Design and Construction of a Novel Water Play Structure To Control Schistosomiasis in Rural Ghana

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CEE 81 Capstone Design Project
Final Report

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Kwabeng, Ghana has experienced increased rates of urinary schistosomiasis (*Schistosoma haematobium*) since the onset of surface gold mining activities in the early 1990s (Bonci et al, 2006). The mining has hydraulically altered the Awusu River and thereby created habitats favorable to intermediate host *Bulinus* snails. Schistosomiasis is a common parasitic disease in tropical areas. The symptoms of the disease include bladder infections, haematuria, and anemia (WHO 2007). Children in Kwabeng contract schistosomiasis by playing in and collecting water from the Awusu River, which contains high levels of the flatworms that cause the disease.

Our task was to choose and design an appropriate engineering intervention to make an impact on the incidence of schistosomiasis in Kwabeng, Ghana. Using data collection from health and community surveys as well as a feasibility study performed by members of the 2004 Capstone group, the most appropriate engineering intervention was found to be a water recreation area (WRA). Our project focuses on the design and construction of the WRA to reduce the incidence and severity of schistosomiasis in children in this rural Ghanaian community. We hypothesize that our proposed play area will minimize children’s exposure to the Awusu River, in which snails of the genus *Bulinus* serve as intermediate hosts.

This paper details the design of a swimming pool to specification and the selection of supplementary technologies to allow implementation of the WRA in Kwabeng for the summer of 2007. Additional considerations include design challenges such as behavior change and site limitations. Additionally, there is discussion and quantitative comparison of the multiple pumping technologies available, as well as figures and description of our preliminary designs to date. We have created several designs, all of which incorporate a wading pool, a water collection area, and a play area with a merry-go-round (MGR). Our final design will use clean, sustainable technology to draw groundwater from the subsurface and pump it into a storage tank which will serve to fill the proposed wading pool. Water will also be available for water collection by community members via a tap. One of our primary goals is to oversee the construction of the WRA by traveling to Kwabeng this summer.
1.0 INTRODUCTION

1.1 Project Definition

The purpose of this Capstone project was to design an intervention to reduce infection rates of Schistosomiasis in Kwabeng, Ghana by reducing children’s exposure to the source of the disease – the Awusu River. We plan on building a Water Recreation Area (WRA) to deter children from spending excess time in the river. If the implantation of our structure is successful, it may serve as a model for other communities in other regions in West Africa where Schistosomiasis is a growing concern.

1.2 Scope

Schistosomiasis, also known as Bilharzia, is a cyclic water-born disease that affects approximately 200 million people world-wide, roughly 80% of whom live in Africa. It is a parasitic disease that causes bladder infections, bloody urine, and anemia in infected individuals.

For our project, we are focusing on controlling Schistosomiasis in Kwabeng, Ghana – a small community of about 5,000 people. Kwabeng has a high number of infected individuals, most of who are between five and twelve years old. The main exposure point for Schistosomiasis is the Awusu River which is inhabited by the Bulinus snail, an intermediate host for the disease. The snails release cercariae (free-swimming organisms) into the river. Anyone who is in the river is at risk for contracting Schistosomiasis because the cercariae can penetrate skin, usually through the feet. Women collect water from the river and children recreate in the river, making these two populations most at risk for contracting Schistosomiasis.

1.3 Introduction to 2007 Capstone Project

Members of the Tufts Civil and Environmental Engineering department have been working to control the problem of Schistosomiasis in Kwabeng since 2004. A Capstone group of Tufts undergraduates in 2004 traveled to Kwabeng to gather preliminary data and make recommendations regarding a wide variety of possible interventions (Caldwell
et al.). Charlene Han, a Master’s student in the Civil and Environmental Engineering department, performed an epidemiologic study in 2005 to examine the prevalence of Schistosomiasis in the community (Han, 2005). A 2006 Capstone group of Tufts undergraduate students traveled to Kwabeng and collected additional data regarding incidence rates of Schistosomiasis. They made recommendations for plans of actions for water distribution and well systems, as well as recommendations for improvements for snail sampling, cercariometry, and epidemiologic techniques (Bonci et al, 2006). With the research provided by previous Tufts faculty and students, we have designed a Water Recreation Area (WRA) to specification to be implemented in Kwabeng, Ghana over the summer of 2007. The main attributes of the WRA will be a pool area, a water storage tank, and a merry-go-round (MGR) pump that will be able to extract enough groundwater to fill the pool.

