Social and Engineering Aspects of an Aquacultural Development Project in the Nakasongola District of Uganda

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Abstract:

Political upheaval and civil war in the 1970's and 1980's, coupled with AIDS deaths in the 1980's and 1990's, have brought hardship on the people of the east African country of Uganda, especially the children. Cornerstone Development Uganda, a charitable organization founded in 1988, has established a 700-head working dairy cattle ranch in Nakasongola District of central Uganda to provide opportunity, education, and income for local families. Another charitable entity, African Children's Mission (ACM), operates a feeding program providing meals to 1300 children daily at primary schools on the ranch and in the neighboring community, and organizes building projects in support of the ranch. ACM needed design assistance to build a training center, waste treatment system, and aquaculture operation on a 50 ha parcel of land adjacent to the ranch. ACM requested technical assistance from Engineering Ministries International (EMI), a U.S.-based group. EMI recruited and organized a group of eleven professionals from various parts of the United States to visit the ranch in October 2001, to complete surveys and collect data for the designs. This paper will present the social and cultural aspects of the visit, and the process of data assimilation and design that has been utilized to engineer the fish ponds and a water reservoir to support a pond aquaculture operation. Some of the challenges of engineering with limited information are mentioned, including estimating precipitation and watershed boundaries. University-trained Ugandans will be involved in the building and operation of this project. It is their hope that the system will provide a model for development for others in their district. The project demonstrates that professionals in developed countries can donate their expertise to provide for improved opportunities for others, and build rewarding relationships in the process.

Introduction:

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The continent of Africa offers a diversity of peoples, animal and plant life, climates, and geography. The history of this continent continues to unfold, and the current condition of the peoples is strongly influenced by past events. Uganda, situated on the equator and neighboring Kenya, Tanzania, Rwanda, the Democratic Republic of the Congo, and the Sudan in east Africa, is a country that is rebuilding its capacity to thrive following civil and political upheaval in the decades of the 1970's and 1980's.

Figure 1: Map of Uganda and bordering nations.

Britain relinquished its political control of Uganda in 1962, at which time Uganda enjoyed a higher standard of living than all of its neighboring states. Political rivalries from the beginning of independence led to upheaval that resulted in coup d'e;tats in 1966 and 1971. The latter coup initiated Idi Amin's eight-year reign of terror, throughout which prominent political, educational, and religious leaders, and anyone in the military who posed a threat to him, were murdered. After another failed attempt at constitutional rule, the country's first Prime Minister, Milton Obote reassumed power and continued the path of brutality. A successful guerrilla campaign to oust Obote, led by Yoweri Museveni, was waged from 1981 to 1985. The opposition was able to organize, train, and exist within two hours of the capital city of Kampala, in a district named Luwero. This district became the location of mass bloodshed as Obote's forces massacred civilians in an attempt to stop their opposition. An estimated 300,000 people lost their lives during this period of time as a result of political murders and war (Tumusiime, 1992), perhaps as many as 200,000 in the area known as the Luwero Triangle (Museveni, 2000; Pirouet, 1995). The broad-based government established in early 1986 had to continue fighting rebels in the north and east of the country until relative calm prevailed in the 1990's.

The social and economic fabric of Uganda has been further strained by the impact of AIDS, which was discovered there in the early 1980's. Later in the decade, Uganda had the highest reported rate of HIV infection in the world (Whitworth, 1999). One study in Uganda showed that slightly more than 10% of the children aged less than 15 years had lost one or both parents (Kamali et al., 1996). Approximately 40% of these orphans had lost an HIV-1-positive parent.

Kamali et al. estimated that the rate of children orphaned in Uganda increased by 50% or more during the two decades prior to their report (1996), due to the AIDS epidemic and civil war in the 1980's. The care of these children has fallen on extended families in the community (Seeley et al., 1993). In areas of the country where the rebuilding of the once-prosperous economy of the country is slow, these family networks face the additional hardship of lack of opportunity. One area where recovery has been slow and social needs are high is the Nakasongola District, located in the heart of the Luwero Triangle, approximately 120 km north of Kampala. A charitable organization working in this area has envisioned a community-based development approach to improve the basic living conditions of the people. The objectives of this paper are to describe the social/cultural and technical aspects of one project, an aquaculture development, in the Nakasongola District of Uganda, and to encourage professional engineers in the more developed world to use their skills to improve the nutritional and economic well being of less fortunate people groups.

