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Rainwater Harvesting Storage Methods and Self Supply in Uganda

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by

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DEDICATION

“Nay, the same Solomon the king, although he excelled in the glory of treasure and magnificent buildings, of shipping and navigation, of service and attendance, of fame and renown, and the like, yet he maketh no claim to any of those glories, but only to the glory of inquisition of truth; for so he saith expressly, ‘The glory of God is to conceal a thing, but the glory of the king is to find it out’; as if, according to the innocent play of children, the Divine Majesty took delight to hide his works, to the end to have them found out; and as if kings could not obtain a greater honour than to be God’s play-fellows in that game.”
-Francis Bacon, *The Advancement of Learning* (1605)

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world-formational Christianity, using engineering to change the world, and avoiding self-referential incoherence.

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ABSTRACT

Self supply is an emerging approach to water supply which focuses on fostering household investment in incremental improvements to their water sources. When successful, it can lower costs and increase sustainability by offering users a larger share of ownership in their own supply, and harnessing the already existing strengths of a community rather than trying to impose an external perspective. In addition to well upgrading and source protection, one of the key self supply areas is rainwater harvesting. Uganda has a diverse selection of rainwater storage options, but many of them are scattered and disparate.

The objective of this study was to create a comprehensive collection of well-established Ugandan rainwater storage options, and to demonstrate the geographical disparities in availability, particularly for Rakai District, where the author lived and worked as a Water and Sanitation Engineer for two years.

Data was gathered by interviewing key stakeholders in rainwater harvesting at the national, regional, and district level in order to gather their collective knowledge in rainwater harvesting storage techniques. In order to understand the availability and

pricing of manufactured products, a survey of Rakai District hardware stores determined the prices and range of volumes at which different manufactured products were available. The study found 11 distinct technologies widely used for rainwater storage: three informal or traditional, three manufactured, and five built-in-place by skilled artisans. The traditional/informal technologies consisted of clay pots, pots and basins, and brick mortar tanks. The manufactured products were plastic tanks ranging from 60 to 24,000 liters, corrugated iron tanks, and 55-gallon metal drums. The built-in-place tank technologies were mortar jars, tarpaulin tanks, ferrocement tanks, partially below ground ferrocement tanks, and interlocking stabilized soil brick tanks. The study also found that while the manufactured products are well distributed, built-in-place options have not spread beyond where they were originally introduced by NGO's trying to promote certain technologies.

With regard to costs, tanks with storage volume less than 1,000 liters had costs that ranged from 182 to 724 UGX/liter, with small plastic tanks being least expensive. For volumes between 1,000 and 10,000 liters, costs ranged between 42 and 350 UGX/liter, with tarpaulin tanks providing the largest storage per unit cost. Above 10,000 liters of storage, tanks ranged from 35 to 341 UGX/liter, with tarpaulin tanks again ranking first by cost per unit volume.

In order for self supply to flourish, these technologies need to be implemented in such a way that fosters a thriving private sector and independent uptake of rainwater harvesting.

This research provides a starting point by laying out the technologies, costs, and volumes available.

CHAPTER 1: INTRODUCTION

1.1 Water, Health, and Millennium Development Goal (MDG) Progress

A body of literature has demonstrated the link between a clean and sufficient water supply, especially as used for sanitation purposes, and improvement in human health (Esrey et al., 1985; Esrey et al., 1991; Fewtrell et al., 2005). It is therefore appropriate that water is an important foundation for all the Millennium Development Goals, and access to it is peripherally relevant to Goals 1 and 3 and particularly targeted by Goal 7.[1] Yet progress in many places is slow: while the target date for achievement of the goals is 2015, one estimate suggests the target for access to improved water sources will not be reached for another four decades in parts of Sub-Saharan Africa if progress does not rapidly accelerate. (UNDP and UNICEF, 2002). An additional study estimates that economic investment in conventional approaches would need to triple in order to foster such an acceleration (Sutton, 2004). Conventional methods need to be supplemented by a new approach.

1.2 Self Supply

Self supply is a promising policy framework which seeks to supplement conventional

[1] Goal 1: Eradicate extreme poverty and hunger
Goal 3: Promote gender equality and empower women
Goal 7: Ensure environmental sustainability. Target 7C: Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation

methods of supplying water by encouraging and enabling users to make small investments in incremental, easily replicable improvements to their own supply (Sutton, 2008). Self supply, in its most rudimentary form, is the ability of a household to access water using their own resources. As such, it has been standard practice for millenia, especially to those populations considered “unserved” by improved water sources; but only in recent years has an effort been made to develop a framework of self supply that brings it into the mainstream of water supply planning. It has been described simply as “an approach to water supply which concentrates intervention and management at the lowest level“ (RWSN, 2003). Figure 1.1 illustrates the process of self supply as breaking down improvement into manageable and user-affordable steps, as opposed to the usual donor-driven approach of making big changes, which consequently require external funding. In Figure 1.1, an unimproved well is shown being upgraded in steps by such improvements as adding a simple covering, installing a formal water lifting device, and building more sophisticated drainage. Self supply is targeted specifically to reach households likely to be missed by business-as-usual approaches, especially rural users, and is typified by simple improvements in the areas of source upgrading, household water treatment, and rainwater harvesting (Sutton, 2011).

In the experience of the author during his two years of serving in Uganda as a Peace Corps Volunteer as part of the Master’s International Program (http://cee.eng.usf.edu/peacecorps/), conventional approaches to water supply often impose an external framework on a community, which decreases the likelihood of long term ownership by the receiving community. For example, there are many boreholes in

Uganda which do not function due to a broken rubber gasket. While the repair is cheap and easy, many of these pumps go without repair, sometimes for years, not just because of a lack of knowledge on the part of the community but because they perceive that borehole as being owned by the government – the agency that installed it. Self supply can overcome some of these problems by placing control and choice back in the hands of users, who are consequently more likely to maintain their water source. Some of these barriers to sustainability of community managed water systems are discussed by Schweitzer and Mihelcic(2012), who assess water projects in the Dominican Republic on their likelihood to be sustainable.

Key pillars of the self supply approach are outlined in Figure 1.2; at a basic level, the self supply approach is built on technology and access to the technical advice necessary to make it functional, financial mechanisms and markets, a capable private sector, and enabling policies with the flexibility to allow self-supply to thrive. One of the key assumptions of the approach is that a more informed populace, with true choice regarding their water sources, will make better, more sustainable decisions about investment than conventional approaches. Pilot programs in Ethiopia (Sutton, 2010a), Mali (Sutton, 2010b), Zambia (Sutton, 2010c) and Uganda (Danert and Sutton, 2010) have explored the early stages of implementation. This policy approach is being encouraged and managed by the Rural Water Supply Network (RWSN), which describes itself as “a global knowledge network for rural water supplies” (Danert, 2010). Further details on RWSN and the self supply approach can be found in Chapter 2 and on their website (http://www.rwsn.ch/).

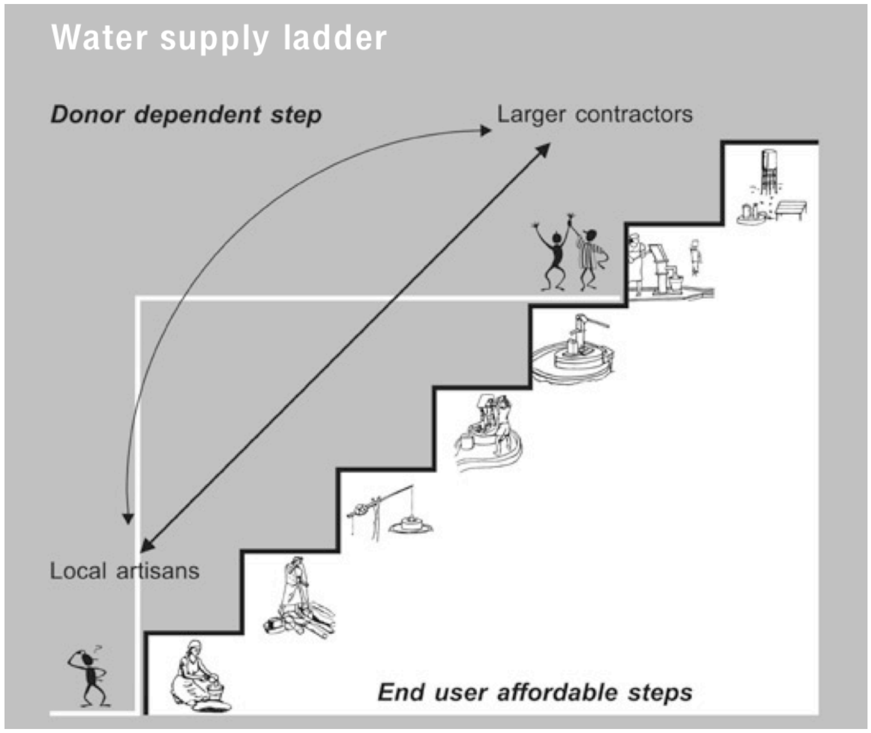

Figure 1.1. An example of a "water supply ladder" which illustrates the steps households can take to improve their supply incrementally (Sutton, 2008, with permission).

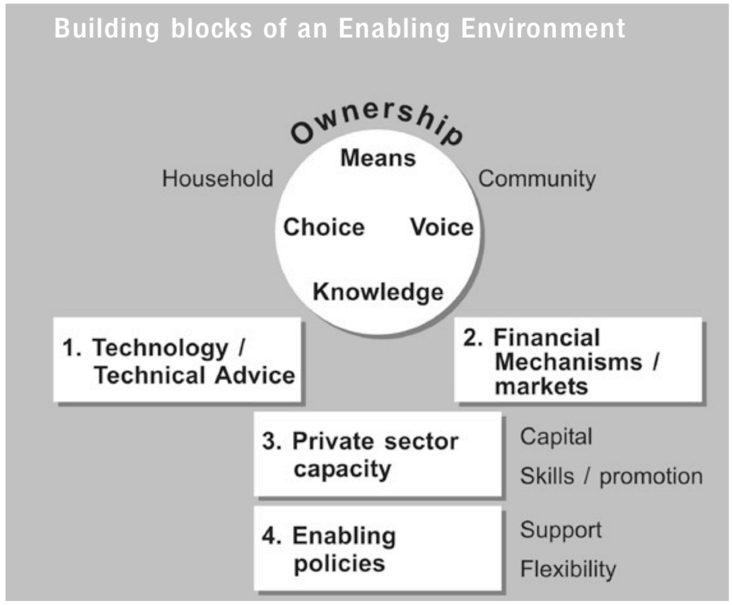

Figure 1.2. Diagram showing four pillars of the self supply approach and an ideal environment for uptake of self supply initiatives (Sutton, 2008, with permission).

1.3 Domestic Rainwater Harvesting (DRWH)

Domestic Rainwater Harvesting refers to the practice of utilizing water that falls as rain on a hard roof and is directed to a storage device for purposes such as consumption, cooking, cleaning, and hygiene/sanitation (Thomas and Martinson, 2007). It is a subset of the broader field of rainwater harvesting which includes other methods such as capturing overland flow. DRWH is a core component of self-supply efforts, encompassing a broad range of practices from informal efforts such as placing pots under eaves during a rainstorm to investment by households in elaborate systems with large built-in-place tanks that may serve as the sole water source year round (Danert and Sutton, 2010). Design and construction details for DRWH systems are available elsewhere (Mihelcic et al., 2009).

The quantity of water a household collects, especially for hygienic use, has been shown to increase with very low collection times (Cairncross, 1987). Mellor reinforces this finding, and adds that it appears households do not decrease their water use below the level necessary for basic needs with long collection times (Mellor et al., 2012). Accordingly, the proximity of rainwater harvesting sources to households can offer a high level of service, and consequent improvement in health. One study in West Africa has demonstrated the significant extent to which DRWH can increase the quantity of water available for water and sanitation needs (Cowden et al., 2008). They found that during the rainy season, a storage device as small as 200 liters could be optimal for enhancing the water supply of many urban households with small, simple roofs throughout the region. Another study translated those results into a more comprehensive picture of how DRWH can impact health (Fry et al., 2010). Fry et al. correlated incremental volumetric increases in water availability with the modes of health risk established by the World Health Organization (WHO**),** measured by disability adjusted life years (DALY's), and found that water storage from DRWH of as little as 400 liters can reduce the diarrheal disease burden by as much as 25%. Moreover their graphic breakdown of the relationship between fields of study (Figure 1.3) is a useful conceptualization of the respective impacts on human health. In the diagram, the inner circle represents human health, and the outer circle represents external factors affecting health. The "Technological and Programmatic Design" block represents interventions to reduce risk, ideally informed by the collective knowledge of engineering, public health, and social science (Fry et al., 2010).

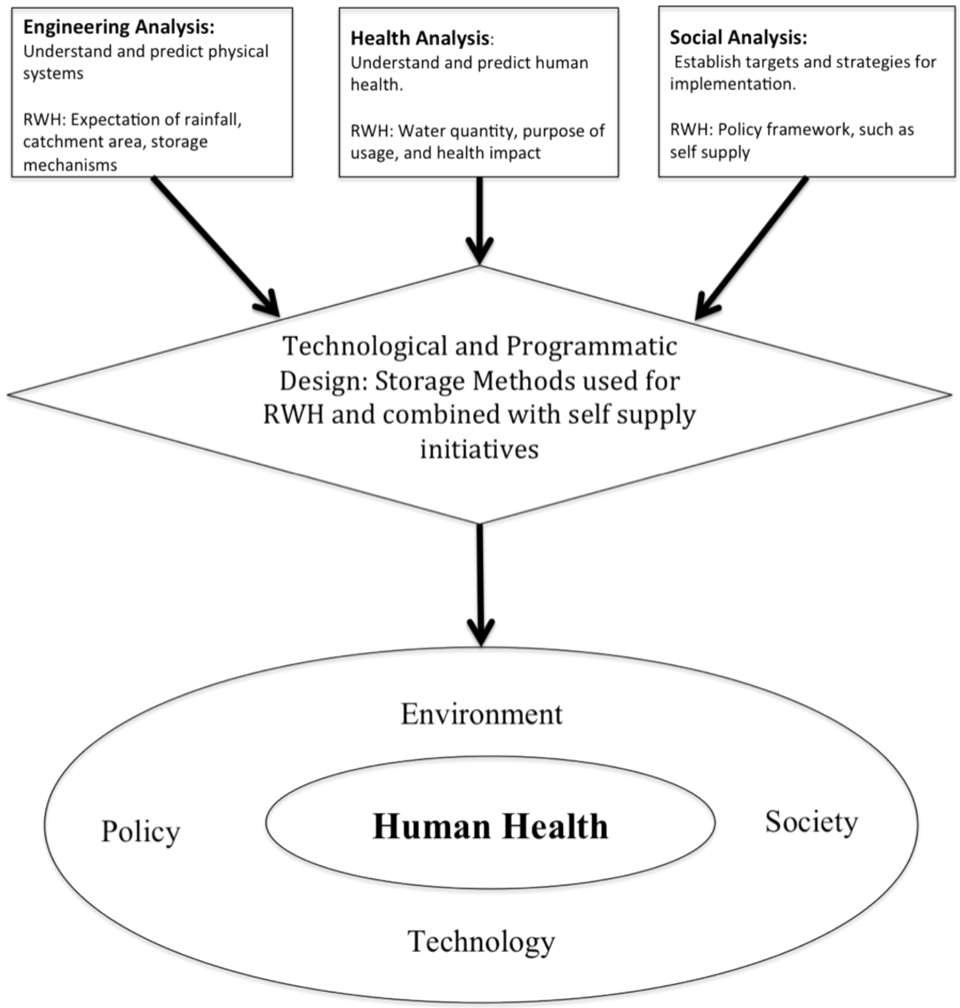

Figure 1.3. Factors contributing to health, adapted to illustrate how the specific concepts of RWH and self supply apply (Adapted from Fry et al., 2010, with permission). Copyright 2010 American Chemical Society.