### 1.4 Individual Responsibilities

Our design team consists of four undergraduate students (Alaina McGillivray, Jessica Pransky, Jesus Sanchez, and Andrew Swanton), who are being advised by Professors John Durant and David Gute, and Ph.D. candidate Karen Kosinski. For her doctoral thesis, Ms. Kosinski is studying the public health aspects of our WRA and will be spending the summer of 2007 in Kwabeng to monitor the incidence rates of Schistosomiasis after the implementation of the WRA.

As a team, the four undergraduate students have fundraised, selected the appropriate engineering intervention, performed cost analyses, and created the design for the structure. Alaina and Andrew created renderings of the WRA using the software program SketchUp. Jessica and Jesus researched various pumping technologies and decided on the most feasible pumping technologies. Jesus created a model of the daily pumping and drainage schedule using Microsoft Excel. Alaina and Jessica have gotten pricing costs and estimates from engineers and contractors. Andrew used a Structural Analysis program (SAP) to determine the loads exerted on the pool and AutoCAD to draw the pool to specification.

### 2.0 OBJECTIVES

The goal of our engineering intervention is to design to specification a WRA to
reduce the incidence rates of Schistosomiasis in children ages five through twelve in Kwabeng. Our objectives were to make the WRA appealing to children, to design the pool to specification, to select the most appropriate pumping technology, to design a drainage infrastructure, and to minimize the cost of the project.

We believe that the best way to divert children from recreating in the Awusu River is to create an alternative play area. As a result, our WRA needs to attract our target population of children ages five through twelve. In our design of the WRA, we combine the appealing aspects of playing in water with the novelty of a built merry-go-round structure to ensure that our design will effectively divert children from playing in the Awusu River. We want design our structure to have a low ecological impact on the community of Kwabeng while still improving the health and quality of life of local children. Our design will therefore include a groundwater pump, a play pool with a depth similar to that of the Awusu River, and a tap for domestic water collection. The play pool will be fed with groundwater that is serviced via a pump.

Construction of the WRA will begin during the summer of 2007. For construction to occur at its proposed start date, it is imperative that we design our WRA to specification by May 2007 so we can begin ordering materials and creating a construction team. This requires selecting a pumping technology to extract groundwater at a rate fast enough to fill the pool and determining a way to drain and clean the pool for sanitation reasons.

In designing the WRA, we tried to minimize the total cost of our project while maximizing the ease of construction. We want to optimize these parameters to be able to construct the WRA in Kwabeng this summer using our existing funds and to make our project in Kwabeng a model for future WRAs to be built in sub-Saharan Africa where Schistosomiasis rates are disproportionately high.
3.0 METHODOLOGY

3.1 Evaluation of Decision Matrix

To determine that a Water Recreation Area (WRA) would be the most practical design solution for mitigating Schistosomiasis in Kwabeng, we evaluated the decision matrix developed by the 2004 capstone group. This group developed various methods to control Schistosomiasis in Kwabeng, and concluded that there were 19 different that could be implemented. We hypothesized that the four most successful interventions would be providing free Schistosomiasis screening and drug treatment, restoring flow or modifying flow to the Awusu River, implementing a town-wide education campaign, and constructing a water recreation area (WRA) that incorporates additional interventions. We believe that a WRA will be the most effective and feasible intervention.

Providing free monthly Schistosomiasis screening for residents of Kwabeng and free drug treatment to individuals who test positive for Schistosomiasis requires continual assistance from trained personnel and a partnership with the local health clinic to restock the supply of treatment drugs. This method requires participation from the entire community to be successful, and appears to be more of a temporary answer than a permanent solution to controlling Schistosomiasis.

We reviewed restoring or modifying the flow of the Awusu River. Increasing the river velocity by restoring flow to the river would likely reduce the Bulinus Africanus snail population and thus reduce the intermediate host. It would also restore the natural hydrology of Kwabeng. However, this intervention would be costly and politically controversial because of land ownership rights between Kwabeng and the gold mining company.

A town-wide education campaign in Kwabeng would focus on educating children and adults about ways to prevent Schistosomiasis. During their trip to Kwabeng, the 2006 Capstone group began an education campaign which taught children to minimize their time in the Awusu River and to not urinate or defecate in the river. For this education campaign to be successful independently, a behavioral change would be required from all members of the community. We believe that, although an education campaign is not a
sole intervention to controlling Schistosomiasis, it should be incorporated into an alternative intervention.

