Design Report for a Small Scale Irrigation Project at Abba Samuel River Watershed, Ethiopia

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1. Executive Summary

Scarcity of water resources and the need for agricultural production are critical issues faced by the community of the Fogera District, Woreta Zuria Kebele Administration, Ethiopia. The region the community is located in experiences rainfall during Kiremt, the summer season lasting from June to early September. Dry conditions persist for the remainder of the year. Exacerbating the annual dry season, the El Nino weather pattern has greatly intensified this year's drought. The United Nations reports that Ethiopia is experiencing the worst drought in over 30 years, with 8.2 million people in urgent need for food (Devastating Drought, 2015). The community of Fogera District, Woreta Zuria Kebele Administration (from the point forward will be termed "Woreta") relies mainly on rainfed agricultural production as a means to provide sustenance and stimulate the local economy. Thus, the challenges faced by the Woreta community, such as food insecurity and economic instability, are continually intensifying. This proposal describes an approach to reduce strains on the community by utilizing surface water storage to extend the duration of agricultural production beyond the rainy season.

2. Background on the Site

The Woreta community is located northwest of Bahir Dar city, about an hour's drive from the city center. Situated in the northern highlands, the community is roughly 1800m above sea level. Woreta is set in the Abbay River Basin, a little over 10 miles from the Lake Tana, the largest lake in Ethiopia.

Figure 2.a: River Basins of Ethiopia. Woreta is located west of Lake Tana, the water body in the northern Abbay River Basin. Source: EthioVisit, n.d.

People of the Woreta community practice traditional farming techniques, such as utilization of animals for labor, and they depend on rainfall for sufficient crop yields to feed the community members and provide income. From June to August, rice is mainly produced. With the remaining moisture available, oats are produced in September. The local Kebele governmental leader has delineated fields into the two following sections: in the watershed and out of the watershed. Other crops grown in the watershed are wheat and beans, while millet, corn, teff, and oil seeds are grown out of the watershed. As a means to extend the short wet season, an irrigation system has been built in Woreta. This system was devised to store rainwater and provide additional water for plants past the last rainfall of Kiremt. However, the system is greatly inefficient and doesn't work properly. It currently allows for small harvests of the dry season crops of onions, potatoes, and tomatoes. According to the Kebele leader, this existing irrigation system provides water for irrigation from October - April.

Figure 2.b.: Traditional system utilized by the Woreta community for irrigation in May 2015.

The existing system uses a concrete dam in the Aba Samuel River to hold water upstream as a means to store flood water from Kiremt. There are two gates in the dam structure. Only one gates connects to distribution channels that irrigate crop fields northwest of the Aba Samuel River. A preliminary assessment of the site conducted by Dr. Jonathan Mellor, Kelsey Reeves, and Yigrem Dingo revealed the following issues with this system: high evaporation losses, lack of proper distribution, leakage from the gates, and stagnant water, which may act as a breeding ground for malaria spreading mosquitos. Pictures provided by Kelsey Reeves further explain the distribution system currently in place. Clearly, major improvements can be made to increase the effectiveness of this structure.

Figure 2.c,2.d,2.e: Photos of distribution from the existing dam site for irrigation. The existing structure consists of two bridges and segments of open flow or built channel flow. Top Center - Locally made bridge. Bottom Left- Segment of open channel distribution. Bottom Right- Segment of built channel distribution with a gate to a crop field.

Leaders of the Woreta community contacted Mama Kassegn from the EIWR seeking engineering support to help devise a new and efficient irrigation system that would service fields southwest of the Aba Samuel River. Through the relationship previously established with EIWR and the UCONN Civil and Environmental Engineering Department, this engineering project was brought to the attention of the UCONN Chapter of Engineers Without Borders (EWB). In this way, the EWB UCONN Ethiopia Program was founded. This senior design team is partnering with EWB to provide engineering designs for the new irrigation system to be implemented in the community of Woreta. The EWB team will separately handle rehabilitation of the existing distribution system.

3. Overview of the Design

The design team is tasked with the goal of designing a system that can be used for irrigation of crops beyond the wet season to fields southwest of the Aba Samuel River. A study on the feasibility of irrigation by surface water was conducted, with considerations for water needs of the existing irrigation system that services fields northwest of the river. The new system was devised in a way that fits well into the context of the community. The design includes using diversions from the seasonal Aba Samuel Stream to ferrocement tanks, where a gravity fed distribution network will be constructed to service crop fields.

4. **Design Objectives**

The design of this project was broken up into four main parts: watershed modeling, storage design, distribution design, and irrigation methods. The watershed modeling allowed for characterization of the region, understanding of where water collects along the river during rainfall events, and estimates of the available surface water resources. This information was used to inform the design of the storage system. Storage capacity was to be used to plan the distribution network, and irrigation techniques were studied to determine the most efficient and practical use of the stored water.

4. 1 Watershed Model

In order to provide estimations needed for the design of the storage and distribution components of the system, the research and development of a computer generated watershed model of the local area was created. The model building methodology and process is broken up into three parts; topography, precipitation, and soil. The success of each component was dependent upon the availability and extent of various datasets, as well as prior research.

4.1.1 Topography

The topographic component was utilized to generate a geographic land surface model in ArcMap. Elevations extracted from collected points, regarding the location of the existing waterways and proposed locations for storage tank sites, were used to determine the feasibility of the design based on predicted flow patterns and accumulation of precipitation resulting from surface topography. The following process was used to create this model.

GPS data points from an EWB assessment trip were imported into the ArcMap program, as well as Google Earth, to determine the coordinates and size of the area requiring topographic information. These data points were also used to label key features, (start of river, biggest potential dam site, existing dam, etc.) and to follow the path of the river intended as the source of water for storage and distribution to the irrigation system.

Next, digital elevation model (DEM) raster data was acquired from the USGS Earth Explorer site for the determined area, with latitude of 11° North and longitude of 37° East. For this model, Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global void-filled data was used. The range of chosen grid cell spans from the higher elevation mountains to the east of the site, to the anticipated end of irrigation in the West, continuing all the way to Lake Tana, the source of the Blue Nile, as shown in Figure 4.1.1.a.

Figure 4.1.1.a Chosen SRTM Land Surface Radar Data for Woreta area

This data source was chosen based on its public availability, reputation as a data source, and finer resolution. The data could be directly downloaded from the USGS Earth Explorer site, and this easy accessibility was desirable. Additionally, The EROS Data Center is a reputable source run by USGS for distribution of this data from NASA thus increasing reliability. A finer resolution, in this case 30 m, was sought to increase the representational accuracy of satellite data, with regard to local topographic features. SRTM data is one of the only major resources with global elevation data available at this resolution. This finer resolution increases accuracy in defining topography and land characteristics, especially for smaller areas. Furthermore, satellite elevation data at coarser resolutions was not able to represent this area, as well as necessary for the project, due to the small site size and unclear high and low points within the coarser resolution grid.

A flow direction grid was calculated based on each cell of the SRTM grid, which showed where water was expected to flow based on the elevations of surrounding cells. Flow accumulation was then calculated based on the results of the flow direction computation. This provided a reasonable estimate of where water tends to pool in the area. The results for the entirety of the chosen grid can be seen in Figure 5.

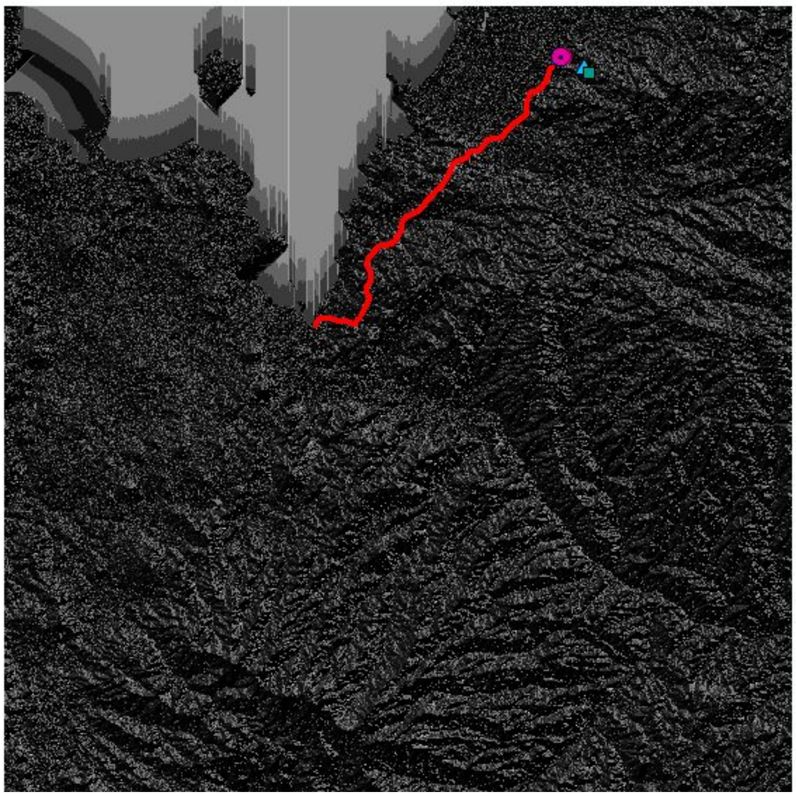


Figure 4.1.1.b Result of flow accumulation gridding process. The lighter colors represent lower elevations in the landscape (higher likelihood for accumulation), and darker colors represent higher points in the landscape (lower likelihood for high levels of accumulation). The large light area represents Lake Tana, an obvious area for high accumulation. The red line represents the road from Bahir Dar to the Woreta community, and the start of the community near the mountains, point of highest accumulation on site, and end of

community are represented by the green square, blue triangle, and purple circle, respectively.

A pour point/outlet was placed at the determined point of highest accumulation, and a watershed was delineated upstream of this point to estimate the anticipated volume of water expected. The resulting watershed was helpful in evaluating potential sites for storage structures.

The model was able to affirm that the point on the site tagged on the GPS as the "Biggest potential dam site" was a reasonable choice for capturing water since it agreed with the calculated point of highest accumulation from the watershed model. This is a low point in the area which seems to accumulate a large amount of precipitation. This is shown in Figure 6, which is a zoomed in view of the flow accumulation grid seen in Figure 5. This helped determine the placement of a storage structure downstream and slightly beyond the west bank of the river.

