</td>
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<tr>
<td><strong># of Pumps Total (rounded)</strong></td>
<td>#</td>
<td>4</td>
<td>26</td>
<td>160</td>
<td>2432</td>
<td>24302</td>
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<td><strong>Total Watts</strong></td>
<td>W</td>
<td>4400</td>
<td>28600</td>
<td>176000</td>
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<td>26732200</td>
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<td><strong>Average Solar Panel Area</strong></td>
<td>m²</td>
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<td>1.3</td>
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<tr>
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<td>175</td>
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<td><strong>Total Modules Needed</strong></td>
<td>#</td>
<td>36</td>
<td>229</td>
<td>1409</td>
<td>21402</td>
<td>213858</td>
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<tr>
<td><strong>Total Modules Needed (rounded)</strong></td>
<td>#</td>
<td>36</td>
<td>229</td>
<td>1409</td>
<td>21402</td>
<td>213858</td>
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<tr>
<td><strong>Total Area Needed @ Each Station</strong></td>
<td>m²</td>
<td>11.7</td>
<td>103.1</td>
<td>606.8</td>
<td>9278.0</td>
<td>92675.6</td>
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<td><strong>Total Area Needed @ Each Station</strong></td>
<td>ha</td>
<td>0.0012</td>
<td>0.010305</td>
<td>0.060675</td>
<td>0.927801</td>
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<tr>
<td><strong>Total Area Needed</strong></td>
<td>m²</td>
<td>46.8</td>
<td>297.7</td>
<td>1831.7</td>
<td>27822.6</td>
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<td><strong>Total Area Needed</strong></td>
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<td>0.0047</td>
<td>0.02977</td>
<td>0.18317</td>
<td>2.78226</td>
<td>27.80154</td>
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<td>Item Description</td>
<td>Units</td>
<td>Materials</td>
<td>Cost/Unit</td>
<td>Equipment/Unit</td>
<td>Labor Hours/Unit</td>
<td>Labor Cost/Hour</td>
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<td>------------------</td>
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<tr>
<td>Intake- Wooden Frame</td>
<td>L.F.</td>
<td>1.05</td>
<td>0.133</td>
<td>1</td>
<td>2</td>
<td>Carp. 30</td>
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<td>Wire mesh Chicken wire</td>
<td>L.F.</td>
<td>1.19</td>
<td>1.37</td>
<td>0.078</td>
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<td>2</td>
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<td>Chain Link 9 ga. Galvanized</td>
<td>L.F.</td>
<td>7.8</td>
<td>2.33</td>
<td>0.133</td>
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<td>2</td>
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<td>Aggregate various diameter</td>
<td>L.F.</td>
<td>B-21</td>
<td>90</td>
<td>0.0</td>
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<td>PVC pipe 15&quot; diameter</td>
<td>L.F.</td>
<td>11.15</td>
<td>0.83</td>
<td>0.087</td>
<td>4</td>
<td>B-21</td>
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<td>Valves 15&quot; butterfly valve</td>
<td>ea.</td>
<td>1800</td>
<td>79</td>
<td>14</td>
<td>7</td>
<td>Q-22</td>
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<td>Bedding for Pipe Conduit aggregate</td>
<td>.5m</td>
<td>18</td>
<td>5</td>
<td>B-6</td>
<td>69</td>
<td>0.0</td>
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<td>diging a trench Clay, 150'...</td>
<td>C.Y.</td>
<td>6100</td>
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<tr>
<td>Backfill and compaction</td>
<td>Dozer and Roller, 6&quot;-12&quot; lifts</td>
<td>C.Y.</td>
<td>1.38</td>
<td>0.018</td>
<td>9</td>
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**Intake Total**: $876,827.4