We intend to build a WRA to draw children away from the Awusu River. The main component of this intervention is the construction of a pool that will be fed by groundwater. This structure will include a storage tank to retain excess groundwater and a merry-go-round (MGR) pump to draw groundwater. We believe that this design is feasible and will help to control the spread of Schistosomiasis in Kwabeng. We plan to continue the education campaign started by the 2006 Capstone group to emphasize the importance of using the WRA to residents of Kwabeng.

3.2 Pumping Technologies

3.2.1 Pumping Technologies Overview

The depth of the groundwater table in Kwabeng ranges from 35 to 55 meters (Bonci et al). To efficiently extract this water, we researched solar, wind, hand, electric, and (MGR) pumping technologies. Solar pumps are powered by solar radiation, making this a sustainable technology with a low operation cost. However, solar panels are expensive, and the panels are highly susceptible to theft. Wind powered pumping technology incorporates the use of a windmill to transfer wind energy into useable energy. Wind powered pumps are sustainable but unreliable because wind patterns in Kwabeng are unpredictable. Although solar and wind pumps are sustainable methods of pumping groundwater, they are not ideal for use in Kwabeng.

3.2.2 Hand pumps

Hand pumps are already used in Kwabeng for water taps, but are labor intensive and require constant maintenance. The three types of hand pumps we evaluated are direct action pumps, the AFRIDEV pump, and the India Mark II pump. Direct action pumps require a low level of maintenance and are relatively inexpensive. However, each pump only serves 200 – 300 residents and cannot draw groundwater from depths greater than 15 feet, making it unsuitable for our needs. The AFRIDEV and India Mark II pumps can
draw groundwater from depths of up to 45 feet and are relatively inexpensive. Assuming constant use, these pumps can only pump groundwater at rates of 990 and 900 L/hr respectively, which is not enough to service our WRA.

3.2.3 Electric Pumps

Electric pumps can pump groundwater at a rate of 1800 L/hr; they are reliable and require little maintenance. The two types of electric pumps we evaluated were submersible and vertical jet pumps. Submersible pumps have a flow rate of up to 2300 L/hr while vertical jet pumps have a maximum flow rate of about 1800 L/hr. However, vertical jet pumps are designed for limited-space areas and can extract groundwater from depths up to 100 m (Grainger). Although vertical jet pumps are expensive and require a dependable supply of electricity, we plan to install one to be used in conjunction with an MGR pump.

3.2.4 MGR Pumps

MGR a technology patented by Roundabout Outdoor (a private design company) and distributed by Play Pumps International, a Non-Governmental Organization located in South Africa. As children play on the platform attached to the MGR pump, a rotational force is generated which can pump groundwater at a rate of 1400 L/hr. Unfortunately, Play Pumps International does not plan on implementing this technology in Ghana until 2010. Karen Kosinski has contacted Play Pumps International to determine whether we can receive and implement their technology in Kwabeng. A comparison of hand, electric, and MGR pumping technologies can be seen in Table 3.1.

Table 3.1 Quantitative Comparison of Pumping Technologies

<table>
<thead>
<tr>
<th>Pumping Technology</th>
<th>Maximum Pumping Rate (L/hr)</th>
<th>Cost (US Dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand (AOV International)</td>
<td>1000</td>
<td>100</td>
</tr>
<tr>
<td>Electric (Cotruvo et al)</td>
<td>1800</td>
<td>400-800</td>
</tr>
<tr>
<td>Merry-go-round (Pump and Play International)</td>
<td>1400</td>
<td>6700</td>
</tr>
</tbody>
</table>
3.3 Design Process

3.3.1 Overview of Design

A play pool will be the main attraction of the WRA because it will allow children to submerge themselves in flowing water. A typical design for our project will consist of three main components; a pool, a pumping system, and a storage tank. A water storage tank is needed to provide water to the pool as needed and to store excess groundwater. We anticipate draining the pool every two days to prevent poor water quality and to maintain sanitary conditions. A pool operator will drain the pool four times a week, and will scrub the pool with a chlorine solution to prevent bacteria and algae from living in the WRA. The operator will also drain the pool if conditions arise that pose an immediate threat to children’s’ health, such as blood, feces, or snails in the pool. We will provide the residents of Kwabeng with a users’ manual to ensure proper use and maintenance of the WRA.

3.3.2 Design Software

We compiled a set of three drawings of our proposed play structure using the rendering program SketchUp. These drawings were shown to Dr. Aboagye, a surgeon at Massachusetts General Hospital who lives in Kwabeng and visited the community in late April, 2007. Dr. Aboayge provided feedback about the needs and desires of the community, and we adjusted our renderings accordingly to create our final design.