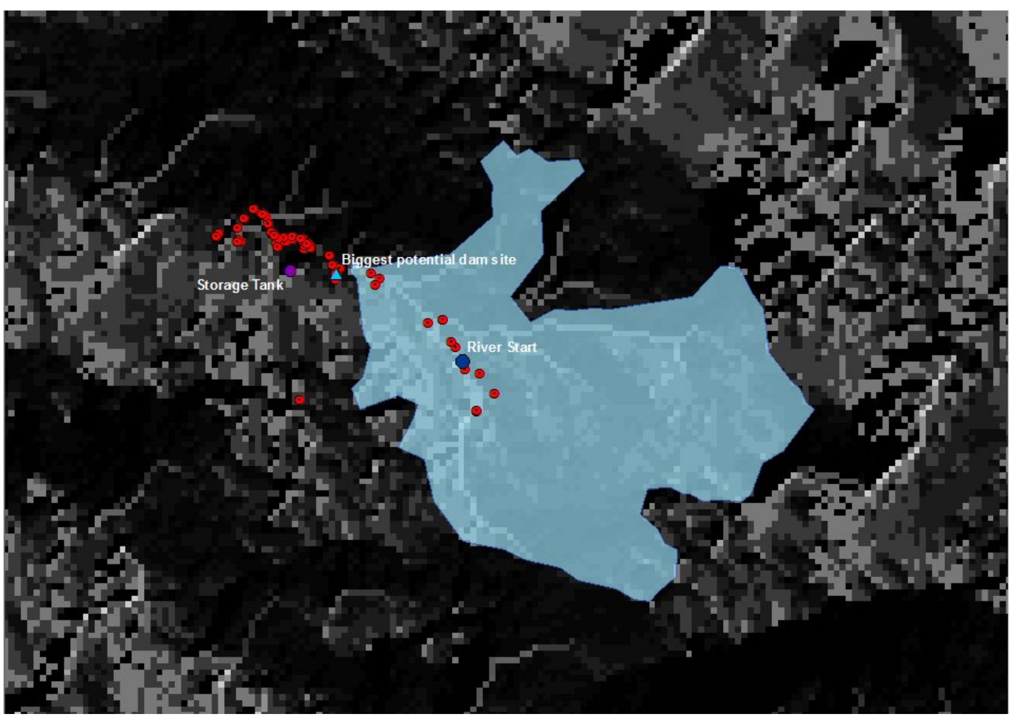


Figure 4.1.1.c Watershed upstream from point of highest accumulation in area, where lighter colors represent higher elevations (lower probability for high accumulation) and darker colors represent lower elevations (higher probability for accumulation). The start of

the River is designated by the dark blue point, the "Biggest potential dam site" representing the low point in the area is designated by the light blue triangle, and the location of the Storage Tank is designated by the purple point. The red points outline the general location of the existing river.

The area of the modeled watershed was calculated to be 2.75 km^2. When designing for the size of the storage structures, however, recorded precipitation data needed to be factored into the total expected volume of water as well. This was necessary given the climate variability in the region, especially pertaining to rainfall, with heavy rains and the majority of precipitation falling over the course of the few months comprising the rainy season.

4.1.2. Precipitation

The precipitation component of the process required various summations and data analysis of rain gauge data from two main sources. The first source of data came from the National Climatic Data Center (NCDC), with daily precipitation data spanning from 1961-1988 for the Bahir Dar Station. The second source of data came from the Ethiopian Institute for Water Resources (EIWR), and provided daily rainfall data for a station in Woreta from 1981-2011.

Some major issues with the given precipitation data were missing data values and uncertainty in accuracy of the measurements. The total rainfall values for 1981-1988 were cross referenced between the two datasets, and the data from the Bahir Dar Station was found to be more reliable and consistent when compared to the Woreta Station. Thus, values for 1961-1988 were summarized based on the NCDC dataset. The EIWR dataset was used to summarize the data from 2001-2011. Data from 1989-2000, and 2006 were excluded from this study due to large amounts of missing or no data values.

The data was summarized and tabulated for each dataset based on total annual precipitation. An average was then calculated, along with 10th, 50th and 90th percentile values. These results are summarized in Figure 4.1.2.a.

NCDC
AvgAnnual (1961-1988)
1.4343

EIWR
AvgAnnual (2001-2011)
1.1324

	NCDC	
10th	50th	90th
1.1182	1.4539	1.7455

	EIWR	
10th	50th	90th
0.7624	1.1454	1.3098

Figure 4.1.2.a Average Annual and 10th, 50th and 90th percentiles for recorded precipitation amounts in meters, from 1961-2011

The average annual rainfall from the NCDC data for Bahar Dar was 1.434 m for the years 1961-1988. The average annual rainfall data from the EIWR data for Woreta was 1.132 m for the years 2001-2011, excluding 2006.

One interesting finding was a significantly low value of 0.8946 m of precipitation recorded at the Bahir Dar Station in 1982. This was the lowest annual precipitation total recorded over the time span of the data. This also happened to correspond with one of the strongest El Nino years on record (1982-83), followed by one of the worst droughts/famines in modern Ethiopian history, as shown in Figure 8 (Lemi, 2005).

Table 1. Chronology of El Niño and drought/famine in Ethiopia

El Niño Years	Drought/Famine	Regions
1539-41	1543-1562	Hararghe
1618-19	618	Northern Ethiopia
1828	1828-29	Shewa
1864	1864-66	Tigray and Gondar
1874	1876-78	Tigray and Afar
1880	1880	Tigray and Gondar
1887-89	1888-1892	Ethiopia
1899-1900	1899-1900	Ethiopia
1911-1912	1913-1914	Northern Ethiopia
1918-19	1920-22	Ethiopia
1930-32	1932-1934	Ethiopia
1953	1953	Tigray and Wollo
1957-1958	1957-1958	Tigray and Wollo
1965	1964-66	Tigray and Wollo
1972-1973	1973-1974	Tigray and Wollo
1982-1983	1983-1984	Ethiopia
1986-87	1987-1988	Ethiopia
1991-92	1990-92	Ethiopia
1993	1993-94	Tigray and Wollo

SOURCE: Wolde-Georgies (1998)

Figure 4.1.2.b Chronological El Nino and drought/famine correlations in Ethiopia

With the uncertainty of precipitation, especially during years with high intensity El Nino patterns, it will be essential to store as much of the fallen precipitation as possible to last through long and difficult dry seasons. Our estimates of precipitation tend to be more conservative, with the knowledge that there may be patterns of very wet years followed by very dry ones, with the major goal of storing and retaining the maximum amount of water possible.

Since the rainfall data gathered was not realistically reliable, it could not be used to determine the amount of water for the tanks. This data was simply used as introductory information to motivate the design. Furthermore, the volume of the tank was designed under the assumption that it would be completely filled at the start of the dry season with enough water stored to meet needs for the entire length of the average dry season.

4.1.3. Soil

The soil component of the hydrologic model was used to determine the estimated amount of surface water lost to infiltration or diverted as runoff. Multiple sources were analyzed and cross referenced in the classification process pertaining to the soil component of the hydrologic model.

First, data from the Bahir Dar University soil mechanics lab was used to classify soil samples based on the results of sieve analysis and hydrometer testing. The average Liquid Limit (LL) was found to be 60.45, with a Plastic Limit of 33.31, and a Plasticity Index (PI) of 27.14. According to the USGS system, the soil was classified as a fat clay (CH or OH) with high plasticity. According to the Food and Agriculture Organization of the United Nations (FAO), infiltration rates associated with this type of soil range from 1-5 mm/hr. A conservative, average value of 2.5 mm/hr was chosen for the design calculations.

The next step was to review both a survey of the Abbay River Basin, provided by the Ethiopian Ministry of Water Resources, to gain a better understanding of the soils in the region, and how to properly classify them according to international standards. From this document, it was determined that the soil type could be considered a Vertisol.

Vertisols are common in semi-arid climates with distinct wet and dry seasons. They typically develop in depressions on the landscape, with excess amounts of smectitic clay. Soils with a high clay content are prone to high rates of expansion and contraction due to changes in water content and the structural fabric of clay particles in soil. Deep cracks are common in the dry season due to shrinkage, and the soil becomes dry and hard. During the wet season, the soil swells and becomes highly saturated, with a plastic and sticky consistency.

According to the survey, it is difficult to accurately measure infiltration rates for Vertisols, due to the contraction and expansion nature of the soil. Resulting subsurface cracking allows water to move both vertically and laterally throughout the soil, resulting in above average levels of infiltration, especially during the dry season.

The last step taken was to determine the specific Vertisol type. According to the African Soil Atlas, the soil type of the Woreta area is classified as VRha, which represents Haplic Vertisols, as shown in Figure 4.1.3.a.

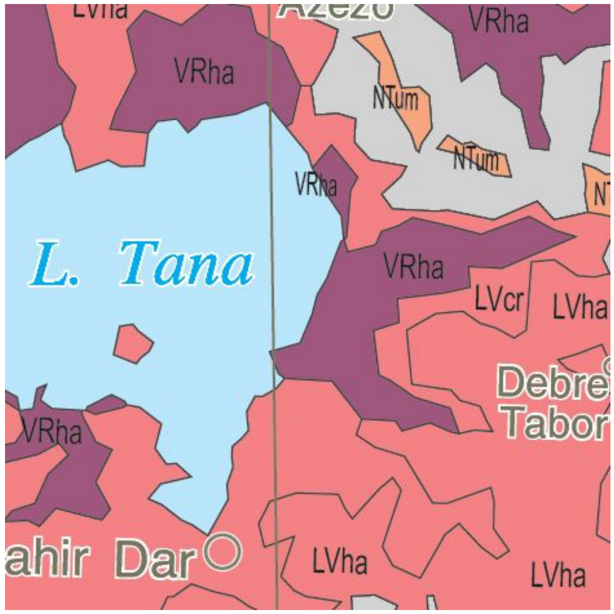


Figure 4.1.3.a Soil Classification from the African Soil Atlas

Although these methods were generally beneficial in soil classification, there are still many unknowns. Due to the lack of data and spatial variability in soil properties, further testing is recommended for the site area, along the river bed, and out to the fields intended for irrigation before implementation of any structure

4.1.4. Additional Data

Some additional data that needs to be obtained is a larger amount of precipitation data, along with evaporation and infiltration data. For the infiltration data, taking more soil samples, especially in the river bed and underneath the tank will be essential to further inform the design. Having some testing done to determine runoff rates and direction would also be beneficial. Additionally, more hydrological data is needed for understanding wet season conditions. A major aspect of this involves flooding and conditions during and after storms. Knowing approximately how much the water levels change, as well as the maximum depth, throughout the existing waterways is an important factor. This could help is determining the elevation of the invert of the inflow pipes, in addition to optimizing the sizing of the pipes and the tank. Also, knowing the magnitude and frequency of the rainfall is needed to determine the capacity of the piping system and tank to handle large amounts of water over small time periods. The design could be optimized based on the gathering of this data.

4.2 Storage

4.2.1 Design Overview

In order to provide ample water for irrigation purposes and prevent losses; a ferrocement storage tank will be constructed to hold a large volume water to irrigate crops south of the Aba Samuel River. The storage tank will be placed at a location calculated to have the highest accumulation of water volume according to the watershed model. This area is located at a low point where large amounts of precipitation accumulates. Two inflow pipes diverting water from the Aba Samuel River will feed the storage tank by gravity and the main line will distribute the water to the fields.