Figure 2: Location of Luwero and Nakasongola Districts

Social Aspects

Cornerstone Development Uganda is a charitable organization established in 1988 for the purpose of addressing the specific physical and spiritual needs of those communities exhibiting the greatest need (Miller, 1999). One of Cornerstone Development Uganda's (CDU) major projects has been the development of a commercial dairy ranch, named Ekitangaala Ranch, in the Nakasongola District. In addition to the farming operation, a primary school, an advanced-level high school, vocational training program, health clinic, and community development program are based at the ranch, where approximately one hundred people reside and are employed. Another charitable organization, African Children's Mission, working under the auspices of CDU, operates a feeding program providing meals to 1300 children daily at primary schools on the ranch and in the neighboring community, and organizes building projects in support of the ranch. ACM needed engineering design assistance to construct a small office, training center, waste treatment system, and pond aquaculture operation on a recently-acquired 50 ha parcel of land adjacent to the ranch. ACM requested the assistance of Engineering Ministries International

(EMI), a U.S.-based group whose purpose includes provision of technical design help to the poor. EMI recruited volunteers from across the United States with skills in various engineering disciplines needed for the projects. The group of eleven professionals visited Ekitangaala Ranch in October, 2001, to complete surveys and collect data for the project designs.

Enroute and upon entry to Uganda, the team was given a briefing on cultural practices and customs within the country. Such training was important to prepare the team to work with Ugandan nationals, and to awaken the team to in-country sensitivities, such as the wearing of any clothing with a camouflage design, which was taboo because of its association with the military, and potential dangers of being in African bush country.

During the days of work at Ekitangaala Ranch, there were opportunities to meet and work with several Ugandan nationals. The nationals assisted with the survey, the location and conceptual development of the aquaculture operation, and the conceptual design and construction techniques for the office and training center. Many of them were young men from the advanced-level high school on the ranch, Cornerstone Leadership Academy (CLA). CLA is a boarding school for disadvantaged men and combines challenging academics with leadership training. Several graduates of CLA have attended Makerere University in Kampala. The intended purpose of developing indigenous leadership is being realized as graduates have returned to take leadership roles in the vocational school, children's outreach, farm operations, school feeding program, and community development project associated with the ranch.

The life story of one of the CLA graduates ties together the past decades of Uganda's history with the hope of a developing future. This young man was born in northern Uganda in 1975; his father was killed in fighting when he was three-months old. Being orphaned, he was taken in by relatives in Kampala, where he experienced the hardships of growing up through the era of tension and bloodshed. At some point he became associated with CDU. He attended CLA and graduated with high marks enabling his entrance to Makerere University, where he is now completing studies in fisheries and wildlife. Part of his program is to plan the aquaculture operation at Ekitangaala Ranch. Intelligent and articulate, he is hopeful that this operation will be a model for the surrounding district. He desires to see opportunity grow for the Ugandan people, including an improved future for his relatives in the north, among whom there are orphans.

The design team visited the primary school on Ekitangaala Ranch at noon one day, helping with the meal distribution and interacting with the children. There was opportunity later in the week to assist with a reading program at the school and to visit students in their homes. The team experienced other facets of native life, attending a worship service, sharing a community meal, and visiting the market.

Technical Methods

The group of eleven professionals from various parts of the United States visited Ekitangaala Ranch from 22 to 28 October 2001 for the purpose of completing land surveys and collecting data for the requested project designs. The group consisted of two agricultural engineers, four civil engineers, one electrical engineer, one architect, two surveyors, and one health care administrator. Attempts to obtain geographical information and meteorological history prior to the visit were only moderately successful. The team was told that maps showing detailed information are kept from widespread circulation because of the history of guerrilla warfare within the country. Much of the meteorological record was interrupted during times of armed conflict within the country.

