Life Cycle Assessment of a Small Garden Drip Irrigation System in Bénin

By

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A REPORT

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This report, "Life Cycle Assessment of a Small Garden Drip Irrigation System in Bénin," is hereby approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE IN CIVIL ENGINEERING.

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Preface

My service as a Peace Corps Volunteer (PCV) began in September of 2007 in Bénin, West Africa. I served as an environmental action volunteer in the rural village of Taïacou, located in the Atakora region of Bénin. Taïacou became my home and the Natemba ethnic group became my family for the next two years. As the days went by, I learned the concerns and needs of my community. Between discussions with locals, missionary friends and my committee members, I was inspired to implement a small garden drip irrigation project.

This report is in submission towards the completion of the requirements for a master's degree in Civil Engineering from the Master's International Program in Civil and Environmental Engineering at Michigan Technological University. This paper applies Jennifer McConville's matrix approach of life cycle thinking for sustainable development work. Unique here is the technology that is assessed and the geographical location. It is my hope that this study will serve as useful information to engineers and development workers.

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Acknowledgements

This paper is dedicated to my mother who has taught me that, above all, faith will overcome any barrier. If I may become half the woman she is I will be ever so fortunate.

And to Kate, who is an inspiration to me and many of the PCVs and staff members in Bénin. Your bright smile and beautiful face are missed. Your kindness and patience with all is admired. You brought sunshine into a room and laughter into our hearts. You are forever instilled in our hearts and in our memories.

A cultural habit in Bénin is the importance of taking the time to recognize people; to welcome them, to thank them, to acknowledge their presence. I would like to take this moment to thank the community of Taïacou, the women's group and the chief of Ouankou, and the staff at Jura Afrique and the Ministry of Hydrology. It is my hope that one day I will return to work with you again. The list of people to thank is endless. To all those individuals who made my service a memorable one, I thank you.

When I went to Taïacou for my post visit, the PCV I was to replace took me to drink *chouk* at this one particular stand in the market. While we were there, the rain hit hard and we all took cover at the primary school. This woman continued to serve us *chouk*, on the house, and we stayed with her for quite some time. Little did I know that this woman would later go on to become my neighbor, my friend, my guardian and my mother. There is not a day that goes by that I do not think of you, Angèle.

To Blair, Bogue and Jim, I leaned on you for support during my service. Thank you for believing in me. And to my family and friends, you are too many to list, but please know how sincerely grateful and blessed I am to have you in my life. Thank you for your love, prayers and faith in me.

Abstract

As in many developing countries, lack of water and food are serious problems in Bénin. In 2007, 35% of Bénin's population did not have access to improved drinking water sources while 70% did not have access to improved sanitation. Recently the rainy season in the Atakora region has been experiencing a decline in its annual rainfall amounts. Small-scale irrigation, coupled with greywater use, could be utilized during the dry season to allow families to grow their own vegetables, thus increasing their food supply and annual income, improving their diets and reducing the need to buy expensive vegetables at the market.

Here, the life cycle thinking assessment method of McConville (2006) is applied to a small scale drip irrigation system in Bénin that utilized greywater. The assessment method uses five assessment factors that cover social, economic, and environmental sustainability and applies them over five life stages of the project. The project overall score was a 61 (out of 100), scoring highest in the needs assessment stage (20/20) and lowest in the operation and maintenance stage (5/20). In terms of sustainability, the project scored highest in socio-cultural respect (18/20) and environmental sustainability (14/20). Lower scores were achieved for community participation (11/20), political cohesion (9/20) and economic sustainability (9/20).

1.0 Introduction

1.1 Bénin

The Republic of Bénin is a small, peaceful country in West Africa. Previously known as the kingdom of Dahomey, its southern coastal border became a trading post for Europeans trading weapons for slaves. Bénin became a French colony in 1872 and later went on to gain its independence from France in 1960. Since the 1990s, Bénin has been a "republic government under multiparty democratic rule" where currently President Boni Yayi has held office since 2006. French is Bénin's official language, however, over 60 dialects may be found throughout the country, with the wider variety spoken in the north. Its religions include Christianity, Islam and Animism. Spread later on by the slaves to the Caribbean and Brazil, Bénin is the birth place of voodoo (U.S. Dept. of State, 2009).

Bénin lies along the southern coast of West Africa. Its southern coastline borders with the Bight of Bénin while the rest of the country is bordered by Togo to the west, Burkina Faso

Figure 1: Map of Africa and Bénin

(Source: http://www.ulm-medicalise.ch/img/benin1.jpg)

and Niger to the north and Nigeria to the east. It is comparable to the state of Pennsylvania in size with a population of about 8.8 million (CIA, 2009). Climate divides the country into two regions, north and south. The northern climate is semiarid consisting of one rainy season and one dry season. The rainy season lasts from about May to October with a variation in rainfall of around 900-1450 mm/year (WFP, 2009a). The dry season lasts from around November to April and includes the Harmattan, the time when the winds from the Sahara Desert blow. While Harmattan is significantly stronger in the north, it leaves a sheet of dust on the vegetation throughout the country. Bénin's southern climate is hot and humid and consists of two rainy seasons and two dry seasons.

Bénin's economy is highly reliant on agriculture which contributes about 33% of the Gross Domestic Product (GDP) (WFP, 2009b). Some of the main crops grown are corn, millet, sorghum, cassava, beans and yams. Much of its population, mainly those living in rural villages, is dependent on subsistence agriculture. The two types of season set the pace for farmers and their yearly crop production.

1.2 Taïacou

Taïacou is a rural village in the Atakora region of northwestern Bénin. It is in the commune of Tanguiéta, located 10 km southwest of Tanguiéta, and has a population of about 7,000 people. It lies 10 km southwest of the Zone Cynegetique de la Pendjari, just south of the

Figure 2: Map of Taïacou in relation to the Atakora Region
(Source: *Institut Géographique National*, 2000)

Parc Nationale de la Pendjari. Taïacou consists of 12 smaller villages, or communities, and sits along the Atakora Mountain Range at an elevation of around 290 m. It is home to the Natemba ethnic group. There is neither electricity nor running water in the village. Community members gather water from pumps, wells or streams. The Ministry of Hydrology is currently working on the design of water towers to be constructed in communities throughout Taïacou.