We developed a model in Microsoft Excel for the drainage schedule of the pool and the times the electric pump will be in use. This model estimates the amount of water in the pool at any time during the day by using a random function to predict the amount of time children will spend using the MGR pump each day. Using a Structural Analysis Program (SAP), we calculated the amount of concrete, gravel, and rebar needed for the foundation of the pool. We designed our pool to specification using AutoCAD.

3.4 Fundraising
The two previous capstone groups working on this project fundraised approximately $18,000 for the WRA. We conducted additional fundraising to provide the best available technology for the WRA and to enable every member of our design team to travel to Kwabeng to oversee the implementation of the WRA. We applied to and received a $3000 undergraduate grant from the Tufts Institute of the Environment (TIE); Karen Kosinski applied for a $5000 graduate grant from TIE, and also received the full amount. In addition, we applied for a grant from the Dean’s Discretionary Fund which has been established by Dean Linda Abriola for undergraduate research. We received $5000 from this fund, bringing our total resources up to $26,000. Applications to the TIE grant and to the Dean’s Discretionary Fun are included in the Appendix.
4.0 STRUCTURAL DESIGN

4.1 Foundation

The first consideration in terms of pool design was to address the type of foundation on which the pool would be built. Since the pool is to be constructed out of concrete, and then filled with water to service recreating children, two important aspects to account for were foundation settlement and concrete cracking.

4.1.1 Settlement

Settlement is a structural consideration at any potential site in Kwabeng due to the nature of the soil. Prior visits by Tufts University students and professors indicate that the soil is composed primarily of alluvial outwash, with a high propensity for settling. As a result, it was determined that compaction of the existing soil, as well as the installation of an additional gravel layer would be required. It is presently unclear the means by which compaction is completed in Ghana, but if mechanical compaction is not a common practice, manual compaction is a feasible alternative. Above the compacted soil layer, 0.3m of gravel is to be placed along the base of the foundation, as well as along the sides of the walls, which will facilitate structural stability and maintenance. A gravel foundation reduces settlement and provides a medium for drainage so that groundwater pressure will not exert additional forces on the structure (Monnet 2002).

4.1.2 Cracking

The inclusion of the above procedures will reduce the likelihood that the concrete will undergo extensive cracking. As soon as a substantial load is placed on the concrete slab it will begin to bend, and there will be areas that experience tension. Since concrete can only withstand compressive loads, the member will crack in these areas of tension. If the soil beneath the structure begins to settle along the foundation, extensive cracking will occur and the concrete member will fail. If installed appropriately, the compacted soil and gravel layers will reduce settlement and thus decrease concrete cracking to an acceptable level, which will lead to successful construction.
4.2 Pool design

Pool dimensions were determined after proposal and consideration of various alternative designs. All preliminary designs include multiple depths to accommodate the varying height and preference of children. Multiple depths allow the structure to service young children as well as older children who may want to submerge themselves in the pool.

Initially, the 3D modeling software Google Sketchup™ was used to generate conceptual designs of what the pool might look like:

![Figure 4.1 Asymmetrical Pool Design](image)

The aesthetic in Figure 4.1 is an advantage to this pool design. Visual appeal is important in the design as this structure will only be effective at reducing Schistosomiasis if it appeals to children. A limitation of this design concerns the ease of construction. While the curvature of the pool walls is appealing, it is unclear whether the construction of a pool as shown in Figure 4.1 can actually be done in Kwabeng. Lack of availability of irregularly shaped concrete casts and additional construction time will complicate installation and increase cost. Figure 4.2 incorporates a simpler wall design for ease of construction.
Figure 4.3 builds on the successful design aspects of the above figures. The pool dimensions indicate that the deepest portion of the pool is only 3 ft, which is important in the attempt to mimic the conditions present in the Awusu River, and as a safety precaution for the small children that will be using the pool. Additionally, this design seems simple in terms of construction. The walls are straight, and the bottom is only partially sloped. However, a few drawbacks of this design include the potential discomfort associated with such a large percentage of the pool bottom being sloped, and the intensity of the change in gradient. Since there is no way of knowing the construction
methods available in Kwabeng, a simpler interior pool design was determined for the final design (Figure 4.4).