1.4 The Ugandan Context

Two-thirds of Uganda's land area experiences more than 1,200 mm of rain per year, and over two-thirds of the roofs it falls on are galvanized iron (Danert and Motts, 2009). This suggests that most rural Ugandan households already have the basic climatic and catchment requirements for a basic DRWH scheme (Danert and Motts, 2009). Since 85% of the population is categorized as rural (UBOS, 2010), and rural access to an improved water source is around 60%, a large demand exists that DRWH implemented through self supply could fill. However, while rural access to improved water sources has increased significantly from around 20% in 1990, it has stagnated at around 60% since 2001 (Danert and Motts, 2009).

The stagnating rural access to improved sources, combined with rising costs to meet the needs of increasingly scattered populations, was the impetus for a self supply pilot project in Uganda. Following a 2005 scoping study which found that as much as one third of rural users already utilize some form of self supply (Carter et al., 2005), two non-governmental organizations (NGOs) were commissioned to implement the pilot encouraging users to improve their water supplies with little to no subsidy. The interventions focused exclusively on shallow groundwater sources, due to the existence of other literature on DRWH in Uganda, and the overall lower cost and high user investment yielded 41 improved sources at a cost to government 85% below conventional means (Danert and Sutton, 2010).

DRWH already constitutes the most popular method of private investment in water supply: about 28% of the 15,000 or so tanks greater than 6,000 liters in Uganda have been privately financed (MWE, 2010), and thus fit under the definition of self supply. Ugandan DRWH storage devices can be broadly seen as fitting into 3 categories: 1) traditional/informal methods (for which formal markets may not exist, but which have been practiced for a long time), 2) manufactured products (centrally produced tanks in a wide range of sizes, available for sale in nearly any town large enough to have a hardware store), and 3) built-in-place tanks constructed by trained artisans. These generalizations provide the backdrop and foundation for the present thesis.

1.5 Motivation, Objectives, and Hypotheses

During his two years serving with the Peace Corps in Uganda, this study's author had significant experience with people and institutions using DRWH as a water source. It was observed that while some manufactured products (especially small plastic tanks) were widely and consistently available, many other DRWH techniques were disparate and scattered – that knowledge regarding alternatives for implementing the approach was fairly limited from location to location and that there was no conglomeration of the collective knowledge of DRWH methods in Uganda.

This observation is reinforced in the self supply literature (Cruddas, 2007; Danert and Sutton, 2010). Roofs and gutters are fairly standard, but there are a number of creative methods for storage spread throughout the country, generally limited in geographic scope and availability to at most a few sub-counties. Reproduction of existing storage methods, and learning from the success and failure of previous efforts – two core values of self supply intended to foster the independent spread and uptake of effective water resource utilization (see Figure 2.1 for more details) – were impeded by this lack of readily available, centralized information. This study was conceived in an effort to fill that gap in knowledge.

Accordingly, the objectives of this study are: 1) to present a comprehensive collection of well-established rainwater storage options in Uganda, and 2) to demonstrate the geographic disparities in the distribution of storage options within Uganda's Rakai District. With regard to the first objective, the information will be presented in a graphical hierarchy, similar to Figure 1.1, organized by cost and storage volume in such a manner as to be useful to water users in making informed decisions regarding selection from the variety of water storage mechanisms available to them. Both Kirsten Danert (RWSN) and Joel Kiwanuka (Chief Sociologist in the Uganda Ministry of Water) have suggested that this kind of centralized hierarchy does not yet exist and would be exceedingly helpful in their efforts to expand the impact of self-supply. The second objective should aid the self-supply concept in targeting its efforts at NGO's, communities, and governmental agencies in order to more effectively aid the acquisition of safe, reliable water supplies. The first objective is thus nationally relevant while the second will be most immediately applicable to the Rakai District, though the principle demonstrated is believed to hold true for all of Uganda. These objectives also reinforce the 2^{nd} and 3^{rd} pillars of self supply (a highly functional private sector and effective technical advice: see Figure 1.2). In order to achieve these objectives, this paper will test three hypotheses.

Hypothesis 1: On a national level, Uganda has a diverse variety of rainwater storage practices encompassing a wide range of volumes and costs.

Hypothesis 2: The Rakai district of Uganda has access to a wide and consistent range of manufactured water storage options applicable to rainwater harvesting.

Hypothesis 3: Conversely, the Rakai district's access to artisan-constructed storage options will be limited, with significant gaps between areas where there is sufficient private sector capacity for implementation of the various methods.

CHAPTER 2: LITERATURE REVIEW

2.1 General Self Supply and History

The history of self-supply begins in Zimbabwe. Prior to 1980, some 30-40% of rural people were served by self-built and self-financed wells, which were associated with disease and prone to pollution during floods. An intensive program, promoted by a wide variety of foreign organizations as well as Zimbabwe's government, built on the recognition of the capacity of these families to improve their own sources by providing support for "Upgraded Family Wells" (UFW's). By 2002, over half a million people were using 50,000 UFW's with simple drainage aprons, windlasses or hand pumps, and basic linings – all at zero cost to the Zimbabwe government (Robinson, 2002).

A similar program was implemented in parts of Zambia from 1998-2002. For 200 pilot systems, simple technologies (well and scoophole lining, wellhead protection, water lifting devices, and hand washing devices) were introduced. Water quality improved significantly, and demand for improvements vastly outpaced capacity of the project. Interviews with users found a willingness to pay more for their own supply than over 40 households together were willing to pay for a communal supply. The success led to support for UFW's incorporation into the national water supply policy (Sutton, 2004).

In 2004, emerging from a global context where it was apparent that conventional water supply methods were not keeping pace with the Millennium Development Goals (MDG's), the Rural Water Supply Network (RWSN) adopted the idea of self supply by publishing a concept note formalizing the nebulous Self Supply concept, and committing itself to rigorously study Self Supply's impact and accomplishments in four countries. Sutton (2008) defined Self Supply as

> …the improvement to house-hold or community water supply through *user* investment in water treatment, supply construction and up-grading, and rainwater harvesting. It is based on *incremental improvements in steps which are easily replicable*, with technologies affordable to users. This self-help approach is complementary to conventional communal supply, which is generally government-funded and which forms the back- bone of rural water supply. However the latter is not equally sustainable everywhere, and is inadequately funded to reach MDG target coverage in sub-Saharan Africa. Self supply at household or community level generally implies strong ownership but also a sharing of the supply with those households nearby, often at no charge, offering effectively a privately managed communal service. *All of the 'unserved' population use Self Supply*, as do an unknown proportion of those regarded as served. [Emphasis added]

The initial document laid out two long-term goals for Self Supply:

> 1. To establish self supply alongside communal supply as an acceptable option in water supply strategies among governments, NGOs and donors.
>
> 2. To make available adequate technical and software information for practitioners and communities to be able to make informed decisions and to improve supplies with minimum subsidy (RWSN, 2003).

From that point on, RWSN began to target studies and reports to pursue these goals.

Later in 2004, RWSN published the Preliminary Desk Report (Sutton, 2004), which identified specific countries whose demographic and climatologic characteristics made them suitable for piloting self supply projects under the RWSN umbrella. It specifically concluded that Tanzania and Uganda were most suited to further exploration of the self supply concept. Country specific progress is explored in Section 2.2 of this thesis.

Since RWSN has shepherded self supply throughout its formal incarnation as a water supply approach, the vast majority of the literature on the subject consists of RWSN's self-published reports developing the concept and then reporting on its progress, a few conference presentations by RWSN staff and affiliates, and some complementary Master's theses from Cranfield University studying the Uganda Self Supply Pilot project.

In a 2004 paper building translating self supply's early success in Zambia into application elsewhere, Sutton developed some of the key operating principles of the concept, which describe the philosophy behind the approach and its intended goals. These are listed in Figure 2.1.

- Technologies are as far as possible replicable with minimum dependence on outside resources, encouraging local investment in systems over which investors have direct control.
- The application of minimum design standards can form the basis for phased and affordable improvements in supply, especially in areas of low population density.
- Local artisans and contractors provide safe water supplies, easier water-lifting devices and promote low-cost options.
- Where possible, linkage is made to economic and nutritional benefits as well as health benefits, increasing the perceived value (and therefore sustainability) of water supply.
- Management is maintained within naturally developed groups, usually the household or existing source user group, and has access to adequate, unbiased information, empowering them to make choices and solve problems.
- An enabling policy environment, combined with low cost and high proportion of private investment, allows rapid advance for large numbers of people, especially those in scattered communities for whom conventional protected systems may not be sustainable.

Figure 2.1 Self supply concepts and values (Sutton, 2004, with permission).

In a 2008 paper designed to introduce self supply to interested parties, Sutton takes these values and begins to construct a theoretical environment in which self supply could thrive (Sutton, 2008). This environment is built upon a foundation of technology and access to the technical advice necessary to make it functional, financial mechanisms and markets, a capable private sector, and enabling policies with the flexibility to allow self-supply to thrive. These pillars and the environment they seek to create are depicted in Figure 1.2. Elsewhere, Sutton has developed a comparison between conventional water supply approaches and self supply (Table 2.1).

Table 2.1 Comparison of conventional and self supply approaches (Sutton, 2004, with permission).

Conventional communal systems	Self supply options
Best suited to nucleated, homogeneous communities with good leadership	Suited to individual households and small groups
Technologies available for a wide variety of conditions, with greater flexibility in siting	Easily established where water is within 15 meters of surface or rainwater adequate
Focuses on outside knowledge and remote technologies	Builds on local knowledge, attitudes, and skills
Serves large numbers of people, who may or may not form a community	Serves households or small groups forming natural management units
Safety and quality of water usually assumed, not always correctly; perceived value among users may be less than assumed	Significant improvements in water quality, comparable to fully protected communal shallow wells but at much reduced cost; high perceived value among users
Generally marketed for health benefits; income generation often difficult because of communal ownership	Often generates multiple benefits including income, improved nutrition, and local employment
Depends on committee management which is not traditional and may take time to develop	Well-defined ownership and management by individual or well-established group
Provides good water within 0.5 to 1 kilometer, but households may have nearer alternative sources	Provides good water, usually within household boundary or within 100 meters
Requires large investment per unit, and very high subsidies (usually around 95 percent; typically US$15–20 per capita)	Low unit cost means that subsidy can be less than 50 percent (Zimbabwe 20 percent) (typically US$3–5 per capita)
Rapid construction, but construction teams not involved in maintenance	Rapid small changes, slower process to reach final product, construction teams also do maintenance
Long-term maintenance is expensive, requiring heavy equipment and transport	Regular and long-term maintenance can be carried out by local artisans, including redeepening at low cost
Higher standards from the start but sustainability may be low	Gradual steps towards high standards, each bringing sustainable improvement
Often donor driven	Develops directly from local demand

Sutton (2008) makes the case that self supply contributes to all of the MDG's – even those not specifically related to water access can see secondary benefits related to household income and nutrition (Table 2.2).

Table 2.2 Self supply impact on the MDG's (Sutton, 2008, with permission).

How Self Supply can contribute to MDGs?

MDG contribution, Self Supply and the Eight Goals

Goal	Self Supply Contribution
1 Eradication of Poverty and Hunger	Homestead –based technologies tend to be used most intensively for multiple uses (enhanced land and water productivity, rural livelihoods and gender equity)[13] In SE Asia irrigation reduced poverty across all study systems[14] and water supply improvements provided the opportunity to create income through micro–enterprises, as well as time released from water collection being converted into income earned[15]. In Mali a survey in 2 regions showed that 85% of water supplies with domestic and productive use were privately owned family wells[9] Families with rope pumps generate an average of $225 more per annum of income (ie about 50% above average) in Nicaragua[16]
2 Universal Primary Education	A 12% increase in Tanzanian school attendance was found when water is available within 15 minutes instead of being more than an hour away[17] In Mali 95% of family wells were within 15 minutes of the home, but only a third of communal wells[9]
3 Gender	Household-level decision-making generally favours greater input from female members. Men are more prepared to collect water from sources nearer the house, especially if access/site hygiene is improved[18]. Water provision close to the house offers women in particular the opportunity for productive use where their mobility is socially constrained[13], and greater women's empowerment through changing gender relations within the household[15].
4 Child Mortality	Among children under 5 years in developing countries, diarrhoeal disease accounts for 21% of all deaths[19] "Children with homes more than 500 m from their water supply had much higher rates of diarrhoea compared with children from houses with their own supply"[20]. Fewtrell's recent systematic review[21] of high quality studies of household water treatment at the point of use and improved storage demonstrated a 34% reduction in diarrhoea
5 Maternal mortality	Reduced burden in water carrying during pregnancy, and possibly better post-natal hygiene can reduce complications
6 HIV/AIDS, malaria /TB	Easier availability of water for hygiene/hand washing which reduce opportunistic diseases and respiratory infections for HIV/AIDS and others[22]. HH Water treatment successfully prevented cholera transmission in adults and children[23]
7 Environmental sustainability	**7.1 Sustainable development** Self Supply offers sustainable technologies and management systems, spreads abstraction of groundwater among diffuse points and reduces concentration of livestock around water points. It may lead to increased abstraction but this tends to be naturally limited by its effect on the water table. **7.2 Sustainable access to safe drinking water** Access can be generally at household level, or near neighbour, where water is available within 15m of surface or as rainwater harvesting. Safety is ensured by household water treatment, which is now being widely promoted.
8 Global partnership for development	**8.1 Capacity building** In co-operation with the private sector, making available the benefits of new technologies, and re-inforcing de-centralised capacity to respond to demands even with minimum resources **8.2 Youth job prospects** Growth in demand for well-diggers, masons, blacksmiths and carpenters expands rural job opportunities. In Sierra Leone in association with new newly-formed well-digger union, ex-combatant youth have been offered job creation and credit systems to develop new marketable skills in water supply.

Finally, Sutton (2009) develops a "road map" (Figure 2.2) for developing Self Supply as an effective approach, using the six "P's" as a mnemonic: Potential, Piloting, Package, Policy and Plans, and finally Promotion/partnerships to represent the stages of taking the approach to scale.

Box 1. The 6 P's - STEPS TOWARDS SELF SUPPLY SCALING UP

- **Potential** – scope, demand, physical suitability, links and possible conflicts with government policy
- **Piloting.** – testing out and demonstrating possible solutions, monitoring impact and user satisfaction/ lessons learnt
- **Package –** developing models relevant to geographic, socio-economic and political conditions
- **Policy and plans-** integration of Self Supply into policies and plans for scaling up

Promotion /partnerships– a continuous advocacy and communications process with government, donors and NGOs to encourage assessment of relevance and effects on policies, budgets and plans.

Figure 2.2 The self supply process (Sutton, 2009, with permission).