Figure 3: View of Taïacou (photo provided by Olga Y. Castro)

Taïacou has two seasons throughout the year, rainy and dry, each lasting about six months. However, the amount of annual rainfall tends to vary. Each year the rain seems to be decreasing, providing less water for agriculture. The community depends on its rainy season for subsistence farming where the main crops grown are corn, millet, sorghum and beans. The dry season is their down time as no farming can be done. During these months, community members are busy constructing homes and attending ceremonies. The mortality rate for elders is highest during this season as well. In Bénin, elders are the most respected community members and therefore it is important to hold a burial ceremony when an elder passes away. These ceremonies last nine days and everyone in the community is invited. It is also tradition to celebrate the death of an elder that passed away years before. *Choukoutou* (*chouk*), the local beer made from millet, and *sodabi*, the moonshine of Bénin, are important items at these ceremonies.

1.3 Problem and Study Objective

As in most developing countries, lack of water and food are serious problems in Bénin. In their efforts towards achieving the Millennium Development Goals (MDGs), The World Bank (WB) reports that in 2007, 35% of Bénin's population did not have access to improved drinking water sources while 70% did not have access to improved sanitation (WB, 2009). Moreover, the World Food Program (WFP) states that in a recent analysis, about 12% of Bénin's population does not have food security and about 13% are at risk. Those mostly affected are households that have low education levels, homes with women as head of the household and households that produce their own food (WFP, 2009a).

The Atakora region of Bénin is one of the four regions that make up the 60% of households without food security on a national level. Around 29% of the region's population is food-insecure. The region also holds the highest percentage of chronic malnutrition in children under the age of five, exceeding the critical limit of 40% (WFP, 2009a).

Recently the rainy season in the Atakora has been experiencing a decline in its annual rainfall amounts. The number of rainy days is decreasing on a yearly basis causing a later start and earlier finish to the growing season. The fluctuation in annual rainfall quantities makes for unstable conditions for crop production, creating major concern to a population dependent on subsistence agriculture. This is especially important in Africa because of the high percentage of farmers who depend solely on precipitation for crop production. To provide a feel for the rainy-dry season in this area, Figure 4 shows the seasonal rainfall pattern for two consecutive years in West Africa.

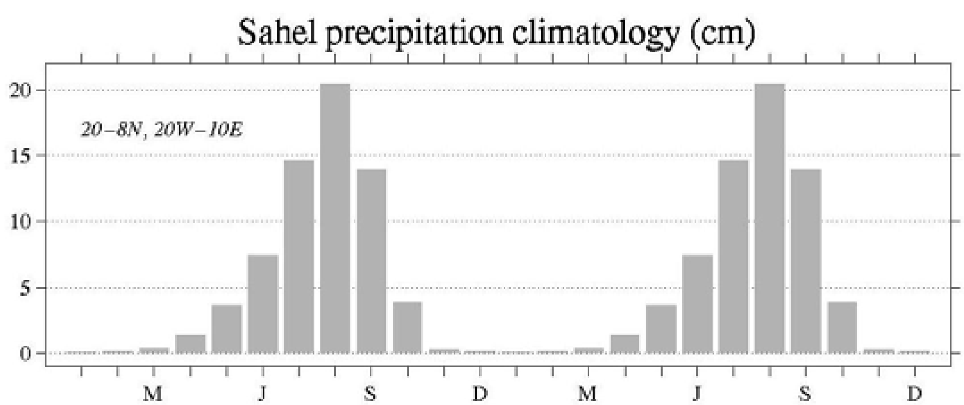


Figure 4: Rainfall Pattern in West Africa for Two Consecutive Years (Solar Electric Light Fund, 2009)

In collaboration between the Beninese government and community and the United States Peace Corps (PC), I was partnered with Jura Afrique as an environmental action volunteer to serve the community of Taïacou. Jura Afrique is an environmental non-government organization (NGO) based in Tanguiéta. Their objectives include protecting the environment, promoting livestock production and micro-finance and fighting against poverty and inequality through women group based activities.

During the 2007-2008 dry season, community members kept talking about how much less of a harvest there has been, meaning less food to feed their families. I listened to these people discuss the rainy season that had just passed. They were concerned with the decrease in rainfall and its effects on their food supply, a major concern to a community that is dependent on subsistence farming. After listening to many of the same conversations over this topic, I was determined to find a research topic that would address their concerns, or at least introduce an idea that may be accepted with time. After several discussions with a variety of community members in the surrounding area, I proposed a garden project using drip irrigation and greywater that could be utilized during the dry season. Families would be able to grow their own vegetables thus increasing their food supply and annual income, improving their diets and reducing the need to buy expensive vegetables at the market. Greywater could be applied to agricultural land, thereby decreasing the amount of greywater haphazardly thrown into the fields and around the homes where it might attract disease vectors. After presenting the project to Jura Afrique, we decided it would be best to work with one of the women's groups in Taïacou and identified the women's group in Ouankou as a strong, hard working and motivated group of women.

Also important to this research, the life cycle thinking assessment method of McConville (2006) had only been implemented on two water/sanitation technologies (i.e., wash area and surface rainwater harvesting) in one geographical setting (Mali). That assessment method has identified five assessment factors that cover social, economic, and environmental sustainability and applies them over five life stages of a water/sanitation development project. Accordingly, this study's research objective was to apply the life cycle thinking assessment method to a small scale drip irrigation system in Bénin.

2.0 Background

2.1 Drip Irrigation

"Because sub-Saharan Africa is subject to more extreme climate variability than other regions, it needs improved water storage capacity" (Tatlock, 2006). Africa's regions with extensive periods of drought and inadequate rainfall contribute to the continent's food shortage problem. While nature cannot be controlled, society does have the ability to develop and practice more efficient water usage techniques in order to improve water supply management. One type of technology that may contribute to the improvement of water supply management and the associated food crisis is drip irrigation.

Drip irrigation is defined as "the slow, frequent application of small volumes of irrigation water to the base or root zone of plants" (Smeal, 2007). More widespread adoption of this technology in recent years began to occur in the late 1960s to early 1970s. Some advantages of a drip irrigation system include: 1) less water loss, 2) reduction in weed growth, 3) less labor requirements, 4) minimal evaporation compared to other watering methods, 5) less usage of fertilizer, 6) reduced soil erosion, 7) equal water distribution and 8) higher crop production. Disadvantages of this technology include: 1) clogging of drip holes, 2) high initial cost, 3) algae growth and 4) easy damage to driplines.