4.2.2 Design Considerations

The size of the water storage tank will need to be calculated using the watershed model and associated precipitation data. In order to create an optimal and efficient system, the size the storage tank will need to be large enough to hold thousands of gallons of water. The height of the tank is restricted to 2m in order for Intake A and B to fed the tank by gravity rather than pumping the water in.

Given the large volume of water that will be stored in the tank, the soil that it will be sitting on must be able to withstand the weight of its contents. The type of structure will need to be chosen whether it be a reinforced concrete tank or ferrocement tank. The method of the tank construction must be suited for use in low income rural areas where materials and tools may be scarce.

4.2.2 Comparison of Design Alternatives – Earthen Dam vs Storage Tank

The main goal of the water storage is to increase the amount of water that can be used for irrigation. Being able to store water during the wet season is crucial for crop production and their livelihood. An earthen dam was considered in early design stages given the low cost of construction rather than producing a water storage tank. After some investigation it was noticed that there were dams already in use in this area, the problem was not so much the leaking but the water loss due to evaporation. The soil is very arid in this region and some losses of water can be seen through infiltration as well. An earthen dam would also prove to be more dangerous during the wet season, if improperly constructed, the earthen dam could fail causing destruction of nearby properties. A water storage tank could fail as well, but building methods for the ferrocement tanks have improved over time. Ferrocement water storage tanks will also reduce evaporation and infiltration of the water.

4.2.3 Justification of Design Choice

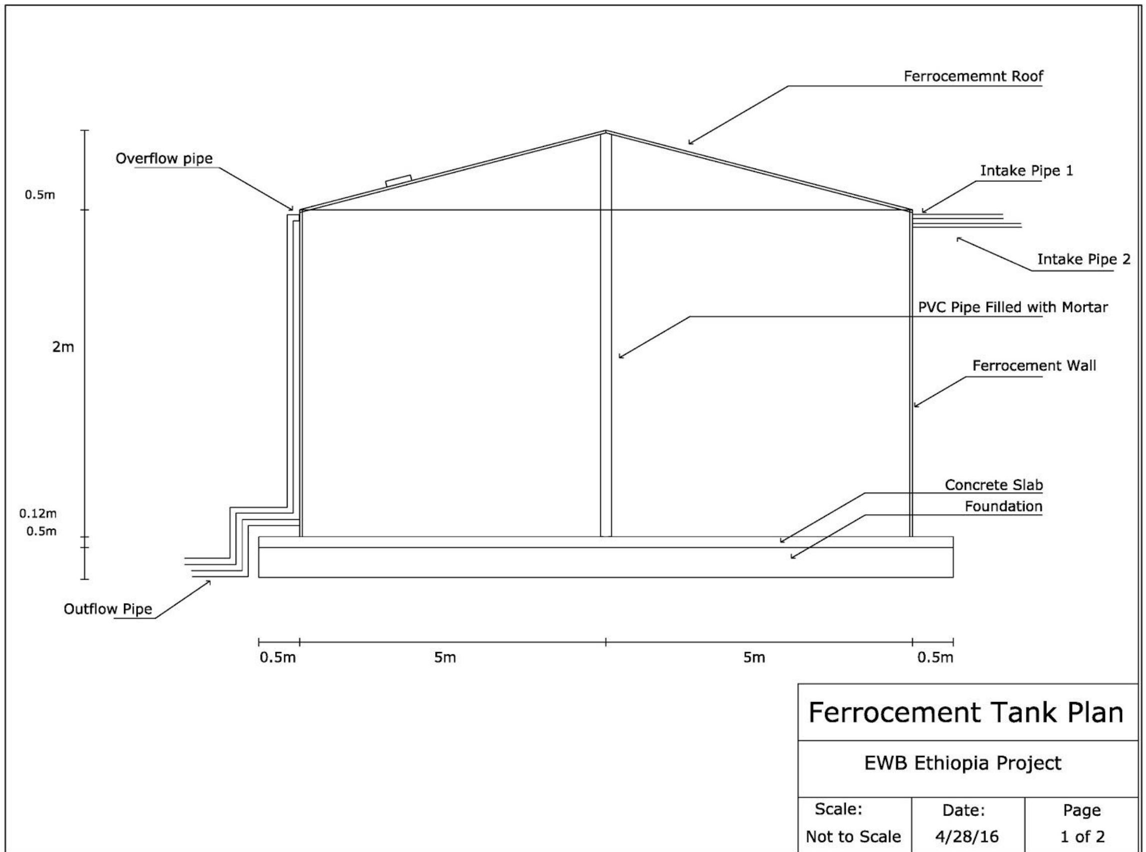
Ferrocement water tanks can be seen in many parts of the world including this community. The advantage of such a tank is that it can be made from commonly available materials, simple skills needed, self-help contribution and simple equipment. A prefabricated tank could have been an option yet would have been too expensive for this application. A tank made of reinforced concrete would have required more equipment, framework and capital.

The water tank that has been chosen is built by troweling a cement rich mortar onto a mesh of wire reinforcement to form cylindrical tanks. Rather than having to build formwork for the reinforced concrete, ferrocement tanks simply used a mix of cement mortar that can be applied to the framework. The rebar reinforcement distributes the loads through the mortar which prevents the concentration in planes of weakness which in turn keeps the tank from failing. Wire reinforced cement mortar has the ability to resist corrosion and its cheapness compared to other materials sets it apart from other methods of construction. The cement mortar is expected to exceed 50 years of continuous use according to the ITACA. These ferrocement tanks have been in use for many years and have been well proven to withstand climatic regions.

4.2.4 Drawings/Spec Sheets/AutoCAD cross sections

The use of Microstation and SAP2000 have been utilized for the design of the ferrocement storage tank. **Drawing 4.2.4a** depicts the overall layout of the water storage tank. Two intake pipes located on the right of the drawing will fill the storage tank with water that has been diverted through these pipes from the Aba Samuel River. An overflow pipe has been added as precaution in the event that the storage tank were to overflow. The overflow pipe will then reintroduce the overflow of water back into the main line or be drained as needed. Given the large diameter of the storage tank, a PVC pipe filled with mortar will be placed in the center in order to withstand the weight of the roof and prevent its collapse. The thick reinforced concrete slab and foundation measuring 0.62m will support the 157.07m^3 of water when at full capacity. Building code recommendations for ferrocement tanks IFS-10-01 have been utilized to ensure the safe and proper construction to avoid any type of failure.

Drawing 4.2.4a: Ferrocement Tank Plan



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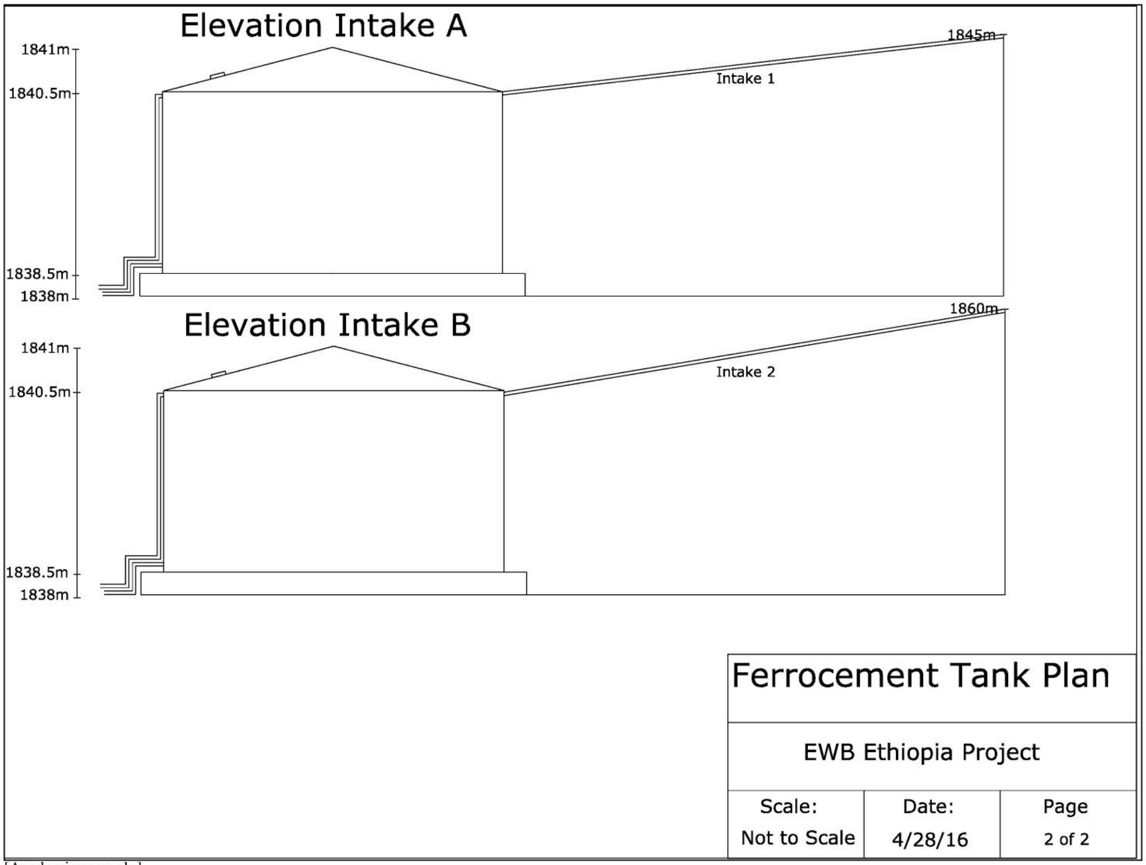
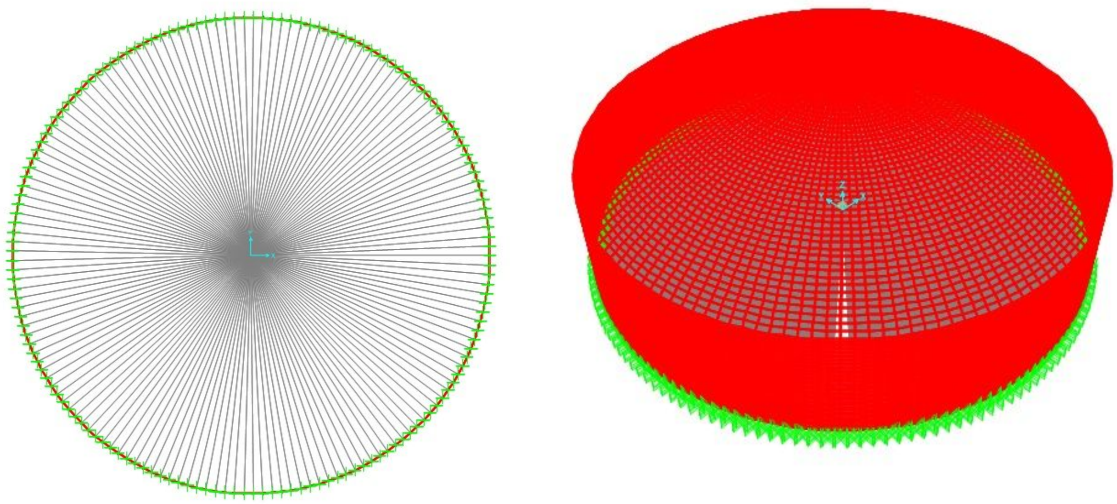
Drawing 4.2.4b: Ferrocement Elevation Plan for Intake A and Intake B



[Academic use only]

The elevation plan of Intake A and Intake B depicted in **Drawing 4.2.4b** shows the cross section layout of both intake pipes going into the tank. The storage tank was placed at an elevation of 1838 m which is located at a low point in the area in order to ensure that the system remained gravity fed. Intake A makes a descent of 7m before reaching the tank and Intake B descends 22m before reaching the top of the tank. The storage tank will not be dug underground, rather where the incline becomes steeper approaching the tank, pipes will be held up by posts in order to arrive at the top of the tank to be filled with water by gravity.