2.2 Country Specific Progress

2.2.1 Zambia

Zambia could be described as the birth place of self supply, as it was the target of a 2002 project whose goal was to "develop models to enable small communities to improve their own supplies within Zambia" (Sutton, 2002). This early foray into an institutionalized approach toward encouraging households to invest in their own supplies met resistance to low cost improvements from some stakeholders who perceived them as a step – except at the community level, where any improvement was welcome. Short term results include provision of funds for continuation of work in all 6 districts where the pilot took place, incorporation of this precursor to self supply into National Water and Sanitation Strategy, publication of manuals on low cost changes in water sanitation and hygiene, improvement of over 200 individual sources, and many more secondary improvements as concepts disseminated and were taken up independently.

Experience in Zambia, particularly in the 2002 study, would prove the jumping off point for one of the first formational documents of self supply (Sutton, 2004). Building on the results of the 2002 study, Sutton began to formulate some of the underlying elements of a more formal self supply approach. These are the principles appearing in Table 2.1 above.

In a 2009 presentation to the 34th WEDC Conference, "Assessing the Potential for Self Supply in Zambia" (Munkonge and Harvey, 2009), Munkonge and Harvey reported on Zambia's national progress toward self supply. They looked specifically at the four pillars of self supply: technology, private sector, financial mechanisms, and government. Technologically, some suppliers had already begun to manufacture improved supplies such as the rope pump, and a few Established Artisan Associations had begun to implement self supply in some scattered communities. With regard to the private sector, there was some reluctance by traders to gain stocks of commodities that would take along time to sell, as would be the case with self supply's encouragement of slow upgrading over time, but overall the sector was slowly maturing. Financial mechanisms were slowly developing with no specific progress to report. Governmentally, policy at that time marginally allowed for a formal self supply approach if the pilot was found to be successful. No specific policy existed, but self supply fit neatly into their existing plans.

The most comprehensive summary of progress in Zambia came in 2010, when RWSN published reports on each of the 4 pilot countries (Zambia, Ethiopia, Mali, and Uganda) and synthesized collective lessons to be learned. The Zambia report (Sutton, 2010b) detailed work primarily in the northern province of Luapula. Central and southern Zambia had very deep groundwater, so traditional hand dug wells were largely irrelevant and the only potential for self supply would have been household water treatment.

Likewise, the potential for rainwater harvesting was limited because even where rain was abundant enough, 80% of Zambian roofs were grass and thus incapable of capturing runoff efficiently. But in Luapula, there was great potential for well upgrading. Unfortunately, much of the momentum built up during the original study, which concluded in 2002, was lost when the government ministries and priorities were reshuffled, but the Ministry of Health continued to promote self supply.

The work in Luapula was implemented by two nongovernmental organizations (NGO's): WaterAid and Development Aid from People to People (DAPP). They worked entirely without subsidy, and while it was initially difficult for households to accept the concept of being assisted by expertise only, once one person bought in, enthusiasm rapidly spread. The NGO's assisted trained artisans in marketing and selling products at a village and sub-district level. The technologies promoted centered around a hierarchical approach to well protection, progressing stepwise from a raise lip to prevent surface inflow to previously open wells, to a mound around the mouth to avoid ponding and seepage, and on to a lid to close the opening, the use of a single rope and bucket by all users, a place to store the bucket to avoid contamination, a roof over the well, and finally a fence to keep out animals. Concrete rings for lining wells and the rope pump were also advocated.

Numerically, the pilot achieved 60 improved wells in 15 northern villages. In one village with 17 wells, four households upgraded entirely (progressing through the entire hierarchy), six households upgraded 80%, and two more reached 40% - a result which indicated strong independent spread of the self supply concept. The lack of subsidy proved to be a key success, as it meant an easier transition from a demonstration project to a self reliant, fully healthy self supply movement.

2.2.2 Ethiopia

A 2007 visit to Ethiopia to survey the potential of a self supply policy approach was also structured around the four pillars of technology, finance, private sector, and government. With regards to technology, it was found that rope pumps and other low cost pumps, drilling equipment and water filters did exist, but were not widely known. In order to reach their potential, rope pumps and similarly low-cost pumps needed a framework for greater spread of ideas and information. The visit also found two examples of traditional financing, which needed to be more formally institutionalized but which represented fertile ground for the self supply approach. The private sector was found to be poorly developed, with small scale contractors only beginning to emerge, but with significant enthusiasm for expansion. Finally, Ethiopia's government was found to be the most enabling of any in sub-Saharan Africa for the Self Supply approach. While they had limited monitoring capacity, they were very good at encouraging self-improvement (Sutton, 2007).

A 2009 presentation by government officials to the 34th WEDC conference continued the trend of enthusiastic governmental adoption of self supply (Workneh et al., 2009). They reviewed the national workshop held and identified key success factors of Self Supply while also adapting it to the Ethiopian context. The authors also announced the incorporation of Self Supply into Ethiopia's ambitious "Universal Access Plan" (UAP) to reach 98% access to improved water sources by 2012. Finally, they detailed their plans for the way forward, including mapping groundwater potential for shallow wells, preparation of technical manuals, and wider distribution of knowledge pertaining to water lifting mechanisms. The most recent update on progress (Sutton, 2010) notes again that Ethiopia is unique among her East African neighbors in that unlike other countries, such as Mali, Uganda, and Zambia which pursued smaller scale piloting of new elements of the self supply approach, it has leaped directly to incorporating self supply into the fabric of its national strategy. RWSN has categorized this move, and the enormous scale of Ethiopia's decision, as both a challenge and an opportunity. There is increased risk of failure where piloting has not already revealed areas for improvement. However, it is also noted that the use of family wells is already very common in some areas, so there is significant potential for building on this 'background level' understanding of self supply principles.

2.2.3 Mali

As with Ethiopia and Zambia, the initial study in Mali (Sutton et al., 2006) surveyed the potential for self supply in Mali in the four primary areas of technology, finance, private sector, and government. Technologically, the concept of well-upgrading was widely accepted but not in a format which fostered further spread. It was recommended that options be more neatly organized, into a ladder of incremental improvement options, in line with WHO rural water quality guidelines. With regard to finance, care needed to be taken to balance conventional and self supply choices so as not to promote inequity. In particular, it was noted that current government policy disincentivized self supply by heavily subsidizing communal systems – caution was urged in piloting self supply options so as not to continue this trend. The private sector was noted to be poorly developed, needing well-diggers and masons to be trained in not only techniques or well construction and upgrading, but also business management and marketing in order for self supply to reach its potential. Finally, the study noted governmental illiteracy with regard to self supply principles, and proposed a pilot project in partnership with local and central government officials so that they can see the potential and test the relevance of the approach for Mali.

Osbert and Sutton's 2009 address to the 34th WEDC conference (Osbert and Sutton, 2009) summarizes progress from piloting in 7 districts dating back to 2007. Several NGO's completed 137 upgraded systems via the self supply approach. Early water testing showed significant quality improvements, and the private sector showed the beginnings of independent adoption of the approach, particularly with well owners and digging contractors. The next planned steps were to introduce some new low cost technologies such as rope pumps and cheaper chlorine supplies, as well as to form advisory services between government, traders, and artisans to coordinate uptake of improvements. Overall, well owners showed a general willingness to invest in upgrades which bode well for the self supply trend.

The 2010 case study from Mali (Sutton, 2010a) reviewed progress up to that point. Similar to Zambia and Zimbabwe, Self Supply had been "adopted" by the government sector responsible for health risk reduction, as opposed to Uganda and Ethiopia which were more closely tied to rural water supply. The 2010 report divided progress into 4 stages: Introducing the idea, Demonstrating what can be done, Increasing self-reliance, and Going to scale. As of yet, districts which had been focal points of self supply interventions had reached the second and sometimes third stages with no specific progress into the fourth. Numerically, 300 demonstration wells had been completed, spread over 9 districts. A further 75 had been improved in a fashion mimicking that of the pilot project, indicating the early stages of independent uptake. With regard to costs, significant reductions of up to 90% over past methods were accomplished, with those independently copying the report reducing the costs even further. The self supply mindset had been largely accepted into the mindset of health officials at the local level: it remained to be seen if the national rural water supply sector would adopt the approach with similar enthusiasm.

2.2.4 Tanzania

Tanzania has had some remarkable success transitioning from NGO sponsored work to healthy private sector participation through self supply principles, particularly with the installation of rope pumps. A five year program starting in 2005 by the Southern Highlands Participatory Organization (SHIPO) subsidized the installation of 500 rope pumps (Haanen and Kaduma, 2011). With a high focus on quality, the technicians who were trained in manufacture and installation have managed to continue as a private business, selling 520 additional pumps without any NGO involvement. Moreover SHIPO reports that the rope pumps are better maintained by the communities that own them than more expensive versions of pumps.

2.2.5 Uganda

Formal self supply work in Uganda began in 2005 with a very comprehensive report (Carter et al., 2005) designed to pave the way for a self supply pilot project. While focused on shallow groundwater and well upgrading, it was one of the first documents to address the potential for rainwater harvesting. Uganda has both a climate and a large enough proportion of the population with hard roofs to make rainwater harvesting attractive. Carter observed that '"informal" or "opportunistic" roofwater harvesting is widespread in Uganda, though unsophisticated in terms of technology and involved limited capital investments. Most importantly for the rainwater harvesting aspect of self supply, Carter et al. introduces the idea of a "ladder" of rainwater improvements: a series of steps households can take to incrementally improve their supply and climb toward roof water as their sole supply. The document originally introducing this concept (URHA, 2004) is reviewed in Section 2.3 of this report.

After briefly touching on DRWH, Carter et al. proceeds to report on an initial reconnaissance trip to document the attitudes on the ground towards self supply in order to pave the way for more effective future interventions. He concludes that, because of some of the problematic ways self supply is perceived, they recommend a new grading scale which allows for the evaluation of incremental improvements to sources. They recommend than any source be given a score of 0 (poor), 1 (medium) or 2 (good) on the criteria of access, water quality, reliability, cost, and management. This, says Carter et al., would allow self supply sources to demonstrate their quality and value to households.

Following the initial report, the pilot project successfully upgraded 39 sources serving 600 households (Carter et al., 2008). The two implementing NGO's, Uganda Muslim Rural Development Association (UMURDA) and Wera Development Association (WEDA), achieved upgrading of springs and shallow wells in Bugiri and Amuria districts at significantly reduced costs over conventional approaches. The pilot proposed a two stage scaling up, based on their success, by first demonstrating the approach with 15 NGO's across the Technical Services Unit regions of Uganda, followed by a full scale national implementation. The NGO's also list ten important lessons learned from the pilot, which are listed in Figure 2.3.

1. **Importance and potential of self supply**. Targeted support to self supply is one important strategy for the provision of safe sustainable water supplies. It has significant potential to serve many more people at low cost than through the conventional approach and with a greater degree of cost-sharing between government and the community.
2. **Drivers**. Self supply initiatives are common in areas where supply is distant, unreliable and costly but with opportunities for shallow groundwater or DRWH possibilities. The drivers which motivate individuals to initiate self supply improvements include personal convenience, the desire for self-improvement, potential for productive water use and the provision of service to the wider community.
3. **Ownership**. At the heart of true self supply is the issue of water supply ownership. Communal ownership and management are problematic, while ownership by a motivated individual provides a greater prospect of functional sustainability.
4. **Technical constraints**. Certain water source technical options are better suited to groundwater source improvements than others. In the Uganda pilot, the focus has been on shallow wells and natural springs, with wells the preferred option. Where deep boreholes are needed, groundwater source improvements may not be an option.
5. **Selecting project locations**. The selection of locations for future pilot projects or scaled-up initiatives needs to take account of technical options, the existence of motivated individuals, the need for improved access to safe water, and opportunities for productive uses of water.
6. **Communicating the concept**. Communicating the concept of self supply to NGOs and CBOs, local Government, and other stakeholders is important, but challenging. It is easy for the concept to be misunderstood, or for some stakeholders to feel threatened by it.
7. **Water safety**. Experience from the Uganda pilot demonstrates (a) that water quality can be significantly improved through groundwater source improvements, but that (b) water users often wish to quickly progress up the "ladder" of improvements, to a covered source equipped with a handpump.
8. **Role of implementing agencies**. The role of organisations which become involved in support to self supply is to promote and encourage self supply initiatives; provide technical and management advice, specialist skills and (limited) material support; promote sanitation and hygiene improvement; all while avoiding the stifling of private initiatives.
9. **Ongoing support to water users**. Implementing agencies must continue to be available to water source owners, providing continuing advice on technical or management problems.
10. **Ongoing support to implementing agencies**. Implementing agencies themselves need continuing support from local and central Government and/or international NGOs, to resource their support activities to water users, and to ensure their knowledge is kept up-to-date.

Figure 2.3 Lessons learned from the self supply pilot project in Uganda (Danert and Sutton, 2010, with permission).

The case study summarizing progress to date published by RWSN in 2010 (Danert and Sutton, 2010b) was the first self supply report detailing on the ground progress in the rainwater harvesting arm of self supply. While neither RWSN nor the pilot had directly promoted DRWH in their interventions, the report covers other's progress, such as the founding of the Uganda Rainwater Association (URWA) and the evolution of government's role in DRWH. Complementing these reports, seven theses published by Cranfield University between 2005 and 2007 supplement the findings of the Uganda Self Supply Study.

In "Self Supply in Busia Town, Eastern Uganda" (Rogenhofer, 2005) Rogenhofer demonstrates the importance of hand-dug wells to the residents of Busia Town, complementing the existing piped water system. She shows that some residents are already accustomed to some aspect of the self supply concept, in that they use as their primary source a well in which they have invested their own money. However, water quality in these wells did not meet WHO standards, and the beginning steps of well upgrading at the Busia wells did not produce the improvements in water quality that studies in Zimbabwe and Zambia demonstrated to be possible. Thus Rogenhofer concludes that the self supply concept exists in practice, but that further technological support in upgrading the wells and improving hygiene conditions could produce positive results in water quality.

In “Analysis of ways to improve water supplies for sedentary cattle-owning communities: a case study in Rwebisengo, Sub-county of Bundibugyo District, Uganda “ (Fouegue, 2007), Fouegue finds that water management for the community as a whole is shaped by provision of water for their livestock. Accordingly, conventional approaches fall short of their goals and are frequently abandoned altogether. Fouegue concludes that the self-supply approach is uniquely suited to the needs of such communities, especially in complementing those places where conventional approaches simply cannot provide for the needs of a mobile community.

In “Impact and Potential of Self Supply in Amuria District, Uganda” (Alford, 2007), Alford conducted a study at one of the self supply pilot sites: the town of Wera, in Amuria District. His findings echo that of the pilot: “supported self-supply is able to achieve significant improvements in water quality, access and sustainability, using simple technologies in line with locally-available skills and materials, and at a lower per-capita cost than more conventional communal approaches.”(Alford, 2007) In particular, he finds communal and private self supply initiatives score a 6 and 7, respectively, using Carter’s scoring framework, compared to 4 apiece for shallow wells and boreholes implemented using conventional methods.

The study, “An investigation into the potential to reduce the cost of constructed rainwater harvesting tanks in Uganda” (Cruddas, 2007), researched a number of different kinds of built in place tanks spread across Uganda. Cruddas divided costs into categories of cement, other imported materials (reinforcing mesh, bars and wire, pipe and tap fittings, waterproofing agents, etc.), local materials (or gatherables, such as bricks), capital costs, transport, and labor. He concludes that materials costs are high nationwide, though with the hope that a maturing market for constructed tanks will reduce this. More importantly for this report, he notes that “The dissemination of designs and construction techniques between sector professionals is not widely practiced, and no central database exists which interested parties can consult. There was also little evidence of innovation in improving existing designs or investigating new low-cost storage options.”(Cruddas, 2007)

Cruddas in particular highlights the potential of the forthcoming National Rainwater Reference Centre. The Centre now exists, albeit under a slightly different name (The Appropriate Technology Centre), but as of 2011 still did not have a centralized database of rainwater harvesting technologies. They do conduct trainings and provide information on a few methods, including demonstration models of ISSB and plastic tanks onsite, but do not have a comprehensive collection of available methods.