The planned building and aquaculture developments were to be situated on a recently-purchased 50-ha parcel adjacent to the ranch. The surveyors invested three days confirming measurements of a local survey of the property, and determining elevations around the perimeter of the plot and through a low-lying area where the aquaculture development was to be located. The survey proceeded slowly due to equipment limitations and vegetation hindrances. During this period interviews were conducted with the field leader of ACM, the national leaders of various organizational units within ACM, and the ranch's construction manager to obtain design input to the various projects and to review local building construction practices. Analyses of the soils were performed. On the final day of work at the site, subgroups of engineers prepared conceptual plans for the four projects and presented them to the ACM field leader and the entire design team. Once the group returned to the United States, the engineers completed the design work for which they were responsible over a period of three months. Plans and specifications were sent to the EMI headquarters; EMI delivered them as one package to ACM's field leader. The engineering team donated a total of 800 hours of their time toward the projects. Each member of the engineering team financed his or her travel to and from Uganda, and a trip overhead cost. The group requesting the engineering assistance, ACM, provided in-country transportation, food, and lodging for the team.

Aquaculture Design

The goal of the design of the aquaculture facility was to situate from three to six 20 m by 60 m ponds along with a reservoir for make up water on a 2.5 ha low-lying portion of the 50 ha parcel. The design strategy was to estimate the water available for the aquaculture operation from precipitation and runoff, to determine the water consumption needs of the operation, and to design a reservoir that could supply an adequate quantity of water to the series of ponds.

Ekitangaala Ranch is remotely located from cities for which precipitation data can be found. Therefore annual precipitation was estimated at 1277 mm, based upon the average of three cities of known precipitation, and of approximately equal distance from, and elevation to the ranch: Kampala to the south, Masindi to the northwest, and Serere to the northeast (Africa Data Dissemination Service).

The aquaculture facility was designed for a ten-year storm event. Two methods were used to estimate the ten-year storm at 130 mm for Ekitangaala Ranch. Actual data were found for Kampala, Masindi, and Serere representing rainfall for each dekad (ten-day period) throughout the year (Texas A&M website). The number of years for which complete records were available is approximately ten, as table 1 below indicates. The greatest rainfall in any single dekad during these years is shown. An assumption was made that two-thirds of the dekad's total precipitation fell during a single storm, the average value resulting in 132 mm.

Table 1: Maximum 10-day precipitation record for three cities in Uganda.

	Kampala	Masindi	Serere	Average of three locations	66.7% of average
No. of years for which a complete record is available	10	9	7		
Ten-day maximum precipitation: [mm]	156	200	238	197	132

An empirical chart located in a design handbook entitled Hand-built Earthen Micro-Dams, published by the Mennonite Central Committee (Goertzen, 1988), was also used to approximate the ten-year storm total. The curve predicts 128 mm for a ten-year event based upon an average annual rainfall of 1277 mm. The ten-year storm estimate for Ekitangaala Ranch was set as a round number, 130 mm, between the values obtained based upon dekad measurements in surrounding cities and a published chart.

SEDCAD 4 hydrology software (Warner et al., 1998) was used to calculate a peak flow rate of 46.2 m^3/s and runoff depth of 98 mm for the watershed associated with the outlet of the aquaculture operation. These values were in reasonable agreement with hand-calculated values based upon the SCS Curve Number Model.

The size of the watershed was estimated to be approximately four and one half km^2. The watershed was sectioned into three subwatersheds (SW1-3) having outlets associated with an existing reservoir 0.5 km from the aquaculture location, the planned aquaculture reservoir, and finally the aquaculture outlet (see figure 3).