Drawing 4.2.4c: SAP2000 Model of the Ferrocement tank



Drawing 4.2.4c is a model of the ferrocement tank using SAP2000. The model on the left shows the rebar reinforcement spacing for the roof of the tank. 157 pieces of 9mm rebar spaced at 0.2m apart all meet together at the central column to provide the framework for the chicken wire and plaster to be adhered to. The model on the right shows the spacing of the rebar vertically and horizontally with the same spacing as the roof supports at 0.2m.

Spec Sheet 4.2.4d: provides a general overview of the specifications of the tank

Capacity	157.07m^3
Diameter	10m
Height	3.12m
Foundation	Compacted Sand/Hollow Cement Blocks
Base Slab	Reinforced Concrete 0.2m thick
Wall	Ferrocement 0.03m thick with 9mm rebar

Roof	Ferrocement 0.03m thick with 9mm rebar
Central Column	Pipe PN20 20mm diameter
Access Opening	0.6m x 0.6m access hatch on roof
Pipe Hardware	Inlet A, Inlet B, Overflow pipe, Main Pipe Line

4.2.5 Staging of the Installation

4.2.5.1 Site Selection

The tank will be placed in an area with the most accumulation of water volume at a low point that was found using the watershed model. Placing the tank in this area will allow for the water to be gravity fed from Intake A and Intake B located at a higher elevation diverting water from the Aba Samuel River.

4.2.5.2 Site Preparation

The site must be cleared of any debris and levelled properly. It is imperative for any loose surface to be compacted using any soil compacting tools that may be available in the area. A compacted and levelled area will be vital for the construction of the foundation and ferrocement tank structure.

4.2.5.3 Foundation

The foundation will consist of a layer of compacted soil surrounded by cement hollow blocks filled with mortar. Hollow blocks will assist in the compaction of the soil within the confinement of the hollow blocks. Use of water may assist in the compaction of the soil if necessary. The compacted soil must also be levelled in order to allow for the reinforced concrete slab to be poured.

The perimeter of the foundation will need to be marked in order to lay the blocks properly. A stake at the center of the location may be used with a string of length 5.2m to draw a circular ring where the cement blocks will be placed. Once the perimeter has been marked, hollow cement blocks will be placed in layers reaching a height of 0.62m around the perimeter. Compacted soil and levelled soil will then occupy the area within the hollow blocks to a height of 0.5m.

4.2.5.4 Concrete Base

A concrete base of 0.5m will be poured above the compacted soil inside the circular ring to ensure that the area is level. The concrete base will provide a platform for the reinforced concrete to be cast upon. This layer of lean concrete will use a mixture ratio of 1:3:5 (Cement, Sand, Aggregate by weight) also provide a watertight layer for the reinforced concrete to be cast.

4.2.5.5 Reinforced Concrete Base Slab

Two layers of 9mm rebar will be placed above the concrete base after it has finished curing. The rebar will create a grid like pattern with a spacing of 0.2m in the x and y direction. At this stage in the process it will be difficult to erect the vertical bars, therefore 9mm rebar will need to be cut to a length of 0.6m and bent into an L shape. There will need to be 157 pieces of this rebar cut and spaced 0.2m apart around the perimeter where the tank will be placed. A new circular perimeter for the tank will need to be marked with a radius of 5m to ensure the correct size of the tank. The L shaped rebar will then be tied into the base slab reinforcement erected upright around the newly measured perimeter.

Once the rebar has been placed, the central column will then need to be tied into the rebar reinforcement in the base slab. Before pouring the concrete it is crucial that all the spacing of the rebar is correct and that the perimeter L-shaped rebar is properly spaced forming a circle with a 5m radius. Concrete with a mixture of 1:2:4 (Cement, Sand, Aggregate by weight) will then be mixed and poured over the rebar reinforcement and erected rebar. The concrete thickness will be roughly 0.7m and should be level with the surround hollow concrete blocks that form the perimeter of the foundation.

4.2.5.6 Wall Reinforcement

Since water pressure decreases with height, the amount of rebar reinforcement will also vary with height. This means that additional rebar will be needed at the bottom of the tank. First, the vertical reinforcement will be tied to the erected rebar from the cast concrete. The rebar reinforcement will consist of 2m long 9mm rebar which will be placed vertically and tied to the protruding rebar in the foundation. There will be 157 vertical pieces in total around the perimeter of the tank at 2m in height. 9mm rebar will also be used to create the horizontal reinforcement around the circumference of the tank. The rebar will be spaced every 0.2m from the base of the tank to the top of the vertical reinforcement.

Drawing 4.2.4.3 depicts the spacing of the rebar which creates a grid like pattern encompassing the circumference of the tank. Given that additional reinforcement will be required near the base of the tank, 9mm rebar of length 1m will be tied to the already placed reinforcement at a spacing of 0.2m. These pieces will be placed vertically between the 2m long reinforcement and tied in place.

4.2.5.7 Chicken Wire

Chicken wire will be tied into the rebar reinforcement on both the inside and the outside of the tank. An access opening on the side of the tank is recommended for ease of movement in and out of the tank.

4.2.5.8 Plumbing

Before the ferrocement mortar is cast, the outflow pipe, intake pipe and overflow pipe will be tied to the chicken wire. It is not recommended to make holes in the plaster when the tank has cured, therefore the fittings must be put into place before any of the plaster is applied.

4.2.5.9 Roof Reinforcement

9mm rebar will be used for the reinforcement of the roof. The rebar for the roof will be tied to the end of each vertical reinforcement and secured to the central column. In total there should be 157 pieces around the circumference of the tank all meeting at the central column. Additional rebar will be tied perpendicularly to the roof reinforcement with a spacing of 0.2m, the will create a circle of rebar on the roof. Each subsequent placement of rebar will create smaller and smaller rings until the central column is reached. **Drawing 4.2.4b** can be referenced for an idea of what the rebar should look like if necessary.

Chicken wire will be placed on the top and the bottom of the roof and tied to the rebar. An access hatch for maintenance has been included in the design, therefore an opening of 0.6m x 0.6m will need to be made to accommodate the hatch.

4.5.5.10 Plastering

Plastering is one of the final steps in the process; before this can be done all the rebar reinforcement, chicken wire and fittings will need to erect. The mortar for the tank will consist of a cement ratio of 1:2 (Cement, Sand by weight) and needs to have a workable consistency. Limiting the ratio between 0.35 and 0.45 will provide the best results for this application.

Once the mortar has been mixed it can then be applied to the chicken wire. It is easier to start from the inside using the access opening and then working on the outer face when the inside is complete. To start off this process it is suggested that someone hold a piece of plywood on the outer face so that the first layer of mortar is easier to apply to the inside. The plaster on the inside when completed will act as the plywood for the outer layer of plaster to be applied.

4.2.6 Suggested Maintenance

A ferrocement tank needs little to no maintenance given the simplistic design. Possible maintenance may include: cleaning the inside of the tank, replacing fittings, remove debris if there are any clogs and plastering any cracks that may occur during continuous use. With proper maintenance a ferrocement tank may be expected to exceed 50 years of continuous use.

4.2.7 Cost Analysis

The cost breakdown of the materials for the ferrocement water tank is provided in Appendix 6.2. The capital costs associated with the construction of the tank are summarized below in **Table 4.2.7a.**

4.2.7.1 Capital Cost

Table 4.2.7.1a: Associated Ferrocement tank costs

Material	Birr	USD
Cement	51212.38	2377.00
Rebar	37565.15	1743.57
Chicken Wire	23010.02	1068.00
Sand	21864.04	1014.81
Aggregates	8957.77	415.77
Misc. Tools	10772.48	500.00
Total Cost	153381.8	7119.15

4.2.7.2 Operation and Maintenance Costs

The ferrocement storage tank will have little to no operation and maintenance costs given the simplicity of the design. The effectiveness of the ferrocement provides long term sustainability while providing cost effectiveness. Possible maintenance cost may include additional ferrocement to patch cracking plaster and replacement of the fittings due to wear and tear. These costs will be minimal and vary in cost based on the extent of the damage

4.2.8 Recommendations

Additional soil samples at the storage tank site will need to be made in order to ensure that the soil is suitable to withstand the weight of the tank and its contents. A survey of the proposed storage tank location will be needed to place the tank in the correct location so that the two inflow pipes will be able to feed the tank solely due to gravity. Incorrect placement of the tank and inflow lines could cause a backup in the system and decrease the amount of water stored.

4.3. Distribution

4.3.1. Design Overview

The distribution system runs parallel to the Aba Samuel River and services fields southwest of the river (Figure 4.3.1). The distribution design includes three main components: inflows, the main line, and branches. The inflow lines divert water from the Aba Samuel River to the storage tank, the main line conveys the water to the fields, and the branches stem from the main line into the fields. Off of each branch, there are furrows for irrigation. All water transport was designed to be gravity fed and consists of high quality (this is an Ethiopian classification) PVC piping.