In recent years, low-pressure drip irrigation (LPDI) systems have been developed for smaller farming areas. For many subsistence farmers, a standard pressurized system is too expensive and complicated, as pressurized systems are intended for large areas of land, and therefore do not match the needs of small subsistence farming (Bustan, 2008). Figure 5 shows the components of a typical LPDI system. These systems are economical and fairly simple to use, thus they are appropriate for subsistence farming in rural areas of developing countries. Because LPDI systems work with gravity-power and are low water pressure, there is no longer a need for operation by an outside power source, therefore reducing the initial cost. With the bottom of the water reservoir sitting at 1-2 m above ground, these systems can generate a flow of about 1 m^3/h (Phocaides, 2007). Dov Pasternak, a drip irrigation specialist from Israel, has combined the LPDI system with an appropriate crop mix to create the African Market Garden (AMG). The AMG generates revenue for small farmers and has been implemented in West African countries such as Senegal, Ghana and Niger. The results have been positive and community members tend to be accepting of the technology.

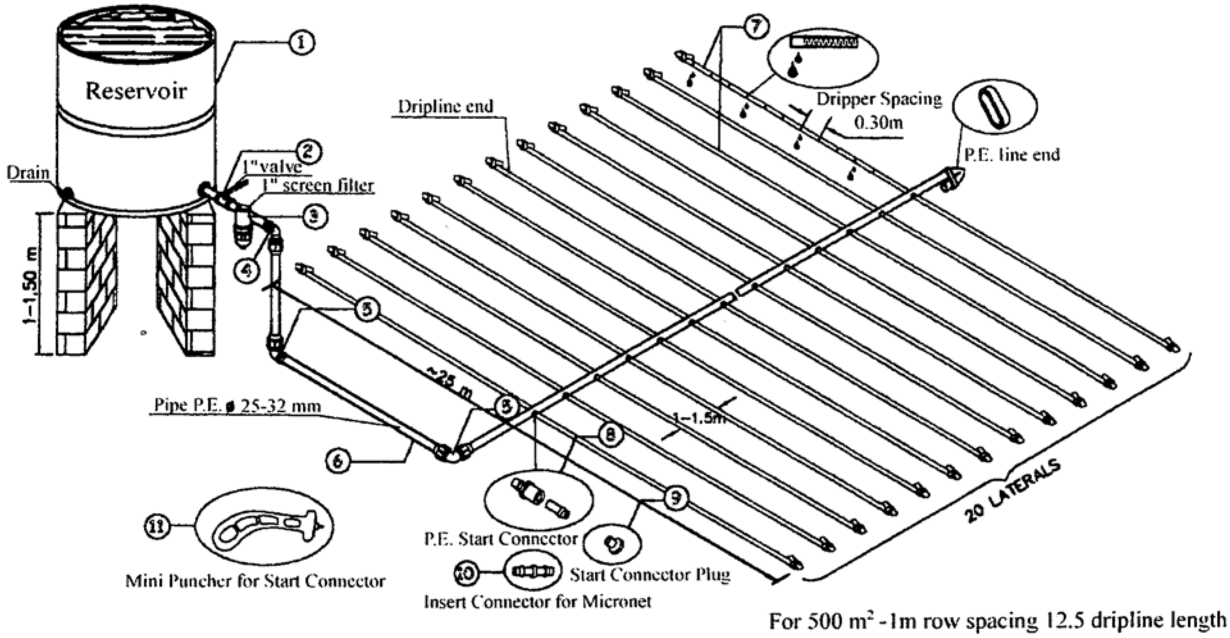


Figure 5: Diagram of the LPDI System (Bustan, 2008)

2.2 Greywater

Greywater has the potential to be reused for irrigation purposes in developing countries. Greywater is defined as “wastewater from baths, showers, hand basins, washing machines and dishwashers, laundries and kitchen sinks” (Morel and Diener, 2006). In addition, the World Health Organization (WHO, 2006) reports that the “sound and sustainable management of water resources is crucial for arid and semi-arid regions.” With the decreasing pattern in annual rainfall in sub-Saharan Africa, it is thus important to look at alternative water supply options for irrigation purposes.

The amount of greywater produced by a household varies depending on the number of house members, their age and water use, and the type of water supply the household uses. Water use in low-income communities is as low as 20-30 liters per person per day (Morel and Diener, 2006). In Djenné, Mali, households using a single water tap as their water source use 30 liters of water per person per day (Alderlieste, 2005). Kennedy (2006) found that the average water use for the Muthara area in Kenya was 16.7 L/capita-day including laundry and 12.3 L/capita-day without laundry. Results from water practice surveys taken in different countries with higher water use indicate that 38%, or 135 L/day, of total domestic greywater in households is produced from laundry water (WHO, 2006).

The WHO has created a "hierarchy of needs," shown in Figure 6, to demonstrate the amount of water necessary for an individual. At the top of the pyramid, the least amount of water is needed for the most important purpose. The top of the pyramid shows the smaller water needs required for short-term survival. The bottom of the pyramid shows how access to additional water resources is required for sanitation, hygiene, and productive uses of water such as agricultural. In Figure 6, the amount of water necessary for crops and recreational gardens is >70 L/day, some of which can be met with use of greywater.