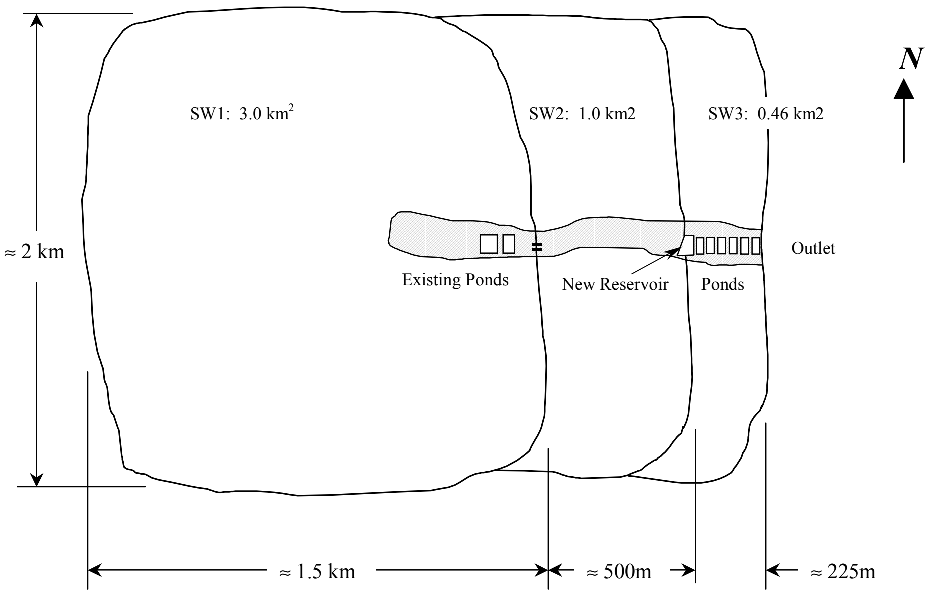

Figure 3: Subwatershed areas and outlets.

The dimensions and slopes of the watersheds from the low-lying areas (indicated by shaded crosshatching in figure 3) to the south boundaries were discerned based on the survey map measurements and field observation. The dimensions and slopes to the north and west were estimated based upon discussion with the ACM field leader, since no detailed topographic maps were available for the area. The watershed crossed brushy and swampy areas and local village lands, which hindered the determination of the watershed boundaries and slopes by measurement. The times of concentration were estimated for each subwatershed and the distance and slope along the flow path from outlet to outlet. Based on soil class D, and the vegetation types observed in the subwatersheds, curve numbers of 89, 89, and 88 were assigned respectively to SW1, SW2, and SW3. The 10-year, 6-hour design storm of 130 mm rainfall depth was used for the simulation. The storm intensity pattern was based on NRCS Type II, which is more extreme than Type I, and may be more representative of the storm outbursts experienced in the area. Another input setting is required for the software, indicating the relative runoff response of the land being studied: fast, normal, or slow. The fast response setting was used as the soil in the watershed was a sandy clay with a crusted surface. During the team's visit, an intense rainstorm was experienced; a rapid runoff was observed. SEDCAD 4 solves the peak flow of each watershed and sums them by convolution, adjusting the peak flow for routing.

A grass spillway was designed to carry the 10-year peak flow around the aquaculture ponds to the south. An iterative procedure of designing for stability, then designing for capacity was used (Wilson, 1999). For the capacity calculations, retardance class B was assumed for the grass in the lowland area, which is the class for 30 to 60-cm tall Bermuda grass. A conservative critical velocity of 1.5 m/s was used. For the stability calculations, a height of 6.2 cm was assumed as a result of grazing; retardance class D was chosen for this case. A spillway width of 50 m was determined to be adequate to carry runoff around the ponds. At this width, the estimated 10-year depth in the spillway would be 0.75 m. This depth seems reasonable given the testimony of ACM's field leader, who stated that the highest he has seen water in the lowland over the past five years was "up to the belly of a horse."

The water needs for the aquaculture operation were calculated based upon these assumptions: six ponds total- three at 0.5 m depth, three at 1.8 m depth; reservoir is to provide makeup water replacing daily evaporation and water change losses plus one fill per pond per year; reservoir to have the capacity to sustain the operation in case of a three-month drought during the dry season (January through March). A water balance was calculated for the ponds as follows:

$$P + I - E - S - OF - O = 0,$$

Where:
- P = precipitation
- I = inflow from reservoir
- E = evaporation
- S = seepage
- OF = overflow of precipitation; assume 50% of P
- O = outflow for fresh water change

Estimates were made of precipitation, evaporation, seepage, and excess precipitation and water change outflow. The inflow of make up water from the reservoir was determined using these estimates. The Penman equation was used to estimate evaporation from the pond surfaces (ASCE, 1990). Dew point temperature data from Nakasongola District were not available; therefore estimates based on recent dew points and seasonal changes were utilized. An evaporation model utilizing the Penman equation was calibrated with data from Texas, USA, an area with similar climate and fauna, and from which input data and evaporation were known. Table 2 shows the components of the water balance for each month of the year, given an average precipitation pattern.