![Figure 4.4 Qualitative Final Design](image)

This design has a number of advantages. Firstly, construction is simplified by the rectangular shape and shallow sloping bottom. Additionally, the varying depths will service a wider age-range of children. The dimensions of the final design were selected based upon the amount of water provided by individual pumps described in Section 3.2. Based upon the selection of these pumping technologies and the corresponding hours of operation, it was determined that a pool volume in the range of 15-20 cubic meters seemed reasonable.

### 4.3 Interior Pool Dimensions

Dimensions specified in this section are those of the interior of the pool. Exterior dimensions include the 0.3m width of the walls. The rectangular pool shown in Figure x.4 was chosen with a length of 7m and a width of 4m. The shallow region of the pool was chosen to have a length of 2.5m and a depth of 0.45m to suit smaller children. The sloped portion of the pool was chosen to have a linear drop in depth of 0.3m and a length 2m to prevent a sharp change in gradient. Lastly, the deep portion of the pool was chosen to have a depth of 0.75m and a length of 2.5m. Using these dimensions, the pool will
have a volume of 16.8 cubic meters.

### 4.4 Concrete and Rebar Analysis in SAP

Using the internal dimensions described above and a given thickness of the concrete, the amount of required steel reinforcement was calculated. A practical concrete thickness of 0.3m was designed for. In order to calculate the area and extent of steel reinforcement required, it is necessary to determine the magnitude and location of moments in the concrete structure. In order to do this, a structural analysis program (SAP) was used. Using a side view of the structure is conservative as the moment will change with varying depth of the structure. The maximum moment can be modeled on an axial cross-section, whereas a cross-section along the width will only provide the moment at one depth in the pool.

![Axial Cross Section](image)

**Figure 4.5 Axial Cross Section**

Structural analysis in SAP is performed on a representative frame which demonstrates the behavior of the concrete walls and base shown above. The frame was modeled using the dimensions of a centerline which would run through the section in Figure 4.5.
The dimensions of this frame were used as an input to SAP with the following coordinates:

<table>
<thead>
<tr>
<th>X</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2.628</td>
<td>0.3</td>
</tr>
<tr>
<td>4.628</td>
<td>0.9</td>
</tr>
<tr>
<td>7.3</td>
<td></td>
</tr>
</tbody>
</table>

The x-axis is horizontal distance, and the z-axis is the vertical distance in Figure 4.6.

**4.4.1 Distributed Loads Applied to Representative Frame**

The next input to SAP required the evaluation of different loadings on the representative frame. In order to this, a tributary depth (i.e. given width in and out of the page of Figure 4.6) of 0.3m was used for ease of analysis. The base slab experiences the following distributed gravitational forces:

- Self-weight of base slab
- Weight of pool water
• Weight of children in the pool

In estimating the load contribution of the weight of the children on the base, the following assumptions were made:

1. Maximum pool capacity of 250 children
2. Each child weighs 50 kg
3. Total weight averaged over the area as a distributed load

The first two assumptions are conservative since the first allows for the presence of nine children per square meter. It is unlikely that there will ever be this many children in the pool as the physical restriction could cause discomfort. The second point is an over assumption because individuals in the target population actually weigh much less than 50kg due to their age and the frequency of malnutrition in the children of Kwabeng.

4.4.2 Point Loads

The following point forces were also applied in the analysis:

• Weight of walls on base slab
• Upward force of gravel on base slab
• Lateral load due to gravel on walls

The force of gravel on the base slab was modeled as springs in the structural analysis program. A coefficient of friction (k₀) for the gravel underlying the structure was assumed to be $1.25 \times 10^7$ kg/m$^3$ (4). Essentially, the frame in Figure 4.6 was broken into a number of different segments:

• 10 segments in the 0.45m depth section
• 8 segments along the sloped section
• 10 segments in the 0.75m depth section

SAP then analyzed the frame as though springs were between each of the 28 segments. These springs were given reaction coefficients ($k_s$) expressed in Equation 4.1.

$$k_s = (1.25 \times 10^7 \text{ kg/m}^3) \times T \times D \quad Equation \ 4.1$$

where $T$ is the tributary width of each spring, and $D$ is the tributary depth of the frame being analyzed (0.3m).

Having accounted for all of the distributed and point loads on the base slab, the next step was to calculate the horizontal pressure on the walls due to the gravel. A soil friction angle of 44.2° (Monnet 2002) was used to calculate the passive pressure coefficient with the following formula:

$$k_p = \frac{1 + \sin \theta}{1 - \sin \theta} \quad Equation \ 4.2$$

where $\theta$ is equal to the friction angle described above. This pressure coefficient was then multiplied by the density of the gravel (14930.82N/m$^3$ (Walker 2006)), the height of the frame on the left and right side, and the tributary depth of 0.3m. Since this structure will not be close to the water table, there is no pore water pressure (conservative). The Microsoft Excel load calculations are location in (APPENDIX WHAT?)