In “Factors Affecting the Cost of Prefabricated Water Storage Tanks for Use With Domestic Roofwater Harvesting Systems in Developing Countries” (Rowe, 2007) Rowe looks at how prefabricated tanks are made and concludes that the cost of materials is the largest contributing factor to their market price, followed by transportation. While, at present, technology has reduced the cost of fabricated tanks as far as possible, he notes, the largest opportunity for cost reduction is reduction in taxes.

In “An Investigation into the Impacts and Challenges of Implementing Self Supply in Eastern Uganda” (Tillett, 2006), Tillett investigates in detail the efforts of the Uganda Muslim Rural Development Association (UMURDA) to upgrade twelve open shallow wells to protected springs. His analysis of water quality finds up to twenty-fold reduction in fecal contamination with the government’s contribution reduced from nearly 2,000,000 shillings for a conventionally improved spring to around 500,000 shillings with the self supply approach.

In “Stakeholders’ Perceptions of Self Supply in the Ugandan Rural Water Supply Sector”(Mills, 2006) Mill conducted semi-structured interviews in order to “identify and classify” perceptions of self supply with key stakeholders in 5 districts and 5 sub-counties. Mills found that most barriers exist in misconceptions of the self supply approach, and that significant enthusiasm and potential for taking the idea to scale exist on the ground.

2.3 Domestic Rainwater Harvesting (DRWH) in Uganda

DRWH is a well-researched phenomenon in Uganda, even apart from self supply. Terence Thomas has done significant research into the economics of DRWH. In a 1999 paper (Thomas and Rees, 1999), the authors perform a benefit:cost ratio analyses of several rainwater usage schemes in combination with supplementary sources, and concludes that sole supply DRWH is probably an inappropriate objective, taking into account both the economics of the investment required and the realities of how rural households use water. The optimally efficient storage volume, his calculations suggest, is somewhere between four and twenty days supply. Five years before the self supply concept paper would be published, he notes that “even where total RWH is an ultimate objective, it makes much sense to reach it in stages by the stepwise extension of an initially partial and seasonal system”(Thomas and Rees, 1999).

Martinson and Thomas build on this conclusion in a 2003 paper (Martinson and Thomas, 2003), which suggests that pursuit of sole source DRWH needs tanks 10-50 times larger, and that this effort has overpriced DRWH in general and hampered enthusiasm for its adoption. Furthermore, they suggest that between the economically optimal tank size and the tanks size required for sole source use, lies a range of “medium performance” DRWH, which with good water management can be just as convenient and reliable as many conventional point sources. Finally, they observe that “in order for the community to make an informed choice among technologies, they will need information about how different sizes systems behave, as well as the costs and trade offs involved in different designs “ (Martinson and Thomas, 2003), which is a crucial cornerstone of the self supply approach.

In a more recent visit to Uganda (Thomas, 2010), the author notes that subsidies have a tendency to destroy private initiative. If there is even the slightest possibility of a future subsidy, potential customers will not invest in a RWH system on their own. Particularly in Rakai, many NGO and government sponsored RWH programs have failed utterly after the pilot stages because subsidized programs could not sustain momentum in a private market.

Most recently, the Uganda Rainwater Association has been promoting the use of women's groups as skilled artisans in constructing small built-in-place tanks throughout Uganda (Baziwe, 2011). In a number of initiatives they have found that the organization of women's groups taps into the already existing strengths of a community, promoting the sustainability of rainwater harvesting as a self supply option. In particular, URWA suggests women are good at listening to end users and involving them in ownership of the tanks they invest in.

The most comprehensive overview of Rainwater Harvesting Policy was conducted in 2004 by the Uganda Rainwater Harvesting Association (URHA, since renamed the Uganda Rainwater Association, or URWA) (URHA, 2004). In a close survey of several districts and a broad look at the country as a whole, they found a generally immature market for rainwater harvesting. Parts and supplies were generally unavailable, except for a good commercial structure and supply chain found in only 15 or so of Uganda's many hundreds of sub-counties. Moreover they found that people were poorly informed as to what options they had for DRWH: "there is little awareness in the country of the range of technologies that have been used in recent years or where to go to obtain most of them." (URHA, 2004) They support Thomas' conclusions on DRWH as a sole source of water, noting that even as the proportion of hard roofs increases, the size of those roofs are generally too small to provide 100% of water needed even to households with abundant rain.

Most importantly for this study, the 2004 URWA report is where the concept of a rainwater harvesting ladder was developed (Figure 2.4). This idea allows for incremental investment as a household slowly increases their infrastructure to bolster their dependence on rainwater. The six rungs of the ladder are described in Table 2.3.

Table 2.3 Description of the rainwater harvesting ladder.

Rung	Title	Description
0	Informal DRWH	No investment necessary, just simple actions such as putting basins underneath the edge of a hard roof during a storm.
1	Opportunist DRWH	Very limited investment, such as a short length of gutter leading to a clay jar or oil drum.
2	Wet-season DRWH	Significant guttering, with storage large enough to span rainstorms and provide most of the household water needs, typically 600-1,200 liters. During the dry season the household will still rely on point sources.
3	Potable DRWH	Similar to rung 2 in infrastructure, but utilized to provide a little water throughout the year. Point sources used for other applications.
4	Adaptive DRWH	Good water management and larger storage meets most water use needs in the wet season but only a few in the dry season.
5	Main-source DRWH	90% of water needs met by a large roof and large, often underground, tank.
6	Sole-source DRWH	100% rainwater. Usually only on islands, and requires very large storage.

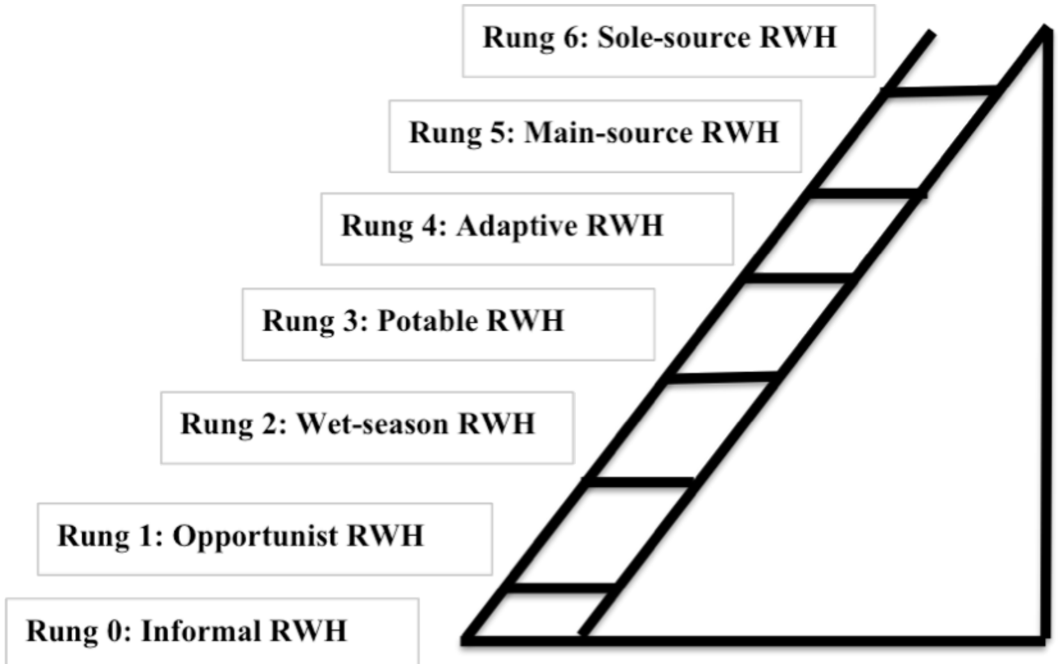

Figure 2.4 The rainwater harvesting (RWH) ladder (adapted from URHA, 2004).

CHAPTER 3: METHODS AND BOUNDARY CONDITIONS

3.1 Rakai District

This study's author spent two years living and working in Kalisizo, a town located in Rakai District. Rakai District is located in the south part of Uganda, as shown in Figure 3.1, abutting Tanzania to the south and Lake Victoria to the east. The most recent census in 2002 placed the population of Rakai District at 405,631 – excluding the population of Kabula County, which subsequently became the separate district of Lyantonde (UBOS, 2002).

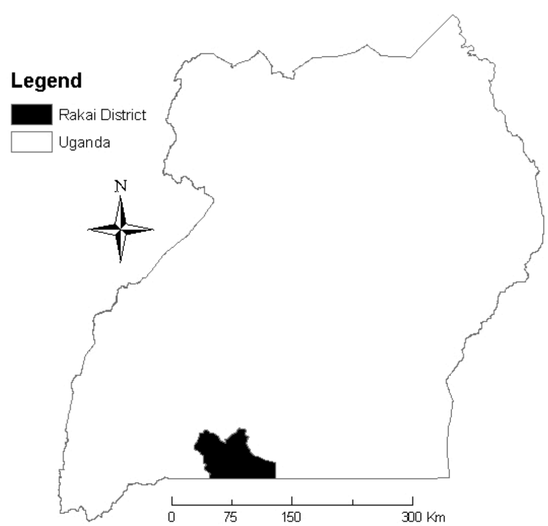

Figure 3.1 Location of Rakai District within Uganda (Map created by Jonathan Blanchard using data from ugandaclusters.ug).

From Uganda's largest city, Kampala, the main highway heads west-south-west, skirting the edge of Lake Victoria, until the major town of Masaka. The highway there splits – one branch continues west to Mbarara, Kibaale, and eventually Rwanda, and the other branch enters Rakai District to the south, passing through Kalisizo and Kyotera before entering Tanzania. A separate paved road branches west from Kyotera to the District Headquarters in the town of Rakai, for which the district is named, where the pavement ends and dirt roads begin.

Figure 3.2 shows that Rakai District is sub-divided into 3 counties (Kooki, Kakuuto, and Kyotera) and 20 sub-counties. It has been proposed that Rakai District sub-divide into two separate districts, but this has not yet been implemented (Nalugo, 2011).

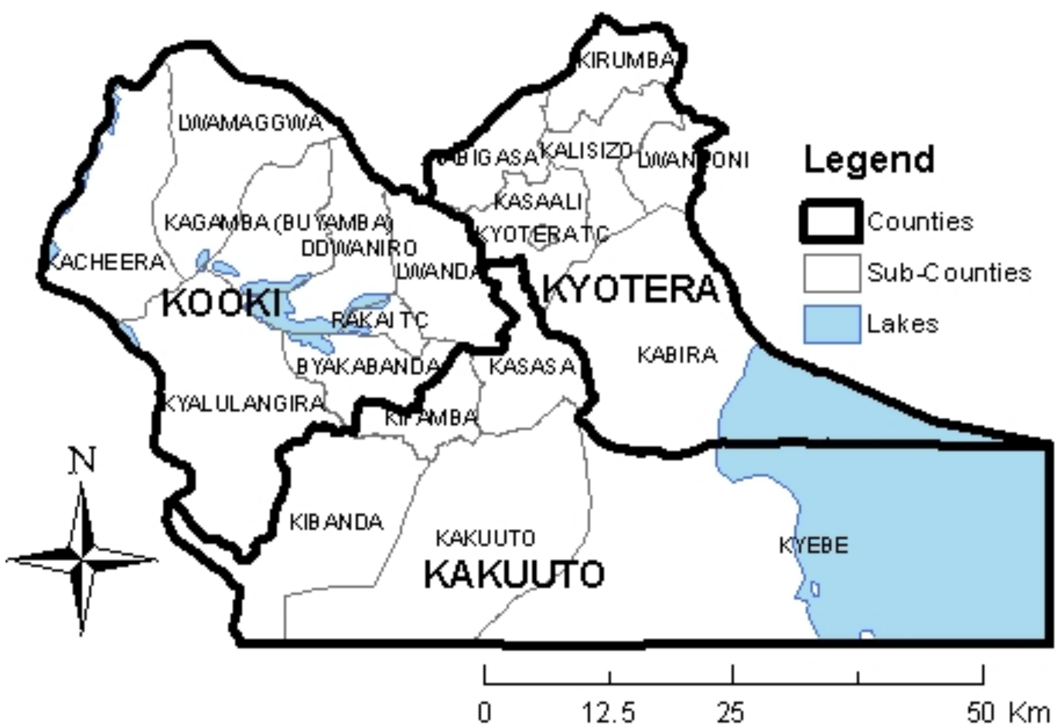

Figure 3.2 Map of Rakai District, with county and sub-county boundaries (Map created by Jonathan Blanchard using data from ugandaclusters.ug).

The author's observation during his two years serving in Uganda as a water/sanitation engineer was that most residents of larger towns had access to a piped water system, while in rural areas boreholes and springs were the major sources of water. Rainwater harvesting was observed, but overall was a minority option for most residents.

3.2 Boundary Conditions

This research examines the self supply water storage technologies associated with rainwater harvesting available on a wide scale - technologies that are still considered experimental, or methods that have been tried and abandoned are not examined here. The district of Rakai is the primary focus, but it is the intent of the research that the findings will be relevant to most of Uganda.

Costs are presented where available, with the caveat that these are more likely representative of expected costs for the central region of Uganda. Costs presented do not include transport to the homeowner; this factor is obviously dependent on the particular location of the consumer, and is not examined here. From the author's personal experience, it is estimated that small tanks, below 500 liters, could be transported for no more than the cost of a passenger, which from Kampala to Rakai District is approximately 13,000 UGX. Rakai District can be crossed end to end in public transport for 8,000 UGX. Tanks above 500 liters of volume may require a dedicated vehicle; it is estimated that any destination in the district could be reached for 100,000 UGX. Guttering costs associated with rainwater collection are also not included. In addition, most types of tanks are very scalable – they can be built in nearly any volume the owner desires. This makes costs difficult to quantify.

The water sector of Uganda has a very wide variety of organizations and groups working toward similar goals in different ways. Accordingly it is believed that by soliciting the input of a wide range of persons and organizations working in the field, a sufficiently comprehensive picture of the rainwater harvesting situation in Uganda has been assembled.

3.3 Data Collection

Two documents that have touched on these topics without a comprehensive review (Danert and Motts, 2009; Thomas, 2010) formed the starting point for this research's methodology. Both documents sketched the outlines of storage options available without a rigorous examination of locations, costs, programs by which technologies had been implemented, or how wide commercial uptake had spread. In particular, Danert and Motts observed that small manufactured products were available on a wide commercial basis, but larger manufactured storage options were available only in very large cities. As for constructed tanks, Danert and Motts observe that they are only available where they have been promoted by NGO's, and only sparingly at that; due to subsidies and a lack of focus on private sector uptake, many programs fail to produce continuing businesses.

Building on this division of rainwater storage into manufactured and constructed options, research was undertaken in three phases, all of which are summarized in Figure 3.3. The first phase was a series of upper-level meetings during the months of July, August, and September 2011 with organizations having an advisory or oversight role in rainwater harvesting (All stakeholders from phases 1 and 2 are described further in Section 3.4.). These include the Ministry of Water and Environment (MWE) at the national, regional, and district levels, the Appropriate Technology Center (ATC), and the Uganda Rainwater Association (URWA).