Table 2: Components of fish pond water balance components

	Inputs		Outputs			
	Precip-itation [mm]	Inflow from Reservoir [mm]	Evapo-ration [mm]	Seepage [mm]	Overflow (est. half of precip.) [mm]	Daily Water Change [mm]
Month	P	I	E	S	OF	O
January	46	230	193	30	23	30
February	38	236	195	30	19	30
March	118	188	217	0	59	30
April	184	131	193	0	92	30
May	162	125	176	0	81	30
June	82	187	168	30	41	30
July	63	212	184	30	32	30
August	104	155	177	0	52	30
September	97	190	208	0	49	30
October	145	161	203	0	72	30
November	151	135	181	0	76	30
December	87	201	185	30	43	30
Totals:	1277	2151	2279	150	639	360

The reservoir was sized to provide make up water for the ponds with consideration for evaporation from the reservoir surface, plus a 20% safety factor. Selection of the surface area to depth ratio balanced the positive attributes of a deeper reservoir against the ease of hand digging a shallower structure. A deeper reservoir provides the needed storage capacity with a smaller surface area and therefore less evaporation loss, cooler water temperatures, and greater capacity to hold sediments. The plan for the reservoir identified a phase 1 and a phase 2 construction. The phase 1 reservoir would provide water for the initial three ponds that are planned. The phase 2 reservoir could be constructed later if additional ponds are dug and the water needs warrant it.

The low-lying area containing the aquaculture design, had a general slope of 0.6%, making it difficult to obtain elevation head to gravity feed make up water from the reservoir to the ponds. Figure 4 shows the elevations chosen for the structures.

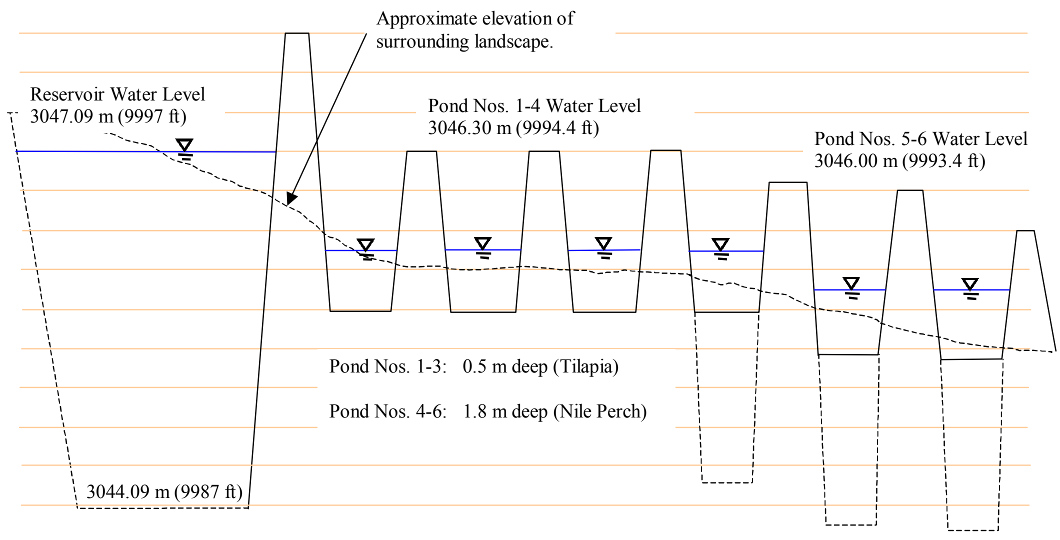

Figure 4: Reservoir and pond water surface elevations

Runoff water available to fill the reservoir was conservatively estimated to be 10 per cent of the precipitation on the water shed. During a year with a normal amount of precipitation, the reservoir surface has been calculated to remain above the pond surface elevations, even with one-month intervals between precipitation events. In drought conditions, it may be necessary to pump water into the ponds to sustain the operation.