4.4.3 SAP Results

All of the loads were then placed on the frame described in Figure 4.6 and input to SAP:
Figure 4.7 SAP Spring Analysis modeling upward force of gravel on the bottom slab

After running the SAP analysis, the calculated moments were depicted in Figure 4.8.

![Figure 4.8 SAP Moment Results](image)

There are a number of conclusions which can be drawn from this figure. Since both walls are bending outwards, reinforcement is only required at the furthest extents of the walls. In the base slab, the bottom portion of the slab is in tension at the sides, but the top portion of the slab is in tension in the middle. This means that reinforcement needs to be placed accordingly. Additionally, the maximum moment occurs at the bottom of the right wall, as well as the right-most portion of the base slab.

### 4.4.4 Reinforcement Selection

A welded-wire fabric was chosen as the optimal type of reinforcement (3). For design, the maximum moment was used, and a corresponding area of steel was determined for the entire structure. For the 0.3m thickness structure in Figure 4.6, an area of steel of 0.0000419 m² per meter of length is required. It should be noted that many portions of this structure will subsequently be over-designed in terms of reinforcement. However, instead of using a number of different reinforcement specifications, for ease of construction, the same welded-wire fabric will be used throughout the entire structure.

### 4.5 Optimizing Cost

The most important consideration for the concrete and reinforcement portion of
the design was to choose a design which would minimize cost. This project is hopefully one which will be successful at reducing Schistosomiasis, and will thus be replicated in other communities world-wide with a high prevalence of the disease. Therefore, it was important for our design to be as affordable as possible. As a result, it was important to determine concrete and rebar specifications which would be both structurally practical but also inexpensive.

In order to do this, in addition to the 0.3m thickness design explained in Section 4.4, the structure was designed for 0.1m, 0.2m, and 0.4m concrete thicknesses. Table 4.2 displays the corresponding areas of steel required:

Table 4.2 Area of Steel for varying concrete thickness

<table>
<thead>
<tr>
<th>Thickness (m)</th>
<th>As (m² per m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.00117</td>
</tr>
<tr>
<td>0.2</td>
<td>0.00024</td>
</tr>
<tr>
<td>0.3</td>
<td>0.00014</td>
</tr>
<tr>
<td>0.4</td>
<td>0.00010</td>
</tr>
</tbody>
</table>

PhD candidate Karen Kosinski of Tufts University used this data to plot a curve relating the concrete thickness chosen with the area of steel required:
She then used the above relationship to determine what the optimal relationship between concrete thickness and steel reinforcement was with respect to cost. From this analysis, she determined that the least expensive option was actually a concrete slab with a thickness slightly greater than 0.1m. However, in the United States, 3” of concrete cover is required for rebar between the center-line of the rebar and the base of a slab for any foundational slab of concrete (Iretom 2003). Therefore, a constraint on the design was that it must be equal to or greater than 6” (3” of cover for the rebar in either direction). Additionally, United States construction code requires 1.5” of cover for the walls (Iretom 2003). Due to these factors, it was decided that the optimal concrete thickness for this project was 0.15m (roughly 6”). Using this value and the equation for the best-fit line in Figure 4.9, a corresponding area of steel (As) was determined to be 0.0003967 m² per meter of length. Because this structure is being designed to United States rebar specifications, this value was converted to 0.202 in² per ft.
A welded-wire fabric with sufficient area of steel was selected from Table A.3(B) from *Design of Reinforced Concrete* by Jack McCormac and James Nelson. W11 x W11 bars were selected at 6” center-to-center spacing, which provides an area of steel of 0.22 in² per ft.

### 4.6 Drawings

Using the internal dimensions, concrete thickness, and area of steel the final drawings were rendered in Autodesk’s Inventor 11. Figure 4.10 includes an isometric view of the final design. The pool is also fully dimensioned on a mm scale as appears in Figure 4.11.
Complete renderings and dimensions appear in Appendix.

### 4.7 Future Considerations for Implementation

Pool contractors have suggested that the walls of the pool be thicker. According to the structural design detailed in Section 4.4, the pool is fully reinforced for the thickness chosen and cracking will not be an issue. However, for implementation it may be important to increase the thickness of the walls to 10”. If this is done, reinforcing may not be required for the walls of the pool, but further analysis should be done to ensure this.