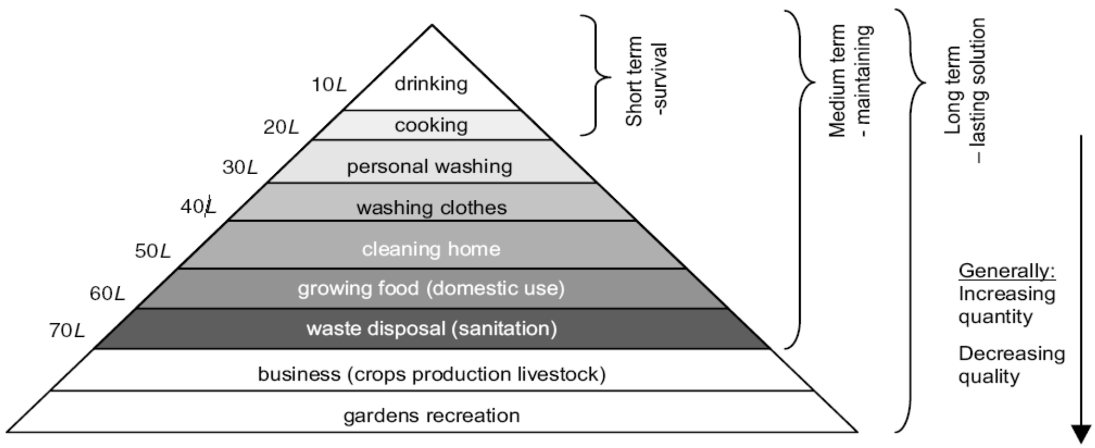


Figure 6: Hierarchy of Water Requirements (after Abraham Maslow's (1908-1970) hierarchy of needs) (WHO, 2005)

While the use of domestic greywater for irrigation may have its health risks, it is an alternative for areas with water shortages. In a recent study (Finley, 2008), the health risks of using untreated shower and washing machine greywater were investigated. A vegetable garden was watered using three different water sources, tap water, treated greywater and untreated greywater. No significant differences in levels of pathogenic contamination between the vegetables irrigated by the three water sources were found. Moreover, the quality of water did not change plant growth or yield. The study revealed that the recycling of greywater is an opportunity for society to conserve water on the domestic level and not further exacerbate the water shortage.

3.0 Methods

3.1 Assessment Method

A major issue in development work has been the lack of sustainability of a project. For example, a high percentage of water projects in Honduras and Madagascar were found to fail due to lack of community involvement, maintenance and upkeep or structural failure (Reents, 2003; Annis, 2006). For a project to be sustainable, development workers need to have a strong and clear understanding of every aspect affecting the project. This includes the economic, environmental and social aspects of a project. For example, many times a development organization will concentrate on the economic feasibility of the design while another organization will emphasize social aspect of a project with a focus on community involvement. However, all aspects of sustainability play an important role in the successfulness of a project and therefore must be taken into account (McConville and Mihelcic, 2007).

Table 1: Five Sustainability Factors Appropriate for Water/Sanitation Development Projects (McConville, 2006)

Social Sustainability	Socio-Cultural Respect	A socially acceptable project is built on an understanding of local traditions and core values.
	Community Participation	A process which fosters empowerment and ownership in community members through direct participation in development decision-making affecting the community.
	Political Cohesion	Involves increasing the alignment of development projects with host country priorities and coordinating aid efforts at all levels (local, national, and international) to increase ownership and efficient delivery of services.
Economic Sustainability		Implies that sufficient local resources and capacity exist to continue the project in the absence of outside resources.
Environmental Sustainability		Implies that non-renewable and other natural resources are not depleted nor destroyed for short-term improvements.

Sustainable development consists of three key factors- social, economic and environmental sustainability. While Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) touch on the environment and economic factors, respectfully, neither one of them act as assessment tools for the social factor. Moreover, McConville (2006), recognizing the significance of social factors in a successful water/sanitation project, divided social sustainability into three distinct components- cultural aspect, community participation and political cohesion.

Thus, in her assessment tool, the "triple bottom line" becomes the "penta bottom line." This assessment method was specifically developed as an assessment tool for water and sanitation projects in developing countries. The five factors considered by the life cycle thinking assessment method of McConville are explained in Table 1 (McConville, 2006; McConville and Mihelcic, 2007).

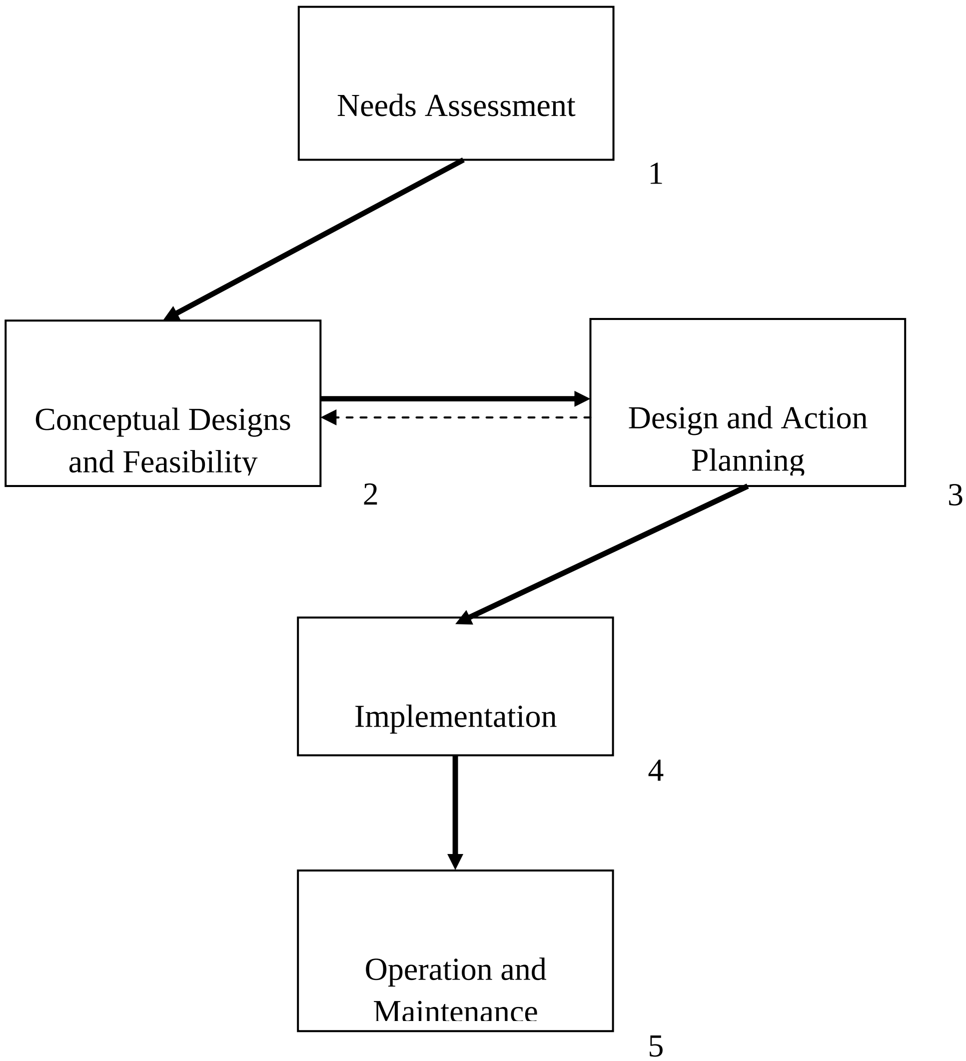


Figure 7: Five Life Cycle Stages for Water/Sanitation Development Work (Solid arrows indicate the flow of the life cycle process. The dotted arrow indicates the potential for iteration between life stages 2 and 3.) (McConville, 2006)