A graph providing estimated fill times for the two volumes of ponds with two pipe diameter sizes, 10 cm (4 in.) and 15 cm (6 in.), was provided to the field. Final selection can be based upon cost, availability, and time requirements. The Hazen-Williams equation with a conservative coefficient (C = 100) was used to size the pipes (Yoo and Boyd, 1994).

Soil borings in the area of the swamp indicated that the upper 30 cm of soil was a sandy clay loam, with an estimated clay content of 30 to 40 per cent. Below 50 cm, the clay content increased to more than 50 per cent. Between 30 cm and 50 cm a band of loamy sand was found. A cutoff trench, backfilled with compacted soil of clay content 35 per cent or higher, was recommended around the perimeter of the reservoir and ponds to seal the structures from seepage loss through the layer of loamy sand.

The recommended slopes were 3:1 for the inside of the reservoir, 2:1 for the inside of the ponds, and 1.5:1 for the outside of the ponds (Yoo and Boyd, 1994). The south side of the reservoir was designed as part of the emergency spillway. The recommended slope for this side was between 3 and 5:1. Figure 5 shows the structure cross sections.

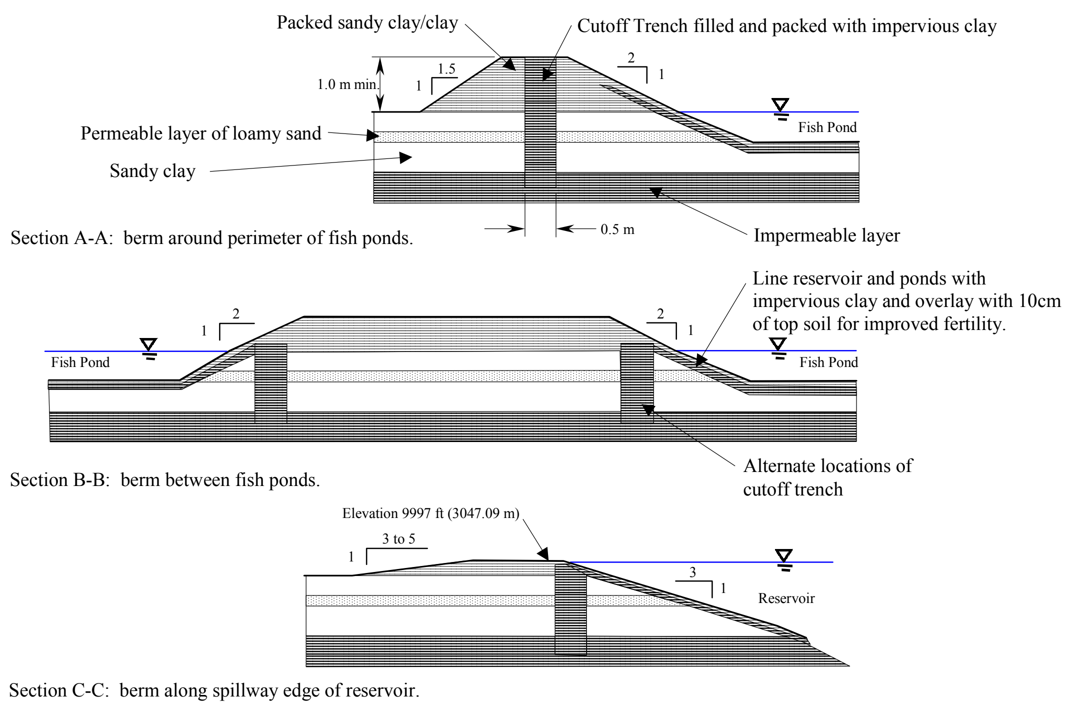

Figure 5: Reservoir and pond berm cross sections

Discussion

Numerous assumptions and estimates were made for input parameters of the hydrologic analysis. Under routine situations these assumptions and estimates would be challenged as not having scientific basis. However, given the limited data available, and understanding the reasons therefore, those attempting to design in these situations must make the best, educated estimates and decisions possible with the given information. Consideration for potential errors include, but are not limited to: actual annual precipitation is less than estimated, seepage losses are more than estimated, the watershed is smaller than estimated. Phase I of the aquaculture project includes construction of three fish ponds and a 3600 m^2 reservoir. The reservoir is oversized to account for uncertainties in the inputs. Two existing reservoirs with a total of 8000 m^2 area and four-meter depth are located on the ranch approximately 0.5 km from the proposed aquaculture operation. Used for watering livestock, these structures have held water through drought years in the past decade. This anecdotal information lends to the confidence of the proposed design.

The data used for the precipitation estimate of 1277 mm, spanned the years from 1971 to 1998 and was accessed from the Africa Data Dissemination website in December, 2001. Additional data has since been located that supports this estimate. A long-term annual rainfall estimate, based upon 727 months from 1915 to 1978, of 1253 mm was found for the region which would include the latitude and longitude position, and elevation of Ekitangaala Ranch (Worldclimate.com). Rainfall data are available on the Center for Natural Resources Information Technology website (Texas A&M) for the last two years from a reporting station in close proximity to the ranch, estimated differences in latitude and longitude are 0.010°S and 0.006°W. The data set is complete for year 2000; total rainfall was reported as 1287 mm.

The Ugandan government is conducting pond aquaculture research within the country. The operation at Ekitangaala Ranch anticipates benefiting from knowledge gained from this research. In fact, the pond areas and depths used for the design were based upon in-country findings.