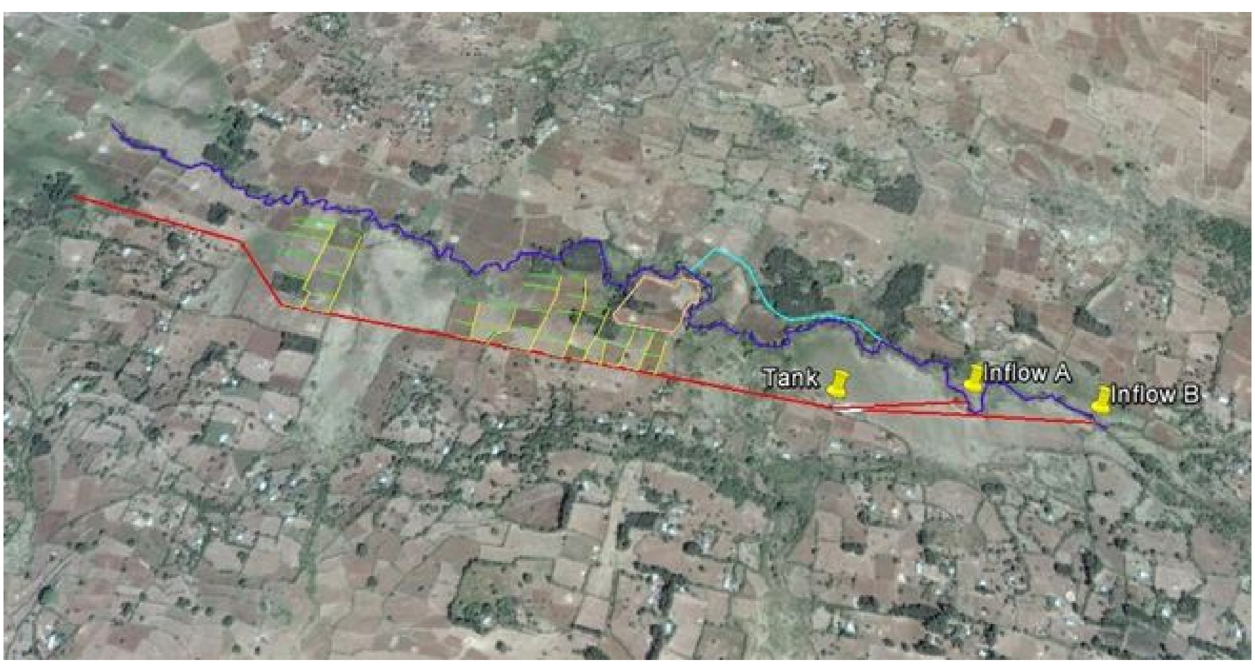


Figure 4.3.1: Depiction of the irrigation system generated using Google Earth. The red lines show the placement of the main line and inflow lines, yellow lines show the branches into the fields, and the green lines show furrows. The dark blue line shows the Aba Samuel River, and the light blue line depicts the existing distribution from the irrigation system in place. Three markers represent locations of key features: Inflow A, Inflow B, and the tank.

4.3.2. Inflows

Two inflow lines were designed to ensure the tank is filled in a timely manner due to the short and highly intense rainy season. Having two inflow lines will allow for greater collection of water from the stream that forms after an intense rainfall. The inflows were named Inflow A and Inflow B (Figure 4.3.1).

The inflows are designed to have a standpipe in the stream bed that will extend 1 foot off of the ground (Figure 4.3.2.a). A screen of 1mm by 1mm grid will cover the pipe to prevent debris from entering the irrigation system. The one foot pipe covered with the screen will connect to a 90 elbow, a ball valve, and then the piping will continue to the storage tank where it will then have a 90 elbow into the tank. The valve will allow operators to shut off the inflow for any circumstance that may require them to do so, such as maintenance of the storage tank, or after the tank is full. The inflow lines are sized to be 200mm diameter pipes.

Figure 4.3.2.a: An inflow pipe submerged under water.

The staging of the inflow lines allows for gravity fed water transfer to the top of the storage tank (Figure 4.3.2.b). This design was achieved using Google Earth elevation measurements. Inflow A is located at 11°55'24.50"N, 37°44'9.84"E, 6037 feet, Inflow B is located at 11°55'23.21"N, 37°44'16.48"E, 6052 feet, and the tank at 11°55'24.21"N, 37°44'2.33"E, 6030 feet. Thus, there is a 7 foot elevation drop from Inflow A and a 22 foot elevation drop from Inflow B to the location of the tank, which allows for the tank to be 2m (6.56 feet) tall and still gravity fed from the river.

Figure 4.3.2.b An autocad drawing of the inflow lines.

As the inflow piping increase in height from the ground to the top of the tank, piping support will be placed in according to the international plumbing code standards (Section 308 Piping Support, 2007). The piping support will be in the form of stands made of eucalyptus trees staked into the ground and cemented in place. Pipe clamps will extend from the top of the stands to hold the PVC (Figure 4.3.2.c). A stand will be placed every 4 feet. For Inflow A and B, 70 and 40 meter of pipe, respectfully, would be elevated off the ground. Thus, 57 stands would be required for Inflow A and 32 stands for Inflow B.

Figure 4.3.2.c: Graphic showing stands holding PVC piping for in the inflow lines.

This type of stand was chosen because the eucalyptus trees are strong and can be provided by the community. During an assessment trip taken by EWB, the Kebele Leader had stated that there was a plot of eucalyptus trees that they wouldn't mind using as materials or land for this project. Because eucalyptus regrows in about four years time, there is no substantial environmental impacts from using the trees for pipe support.

4.3.3. Main Line

The main line extends from the bottom of the storage tank to the location of the fields. The goal of the main line placement was to have it be gravity fed, while also irrigating the greatest number of fields possible. Google Earth elevation data was used to find possible paths of gravity fed distribution. The site is located within a valley with an overall slope to the west and the river is at the lowest elevation. Because the river is at the lowest elevation, it is difficult to irrigate fields far to the south using the river while depending on elevation differentials for distribution. The main line depicted on the Figure 4.3.1 presents the greatest compromise for the number fields that can be irrigated by gravity fed distribution using changes in elevation to the west and north.

A valve will be placed directly after the storage tank to control the feed of water to the fields. The pipe that extends from the tank to the first branch will be 90mm diameter. Directly before the first branch, the pipe size will be reduced to 75mm diameter via a reducing coupling. The reduction in pipe size will allow for a greater pressure to force flow through the main line to the branches. It will also reduce costs of materials. All of the mainline will be 75mm diameter piping.

There are eleven branches off of the main line via Tee pieces (75 mm diameter). Valves will be placed after branch 4, 9, and 11 to regulate how many fields will be serviced at any given time. Into the late dry season, the community leaders may see it fit to reduce the number of fields that are being irrigated in order to concentrate available water for sufficient crop yields to select fields. These valves will allow for them to do so.

After branch 11, there is a layout for the mainline to continue. This line shown on Figure 4.3.1 is provided in the case that the community or EWB decides to expand the irrigation system in later years. The path shown for the mainline can serve as a guide for where the line could be placed in order to achieve gravity fed distribution beyond branch 11.

4.3.4. Branches

Each of the 11 branches are designed to be sized to 50 mm diameter pipe. A reducing coupling from the main line diameter of 75mm will be placed at the beginning of each branch. A valve (size 50mm) will also be placed directly after the coupling. This way any of the branches can be turned off as needed to conserve flow for branches located at distances furthest from the tank. Along the branch, there will be Tees. Each Tee will connect immediately to a valve, and the valve will be in line with a furrow. At the end of the branch, there will be a 90 degree elbow that will also connect with a valve to the last furrow. The users of this system can regulate which fields received water and when they receive water using these valves off of the branches. It is suggested the users of this system close off flow to furrows closer to the main line after they are properly irrigated in order to ensure sufficient irrigation of fields at lower elevations (located closer to the river).

4.3.5. Comparison of Design Alternatives - Pipes VS Open Channels

The traditional distribution system currently in place servicing fields northwest of the river uses a series of concrete channels and overland flow (Figure 2.c, 2.d,2.e, Figure 4.3.5.a., and Figure 4.3.5.b). Pipe distribution was chosen over open topped concrete channels or overland flow because it has far less losses of water. In an arid and drought stricken climate, these losses are substantial. For concrete channels, there are great losses due to evaporation, and for overland flow, there are many losses from unrestricted flow paths, evaporation, infiltration, and transpiration. Pipes are also generally easier to repair than concrete channels.

High quality PVC was the pipe type chosen because it is durable. In order for the system to be maintainable by this community, maintenance costs will need to be low. This pipe was chosen in hope that it would break the least amongst the other pipe types available for the design and that its capital cost outweigh its maintenance cost relative to the other pipe options. Other types of pipes considered were irrigation hose lines, corrugated plastic, and low quality PVC. Both the corrugated plastic and PVC were durable compared to the irrigation hose lines, but the PVC was the more economical option.

Figure 4.3.5.a.: A segment of the existing open concrete distribution servicing fields northwest of the river.

Figure 4.3.5.b.: A segment of the existing overland flow distribution servicing fields northwest of the river.

4.3.6. Distribution Figure

The modeling software EPANET was used to model the distribution piping system of the irrigation network. In order to run the model of water flow from the river intakes to the field outlets, the layout of pipes from Figure 4.3.1 were set into EPANET where each node was set to a specified coordinate and elevation matching the points laid out in the Google Earth site plan. A node was used to represent the intakes of the system, connections between pipes, connections to the storage tank, and endpoints where water flows into the fields. The main features of the system were then added by attaching each one to a specific node. These features include, reservoirs, tank, pipes, and valves.

The layout of these features is shown in Figure 4.3.6. In this representation, it is clear that the distribution maintains the same shape and layout as the Google Earth image illustrated in Figure 4.3.1. In order to run the model successfully, there were many input variables that had to be considered. For the intake reservoirs, it was important to specify the proper total head. This was accomplished by using our Google Earth site plan and finding the difference in elevation between the river at the intake point and the tank. A difference of 0.3 meters was added as the depth of water in the river flowing into the system.

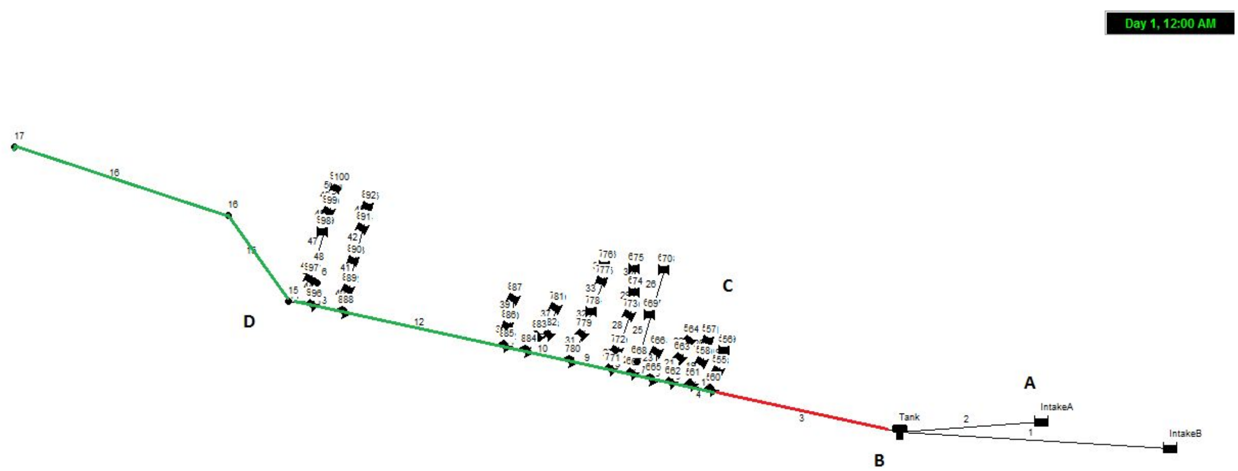


Figure 4.3.6.: EPANET representation of the distribution network from the intake reservoirs to outlet valves. Intakes are represented by blocks labeled at point A. Tank represented by symbol at point B. Branch lines are perpendicular to the green mainline labeled C.