The life cycle thinking approach takes into consideration the five factors for effective sustainable projects over the entire life cycle of the project. The complete life cycle of a water/sanitation development project can be represented as shown in Figure 7. The five life stages are: 1) needs assessment, 2) conceptual design and feasibility study, 3) design and action planning, 4) implementation and 5) operation and maintenance. It should be noted that, due to constraints which may arise during planning in life stage 3, there may be the need to backtrack to life stage 2 and adjust the design, before continuing forward. This is represented by the dotted line between life stages 2 and 3.

The complete assessment tool combines the five life stages (Figure 7) with the five sustainability factors (Table 1) in a 5*x*5 matrix form shown in Table 2. As reported by McConville (2006), the project is evaluated and rated for each of the 25 elements in the matrix. A 65-page Appendix presented by McConville provides the "sustainability recommendations" that are addressed for each life stage and sustainability factor of the project. The evaluator

Table 2: Sustainability Assessment Matrix (The matrix dimensions show five life stages of a water/sanitation development project and five factors of sustainability.) (McConville, 2006)

	Sustainability Factor					
Life Stage	Socio-cultural Respect	Community Participation	Political Cohesion	Economic Sustainability	Environmental Sustainability	Total
Needs Assessment	1,1	1,2	1,3	1,4	1,5	20
Conceptual Designs and Feasibility	2,1	2,2	2,3	2,4	2,5	20
Design and Action Planning	3,1	3,2	3,3	3,4	3,5	20
Implementation	4,1	4,2	4,3	4,4	4,5	20
Operation and Maintenance	5,1	5,2	5,3	5,4	5,5	20
Total	20	20	20	20	20	100

assigns a rating (0-4) to each matrix element, depending on the number of sustainability recommendations completed. If none of the recommendations are met the matrix element is assigned a score of zero, a poor evaluation. If all of the recommendations are met the matrix element is assigned a score of four, an excellent evaluation. Thus each of the five sustainability factors can achieve a total score of 20 with an overall possible project score of 100.

This method is an effective assessment tool because it allows each element of the matrix to be evaluated separately. Thus, an assessment of individual elements in the matrix can highlight strengths and weaknesses in project approaches, allowing decision makers to identify key areas for improvement (McConville, 2006).

This assessment tool was first applied by McConville to evaluate two water and sanitation projects implemented in Mali, West Africa. Her first case study was a top well repair and wash area construction project in Kodougouni where she was involved in the design, planning and implementation. The second case study was a rainwater harvesting pond in Zambougou-Fouta where she served as a consultant and translator for an out-of-country NGO. Her results showed that both projects started off strong in the needs assessment stage and gradually weakened as the project progressed through the life cycle. One of her overall conclusions was that turning over ownership to the community did not take place (McConville, 2006). Most recently, the life cycle thinking approach has been applied by the author to small scale drip irrigation and to three biogas projects in central Uganda by S. Ocwieja.

3.2 Case Study: Small Garden Drip Irrigation

The project site is situated approximately one and a half km west of the Atakora Mountain Range in Ouankou, one of the 12 communities that make up the village of Taïacou. Ouankou has a population of approximately 400 people and is located about five km from the center of village. Like the rest of Taïacou, the community of Ouankou is dependent on subsistence farming: corn, millet and sorghum.