**Pump House**

<table>
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<tr>
<th>Item Description</th>
<th>Units</th>
<th>Materials</th>
<th>Cost/Unit</th>
<th>Equipment/Unit</th>
<th>Labor Hours/Unit</th>
<th>Labor Cost/Hour</th>
<th>Hours</th>
<th>Estimated units for Project</th>
<th>Cost</th>
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<tr>
<td>Concrete columns Cast in Place, Min Reinforcing</td>
<td>C.Y.</td>
<td>242</td>
<td>60</td>
<td>16.72</td>
<td>3</td>
<td>Conc-1</td>
<td>60</td>
<td>2675.2</td>
<td>160</td>
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<tr>
<td>Clay Structural brick wall</td>
<td>S.F.</td>
<td>3.68</td>
<td>0.163</td>
<td>8</td>
<td>D-8</td>
<td>125</td>
<td>104.3</td>
<td>640</td>
<td>$15,395.2</td>
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<tr>
<td>Roof deck, laminated 3&quot; thick pine</td>
<td>S.F.</td>
<td>2.83</td>
<td>0.038</td>
<td>1</td>
<td>2</td>
<td>Carp. 30</td>
<td>13.7</td>
<td>360</td>
<td>$1,429.2</td>
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<td>Lumber for roof</td>
<td>L.F.</td>
<td>1.52</td>
<td>0.028</td>
<td>1</td>
<td>2</td>
<td>Carp. 30</td>
<td>4.8</td>
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<td>Frame Walls</td>
<td>L.F.</td>
<td>0.535</td>
<td>17.391</td>
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<td>2</td>
<td>Carp. 30</td>
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<td>$208,906.0</td>
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<td>Monorail 250 lb Capacity</td>
<td>ea.</td>
<td>105</td>
<td>0.381</td>
<td>1</td>
<td>2</td>
<td>Carp. 30</td>
<td>0.4</td>
<td>1</td>
<td>$116.4</td>
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<tr>
<td>Structural Pit Excavation</td>
<td>1 C.Y.</td>
<td>Bucket, Common Earth</td>
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<td></td>
<td>$862.0</td>
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<td>Compaction, Structural Vibratory plate</td>
<td>C.Y.</td>
<td>0.88</td>
<td>0.036</td>
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<td>B-10D</td>
<td>93</td>
<td>1.8</td>
<td>50</td>
<td>$167.4</td>
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**Pump House Total**: $426,509.4

**Pump House X3**: $1,279,528.1

**Pumps**

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Units</th>
<th>Materials</th>
<th>Cost/Unit</th>
<th>Equipment/Unit</th>
<th>Labor Hours/Unit</th>
<th>Labor Cost/Hour</th>
<th>Hours</th>
<th>Estimated units for Project</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumps 25' thru 500' 30 HP</td>
<td>ea.</td>
<td>4650</td>
<td>21.92</td>
<td>7</td>
<td>Q-22</td>
<td>60</td>
<td>43.8</td>
<td>2</td>
<td>$11,930.4</td>
</tr>
<tr>
<td>Solar panels 4'x8' liquid and copper plate</td>
<td>S.F.</td>
<td>545</td>
<td>1.68</td>
<td>1</td>
<td>2</td>
<td>Carp. 30</td>
<td>0.0</td>
<td></td>
<td>$0.0</td>
</tr>
</tbody>
</table>