The setup of the tank required adjustments of variables for the dimensions of the type of mixing and the minimum and maximum levels of water in the tank. The type of mixing was important to research in order to simulate proper flow in and out of the tank. The mixing model chosen was “mixed” because it is assumed that the water is mixed instantaneously and continuously as it enters and exits the tank.

When designating variables to the system, the pipes required the most research and adjustment. The values of length, diameter, loss coefficient, and roughness coefficient needed to be specified. The length of each pipe was simply found by measuring with the ruler tool on the Google Earth site plan which is seen in Figure 4.3.1. The loss coefficient of each pipe was determined by the features it contained such as an elbow, tee junction, valve, and exit. For example: if a pipe contains a ball valve, then the loss coefficient is 10, if a pipe has a 45 degree elbow (such as at section D), then the loss coefficient is 0.4, if the pipe has an exit (such as where the water leaves the pipes to the field), then the loss coefficient is 1. These coefficients are found in the EPANET users manual (Rossman 2000). The roughness coefficient for each pipe was equal because it was determined by the material of pipe and each was made of high quality PVC.

A process of trial and error while running EPANET models were needed to determine the ideal diameter of each pipe. By basic principles of fluid mechanics, it was known that in order to maximize pressure, the pipe diameters must progressively decrease as the system flows from intake to output. Initially the model was tested using the largest pipe size available at the local hardware store, 220mm, for the flow from the reservoirs to the tank. These pipes created an adequate flow through the system, however a pipe of 110mm was used instead in order to reduce the cost by over a half. The rest of the system was tried and tested many times using a combination of pipes of decreasing diameters. When the model was run for each of the combinations, the theoretical flow through the outlets was found. The pipe network which enables the maximum flow involved a 90mm pipe from the tank to the first branch (this section is represented by a red line in the network in Figure 4.3.6). The rest of the pipe along the mainline was decided to be 75mm in diameter (this section is represented as a green line in Figure 4.3.6). It was found that in order to maximize flow to the fields the branch pipes should be 50mm.

It is expected that by the end of the dry season the flow in the river will not be sufficient to keep the tank full. By running an EPANET simulation, it was found that when the level of water in the tank reaches half way, there will not be enough pressure to force water out all the emitters and into the fields. In order to solve this issue, valves must be closed to shut off flow to individual sections and allow more flow to others. The system was then ran though the model. As more segments of the network were shut off, the pressure in the open pipes could be brought to values of flow equal to that of when the tank was at full capacity. This capability of the EPANET software demonstrates that the farmers can continue to farm the fields even as the water level in the storage tank drops. If there is not enough pressure to reach every field, the farmers can close sections off for a period of time to supply water to other areas.

To explain an example of this shut off system two feeder pipes will be monitored, this will be feeder 11 (directly off pipe segment 13) and feeder 1 (directly off pipe segment 3) in figure 4.3.6. If the model is run when the tank is filled to capacity and all valves are open, the resulting flow in feeder 11 is 0.03 liters per second and flow in feeder 1 is 00.4 liters per second. With these two feeders being first and last in the network, this demonstrates that there is sufficient flow to the entire system when the tank is full.

If the model is run when the level of water in the tank is only half full there is a drop in pressure to these feeders. The flow in feeder 1 drops to 0.01 liters per second and the flow value given for feeder 11 is N/A, meaning that there is no water flow through this pipe. Other feeders closer to the beginning of the mainline will also have insufficient flow. Feeder 9 above pipe segment 12 also has a flow value of N/A.

In this situation flow can be compensated to feeder 9 by closing the valve in pipe 12. When the model is run with this valve closed, feeder 11 is no longer receiving water, the flow in feeder 9 increases to 0.01 liters per second, and the flow in feeder 1 increases to 0.03 liters per second.

4.3.7. Staging of the Installation

Building of the distribution design will be done by the community in the form of in-kind labor. No major equipment or machinery will be needed. The cost of all materials includes transportation costs to the area, so it is likely that the community will only need to walk materials from, at minimum, the primary school's location. The location of the primary school should be familiar to the EWB team. A list of materials needed and costs is provided in Appendix 6.1. EWB partners at Bahir Dar University and the Ethiopian Institute of Water Resources will assist the EWB team with implementing the distribution design as well as the rest of the total design for this project. Engineering faculty member Habtamu Tsegaye of BDU, a partner of EWB, is an irrigation engineer professional who can ensure that all components of the system are implemented appropriately and safely.

4.3.8. Suggested Operation and Maintenance

Daily operation required includes managing the water flow. Valves should be turned on and off based on what fields need flow and how much water is required per field. EWB will assist the community with learning how to regulate flow as needed.

During the wet season when the tank is receiving water from the inlet lines, the screen over the inflow pipes in the river should be cleaned often. Trial tests with the system running will be needed to determine how often the screen needs to be cleaned in order to ensure continuous flow to the tank. After the tank is filled, the inflow line valves should be turned off.

Although it is hard to predict how often the system may experience breakages or failures, PVC is generally known to have a lifetime of greater than 50 years for piping underground (InterNACI, 2016). Piping exposed to the sun is likely to have a shorter lifetime, however, the exact relationship between sun exposure and PVC lifetime is unknown. Thus, the lifetime is taken to be approximately 50 years and maintenance is not suspected to be required until decades after the distribution system is built. However, if something should break, the community will be trained by EWB on how to fix it.

The distribution system was designed with consideration for social factors that may lead to breakages in the pipes. During an assessment trip by EWB in January 2016, there were visibly many cows and animals roaming in the grazing lands near to the proposed sites for inflow lines and this posed a concern for project sustainability due the potential for the animals to walk into the elevated pipes or onto ground level pipes. However, the EWB team was told by the Kebele leader that these animals should not be of concern, for they would soon be removing the grazing land near to the project site and thus the system would not be exposed to large animals. Because this obstacle will be removed, there are no obvious reasons for the designed distribution system to experience a lifetime less than at least 50 years.

4.3.9. Other Data Required

Prior to implementation, it is advised that the EWB team manually check the elevations for the distribution system. Google earth elevations were used to ensure gravity fed distribution, however there is error associated with this source. Thus, the EWB team should use the coordinates from the distribution design and survey the exact locations in person.

Additionally, the EWB team should investigate if the stands for pipe support on the inflow lines from the river need to be cemented in place or if they can be staked into the ground. This will depend on soil types and soil stability.

4.3.10 Cost Analysis

4.3.10.1. Capital Cost

The breakdown of all costs for the design of the distribution system are in Appendix 6.1. A summary of the capital costs is provided below:

Table 4.3.10.1: All costs associated with the distribution design.

Location	Birr	USD
Inflow Lines	71741	3416.24
Main Lines	67582	3219.19
Branches	49692.6	2366.31
Total Cost:	**189015.6**	**9001.74**

4.3.10.2 Operations and Maintenance Costs

There should be no operation and maintenance costs until something breaks and needs repair. As stated in Section 4.3.8, the amount of short term maintenance required should be minimal due to the estimated lifetime of PVC pipe being greater than 50 years. As for operation costs, the community will perform all operations for the system as part of their daily agricultural work. Because the system will benefit their lives via greater agricultural production, ideally the community would not expect a monetary reward for operating the irrigation system.

4.4 Irrigation

4.4.1 Overview

The investigative field trip taken by Engineers Without Borders UCONN helped our design team understand the land which we are working on in multiple ways including: topography of the area, soil properties, stream properties, and the current irrigation practices in the community. The information gathered allowed the design team to reevaluate the plans made in the fall and create a new plan that will be a practical into the community. The new approach will require much less modification to the current irrigation system as well as the current farming practices which have been consistent for many generations.

4.4.2 Previous Irrigation Plan

In the design team's initial project proposal, the main goal was to implement a system of drip pipes that would irrigate many fields around Woreta's Abba Samuel River. According to the previous plan, the water would be fed from stored water in cement tanks by using either gravity or pumps. Drip irrigation was the team's first choice because it is the most efficient in terms of delivering water directly to the crops. Once the fields were surveyed and the agricultural practices observed, it became clear that a drip-line irrigation system would not be practical in this environment. The previous plan would not work because of the topography, technical capabilities, and the agricultural practices of the community.

4.4.2.1 Topography

When planning a drip irrigation system, water pressure is a very important aspect. Pressure is needed to push water through the tiny holes in the pipe to the soil. This can be acquired through a large change in elevation or pumps. The investigative field trip found that there is very little elevation change between the water collection area and the fields being irrigated.

4.4.2.2 Technical Capabilities

The issue with pumps is that they require a great deal of technical knowledge and maintenance. The community has very little experience using a system of pumps and filters which would be necessary to keep the irrigation flowing in the future. The challenges would be in constructing the system and maintaining each part when there are damages and malfunctions.

4.4.2.3 Effect of Agricultural Practice

Ag. Practices: A drip line would also make the farmers' functions in the fields very difficult. In a drip line system, it is common practice for the lines lie down the crop rows from seed to harvest. In Woreta and much of Ethiopia it is common practice to till the fields often. The farmers of this community till as frequently as once every 3 weeks. Tilling this often would make drip irrigation impractical because the drip line would need to be removed and reinstalled every time that the field is tilled.

4.4.3 Current Irrigation System

Investigation of the current irrigation system in Woreta lead the design team to realize that the new irrigation system must fit into what already exists with as little modification as possible. Most agricultural fields in the community do not use any irrigation and rely on rainwater during the wet season to water the crops. There is such little rain during the dry season that these fields become arid for months.

The fields that do use irrigation involve simple furrow systems. Most often a field would have one or two furrows running down the length of the plot with about 10-20 crop rows in between each furrow. Many of these furrows were observed to be in poor condition with the water not extending down the length of the field. The prosperity of the crops depends on the ability for water to reach all parts of the fields.

4.4.4 New Irrigation Plan

4.4.4.1 Furrow Irrigation Overview

The new plan is to modify the current fields as little as needed in order to provide a system of water supply to the crops. Each field will be connected to the water distribution system from one input. Depending on the size and shape of the field, multiple inputs may be required. These inputs will be pipes transporting the water downhill from a storage tank.