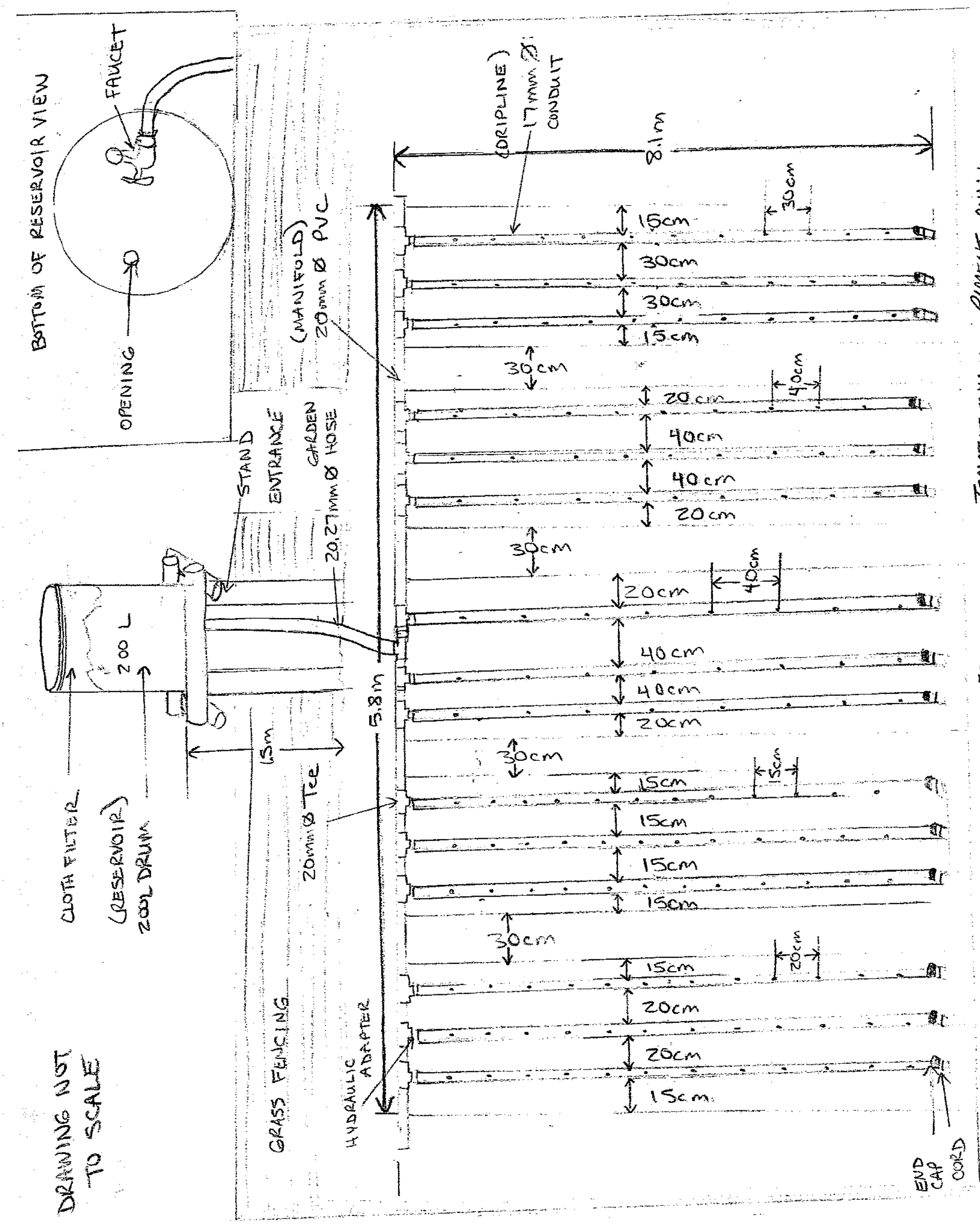
The women's group in Ouankou has a history of working on projects with Jura Afrique and other NGOs because of their motivation and hard work. Past projects include implementing improved mud cookstoves and planting moringa. Currently, the group is working with the Ministry of Agriculture on a rice project and Jura Afrique on a shea butter project. The present group consists of 14 strong and dedicated women. When presented with the irrigation project, they gladly accepted. When Jura Afrique introduced the project to the group, it was explained to them that this was to be a pilot project introducing the technology of drip irrigation and beneficial use of greywater to the community. Because the technology and ideas to be implemented were new to the group and the project was a demonstration pilot project, success depended more on the acceptance of the technology and understanding of the concept rather than actual visual results.

The design used in this study was selected after researching drip irrigation projects successfully implemented in West Africa. The LPDI system became the basis for the final irrigation design. The most important decision in selection of the design was local availability and cost of materials because this was to be a small-scale and low budget pilot project. Rather than purchasing a drip irrigation kit available from outside vendors, the system was to be manually constructed from locally available materials. The design was presented to the group and they were encouraged to ask questions and make suggestions. Jura Afrique then discussed greywater and its potential to be used for irrigation purposes. Since collecting bath and kitchen greywater would be difficult as it currently flows into the ground or is used to feed livestock, it was decided that only laundry greywater would be used.

Figure 6 suggests the quantity of greywater associated with laundry is approximately 10 L/capita-day. The group was given the task of finding out how many basins of laundry greywater each of their households collected within one week's time. They were given full responsibility of what was to be planted in the garden, with the exception that root crops were not acceptable because it is not currently advised to apply greywater to them for irrigation purposes. The crops also needed to have a similar growing season. Chile, tomatoes, *krenkren, bouma* and *sauce griant* were selected.

With the basic project idea in mind, Jura Afrique and the women's group agreed to meet on a weekly basis and a tentative schedule of activities was prepared. Funding for majority of the materials was provided by a private donation from the expatriate community. Other materials were provided by the local community. The chief of Ouankou kindly donated the land and a handful of men contributed with manual labor though the majority of the manual labor came from the women's group.

Figure 8: Detail Drawing of the Drip Irrigation Design



After choosing the land, the women's group started clearing the area of weeds. While they were hoping to work with a large area, a hectare or more, Jura Afrique felt it was best to start with a small plot of land as this was an experimental project. It was decided that a 40 m^2 plot would be an appropriate size. Figure 8 provides details of the drip irrigation design while Table 3 provides a detailed materials list for the design shown in the figure.

Table 3: Materials List for Drip Irrigation System Covering Around 40^2 m

Item	Unit	Quantity	Cost (CFA)
20mm PVC	Meter	12	4,000
20mm hose	Meter	2	1,500
Saw	Each	1	3,000
End caps	Each	20	4,000
Tees	Each	20	2,000
Black paint	Can (4kg)	1	12,000
Drum	Each	3	15,000
Drum lids	Each	3	2,100
Faucet	Each	1	4,000
Grass	Bundles	250	5,000
Adhesive	Can	1	3,900
Conduit	Roll (70yds)	2	20,000
Fabric	Square Meter	2	Donated
Paint brushes	Each	2	600
Cord	Roll	1	350
Sand paper	Sheet	1/2	225
Safety pins	Pack	1	Donated
Matches	Box	1	25
Candles	Each	2	Donated
Seeds	Each	many	Donated
Seeds	Pack	2	2,000
Hydraulic adapters	Each	16	12,800
Hose clamp	Each	1	400
Wire	Roll	1/16	Donated
			Total: 92,900

Note: The exchange rate was 500 CFA to 1 USD at the time of project.

After clearing out the area, a grass fence was built around a 12 m *x* 10 m space. The intended size of the garden was to be 8 m *x* 5m, or 40 m^2, however, the actual size measured 8.1 m *x* 5.8 m, exceeding in size by about 7 m^2. The garden consisted of five beds of three rows each, with each bed distanced 30 cm apart. A 200-L oil drum that had been cleaned served as the water reservoir. Because the system is a gravity fed drip system, the bottom of the reservoir was elevated 1.5 m above ground level on a stand constructed from logs. The top of the reservoir was covered by one square meter of local fabric and tied down by a cord. The purpose of the fabric was to serve as a filter when the laundry greywater was poured into the reservoir. Two openings were located in the bottom of the reservoir. One was to flush out the system and

Figure 9: (left) Building the Fence (photo provided by Olga Y. Castro)

Figure 10: (right) Construction of Reservoir Stand (photo provided by Olga Y. Castro)

the second opening is where the faucet was attached for watering the garden. A 20.27-mm diameter garden hose, measuring 1.5 m in length, was attached to the faucet with a hose clamp.