Additionally, because the rebar required for reinforcement is larger than typical welded-wire fabric manufactured in the United States, one suggestion is to not use welded-wire fabric at all. Rather, individual reinforcing rebar should be purchased and brought to the site. This rebar should then be tied together on site at the same center-to-center spacing with the same bar size prior to the pouring of the concrete. One last note is that if welded-wire fabric is not used during implementation, additional calculations
should be performed to assess if spacing can be reduced in the shallow end of the pool to a value of 12” as opposed to 6” to reduce cost.

4.8 Cost

We tried to minimize the cost of the WRA by using low-cost materials and construction methods in designing our pool. For example, we chose to apply a pour-concrete base instead of a gunite (spray concrete) base to save over $8,000 in construction costs. We also chose to couple an electric pump with the MGR pump to minimize the cost of electricity to the community.

We estimate that the cost of materials for this project is approximately $14,000, pending the rights to use the MGR structure from Play Pumps International. This structure – which costs about $6,700 – includes the cost of the MGR pump and the water storage tank. All of the prices used were calculated to United States pricing, as those were the only unit costs available. To account for this variation, a 25% contingency was added to the final cost of the project. A table detailing the individual costs is displayed below:

<table>
<thead>
<tr>
<th>Item</th>
<th>Total Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compaction</td>
<td>80</td>
</tr>
<tr>
<td>Concrete</td>
<td>990</td>
</tr>
<tr>
<td>Electric Pump</td>
<td>800</td>
</tr>
<tr>
<td>Excavation</td>
<td>980</td>
</tr>
<tr>
<td>Gravel</td>
<td>130</td>
</tr>
<tr>
<td>MGR Pump &amp; Tank</td>
<td>6700</td>
</tr>
<tr>
<td>Rebar (black)</td>
<td>330</td>
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<tr>
<td>Waterproofing</td>
<td>1100</td>
</tr>
<tr>
<td><strong>Raw Total</strong></td>
<td><strong>11,000</strong></td>
</tr>
<tr>
<td><strong>Total + 25% Contingency</strong></td>
<td><strong>14,000</strong></td>
</tr>
</tbody>
</table>

This cost does not include the cost to run the electric pump or the cost to hire
someone to perform operation and maintenance on the pool. For a detailed description as to how these costs were estimated see the Appendix.


5.0 PUMPING TECHNOLOGY

5.1 Selection of Groundwater Pumps

The pool designed for the WRA requires a reliable and sustainable source of water in order to be filled on a periodical basis. Because there is a high demand of water to initially fill the pool and lower demand there after, the pumping system installed must be able to provide a pumping rate that can be adjusted throughout the day. These criteria led to the selection of pumping system that operates by coupling two pumps: electric and MGR pumps. This parallel water supply system provides the groundwater required to fill the pool based on the proposed operation and maintenance schedule.

5.1.1 Function of Electric Pump

An electric pump will provide a reliable pumping mechanism and a high pumping rate (1.8 m$^3$/hr). However, due to the operation cost of electricity and the uncertainty of hourly electricity availability in Kwabeng, the electric pump will only be used to fill the pool to about 60% full, when empty. The pool is expected to be empty in the early-mornings when the pool is being cleaned according to the operation and maintenance schedule.

5.1.2 Function of MGR Pump

Operating in parallel will be a MGR pump that will operate variably at a lesser pumping rate than the electric pump. The MGR pump operates variably because the pump only extracts water from the well when children play on the structure. Because the operation of the MGR is variable, this pump will supply the amount of water required to finish filling the pool alongside the electric pump. Once the pool is completely filled, the pool manager will redirect the inflow to the storage tank for community use.

By combining electric and MGR pumping technologies, the pumping system will provide the ground water required to fill the pool at the required rate. In addition, this
combination of technologies will provide the community families with water, while using less of their children’s time and labor.

5.2 Analysis of the Change in Pool Volume over Time

In order to ensure that the pumping system will supply the amount of water necessary to fill the pool an excel model was built to simulate the volume of water in the pool as a function of time. The model operates under three parameters:

- Variability of play on the MGR
- Maximum variable inflow to the pool from the MGR pump (0.7 hr of variable operation per hr)
- Proposed operation and maintenance schedule

Figure 5.1 is a graph of the pumping system’s operation and the change in volume of the pool over a period of one day.
The Electric Pump will operate from 9AM to 1PM on Monday, Wednesday, Friday, and Saturday.