The water will exit a nozzle off the feeder pipe at the highest end in the field. From this point the water will flow into the field channel running along the edge of the field. As shown in Figure 4.4.4.1a the pipe will open onto a platform of rocks in order to slow the flow before entering the field and prevent soil erosion. Each platform is made of stones about 1 inch in diameter. The platform itself will be about 6 inches tall and 2 feet in diameter. The water will then be distributed across the top of the field in a field channel. The field channel runs along one side of the field with the highest elevation. The point where the distribution pipe enters the field channel will be directly adjacent to the feeder pipe.

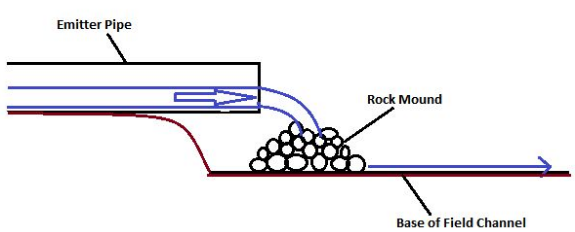


Figure 4.4.4.1a Side View: Flow from emitter pipe onto rock platform to field channel

As shown in Figure 4.4.4.1b below, the rows will then line to the downhill side of the field, perpendicular to the field channel and the water will flow freely. Straight line furrows will be used in order to maintain the farming practices. Straight lines allow farmers to continue plowing and tilling the fields without disturbing the furrows.

At the downhill side opposite of the field channel, the excess water will drain into an exit channel. If there are fields adjacent and downhill to the field used, this water can be drained into that field's furrow. This maximizes the efficiency of the system. If there are no fields that excess water can be drained into, the water flowing into the field should be reduced. A valve on the input pipe can reduce to flow minimize the amount of water pooling at the exit channel.

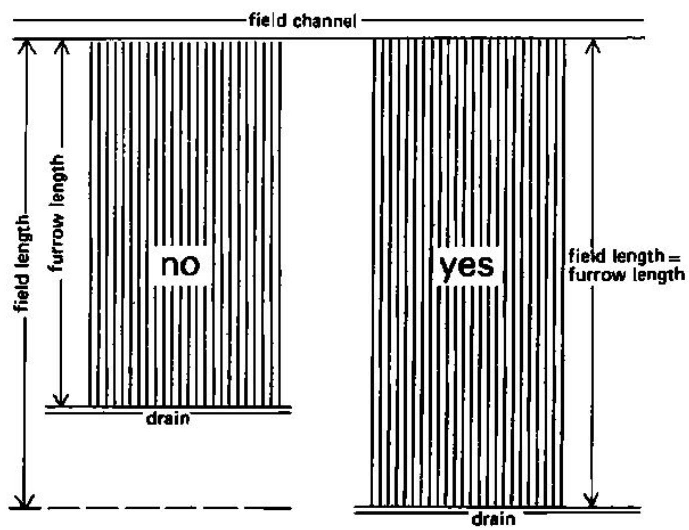


Figure 4.4.4.1b Straight Line Furrows

4.4.4.2 Flow to Furrows

The field channel will run along the top edge of each field. It will lie an inch or 2 above the level of the furrows. Small openings in the wall of the field channel will allow water in the field channel flow into each furrow at an equal rate. The openings will be level with each other ensuring that water begins flowing into the furrows at the same time and rate. Figure 4.4.4.2 below demonstrates the water flow from field channel to furrows (FAO UN 2016).

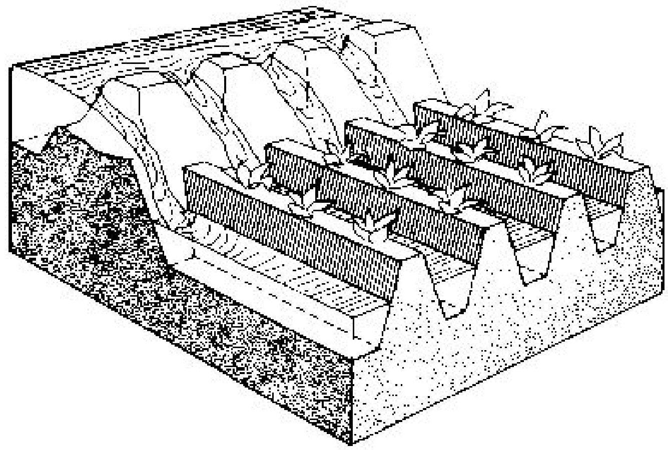


Fig. 4.4.4.2: Water flows into the furrows through openings in the bank

4.4.4.3 Soil Considerations

Most types of soils can be used in furrow irrigation, however sandy soils are less desirable because they infiltrate very rapidly. By observing and testing the soil, the soil in Woreta was determined to be either clay loam to clay soil. These have estimated infiltration rates of 1-10 mm/ hour (Food and Agriculture Organization of the UN 2016). This is an ideal soil to use in furrow irrigation. It is ideal because it will have a slow infiltration rate and the length of the furrows can be maximized. The introduction of new soil to construct the furrows would not be necessary.

4..4.4.4 Furrow Spacing

In order to maximize the production of the fields while conserving water, modifications can be made to the spacing of existing furrows. In clay soils, there is much more lateral movement than that of a sandy soil. With the soil in Woreta, the furrows can be spaced farther apart than in regions with coarse grain soil. Typically in a clayey soil, adjacent furrows should be 75-150 cm apart. Due to the farming practices used in the community, we recommend that the farmers can expand this distance and use a double ridged furrow, also known as a bed. These beds can be spaced 2-4 meters apart.

With a clay soil, the furrows can be made wider and shallower to maximize the area that the water will infiltrate. This will ensure that the crops on the innermost rows of the bed receive the irrigation. According to recommendations by the Food and Agriculture Organization of the UN, the width of the furrow should be 5- 10 times the depth of the furrow (FAO UN 2016). Figure 4.4.4.4 below shows the recommended shape of the furrow.

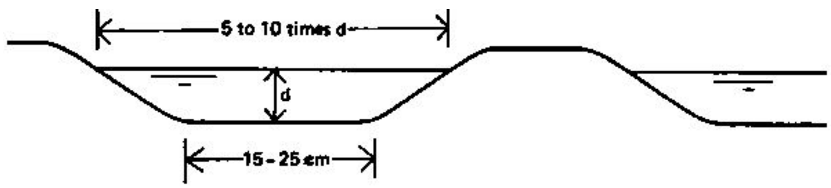


Figure 4.4.4.4. Wide, Shallow Furrow on a Clay Soil

4.4.4.5 Construction/ Modifications

The irrigation design plan will irrigate fields that currently have no furrows or could use more furrows. This requires the construction of new furrow ditches. These furrows can be constructed using supplies accessible to farmers in the community and can be powered by animal or hand drawn tools.

If the field is flat or has a mild slope, the furrows can be set in a straight line. The recommended maximum slope for this field is 0.5%. In order to set a straight line to follow, a rope or string can be stretched down the length of the field. Ranging poles should be used incrementally to keep the string tight and in a straight line.

If the field has a slope greater than 0.5% then the furrows should be constructed along the contour of the slope. The first guide furrow should be set along the upper edge of the field. A leveling device can be used to keep the furrow running along the contour. The next guide furrow is then set 4-6 meters parallel to the first furrow. A simple line level would be sufficient to lay down a general contour (FAO UN 2016).

A tool such as a ridger-plow can be used to construct each furrow one at a time. This is a tool used by most farmers in this community and can be operated by hand or with the use of animals like cattle.

For the fields that already have furrows, if they are on sloping land and do not follow the contour, the furrow can be modified. A new line can be set along the contour and a new furrow can be dug. It is recommended that the furrows are set about 2-4 meters apart on flat ground and 4-6 meters apart on a slope because water will infiltrate farther downhill.

4.4.4.6 Furrow Maintenance

For the efficiency of the irrigation system it is important that the furrows are inspected and maintained regularly. While inspecting the existing furrows, it was observed that many are damaged or beginning to collapse. It was also observed that many furrows have dry spots as well as places with weeds and other vegetation.

The furrows should be cleared of all weeds regularly. This vegetation takes water which should be infiltrating to the roots of the crop being cultivated.

After many seasons of use, the water flowing down the furrows can begin to erode the soil along the upper part of the channel and deposit sediment in the lower end. This case should be checked for at the beginning of each irrigation cycle. If it is observed that sediment is accumulating on the downhill end of the furrow, this sediment should be removed and replaced to the uphill side (Woodgate 2016).

This maintenance must be conducted whenever erosion is observed. If this is not done regularly, the furrow uphill will collapse and cause excess amounts of water to be spread out on the input of the beds. The downhill part of the furrow will narrow and receive much less irrigation than is necessary. The crops downgrade will suffer.

4.4.5 Cost Analysis

4.4.5.1 Capital Costs

The mechanisms requires to move water from the exit of the distribution line (feeder pipes) to the crops themselves will be constructed from natural materials found in the community. The only materials in this mechanism will be clayey soil and rocks. The clayey soil will form the field channels and furrows and the rocks serve to slow dissipate the erosive strength of the water from the nozzle. The fields being irrigated are already made up of clayey soil and contain necessary rocks. For this reason the materials costs for irrigation will be negligible.

The cost of constructing the field channels and furrows will also be neglected. For the reason that this projects will be implemented by a non-profit organization, the individuals who will be constructing the irrigation will be volunteers of the farming community in Woreta. The farmers have been constructing and using field channels and furrows for generations. They already posses the necessary tools for the construction of new furrows, and modifications to old. These tools include shovels, ridge-plows, and cattle for pulling the plow.

4.4.5.2 Operations and Maintanence Costs

The furrows and field channels will be need regular inspection and maintenance to ensure that the water will reach the crops in the field. This system will be maintained and inspected by the farmers using the fields. The same tools and materials will be needed as in the construction of furrows and field channels. As with the construction furrow and field channel construction the maintenance costs will be negligible.

5. References

"As Ethiopia Battles Devastating Drought, UN Sends in Emergency Health Team." *UN News Centre*. United Nations, 4 Dec. 2015. Web. 6 Dec. 2015.

Dewitte, O., Jones, A., Spaargaren, O., Breuning-Madsen, H., Brossard, M., Dampha, A., ... & Kilasara, M. (2013). Harmonisation of the soil map of Africa at the continental scale. *Geoderma*, *211*, 138-153.

Food and Agriculture Organization of the UN. (2016) *Irrigation Water Management*: *Chapter 3: Furrow Irrigation and Chapter 5: Irrigation System.* http://www.fao.org/docrep/s8684e/s8684e04.htm Online. Feb. 2016

"InterNACHI's Standard Estimated Life Expectancy Chart for Homes." *InterNACHI*. International Association of Certified Home Inspectors, 2016. Web. 02 Apr. 2016. https://www.nachi.org/life-expectancy.htm

Jones, A., Breuning-Madsen, H., Brossard, M., Dampha, A., Deckers, J., Dewitte, O., Gallali, T., Hallett, S., Jones, R., Kilasara, M., Le Roux, P., Micheli, E., Montanarella, L., Spaargaren, O., Thiombiano, L., Van Ranst, E., Yemefack, M. , Zougmoré R., (eds.),2013, Soil Atlas of Africa. European Commission, Publications Office of the European Union, Luxembourg. 176 pp.