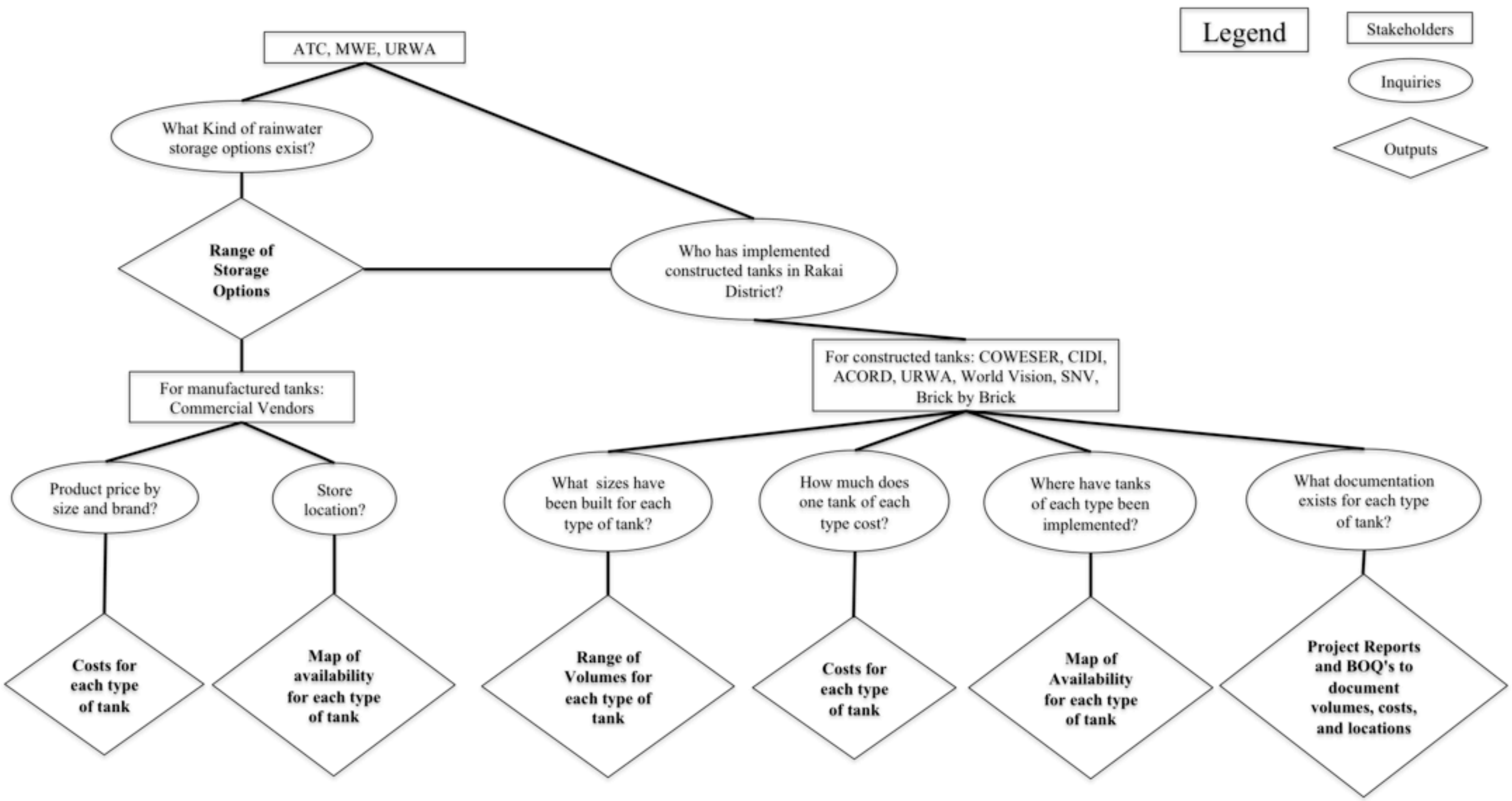

Figure 3.3 Summary of stakeholders, inquiries, and outputs of this research.

A total of six meetings were held: two with MWE at the national level, and one each with the other levels of government and organizations. Each stakeholder confirmed the central hypothesis of this research: that a centralized documentation of rainwater storage options is lacking and would be useful. Subsequently, each meeting had two outputs: the stakeholder's perspective on all the commonly available storage technologies available in Uganda, and knowledge regarding which organizations had been involved in implementing each technology in Rakai District. These outputs are summarized in table 3.1.

Table 3.1 Inquiries and outputs from meetings with advisory/oversight organizations.

Inquiry	Output
What are all the widely available ways that people store rainwater in Uganda?	Informal: pots/pans/basins, Manufactured: Oil drums, corrugated iron, plastic tanks Constructed: mortar jars, ferrocement, tarpaulin
What are the organizations implementing each type in Rakai District?	All Manufactured types – commercial vendors Mortar Jars – URWA, SNV, Kigezi Diocese Ferrocement – URWA, ACORD, COWESER Tarpaulin – ACORD

The second phase was a series of meetings with the implementing organizations suggested during phase 1. These organizations were the Agency for Cooperation and Research in Development (ACORD), Community Welfare Services (COWESER), Netherland Development Organization (SNV), and URWA – which does some implementation activities as well as advising and oversight. These organizations were also asked to confirm the hypothesis that some form of centralized documentation of rainwater storage options would encourage and enable uptake. They were then asked about the volumes, prices, and locations of the various programs implementing each kind of tank. They were also asked to provide documentation that would substantiate this information. Finally, they were asked if they themselves had implemented other kinds of tanks, or if they were aware of other organizations implementing the same or other kinds of tanks. Only ACORD testified to the work of an as yet unknown stakeholder, CIDI, which had also built tarpaulin tanks in Rakai District. ACORD also suggested adding the partially underground tank, which they were promoting in the south-west region. Brick by Brick's work with Interlocking Stabilized Soil Brick (ISSB) tanks were added due to the author's first-hand experience. In-person meetings were conducted with ACORD and URWA, while SNV and COWESER corresponded over email.

Table 3.2 Inquiries and outputs from implementing organizations.

Inquiry	Outputs
What size tanks were built?	Range of volumes
How much did they cost?	Price lists
Where were the tanks built?	Locations with knowledge of each method.
Can you provide documentation	Project reports, BOQ's

The first two phases provided data on constructed tanks. The third phase collected data on manufactured tanks. The inquiries and outputs of phase 3 are summarized in Table 3.3. In order to obtain data on the availability and pricing of manufactured products (i.e. plastic tanks, corrugated metal tanks, and oil drums), a survey of Rakai District and the closest large town (Masaka, including its suburb, Kyabakuza) was conducted. It was decided, in consultation with a local resident familiar with the district, that there were only 10 or so trading centers in the district large enough to have hardware stores selling these smaller manufactured tanks. These towns and the number of stores where manufactured tanks can be purchased are outlined in Table 3.4 and also presented in the next chapter in Figure 4.1. The town of Masaka was included, even though it is not technically within Rakai District, because it is the nearest large town, and it is common for Rakai District residents to source locally unavailable goods from Masaka.

In order to avoid the tendency of vendors to overcharge Americans and obtain costs indicative of those at which Ugandans could actually purchase these products, the author's assigned counterpart from his term as a Peace Corps Volunteer (a trusted Ugandan and resident of Rakai District) visited all of these stores between August 17 and September 6, 2011. He was instructed to examine, as an interested consumer, the types of manufactured storage products available at each store and inquire as to their purchase price. The material (plastic, metal), brand (where relevant), and size of available manufactured tanks were noted and respective costs solicited and recorded using the form in Table 3.5. Due to the relatively small study area (one district), sampling was not necessary; within the time and budgetary scope of the research, the price of each kind of manufactured tank at every commercial source available to Rakai residents was collected. In addition to the survey of Rakai stores, Crestank – a major national supplier of plastic tanks ranging from 60-24,000 liters – supplied their price list via email.

Table 3.3 Phase 3 inquiries and outputs.

Inquiries	Outputs
What town is the store located in?	Map of where manufactured products are available.
What materials are storage products available in?	Generic metal oil drums, corrugated iron tanks, plastic tanks
What companies are distributing tanks?	For plastic tanks: Victoria Nile, Techino, Rajol, AfroPlast, VNPL, SkyPlast, Premier, Crestank, Arsalan, Poly Fibre, generic chemical barrels.
What volumes are available?	Range between 60-24,000 liters
What are the costs of each type, brand, and volume of tank?	Varied: see Chapter 4 for details

Table 3.4 Availability of manufactured storage tanks.

Town	Number of Stores
Masaka	11
Kyabakuza	3
Kalisizo	1
Kyotera	3
Lwamaggwa	1
Mutukula	3
Ssanje	2
Kibaale	5
Rakai	1
Kasensero	2

Table 3.5 Template for collection of manufactured storage data.

Survey of Manufactured Rainwater Storage Products in Rakai District, Uganda

Date: ___________Town: _____________Name of Store: ____

Material	Brand	Volume	Cost

Finally, the data were organized graphically so as to present a range of storage methods, volumes, associated costs, and locations where they are available within Rakai District.

3.4 Stakeholders

The stakeholders who contributed to this research are summarized in Table 3.1 then discussed in further detail. As shown in the table, they represent the Ministry of Water and Environment, Technical Services Unit 7, the Rakai District Water Office, the Uganda Rainwater Association, the Appropriate Technology Center, World Vision, the Netherlands Development Organization, the Association for Cooperation and Research in Development, the Community Integrated Development Initiative, Community Welfare Services, and Brick by Brick.

Table 3.6 Representatives, descriptions, mode of contact, and websites for the stakeholders interviewed for this thesis.

Organization	Representative	Description	Contact	Website
MWE	Paul Bisoborwa,, Joel Kiwanuka	Arm of national government responsible for national water policy and implementation	In person	www.mwe.go.ug
TSU 7	Kristin Kakuruga	Regional advising office of the MWE for Rakai and surrounding districts.	In person	none
Rakai District Water Office	George Kasibante	Rakai District office of MWE.	In person	www.rakai.go.ug
URWA	Paito Obote, Dorothy Baziwe	Ugandan NGO promoting, studying, and improving RWH across Uganda; has implemented ferrocement tanks and mortar jars.	In person	www.gharainwater.org/urwa_aboutus.html
ATC	Isaac Bukenya	National center advising in appropriate water and sanitation technologies including RWH.	In person	none
World Vision	Paul Ahura	International NGO working in Rakai; has encouraged tarpaulin tanks.	In person	www.worldvision.org.nz/WhereWeWork/uganda/
SNV	Chemisto Satya	International NGO working in Rakai and elsewhere in Uganda.	Email	www.snvworld.org/en/countries/uganda/Pages/default.
ACORD	Dunstan Damulira	International NGO working in Rakai; has implemented tarpaulin, ferrocement, and partially underground tanks.	In person	www.acordinternational.org/index.php/base/uganda
CIDI	Dan Kigula, Edward Kyabaggu	Ugandan NGO working in Rakai; has implemented tarpaulin tanks.	In person	www.cidiuganda.com/
COWESER	Joseph Mubiru	Local Rakai NGO; has implemented ferrocement tanks.	Email	www.betterplace.org/en/organisations/coweser
Brick by Brick	Jonathan Blanchard	Local Rakai business constructing ISSB tanks.	In person	www.positiveplanet.net/what-social_entrepreneur.php

The Ministry of Water and Environment's mission is "to promote and ensure the rational and sustainable utilization, development and effective management of water and environment resources for socio-economic development of the country" (MWE, 2011). Policy is set at the national level, but each district has significant leeway to operate independently. Regional Technical Services Units (TSUs) advise and build the capacity of the district water offices. A pilot program in 2005-2006 demonstrated that a cost sharing approach between government and households was financially feasible, and also established the MWE's policy of only supporting RWH storage tanks of 6,000 liters and larger (MWE, 2006). This was due to their rough calculation that 6,000 liters is the minimum volume required to provide an average household with sufficient water throughout the dry season based on the range of roof sizes from 55-150m^2.

The Uganda Rain Water Association (URWA) is an NGO whose mission is "to promote rainwater management for sustainable domestic water supply, production, and environment conservation in Uganda" (URWA, 2009). They partner with the Uganda Government through the MWE, as well as numerous other organizations such as SNV and the World Bank. URWA has 4 focus areas: advocacy and lobbying (for example, encouraging the government to reduce the minimum volume of RWH storage tanks that they will subsidize, currently set at 6,000 liters), capacity building, research and development, and networking and collaboration.

The Agency for Cooperation and Research in Development (ACORD) is an international NGO with a history of pioneering and championing rainwater storage techniques especially in the central region of Uganda. Their mission is "to work in common cause with people who are poor and those who have been denied their rights to obtain social justice and development and be part of locally rooted citizen movements" (ACORD, 2011).

The Appropriate Technology Center is an initiative of the Ugandan government that aims to demonstrate and disseminate information regarding different water supply and sanitation options. Their facility in Mukono (2 hours east of Kampala) not only has examples of several kinds of rainwater tanks, but also conducts trainings in construction with interested parties.

Community Integrated Development Initiative's (CIDI) mission is "to work towards poverty eradication and creation of self sustaining communities in Uganda through the provision of integrated technical and material support, in broad areas of sustainable agriculture, water and sanitation, environmental protection, income generation and civil society empowerment" (CIDI, 2011). Their Rakai District office is located in Kyotera. A component of their work with farmers in Rakai is training in and subsidy of tarpaulin tank construction.

World Vision is an international Christian NGO working in Uganda since 1986. They focus on improving the lives of children in such areas as education, health care, and HIV/AIDS support (World Vision, 2010).

The Netherlands Development Organization (SNV) is an international NGO working in 36 countries, including Uganda since 1989. They chiefly provide advisory services government, civil society, and the private sector in such areas as water and sanitation, energy, and agriculture (SNV, 2011).

Community Welfare Services (COWESER) is a small NGO based in Kalisizo, Rakai District. The author was officially assigned to work with COWESER as a part of his Peace Corps assignment and had exposure to their work in water and sanitation.

Brick by Brick is a business started by the author during his time as a Peace Corps Volunteer. Utilized the ISSB technology, which is being promoted by Professor Muzaazi of Makere University, Brick by Brick constructs large rainwater storage tanks for households and institutions throughout Rakai District and beyond.

CHAPTER 4: RESULTS & DISCUSSION

This thesis' first major objective is to present a comprehensive collection of Uganda's rainwater storage options. This chapter presents 11 technologies, spanning a volumetric range of storage from 5 to 50,000 liters. The storage techniques are categorized into three categories: 1) traditional/informal methods, 2) manufactured products (products purchased and transported to a house), and 3) built-in-place tanks (constructed by private artisans, which generally require training and some mechanism for quality assurance). The kinds of storage types identified in this study within each category are outlined in Table 4.1.

Table 4.1 Categories of rainwater storage methods.

Categories	**Types of Tanks Observed in Uganda**
Traditional/Informal	Clay Pots, Pots/Basins, Brick Masonry Tanks
Manufactured	Plastic Tanks, Metal Corrugated Tanks, Oil Drums
Built-in-place	Mortar Jars, Ferrocement Tanks, ISSB Tanks, Tarpaulin Tanks, Partially Below Ground Ferrocement Tanks

The types of tanks described in Table 4.1 are those that achieved some measure of common practice in Uganda. It is certain that several others have been piloted or experimented with, but as they have not yet achieved wide knowledge or implementation, they are excluded from this study. Because of the informal nature of the first category (top row in Table 4.1), those kinds of tanks are described but no firm data is available. For the second and third categories, results cover three attributes for each kind of tank: location, volume, and cost. Each technology is presented individually, then collectively compared in Section 4.4.