Figure 5.1 Percentage of pool full for throughout the day

The graph above shows the pumping system operating on the day after the pool has been drained and cleaned. The following is a detailed explanation of the processes occurring over the period of the day:

- The pool is empty at the beginning of the day.
- Model Assumption: Children play on the MGR variably between sunrise and sunset (i.e. 5AM – 5PM); therefore, the MGR pump will operate variably between these hours.
- Model Assumption: The electric pump will operate according to the operation and maintenance schedule, 9AM – 1PM.
- Between 5AM – 9AM the volume of water in the pool increases slowly at a variable rate.
- The rate of inflow greatly increases when the electric pump is operating. The small increases in pumping rate during the electric pump operation period are the contributions being made by the MGR pump.
- After 1PM the MGR continues to be used until sunset.

The graph in Figure 5.2 below demonstrates the pool model operating over the period of one week. This simulation exemplifies the characteristics of the operation and maintenance schedule’s drainage periods.
Figure 5.2 Percentage of pool full with pumping and draining over the course of a week

The simulation in Figure 5.2 shows the fluctuation in pool volume throughout the course of one week. Assuming the previous image was a Monday, one can see how the volume of the pool stays the same over the night and slowly increases throughout the next day when the children play on the MGR. On Tuesday evening, the pool manager will drain the pool and the pool will be empty by next morning. This cycle appears twice more in the week with the exception of the Friday schedule. Because the model assumes that the pool manager will only be working Monday through Friday, the pool gets filled and drained on Friday to prevent the pool from being too dirty over the weekend. The model starts over on Sunday night/ Monday morning.

5.3 Drainage Area Analysis

Since the pool will be visited by many children throughout the course of a day, the pool must be cleaned frequently. The design team researched the feasibility of a pool filtration system but the cost associated with the technology, and its social acceptability, seemed outside the scope of this project. By cleaning the pool frequently the pool will be less susceptible to algae growth, the pool will be less likely be a source of infection or disease, and be more aesthetically pleasing to its occupants.

In order to ensure that the pool can be drained according to the operation and maintenance schedule, the drainage period must satisfy two conditions: (1) The drainage period must be shorter than the time between initial drainage and cleaning, approximately 10 hour; (2) the drainage period must short enough to allow the pool manager to drain
and clean the pool in case of an emergency (i.e. a situation where feces, blood, or snails are present in the pool).

Given these criteria an excel model was built to calculate the effectiveness of various drainage sizes Figure 5.3. The analysis shows that a 1.5” diameter pipe will provide a 2 hour drainage period, which the design team deemed acceptable.

![Decreasing Pool Height vs Time After Drainage](image)

**Figure 5.3** Drain diameter related to the time it takes to drain the entire pool
6.0 DISCUSSION

DISCUSSION (about 3 pages) - Discuss what you have discovered during your design effort and, in particular, what are the advantages and disadvantages of your final design solution compared with others that either exist or have been considered for similar projects.

6.1 Decision Matrix

The decision to design a WRA was made after evaluating other possible engineering interventions proposed by previous Capstone groups. The 2004 Capstone group designed a decision matrix which evaluated specific interventions aimed at reducing the incidence and severity of Schistosomiasis on the residents of Kwabeng. The decision matrix is included as Figure 6.1 and was used to rate multiple interventions based on the following criteria:

- Cost
- Feasibility
- Community Acceptance
- Efficacy
- Sustainability
The highest rated interventions were not selected for implementation. The following discussion details the reason for elimination of the intervention and a comparison between the intervention in question and a WRA.

### 6.2

- decision matrix: what would’ve happened if we had chosen a different alternative?
  - Restoring river flow, medication, etc.
  - Incorporated education into our project: poster and rules → Karen’s PhD allows for future support of project that wouldn’t have been available with other alternatives
  - if we had chosen a different type of pump: if we don’t receive P&P technology → how it affects project (costs, not as attractive children)
  - original design w/o pool (overhead shower): how successful that would’ve been → not as appealing to children who want to be submerged
7.0 RECOMMENDATIONS

RECOMMENDATIONS (about 1 page) - Recommendations to the client and future scope of work if applicable.

- canopy over pool to avoid too much heating
- screened drain to avoid clogging
- list of tasks for pool manager
8.0 CONCLUSIONS

CONCLUSIONS (about 3 pages) - Briefly state and comment on the final design solution you developed. Show how your design meets the scope of your project. Discuss ideas you would like to explore if you had more time.
REFERENCES


<http://www.simetric.co.uk/si_materials.htm>