The garden hose connects the reservoir to the manifold. For the manifold, 20-mm diameter PVC pipe was used. The manifold measured 5.8 m, the length of the garden. PVC Tees were used to attach the driplines to the manifold. To do this, the manifold had to be cut into sections measurable to the distance between each bed and individual row (see Figure 8). The Tees were permanently attached to the PVC with adhesive. Hydraulic adapters were used to connect each dripline to the manifold at the Tees. Orange conduit was used for the driplines which were constructed using safety pins and candles or matches to burn small holes, spaced a measured distance apart. To protect the driplines from algae growth that can occur inside, they were painted black. Although they were not constructed using a clear hose, we had consulted with a local foreigner that had some experience using this type of hose and he recommended that they be painted black. From experience, algae tend to grow rather quickly even in non-clear containers. Each dripline was bent at the end and tied with wire or cord. End caps were placed at the ends.

Figure 11: Drip Irrigation System
(photo provided by Olga Y. Castro)

The reservoir capacity and plot size depend on the daily evapotranspiration (ET), evaporation of water from the crops and transpiration of water from the soil. Table 4 provides average reference evapotranspiration (ET_o), or ET for reference crop, for tropical and subtropical regions. In a tropical semiarid region such as northwestern Benin, the average ET_o rate at a

Table 4: Average ET_o for Different Agroclimatic Regions in mm/day
(FAO, 1998)

Regions	Mean Daily Temperature (°C)		
	Cool 10°C	Moderate 20°C	Warm >30°C
Tropics and subtropics			
-humid and sub-humid	2-3	3-5	5-7
-arid and semi-arid	2-4	4-6	6-8

warm temperature is 6-8 mm/day. The AMG method developed an economical system more specific to women with small home gardens, or in general, those with inadequate resources. Since a 200-L oil drum is easy to find, the economical system makes use of the drum to supply a 40 m^2 plot with an irrigation rate of 5 mm/day (Bustan, 2008). This system was used for this project.

4.0 Results, Conclusions and Discussions

4.1 Results

The assessment tool discussed in Section 3 was used to evaluate the drip irrigation project in Ouankou. Table 5 provides the score for each element in the matrix. The project overall score was a 61 (out of 100), scoring highest in the needs assessment stage (20/20) and lowest in the operation and maintenance stage (5/20). The evaluation and scoring of Element 3,3 (Design/Action Planning, Political Cohesion) is provided in the Appendix A to allow for a better understanding of how the scores were derived.

Table 5: Life Cycle Thinking Assessment of the Drip Irrigation Garden

	Sustainability Factor					
Life Stage	Socio-cultural Respect	Community Participation	Political Cohesion	Economic Sustainability	Environmental Sustainability	Total
Needs Assessment	4	4	4	4	4	20/20
Conceptual Designs and Feasibility	4	1	4	1	3	13/20
Design and Action Planning	4	4	0	1	3	12/20
Implementation	3	1	1	3	3	11/20
Operation and Maintenance	3	1	0	0	1	5/20
Total	18/20	11/20	9/20	9/20	14/20	61/100

McConville (2006) observed that, because PCVs live in the community, projects they are directly involved with tend to receive a high score in the needs assessment stage. This study supports her conclusion as the assessment for this life stage with regard to all five sustainability factors received a 20/20. Furthermore, the project received a score of 18/20 in the socio-cultural respect sustainability factor. Residing in the community allows for a better understanding of the culture and local customs which need to be considered throughout the life of the project to increase its sustainability.

The project scored much lower in the conceptual design/feasibility life stage (13/20) and the design and action planning life stage (12/20). During the conceptual design and feasibility stage of the project, the women's group was not provided the opportunity to choose the specific design. This technology does not have widespread visibility in the study area. Several types of drip irrigation projects in West Africa were researched and the most suitable design was chosen for this project. The group was, however, presented with that particular design and asked for their input at a meeting prior to continuation of the project. Moreover, costs were not estimated prior to beginning of construction because materials were chosen as the project progressed. While the women's group was asked to contribute in non-monetary terms, no financial obligation was given to them. This resulted in low scores of 1/5 for both community participation and economic sustainability factors.

During the design and action planning stage, the political cohesion and economic sustainability factors received the lowest scores (0/5 and 1/5, respectively). In this study, partner institutions were not sought out. Because the materials were selected as the project progressed, verifying costs and availability of resources ahead of time was also not possible. However, the community's contributions were confirmed prior to the purchase of materials and equipment.

In the implementation life stage, community participation and political cohesion sustainability factors received the lowest scores, receiving a score of 1/5 for each of these factors. No local representative was assigned to organize or supervise daily construction activities, monitor public safety concerns, hold briefings on tasks to be fulfilled or manage work crews. Also, there was no finalization of a management plan. The group was not involved in planning for operation and maintenance and responsibility for the system was not officially transferred to them. Jura Afrique kept the responsibilities and worked together with the women's group to set up the system and have it up and running. Other than the community learning how the irrigation system worked as the project progressed, no extra training was conducted due to the seasonal difficulty encountered to work with community members once the rainy season began. No partner institutions were contacted that would assist in identifying operation and maintenance roles. Moreover, there were no partner organizations within the area that had experience in drip irrigation work.

Figure 12: Tending to Garden (photo provided by Olga Y. Castro)

The operation and maintenance life stage had the overall lowest score (5/20). Many complications arose that made it difficult to continue with the project and make improvements. The project was interrupted during this phase due to the beginning of the rainy season and subsequent planting season. The timing of the project was restricted because of the time limitation placed on the PCV's service in the community. While an attempt was made to continue working, the reasonable decision was to stop. These difficulties generated a score of 0/0 for the already low scoring political cohesion and economic sustainability factors thus resulting in the lowest scores of 9/20 for both factors.

4.2 Conclusions and Discussion – Assesment

This assessment was performed after the project had been implemented. The assessment was useful in evaluating the first two stages of the garden's life cycle. As can be seen from the scores, there was a clear understanding of the community's needs with respect to all five sustainability factors. This is due partially to the involvement of a PCV on the project. Living in the community provides a development worker a better understanding of socio-cultural respect, community participation, political cohesion and economic and environmental sustainability. With regards to conceptual design and feasibility, the drip irrigation system chosen was designed with the idea of environmental sustainability in mind and has been successfully implemented in other West African countries with similar environment conditions.