Lemi, A., 2005. Rainfall Probability and Agricultural Yield in Ethiopia. *Eastern Africa Social Science Research Review* Vol. **21**(1), pp. 57–96. Table 1. p. 61

"Major Rivers of Ethiopia." *About Ethiopia*. EthioVisit, n.d. Web. 06 Dec. 2015.

Ministry of Water Resources (1999). Semi-Detailed Soil Survey. Abbay River Basin Integrated Development Master Plan Project. Phase 2, Volume IX, Land Resource Development, Part 2, Addis Ababa, Ethiopia..

Rossman, Lewis A. *EPANET 2 User's Manual*. National Risk Management Research Laboratory.

United States Environmental Protection Agency. Sept. 2000.

"Section 308 Piping Support." *International Plumbing Code.* International Code Council, 2007. Web. 02 Apr. 2016. <http://publicecodes.cyberregs.com/icod/ipc/2012/icod_ipc_2012_3_sec008.htm>.

Tóth, G., Montanarella, L., Stolbovoy, V., Máté, F., Bódis, K., Jones, A., ... & Van Liedekerke, M. Soils of the European Union.

Woodgate G.B. (2016) *Soil Erosion Control*. University of Melbourne Veterinary and Agricultural Sciences. http://trove.nla.gov.au/ndp/del/article/57495950 Online. Feb. 2016

6. Appendix

6.1. Distribution System Costs

6.1.1. Costs and Materials Needed for the Inflow Lines of the Distribution

Stand Pipe in River for Water Collection: Pipe Size = 110 mm

Length: 0.3 m

90 Degree Elbow Cost: 420 birr

Screen Over Pipe Inlet

Screen type: 1mm by 1mm grid wire

Cost: 120 birr for 1 meter squared of the screen material

A Valve to Shut Off Inflow Cost: 3400 birr

Pipe going from the standpipe to the top of the tank: Pipe Size = 110 mm

Length of Pipe for Inflow A: 228 meters Cost= 20,976 birr

Length of Pipe for Inflow B: 429 meters Cost = 39,495 birr

**These pipe costs include the cost of the 0.3m of standpipe*

Stands for Pipe Support of Elevated Piping

Distance between stands: 1.22 meters

Number of stands for Inflow A: 57

For Inflow A, needs stands for 70 meters of the length of pipe.

Number of stands for Inflow B: 32

For Inflow B, needs stands for 40 meters of the length of pipe.

Pipe Clamps

Cost for Number of Stands of Inflow A: 1,710 birr

Cost for Number of Stands of Inflow B: 960 birr

90 Degree Elbow into the top of the tank   Cost: 420 birr

Table 6.1.1: Breakdown for total costs of the distribution inflow lines. All materials are for 110 mm diameter.

Material	Inflow A Cost (birr)	Inflow B Cost (birr)
90 Degree Elbows	840	840
Screen	120	
Valve	3400	3400
Pipe	20976	39495
Pipe Clamps	1710	960
Total Cost (birr)	27046	44815
Total Cost for the Distribution Inflow Lines (birr)		71741
Total Cost for the Distribution Inflow Lines (USD)		$3,416.24

*One purchase of the screen material will be enough for both inflows.

6.1.2. Costs and Materials Needed for the Main Line of the Distribution

Tank to Branch 1: Pipe Size = 90 mm

Length of Pipe: 298 meters

Valve Directly After Tank   Cost: 2600 birr

Reducing coupling directly before Branch 1

Size: 90mm – 75 mm   Cost: 180 birr

To Connect Branches to the Main Line: Pipe Size = 75 mm

Tees

Number required: 11 Cost 11 Tees: 2,090 birr

Branch 1 to Branch 9 pipe stretch: Pipe Size = 75 mm

Length of Pipe: 336 meters

Valve after Branch 4 Located on the Main Line Cost: 2000 birr

Valve after Branch 9 Located on the Main Line Cost: 2000 birr

Branch 9 to Branch 11 pipe stretch: Pipe Size = 75 mm

Length of Pipe: 342 meters

Valve after Branch 11 Located on the Main Line Cost: 2000 birr

Table 6.1.2: Breakdown for total costs of the distribution main line.

Material	**Cost (birr)**
90 mm Valves	2600
Reducing Coupling (90mm to 75mm)	180
75 mm Tee	2090
75 mm Valves	6000
298 meters of 90 mm Dia. Pipe	21456
678 meters of 75 mm Dia. Pipe	35256
Total Cost for Main Line (birr):	67582
Total Cost for Main Line (USD):	$ 3219.19

6.1.3. Costs and Materials Needed for the Branches of the Distribution:

Table 6.1.3: Breakdown for costs of the distribution branches. All branches are sized to 50mm diameter high quality PVC pipe.

Branch Number	Length of Pipe Required (mm)	Cost for this Length of Pipe (birr)	Number of Tees Required	Cost of Total Number of Tees (birr)	Number of Valves Required	Cost of Total Number of Valves (birr)	Cost of 90 Degree Elbow (birr)	Cost of Reducing Coupling (75mm to 50mm) (birr)
1	67.9	977	2	240	3	2040	120	90
2	79	1137	2	240	3	2040	120	90
3	80.3	1152	2	240	3	2040	120	90
4	44	633	1	120	2	1360	120	90
5	114	1641.6	3	360	4	2720	120	90
6	164	2361	4	480	3	2040	120	90
7	160	2304	4	480	3	2040	120	90
8	90.1	1296	2	240	3	2040	120	90
9	73.7	1051	2	240	3	2040	120	90
10	170	2448	4	480	5	3400	120	90
11	196	2822	5	600	6	4080	120	90
Totals:	1239	17822.6	31	3720	38	25840	1320	990

Total Cost for the Distribution Branches (birr): 49692.6

Total Cost for the Distribution Branches (USD): $2366.31

6.1.4. Cost of Other Materials Needed for the Distribution System:

Table: Material costs associated with project implementation.

Object	Cost	Description
Super Glue	$14.87 at Walmart	To Fasten Screen onto PVC Pipe for Inlet of Inflow Lines
PVC Cement	1000 gm = 800 birr	Glue and Primer

6.2 Storage Tank Costs

6.2.1 Bill of Quantities and Material Specifications

Table 6.2.1a: Material quantities and specifications for the construction of the ferrocement tank.

Items	Quantity	Unit	Material Specifications
Sand	44.122	m^3	Well graded sand with no organic or chemical impurities
Hollow Blocks	236	pieces	0.20m x 0.40m hollow cement blocks
Cement	6424.338	kg	OPC Type Cement
Coarse Aggregate	11.879	m^3	2cm size gravel
Reinforcement Bar	2309	m	9mm Rebar

Chicken Wire	178	m	Galvanized mesh with 3x3cm mesh opening
Central column	2.7	m	Pipe PN 20 with 20mm diameter

6.2.2 Ferrocement Construction Tools

List of ferrocement construction tools needed are provided below:

- Hammer
- Plumb Bob
- Wire Snips
- Hack Saw
- Wood Saw
- Wire Brush
- Sieve
- Chisel
- Sledge Hammer
- Wheel Barrow
- Paint Brush
- Shovel
- Nails
- Mixing Platform
- Hoe

*The following tools will be needed during the construction process. Some of these items are specific and will be bought on site. Prices for a majority of these tools are unknown, therefore $500 has been included in the overall price of the tank for the purchase of these tools.

6.2.3 Cost of Materials needed for the Ferrocement Tank

The materials and costs related to the construction of the ferrocement tank are provided in **Table 6.2.3a** the costs have been broken down for the: Foundation, Base Slab, Ferrocement

Walls, Ferrocement Roof and Central Column. Five hundred dollars has been added to the final overall cost for the purchase of necessary ferrocement construction tools.

Table 6.2.3a: Breakdown of total costs of the ferrocement tank.

		Material	Quantity	Unit	Price Per Unit	Total Price (birr)	Total Price (USD)
Foundation	Substructure	Sand	35.34	m^3	\$23 per 1 m^3	37.74	812.82
		Hollow Blocks	236	pcs	\$1.33 per block	14.57	313.88
					Total Foundation Price	**52.31**	**1126.70**
		Material	Quantity	Unit	Price Per Unit	Total Price (birr)	Total Price (USD)
Base Slab	Lean Concrete	Cement	943.351	kg	\$0.37 per kg	16.20	349.04
		Sand	2.063	m^3	\$23 per 1 m^3	2.20	47.45
		Stone	3.483	m^3	\$35 per 1 m^3	5.66	121.91
		Water	0.672	m^3			
	Rebar Reinforcement	RB 9mm	1760	m	\$1.35 per kg	110.31	2376.00
	Concrete	Cement	3016	kg	\$0.37 per kg	51.81	1115.92
		Sand	4.241	m^3	\$23 per 1 m^3	4.53	97.54
		Stone	8.396	m^3	\$35 per 1 m^3	13.64	293.86
		Water	1.768	m^3			
					Total Base Slab Price	**204.35**	**4401.72**
		Material	Quantity	Unit	Price Per Unit	Total Price (birr)	Total Price (USD)
Ferrocement wall	Chicken Wire	Wire Mesh	126	m	\$6 per m	35.10	756.00
	Ferrocement	Cement	1224.026	kg	\$0.37 per kg	21.03	452.89
		Sand	1.224	m^3	\$23 per 1 m^3	1.31	28.15
		Water	0.487	m^3			
	Rebar Reinforcement	RB 9mm/2m	314	m	\$1.35 per kg	19.68	423.90
					Total Ferrocement Wall Price	**77.11**	**1660.94**
		Material	Quantity	Unit	Price Per Unit	Total Price (birr)	Total Price (USD)
Ferrocement Roof	Rebar Reinforcement	RB 9mm/5m	235	m	\$1.35 per kg	14.73	317.25
	Chicken Wire	Wire mesh	52	m	\$6 per m	14.48	312.00
	Ferrocement	Cement	1033.961	kg	\$0.37 per kg	17.76	382.57
		Sand	1.044	m^3	\$23 per 1 m^3	1.11	24.01
		Water	0.4176	m^3			
					Total Ferrocement Roof Price	**48.09**	**1035.83**
		Material	Quantity	Unit	Price Per Unit	Total Price (birr)	Total Price (USD)
Central Column	Pipe	PN 20 20mm	2.7	m	\$5.34 per m	0.67	14.42
	Mortar	Cement	207	kg	\$0.37 per kg	3.56	76.59
		Sand	0.21	m^3	\$23 per 1 m^3	0.22	4.83
		Water	0.8	m^3			
					Total Central Column Price	**4.45**	**95.84**
					Total Overall Cost	**11158.79**	**8821.02**