4.1 Traditional/Informal

4.1.1 Clay Pots

Clay pots have likely been used for millennia in Uganda as a part of the informal rainwater harvesting process. While they have been largely phased out in favor of cheaper, more durable products (i.e. the universal “jerrycan”), there are still rural areas in Rakai District and elsewhere which preserve the knowledge of making and using clay pots of various capacities – though it is noted that the preferred use seems to be for storing drinking water inside the home, rather than for gathering rainwater from the roof. The author located one woman in a rural area outside Kalisizo, within Rakai District, who maintained this knowledge but no longer has a market for her goods. No attempt to quantify costs was made, due to the widely scattered nature of those few people still involved in the creation of these vessels, and the judgment that this trade did not exist in an established, cash-based marketplace but rather in a communal society.

4.1.2 Pots and Basins

Another informal method Ugandan households use is to simply arrange their pots and basins underneath the edge of their roof during a rainstorm. This rudimentary approach does not require guttering, and while storage capacity is certainly low it provides at least a day's worth of water for cooking, drinking, washing, and possibly bathing. Moreover the marginal cost for rainwater harvesting with this method is negligible since the already existing cooking vessels and universal plastic basins are used.

4.1.3 Brick Masonry Tanks

Brick masonry tanks are an older technology utilizing the standard burned clay bricks arranged circularly on a concrete foundation and mortared with cement. From first hand observation, it would appear that most of these tanks are very old and a high percentage of them are inoperative. Costs were also not gathered for this technology because the implementation of it is so informal: no government agency or NGO's are training artisans in the method because there are more economical methods of constructing storage vessels. It would appear the technology persists simply by informal groupings of masons being hired to construct these kinds of tanks. Furthermore, it is likely that costs widely vary depending on each individual mason's method and style.

4.2 Manufactured Products

Manufactured products represent the most widely and readily available method of rainwater storage. This is not only because they are available for purchase in many locations, but also because they can generally be easily transported anywhere they are not available for sale. Transportation is fairly well organized: the larger manufacturers offer to deliver anywhere in the country, while the informal transport sector is well developed. The mini-busses, or "matatus", which serve nearly every village of the country regularly and readily move cargo ranging from livestock to luggage and can easily be contracted to haul storage containers to even the most remote settlement. Trucks carrying livestock and agricultural goods to centralized areas for sale regularly visit even those areas removed from villages of any size. These trucks also arrange to informally transport materials of any kind.

Figure 4.1 shows the towns and locations where hardware stores that serve Rakai District are located. Sections 4.2.1, 4.2.2, and 4.2.3 discuss in detail the pricing and availability of each of the three different kinds of manufactured storage products.

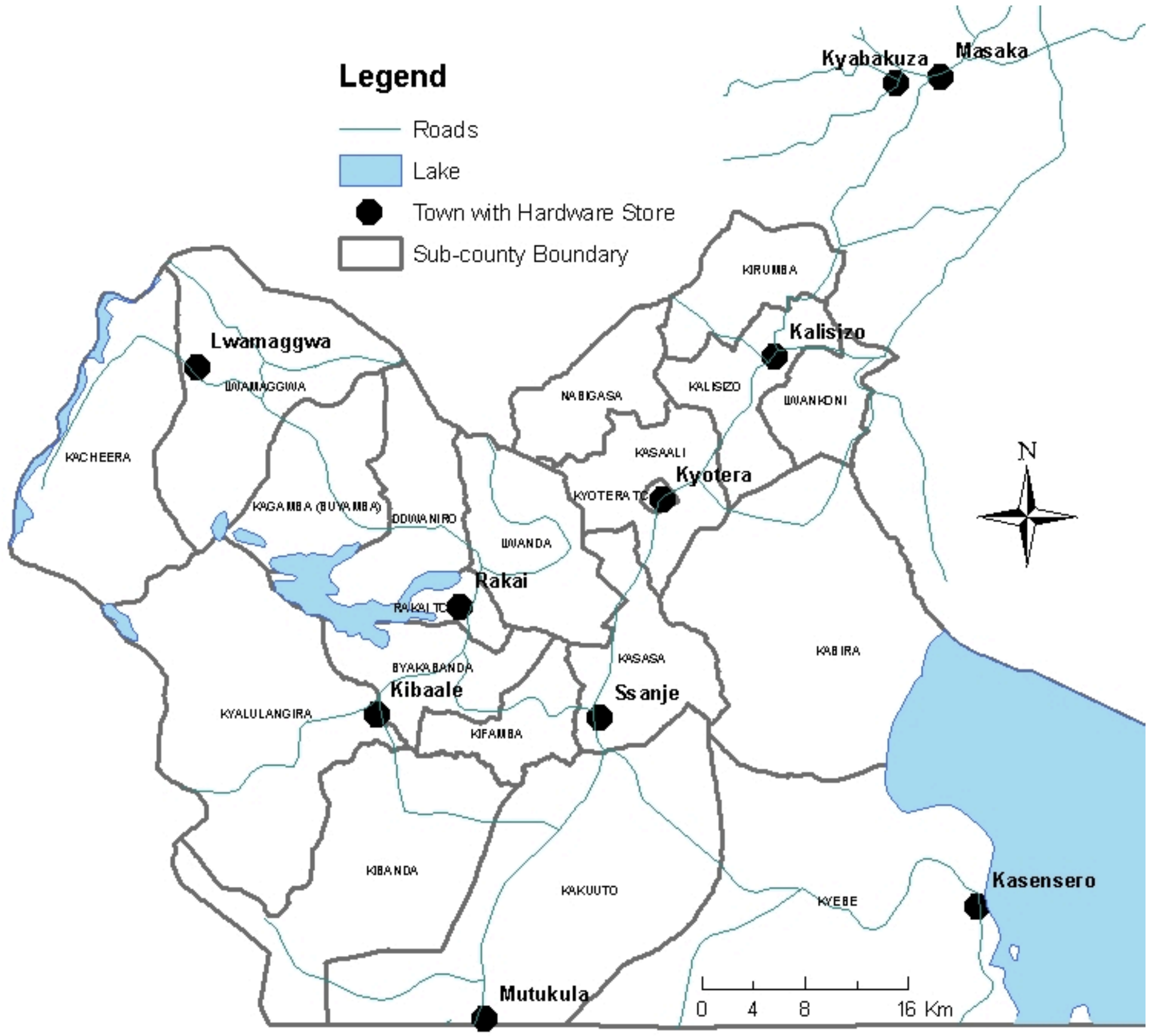

Figure 4.1 Locations of suppliers of manufactured rainwater storage products serving Rakai District (Map created by Jonathan Blanchard using data from ugandaclusters.ug and diva-gis.org).

4.2.1 Fifty-Five Gallon Metal Drums

A common reuse of the standard oil drum, once empty, is for rainwater storage. It is not uncommon to see even the smallest house erect just a meter of guttering directed into a reused oil drum. These drums could be categorized as “traditional” since they seem to have been used in Uganda longer than the other manufactured products; however, since they are sold in hardware stores and in many applications are used exclusively for rainwater harvesting, for the purposes of this study they are considered a manufactured product. These empty drums (standard size 55 gallons, or 208 liters) are available in some hardware stares. The survey of Rakai District (including Masaka town) yielded six separate stores where these drums are sold at consistent prices (either 75,000 or 80,000 shillings: see Table 4.2 for details). There was one store located in each of Rakai Town, Kibaale, Masaka, and Kalisizo and two stores in Kyotera (refer to Figure 4.1 for geographic locations for each of these).

Table 4.2 Locations and prices of 55-gallon metal drums.

Town	**Store**	**Price (Uganda Shillings (UGX)) for 55-gallon metal drum**
Rakai	Mutima Hardware	75,000
Kibaale	Sserwanja	80,000
Masaka	Kabuwoko Hardware	80,000
Kyotera	Continental Hardware	80,000
Kyotera	Muto Hardware	80,000
Kalisizo	H/B Mukasa	75,000

4.2.2 Corrugated Iron Tanks

Tanks built of curved, corrugated iron sheets welded into cylindrical tanks are a common sight on Ugandan roadsides. These are generally not sold at hardware stores, but at specialized metalworks. Tank size ranges from 2,000 to 15,000 liters. None of these metalworks operates within Rakai District, but there are three in the town of Kyabakuza, just outside of Masaka. Each of these works with the same materials (24 or 26 gage iron sheets), in similar volumetric configurations with comparable prices, shown in Table 4.3. The pricing is fairly consistent from store to store, and the gage is a major contributor to cost. The thicker gage 24 is more expensive than gage 26, but tanks of the thicker material also tend to last longer.

Table 4.3 Volumes, metal gages, and prices (UGX) of metal corrugated tanks available to Rakai District.

Volume (liters)	**Gage**	**Kyabakuza Metalworks Price (UGX)**	**Walugembe Metalworks Price (UGX)**	**Kiijjabwemi Metalworks Price (UGX)**	**Average Price (UGX)**
2,000	26	N/A	300,000	N/A	300,000
3,000	26	350,000	N/A	N/A	350,000
4,000	26	450,000	450,000	400,000	433,333
4,000	24	N/A	N/A	550,000	550,000
6,000	26	650,000	550,000	N/A	600,000
8,000	26	800,000	780,000	750,000	776,666
8,000	24	N/A	N/A	900,000	900,000
10,000	24	1,100,000	1,100,000	1,200,000	1,133,333
12,000	24	1,300,000	N/A	N/A	1,300,000
15,000	24	1,500,000	N/A	N/A	1,500,000

4.2.3 Plastic Tanks

There are two national, centralized manufacturers and distributors of plastic tanks in a wide range of volumes (100 liters – 24,000 liters). The most prominent of these is Crestanks, a subsidiary of Kentanks in Kenya, whose prices appear in Table 4.4. The other major company (Poly Fibre) was unresponsive to inquiries for their catalogues and costs, though it is believed they are similar in price and quality. This conclusion is reinforced by a previous study that was able to compare the two (Rowe and Carter, 2007).

Table 4.4 Crestank's catalogue and pricing as of October 1, 2010. These prices had not been changed as of August, 2011

CRESTANKS

Innovating Solutions • For Water & Sanitation

PRICE LIST • EFFECTIVE 1ST OCTOBER 2010

TANKS				
PRODUCT CODE	CAPACITY LITRES	PRICE Excl. VAT	VAT 18%	AMOUNT Incl. VAT
CV-10C	100	57,500	10,350	67,850
CV-15C	150	92,000	16,560	108,560
CV-25C	250	103,500	18,630	122,130
CV-50C	500	172,500	31,050	203,550
CV-75C	750	258,750	46,575	305,325
CV-100C	1,000	316,250	56,925	373,175
CV-150C	1,500	431,250	77,625	508,875
CV-200C	2,000	546,250	98,325	644,575
CV-250C	2,500	661,250	119,025	780,275
CV-300C	3,000	776,250	139,725	915,975
CV-400C	4,000	1,121,250	201,825	1,323,075
CV-500C	5,000	1,265,000	227,700	1,492,700
CV-600C	6,000	1,610,000	289,800	1,899,800
CV-600C(SP)	6,000	1,610,000	289,800	1,899,800
CV-800C	8,000	2,012,500	362,250	2,374,750
CV-1000C	10,000	2,645,000	476,100	3,121,100
CV-1000C(SP)	10,000	2,645,000	476,100	3,121,100
CV-1600C	16,000	4,625,000	832,500	5,457,500
CV-2400C	24,000	6,875,000	1,237,500	8,112,500

There are also manufacturers that seem to focus on smaller tanks. Table 4.5 demonstrates the various brand names, sizes, and availability of the plastic tanks available at hardware stores throughout Rakai District and Masaka town. The selection breaks down into four categories: Victoria Nile; brands available at more than one location but not widely competing with Victoria Nile; tanks available at only one location; and finally tanks available from the manufacturers of generally larger tanks (Crestank and Poly Fibre).

Victoria Nile is the clearly dominant supplier, available at 28 separate stores. Victoria Nile prices and volumes are provided in Table 4.6. The second group, consisting of brand-less plastic chemical drums, AfroPlast, and VNPL are available at four, two, and two stores respectively, making them less of an outlier than those tanks available at only one location, but not nearly as competitive as Victoria Nile. These tanks are broken down by cost and volume in Table 4.7. The third category is of tanks available only in one location: Techino, Rajol, Arsalan Barrel, Skyplast, and Premier. These are described in Table 4.8. Finally, two stores were identified that carry Crestank and Poly Fibre products, however, because these are available for purchase directly from the manufacturer, they are detailed separately in Table 4.9.

Table 4.5 Volume range and availability of plastic tank brands.

Brand	**Available Sizes (liters)**	**# of Shops identified in this study**	**Location**
Victoria Nile	65, 120, 220	28	Kibaale, Masaka, Ssanje, Mutukula, Kasensero, Rakai,Lwamaggwa, Kyotera, Kalisizo
Plastic chemical drum, no brand	210; 220; 240	4	Masaka, Kyotera,
AfroPlast	60	2	Ssanje, Mutukula
VNPL	100	2	Mutukula, Kyotera
Techino	1,500; 3,000	1	Masaka
Rajol	250	1	Masaka
Arsalan Barrel	1,000	1	Masaka
SkyPlast	210	1	Kalisizo
Premier	100	1	Kalisizo
Crestank	1,500	1	Rakai
Poly Fibre	100;1,000; 2,000; 5,000	1	Kyotera

As Table 4.5 shows, only Victoria Nile widely distributes small rainwater storage containers. Table 4.6 lists each individual price identified for the three sizes of Victoria Nile plastic tanks. In addition to the dominance in availability at stores, only Victoria Nile is known to have an active distribution mechanism. District authorities as well as shop owners report that a truck regularly passes through major towns of Rakai District, selling Victoria Nile tanks in all sizes at wholesale prices to hardware stores.

Table 4.6 Victoria Nile tanks sizes and prices.

Volume (liters)	**Price (UGX)**	**Location**	**Range of volumes (liters)**	**Average Price (UGX)**
65	18,000; 18,000; 20,000; 18,000; 20,000; 18,000; 15,000; 18,000	Kibaale, Masaka, Mutukula, Kalisizo	15,000-20,000	18,125
120	24,000; 27,000; 25,000; 25,000; 25,000; 25,000; 25,000; 35,000; 30,000; 30,000; 25,000; 27,000; 25,000; 25,000; 25,000; 25,000; 25,000; 35,000; 25,000; 25,000; 26,000; 25,000; 25,000; 24,000	Kibaale, Masaka, Ssanje, Mutukula, Kasensero, Rakai,Lwamaggwa, Kyotera, Kalisizo	24,000-35,000	26,375
220	45,000; 50,000; 45,000; 45,000; 45,000; 50,000; 47,000; 48,000; 50,000; 48,000; 50,000; 47,000; 48,000; 45,000; 45,000; 45,000; 48,000; 45,000; 48,000; 48,000; 47,000; 45,000; 44,000	Kibaale, Rakai, Masaka, Ssanje, Mutukula, Kasensero, Kyotera, Kalsizio.	45,000-50,000	46,870

Prices for the 65, 120, and 220-liter Victoria Nile tanks are quite consistent. Charges of 35,000 and 30,000 UGX for the 120-liter tank appear to be somewhat overstated, especially since all four occurrences took place in towns where the same tank was available in other stores for 25,000 UGX.