**Pump Total**: $11,930.4

**Pumps X3**: $35,791.2

**Routing**

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Units</th>
<th>Materials</th>
<th>Cost/Unit</th>
<th>Equipment/Unit</th>
<th>Labor Hours/Unit</th>
<th>Labor Cost/Hour</th>
<th>Hours</th>
<th>Estimated units for Project</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC Pipe 15&quot;</td>
<td>L.F.</td>
<td>11.15</td>
<td>0.83</td>
<td>0.087</td>
<td>4</td>
<td>B-21</td>
<td>90</td>
<td>8073.6</td>
<td>92800</td>
</tr>
<tr>
<td>Valves 15&quot; butterfly valve</td>
<td>ea.</td>
<td>1800</td>
<td>79</td>
<td>14</td>
<td>4</td>
<td>B-21</td>
<td>90</td>
<td>70.0</td>
<td>5</td>
</tr>
<tr>
<td>Labor including digging a trench Common Earth</td>
<td>150'...</td>
<td>C.Y.</td>
<td>0.06</td>
<td>6</td>
<td>B-12K</td>
<td>52</td>
<td>15660.0</td>
<td>261000</td>
<td>$814,320.0</td>
</tr>
<tr>
<td>Compaction Dozer and Roller, 6&quot;-12&quot; lifts</td>
<td>C.Y.</td>
<td>1.38</td>
<td>0.019</td>
<td>9</td>
<td>B-10D</td>
<td>93</td>
<td>4959.0</td>
<td>261000</td>
<td>$461,187.0</td>
</tr>
</tbody>
</table>

**Routing Total**: $3,052,151.0

**Storage**

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Units</th>
<th>Materials</th>
<th>Cost/Unit</th>
<th>Equipment/Unit</th>
<th>Labor Hours/Unit</th>
<th>Labor Cost/Hour</th>
<th>Hours</th>
<th>Estimated units for Project</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor to dig the pond 100'x200'x15'</td>
<td>C.Y.</td>
<td>3.72</td>
<td>0.044</td>
<td>4</td>
<td>B-21</td>
<td>90</td>
<td>396.0</td>
<td>9000</td>
<td>$35,640.0</td>
</tr>
<tr>
<td>transport clay from the lake to line for 100 x 200 pond (plastic fabric) 3 ply membrane felt</td>
<td>S.F.</td>
<td>0.47</td>
<td>0.14</td>
<td>0.027</td>
<td>1</td>
<td>2</td>
<td>Carp. 30</td>
<td>553.5</td>
<td>20500</td>
</tr>
</tbody>
</table>

**Storage Total**: $63,110.0

**Total**: $5,307,407.8

**Contingency 15.0%**: $6,103,519.0
### A5.2
Estimated Work Crew Wages

<table>
<thead>
<tr>
<th>Reference Number</th>
<th>Type</th>
<th>People and Equipment</th>
<th>Average wage/hr</th>
<th>Total pay per hour to use the crew</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 Carp.</td>
<td>2</td>
<td>15</td>
<td>30</td>
<td>2 Carpenters with Equipment</td>
</tr>
<tr>
<td>2</td>
<td>Const. Crew</td>
<td>4</td>
<td>30</td>
<td>120</td>
<td>Sample Construction Crew</td>
</tr>
<tr>
<td>3</td>
<td>Conc-1</td>
<td>2</td>
<td>30</td>
<td>60</td>
<td>2 Concrete Workers</td>
</tr>
<tr>
<td>4</td>
<td>B-21</td>
<td>3</td>
<td>30</td>
<td>90</td>
<td>Forman, Skilled Worker, Laborer</td>
</tr>
<tr>
<td>5</td>
<td>B-6</td>
<td>3</td>
<td>23</td>
<td>69</td>
<td>2 Laborers, Equipment</td>
</tr>
<tr>
<td>6</td>
<td>B-12K</td>
<td>2</td>
<td>26</td>
<td>52</td>
<td>Crain Operator and Oilier</td>
</tr>
<tr>
<td>7</td>
<td>Q-22</td>
<td>2</td>
<td>30</td>
<td>60</td>
<td>Plumber and Apprentice</td>
</tr>
<tr>
<td>8</td>
<td>D-8</td>
<td>5</td>
<td>25</td>
<td>125</td>
<td>3 Brick Layers, 2 Helpers</td>
</tr>
<tr>
<td>9</td>
<td>B-10D</td>
<td>3</td>
<td>31</td>
<td>93</td>
<td>Dozer, Roller, Driver, Laborer</td>
</tr>
<tr>
<td>10</td>
<td>B-34C</td>
<td>1</td>
<td>30</td>
<td>30</td>
<td>Driver, Truck</td>
</tr>
</tbody>
</table>