Life cycle stages 3 and 4 were difficult to evaluate in this project. This perhaps points to a limitation of the assessment tool; that is, it may not be appropriate for evaluating life cycle stages 3 and 4 of a pilot project. For example, because this was a pilot project, it was difficult to develop a specific schedule and plan to follow, other than the need to be completed by the end of the dry season. Action planning was taking place at the same time as the actual implementation of the project. At times, implementation took place without any planning. Stage 5 was unfairly evaluated in this assessment. While the system did reach operational status, due to the change in season and time constraints, the operation, maintenance and financial issues were not fully addressed. The system was up and running for a short amount of time, not allowing the necessary time for a good understanding of details for the system.

This assessment brought attention to the usefulness of outside organizations and institutions for possible partnerships. The more you include people from the community, the more sustainable a project becomes. During the construction period, the Ministry of Agriculture became interested in the project and requested a meeting when results were to be available. Due to the PCV's time constraints regarding end of service, the meeting did not take place. Had the Ministry of Agriculture been involved in this project from the beginning, there could have been the possibility of their institution supporting the project and taking over after the PCV had completed her service.

Figure 13: Interested Community Members (photo provided by Olga Y. Castro)

Perhaps this assessment tool could be made adaptable to target new technology. One of the reasons for not involving outside organizations in this project was because political leaders and institutions want to know that the project will bring in positive results. When implementing a pilot project, you only have results from similar projects performed in other areas to share with others. Recommendations as to how to engage outside institutions and political leaders in projects involving new technology would be valuable. Moreover, this assessment could expand its recommendations to pertain to other possible water and sanitation projects. For this small garden drip irrigation project, questions pertaining to the water availability and the water's use for agricultural purposes would have been useful.

4.3 Conclusions and Discussion – Technology

Drip irrigation is a technology that contributes to the improvement of water supply management and the associated food crisis, both high issues for the community of Taïacou. The LPDI system, combined with greywater, addresses the needs of the Ouankou women's group. The design is appropriate as it conserves water. The construction is suitable as it was fairly simple to construct and low cost. The total project cost was 92, 900 CFA, under 200 USD. At the end of construction, Jura Afrique and the women's group were able to see the system be operational.

Several recommendations could be made for future work on this project. Experimenting with different materials would be beneficial. There were problems with the attachment of the driplines to the manifold. The hydraulic adapters used were difficult to screw in to the PVC and too big to fit easily into the conduit. Perhaps a different type or size of hydraulic adapters or connectors could be used. It might be better to use a bigger size diameter conduit if available. There needs to be a better exchange of knowledge between Jura Afrique and the women's group. Greywater is an alternative water supply option that is new to the community of Taïacou; thus, it is not something easily accepted. Jura Afrique needs to spend more time educating the women

Figure 14: Some Members of the Women's Group in Ouankou

(photo provided by Olga Y. Castro)

on the usefulness of greywater and its benefits for irrigation purposes. As previously discussed, outside institutions such as the Ministry of Agriculture should be involved. Even if they are not to be physically involved, it would have been a good idea to share the project ideas, and if willing, update them on the progress.

Expanding its recommendations to other types of water and sanitation projects, as well as adapting to new technology, this life cycle thinking assessment would be an extremely useful tool in evaluating agricultural related water and sanitation projects such as this small garden drip irrigation project. With more experimentation of materials, involvement of outside institutions and education of community members, the technology is a suitable design to meet the needs of this community. Taking into consideration the time constraints of the PCV and introduction of new technology to the community and Jura Afrique, this small garden drip irrigation project resulted in a fairly sustainable small scale garden pilot project.

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Appendix A. Example of How Scoring is Performed

The following is the evaluation and scoring of Element 3,3 (Design/Action Planning, Political Cohesion) of the matrix for the small garden drip irrigation project described in this report. The four open boxes indicate that if a majority of the questions/issues are addressed, the box is checked which results in a score of 1. If the majority of questions/issues are addressed for all four open boxes, the matrix element would score a 4.

□ The roles and responsibilities of partner institutions are defined in a detailed action plan. – not done (partner institutions were not involved)

- What level of involvement is each organization willing to commit to?
  - Financial support – Jura Afrique found funding
  - Consulting – Jura Afrique did the consulting
  - Sub-contracting – not needed
  - Training and Education – Jura Afrique did the training and educating
  - Direct community involvement – Jura Afrique was fully and solely involved
- What specific reporting or procedural requirements does each organization need?
  - Progress and monitoring reports – none, kept notes
  - Contracts – none
  - Site visits – weekly visits but
  - Education or capacity building activities - none
  - Other paperwork - none
- xWho needs to be informed of project activities? - Jura Afrique, women's group
- Who will supervise the project? – Jura Afrique
- Who will monitor progress? – Jura Afrique
- Who will work directly with the community? – Jura Afrique
- Who will recruit skilled laborers? – Jura Afrique

□ Agree on financial commitments. – not done

- Who will contribute to project financing? – privately funded
  - How much? – 300 USD

    - When will funds be available? – just after women's group agreed to work on the project
- Who will control the project budget? – Jura Afrique
- What strings are attached to institutional funds? – none
    - Earmarks
    - Reporting requirements

□ A timeline is drafted that meets the requirements of all institutions involved. – not done

- What are the funding and reporting schedules of the institutions? – no schedules
- When will work start? – as soon as possible
- When are progress and final reports due? – none due
- When will work be completed? – before rainy season begins
- Are institutional deadlines respected? – no deadlines

□ Final project design and action plan are presented to partner institutions and local, regional, and/or national level authorities. – not done

- Are all parties aware of their role and the timeline agreed upon? – no other parties involved
- Have all parties seen the finalized design? (Even if they are not directly involved, they appreciate being informed.) – no other parties involved

Scoring: Possible ratings for each matrix element is 0-4.

If none of the recommendations were met the matrix element is 0, a poor evaluation.

If all of the recommendations were met the matrix element is 4, an excellent evaluation.

For the small garden drip irrigation project, Element 3,3 received a score of 0 because none of the recommendations were met.