Table 4.7 lists the prices and locations of tanks available in more than one location, but still outliers with insufficient data to merit in depth analysis or comparison. AfroPlast 60 liter tanks were available in one hardware store each in the towns of Sanje and Mutukula; VNPL 100 liter tanks were also found in one hardware store each in Mutukula and Kyotera. (The author suspects that VNPL may actually be an abbreviation of the "Victoria Nile" company, whose widespread tanks are analyzed in Table 4.6, but there is no evidence for this beyond a guess at the acronym). Isaac Bukenya at the Appropriate Technology Center suggested to the author of this study that the brand-less plastic chemical drums are actually the barrels that Coca-Cola and other large beverage manufacturers use to import the syrup for their sodas into, and when they are disposed they get recycled into the rainwater storage market.

Table 4.7 Tanks with more than one but fewer than five instances of sales.

Brand	**Volume (liters)**	**Price (UGX)**	**Location Where Available**
Plastic chemical drum – no brand	210	70,000; 80,000	Masaka, Kyotera
Plastic chemical drum – no brand	220	40,000	Masaka
Plastic chemical drum – no brand	240	80,000	Kyotera
AfroPlast	60	17,000; 18,000	Sanje, Mutukula
VNPL	100	23,000; 25,000	Mutukula, Kyotera

Table 4.8 details the prices of brands of tanks only available in one location. The Skyplast and Premier tanks are available at the same hardware store in Kalisizo and nowhere else. All are competitively priced with tanks of other brands with similar sizes (for example, compare the 1500 liter Arsalan barrel at 480,000 UGX to the 1500 liter Crstank, listed at 508,373 UGX in Table 4.4), with the exception of the Rajol barrel, which at 80,000 is priced far above the Victoria Nile 220 liter tanks, more than the extra 30 liters of capacity merits. In the opinion of the author, the lack of wide distribution suggests these are the remnants of now defunct companies, though it possible these companies still exist but are focusing on other areas.

Table 4.8 Tanks only available in one location.

Brand	Size	Price	Location
Arsalan	1,000	300,000	Masaka
Techino	1,500	480,000	Masaka
Techino	3,000	1,050,000	Masaka
Rajol	250	80,000	Masaka
Skyplast	210	49,000	Kalisizo
Premier	100	27,000	Kalisizo

Of the 29 hardware store surveyed, two had tanks manufactured by the national distributors of larger tanks available for resale. Table 4.9 shows these prices. It is supposed that these are hardware store owners selling tanks at a markup since the prices can be compared to the catalog (directly in the case of Crestank, and inferred by comparison to Crestank's prices in the case of Poly Fibre). Clearly these same tanks can be purchased directly from the manufacturer at a significantly lower price.

Table 4.9 Crestank, Poly Fibre tanks available at hardware stores in Rakai District.

Brand	**Volume (liters)**	**Cost (UGX)**	**Location**
Crestank	1,500	800,000	Rakai
Poly Fibre	100	80,000	Kyotera
Poly Fibre	1,000	450,000	Kyotera
Poly Fibre	2,000	800,000	Kyotera
Poly Fibre	5,000	1,800,000	Kyotera

4.3 Built-in-Place Products

It is difficult to discern exactly where private sector capacity for trained artisans constructing built-in-place tanks exists. It was hoped at the beginning of this study that the Rakai District water office would have complete documentation on all the rainwater harvesting initiatives initiated by NGO's in the district for the past decade or so, but this was not the case. No comprehensive compilation of rainwater harvesting interventions exists for Rakai District. To truly document the available capacity for rainwater tank construction, specifically for built in place tanks, an exhaustive tour of Rakai District would need to be undertaken to determine where each different kind of tank exists and whether the masons are still operating. This kind of tour was beyond the scope of this study. However, three reports from major training programs in the district are available, and in conjunction with information gleaned from interviews, it is believed these suggest a fair representation of what exists on the ground. Certainly some initiatives are undocumented, purely private ventures on the part of enterprising masons. Others that are documented have certainly ceased to function actively. But this is where and how several of the major stakeholders have focused their efforts.

4.3.1 Mortar Jars

Mortar jars are an inexpensive option for storing moderate volumes of water at households. They are constructed by pouring a circular concrete base, into which the tap is embedded. A wooden mold approximating the interior shape of the jar is erected on the base, and thin layer of mud is applied to the exterior, in order to provide a smooth surface for plastering. The exterior is plastered with a 10-12 mm thick layer of cement, and allowed to cure for at least 48 hours. Then the wooden molds are removed, and the mud scraped from the inside before an additional waterproofing layer of cement 1-2mm thick is applied to the interior. The jars are transported to households in a handcart, or by vehicle if properly protected.

The Uganda Rainwater Association (URWA) conducted a training of rural masons in this technology in seven sub-counties of Rakai District in 2006. Three masons were trained per sub-county, as well as a total of twelve apprentices. Costs for these tanks appear in Table 4.10.

Table 4.10 Volumes and costs of mortar jars

Mortar Jar Volume (liters)	Cost (UGX)
420	152,000
2,000	321,000
3,000	498,000

Table 4.11 Location of mortar jars constructed by Uganda Rainwater Association in Rakai District.

Sub-county of Rakai District	**Number of subsidized jars**
Byakabanda	70
Dwaniro	71
Lwanda	62
Lwamagwa	64
Kakuuto	40
Kifamba	46
Nabigasa	73

Table 4.11 shows the distribution, by sub-county, of mortar jars built by URWA. These sub-counties are highlighted on the map in Figure 4.2. As the map makes evident, URWA's focus area for this project was the central region of Rakai District.

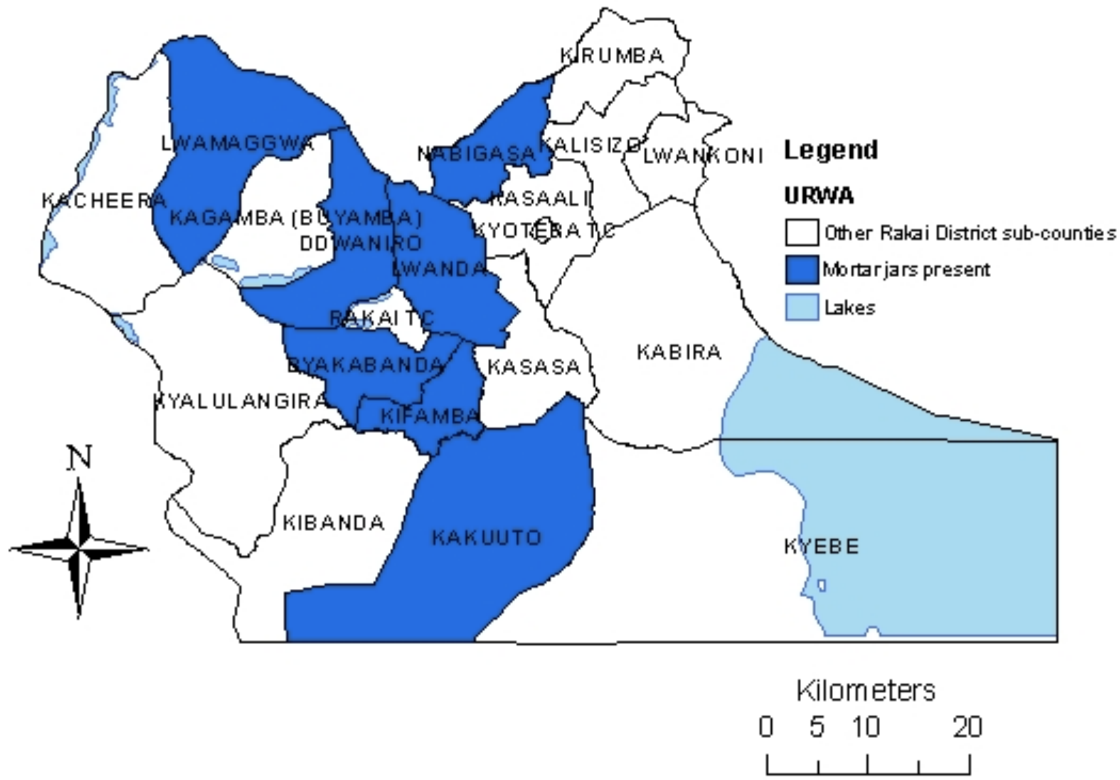

Figure 4.2 Mortar jars present in Rakai District through URWA (Map created by Jonathan Blanchard using data from ugandaclusters.ug and diva-gis.org).

4.3.2 Tarpaulin Tanks

Tarpaulin tanks are a very low cost option for rainwater storage. Typically a hole is excavated (often by the household where the tank is being installed) by hand, and covered by a small brick structure, wooden beams and iron sheets roof. Then the pit is lined with a locally available tarpaulin.

CIDI has two projects operating in Rakai District and managed from their office in Kyotera. The projects are named for their respective funders; Central Archdiocesan Province Caritas Association (CAPCA), working in Lwanda, Kasasa, and Kakuuto sub-counties, and the McKnight Foundation working in Kalisizo sub-county. These locations are highlighted on the map in Figure 4.3.

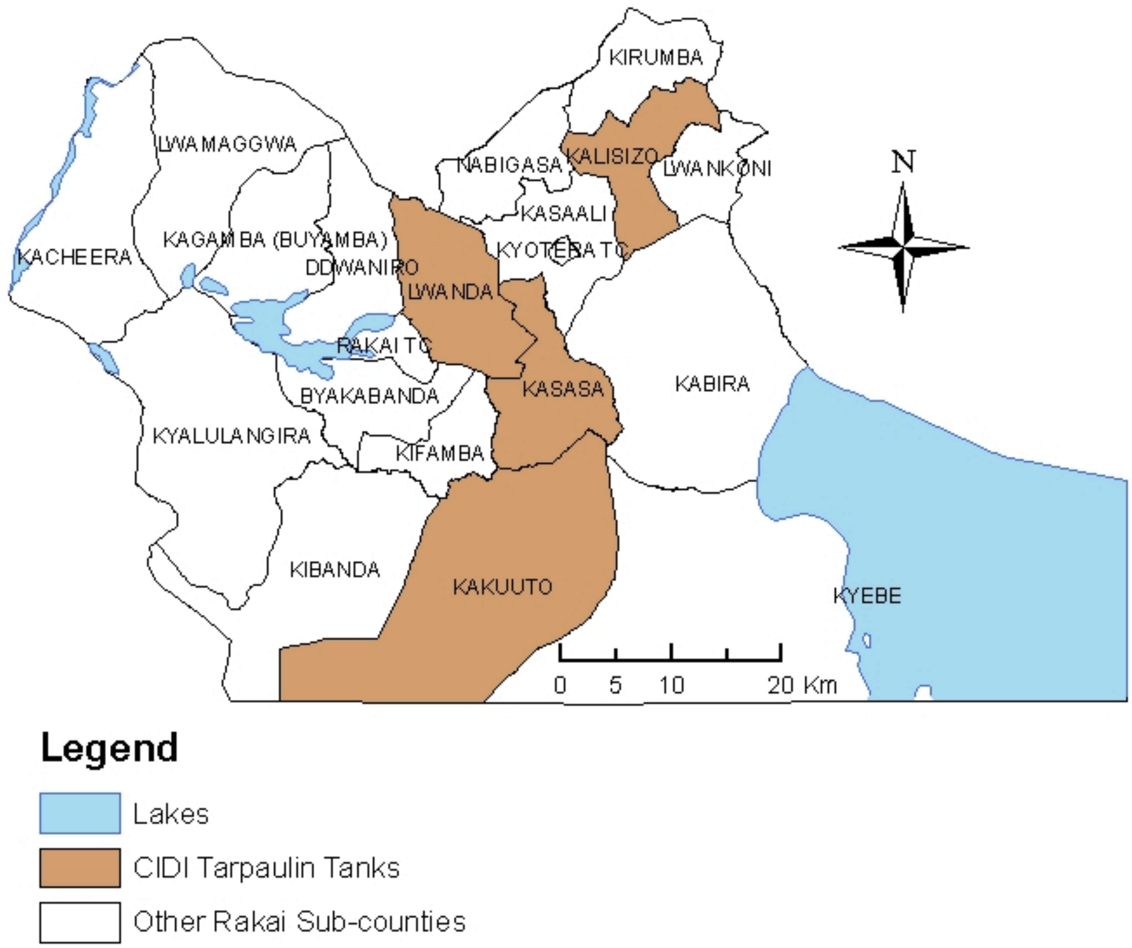

Figure 4.3 Location of CIDI's farmer groups working with tarpaulin tanks (Map created by Jonathan Blanchard using data from ugandaclusters.ug and diva-gis.org).

CIDI's prices, which appear in Table 4.12, could not be compared with any provider building them outside of Rakai District, so they are presented for reference's sake with the caveat that they are likely to be indicative of a larger range of possible prices for this method, as compared to other methods. World Vision has also worked with tarpaulin tanks within Kooki County, but was unable to produce documentation for where their work took place, so they are not included in this analysis.

Table 4.12 Tarpaulin tank sizes and costs.

Tarpaulin Tank Volumes (liters)	Cost (UGX)
8,000	336,000
15,200	534,500
17,600	609,500
25,000	1,166,000

4.3.3 Ferrocement Tanks

The ferrocement tank construction method has become popular in recent years. It consists of a wire mesh framework around which a tarp is wrapped, and cement mortar packed against the tarp and around the reinforcement from the interior. Once the inside has dried (usually 2 or 3 layers), the tarp is removed and the process repeated on the outside. Both ACORD and COWESER have built ferrocement tanks extensively throughout certain sub-counties of Rakai District. URWA has not held any trainings or constructed any ferrocement tanks specifically in Rakai District, but they are actively promoting the technology nationally and their cost estimations for the method are relevant for the central region of Uganda in general.

In 2010, ACORD implemented a project building ferrocement tanks in the Rakai sub-counties of Kachera, Lwamagwa, Kyalulangira, and Ddwaniro. They trained 68 masons (51 female, 17 male), who subsequently built 170 tanks across the four sub-counties in

2010. They gathered GPS coordinates for 64 of the 170 tanks, so the dots appearing in Figure 4.4 are all the available data points but represent just over one third of the full scope of the project.