ACM intends to construct the reservoir and ponds with local labor. Although the project will proceed more slowly by hand than if heavy earth-moving equipment were used, there is a short-term benefit of job opportunities for people in the surrounding community, and the key long-term benefit of community ownership in the operation. Funds to pay for wages, materials, and start-up costs will come from private donations obtained primarily from contacts in the United States.

Relationships made with nationals were a valuable and motivating aspect of the team's experience. The Ugandans highly value relationships; conversation and human closeness are important, which taught the team that these relational aspects are as important, or more important to the future of the envisioned projects than the technical aspects are. The EMI team found that more was gained from than given to the friendships made during the visit.

Surveying and geographic information tools exist that could have increased the speed of the topographic survey at the ranch site. One of the challenges of assembling a regionally-distributed team of members who are not familiar with one another is the determination of who will bring which pieces of equipment on the journey. Detailed pre-trip communication is recommended to decide the equipment to be transported, given the rigors of travel, the value of the tools, and the needs of the project.

Conclusion

A design team of eleven professionals, including two agricultural engineers, visited a working dairy-cattle ranch in Nakasongola District of central Uganda at the request of African Children's Mission, for the purpose of designing buildings and a pond aquaculture operation near the ranch. The team was recruited from various parts of the U.S. by Engineering Ministries International, a non-profit organization dedicated to serving the poor by donating design skills. African Children's Mission works under the auspices of Cornerstone Development Uganda, a charitable organization chartered to meet the needs of the poor of Uganda. A key component of Cornerstone's work is the establishment of schools to provide education and vocational and leadership training for the people of the remote surrounding villages.

The design team worked with national Ugandans, many who will be involved in the construction phase of the project and in the operation of the new programs associated with them. The relational aspects of the visit were key in providing information for the designs, and in developing local support for the work. Climatic and topographic information for the remote region was limited, necessitating the use of assumptions during the design of the pond aquaculture operation. Intense search of internet databases may have yielded more information.

Historical events can change the living conditions of a population. Engineers living in conditions of sufficiency can make themselves and their technical talents available to improve the living conditions of peoples through community development aimed at returning the society to self-determination. Today's political events will create tomorrow's opportunities to serve.

More Information can be received on Cornerstone Development Uganda by writing to them at: Cornerstone Development Uganda/P.O. Box 9242/Kampala, Uganda.

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