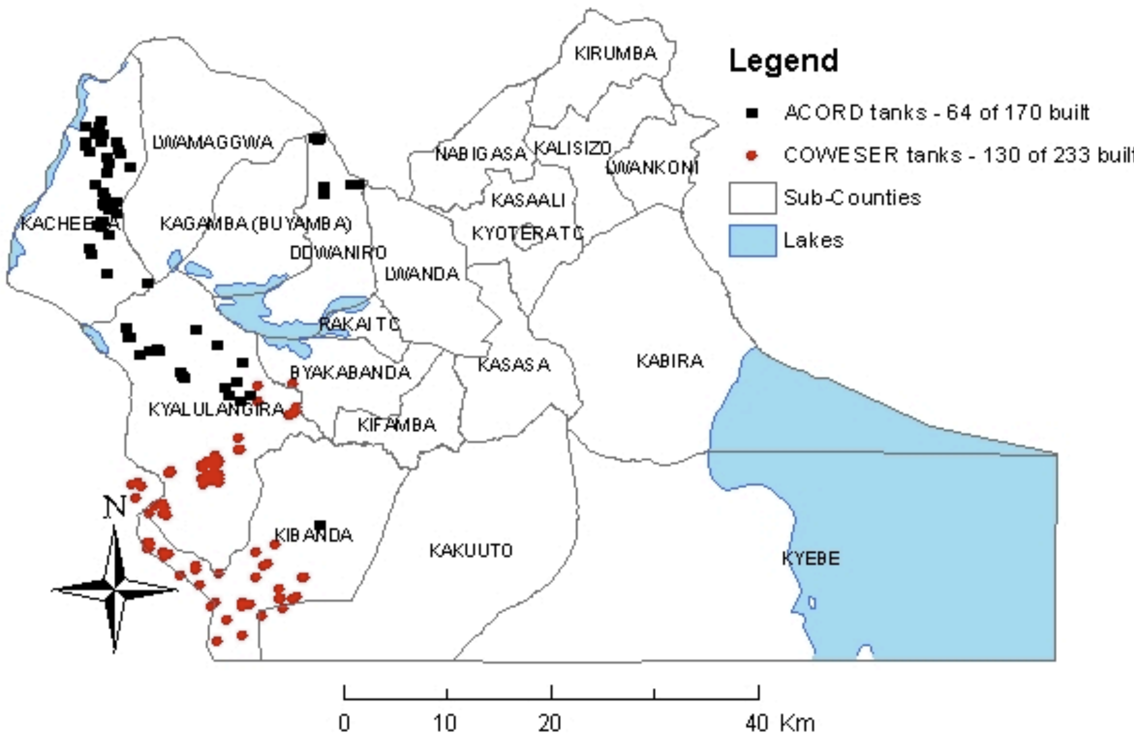

Figure 4.4 Rakai ferrocement tanks from ACORD and COWESER (Map created by Jonathan Blanchard using data from ugandaclusters.ug and diva-gis.org).

From 2006-2008, COWESER implemented, on behalf of the Network for Water and Sanitation in Uganda (NETWAS (U)), construction of 233 household and institutional ferrocement tanks in Kibanda and Kyalulangira sub-counties. This project, entitled Roof Catchment Rainwater Harvesting and Management Pilot Project, was funded by the Africa Development Bank, and also included similar efforts in Bugiri and Kamwenge districts. As with ACORD's tanks, COWESER only gathered GPS coordinates for 130 of the 233 tanks constructed, so the coordinates plotted in Figure 4.4 are representative of the geographic range of the work, but only a little more than half of the quantity of work. Prices for ACORD, COWESER, and URWA tanks appear in Table 4.13, and a comparison of prices across all three organizations appears in Figure 4.5.

Table 4.13 Pricing of ferrocement tanks built in Rakai District.

Organization Implementing Ferrocement Tanks	**Tank Volume (liters)**	**Price (UGX)**
ACORD	5,000	1,251,000
ACORD	6,000	1,320,700
ACORD	7,000	1,517,350
ACORD	8,000	1,668,950
ACORD	10,000	1,778,200
ACORD	30,000	2,749,500
ACORD	40,000	3,536,850
ACORD	50,000	4,645,200
URWA	4,000	997,500
URWA	5,000	1,114,000
URWA	6,000	1,346,000
URWA	7,000	1,481,000
URWA	8,000	1,661,750
URWA	10,000	1,946,500
URWA	20,000	2,902,000
COWESER	6,000	1,573,200
COWESER	10,000	2,073,800
COWESER	20,000	3,391,800

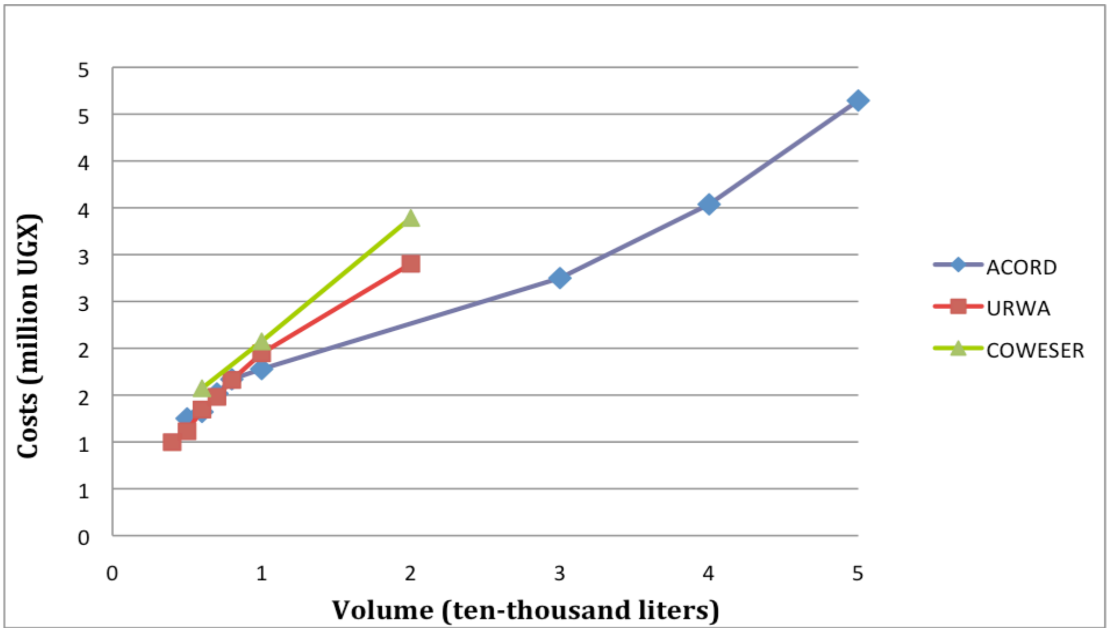

Figure 4.5 Ferrocement costs versus storage tank volume for the three organizations that construct them.

Prices are fairly comparable between the three organizations implementing ferrocement tanks at the low end of the size spectrum. For example, the price range for the 6,000 liter tank differs by only 250,000 UGX, or less than 20% of the lowest priced tank for that volume. The prices diverge as size increases, and it appears ACORD is significantly more efficient with building larger tanks: they claim to be able to construct a 30,000 liter tank for less than either URWA or COWESER can build one of 20,000 liters,

4.3.4 Partially Below Ground Ferrocement (PBG) Tanks

ACORD is currently encouraging and promoting the use of partially below ground ferrocement tanks. These too are low cost, though uptake seems slower than the ferrocement and mortar jar options. This may have something to do with the perceived prestige of having a tank visible aboveground.

These kinds of tanks are appropriate for lateritic and stable soils, but not rocky soils. They are similar in form to above ground ferrocement tanks, but the below ground feature offers numerous opportunities for savings. The excavated pit offers external resistance to water pressure, which means that the reinforcement – a major source of expense in above ground tanks – can be reduced. A small dome covering the tank, and with an access point or tap for the pump, is all that is visible above ground.

No specific sites are known where this technology has been implemented in Rakai District, but the ACORD office in Mbarara is actively promoting it in the south-west region of Uganda, so for the purposes of this study it is considered a proven technology with potential for application elsewhere. As with the tarpaulin tanks, prices are not available for national comparison so the likely price ranges are not well defined. ACORD's available volumes and prices are provided in Table 4.14.

Table 4.14 Partially below ground ferrocement tank cost (obtained from ACORD).

PBG Tank Volume (liters)	Cost (UGX)
6,000	494,400

4.3.5 Interlocking Stabilized Soil Brick (ISSB) Tanks

The most recent contributor to rainwater storage facility construction in Rakai District is Brick by Brick, a business constructing rainwater tanks out of Interlocking Stabilized Soil Bricks (ISSBs).[2] ISSB's are bricks formed from a moistened mixture of Ugandan sub-soil

[2] Disclaimer: this study's author was extensively involved with the creation and management of Brick by Brick during his time in Uganda.

and 5-10% cement, which are subsequently compressed using a manual steel press to create an interlocking brick, with tongue and groove on opposite ends, as well as the top and bottom of the brick. Straight bricks can be made for standard building applications, or a separate curved brick press can create curved bricks for use in rainwater tanks. When rainwater tanks are being built, cement mortar is used between every horizontal and vertical joint between bricks, and then the walls are plastered both inside and out. The roof can be made of iron sheets spread over wooden beams, or a concrete roof can also be used. Dr. Musaazi of Makerere University has been involved with fostering and propagating the use of this technology throughout Uganda for most of the last 20 years, though it is believed Brick by Brick is the most ambitious commercial application. Brick by Brick is based in Kalisizo, but is prepared to work throughout the district and beyond because of the portability of the press. Brick by Brick's standard volumes for tanks and respective prices are in Table 4.15.

Table 4.15 ISSB tank volumes and prices.

ISSB Tank Volumes (liters)	**Cost (UGX)**
10,000	2,000,000
15,000	2,600,000
20,000	3,100,000
25,000	3,400,000

4.4 Discussion

4.4.1 Rainwater Storage Technologies

This study found 11 distinct rainwater storage technologies, ranging in volume from as little as 5 to as much as 50,000 liters of storage, and ranging in cost from zero to over 8 million shillings. These appear in Table 4.1.This fulfills the first hypothesis of this thesis, which is that Uganda as a whole has access to a diverse selection of rainwater storage methods encompassing a wide range of volumes and costs.

4.4.2 Access

Section 4.2 confirms the second hypothesis of this thesis: that Rakai District has access to a wide and consistent variety of manufactured rainwater storage options. Residents can purchase small plastic tanks from 31 different hardware stores in 9 towns widely spread throughout the district, with very similar prices indicated a competitive and well developed private sector for manufactured products. Alternatively they can acquire larger plastic tanks from the centralized distributors Crestank or Poly Fibre. Residents can also purchase the 55-gallon metal drums from six different stores in 5 different towns – not as widely spread as the small plastic tanks, but still available to anyone who wants to acquire one. Finally Rakai residents can choose the corrugated iron tanks from three metalworks in Kyabakuza.

In contrast to the manufactured sector, Rakai District resident's access to built-in-place technologies for water storage is much more limited. Figure 4.6 shows the access Rakai District residents have to the built-in-place technologies identified in this study, broken down by sub-county. Access is defined as the presence within that sub-county of at least one, but preferably many, kinds of rainwater storage. This is crucial for a healthy self-supply environment, where households can make informed choices and imitate what works for their neighbors.

ISSB's are ignored for the present moment; while Brick by Brick is an active and ongoing enterprise, willing and able to travel, they have not yet achieved the market penetration necessary to truly say that all of Rakai District has access to their service.

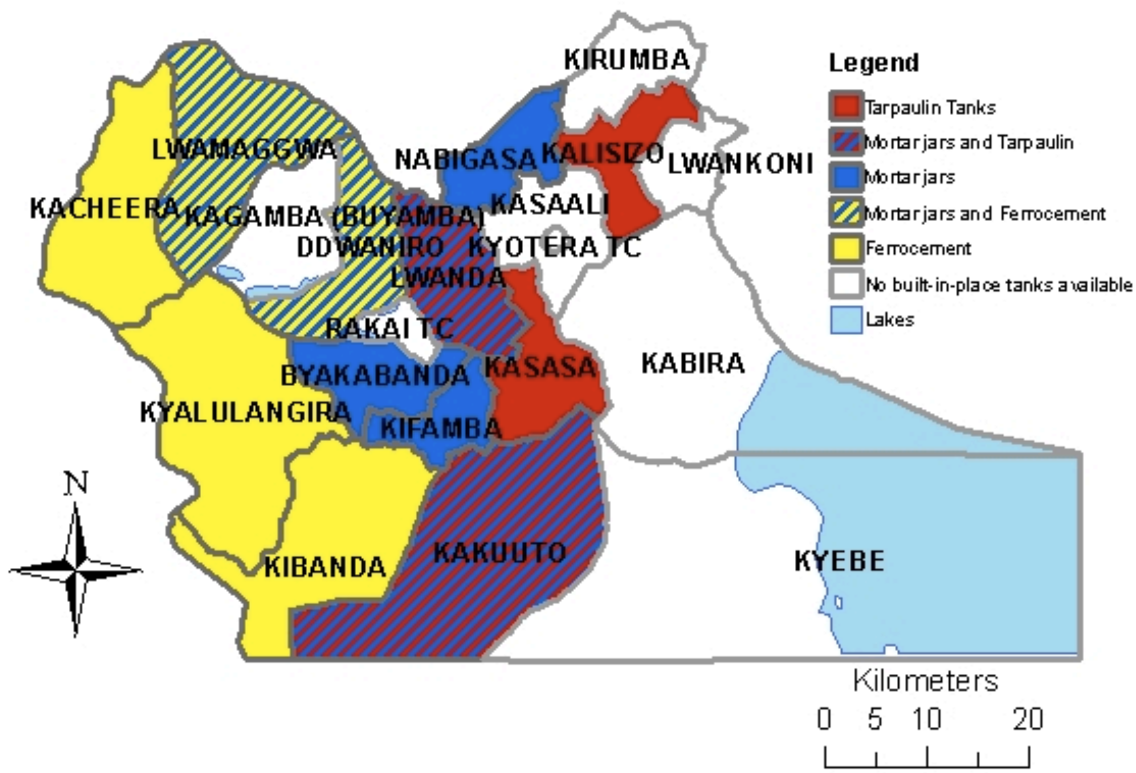

Figure 4.6 Availability of tarpaulin tanks, mortar jars, and ferrocement tanks.

Figure 4.6 shows which areas have access to the three built-in-place technologies widely available within the district: Mortar jars, ferrocement tanks, and tarpaulin tanks.

Ferrocement is available in the western sub-counties of Kibanda, Kyalulangira, Kacheera, Lwamaggwa, and Ddwaniro. Mortar jars occupy the central part of the district, overlapping with ferrocement access in Ddwaniro and Lwamaggwa, and extending further east into Byakabanda, Kifamba, Nabigasa, Kakuuto and Lwanda. Tarpaulin tanks extend still further east, providing access in Kakuuto and Lwanda (together with mortar jars), as well as Kasasa and Kalisizo. All of the sub-counties bordering Lake Victoria (Kyebe, Kabira, and Lwankoni) have no access; nor do Kirumba to the north, Kasaali and Kyotera TC, Rakai TC, and Kagamba (Buyamba). Table 4.16 summarizes which sub-counties truly have a choice of built-in-place technologies: eight sub-counties have zero access, and a further eight have access to only one. Only four sub-counties have a choice between two different built-in-place technologies, and none are able to choose between all three. This confirms the third hypothesis of this thesis: access to artisan-constructed storage options is limited, with significant gaps between areas where there is sufficient private sector capacity for implementation of the various methods.

Table 4.16 Built-in-place tank choices available to Rakai District sub-counties.

Sub-county	Number of tank types available	Types of tanks available
Kyebe	0	N/A
Kabira	0	N/A
Lwankoni	0	N/A
Kirumba	0	N/A
Kasaali	0	N/A
Kyotera TC	0	N/A
Rakai TC	0	N/A
Kagamba (Buyamba)	0	N/A
Kalisizo	1	Tarpaulin
Kasasa	1	Tarpaulin
Kifamba	1	Mortar jar
Byakabanda	1	Mortar jar
Nabigasa	1	Mortar jar
Kibanda	1	Ferrocement
Kyalulangira	1	Ferrocement
Kachera	1	Ferrocement
Kakuuto	2	Mortar jar, tarpaulin
Lwanda	2	Mortar jar, tarpaulin
Ddwaniro	2	Mortar jar, ferrocement
Lwmaggwa	2	Mortar jar, ferrocement

Three reasons are proposed for this lack of access. The first is the heavy use of subsidies when implementing programs. It was previously noted in Section 2.3 that possibility of subsidy makes private investment unlikely (Thomas, 2010). All of the programs implementing built-in-place technologies in Rakai District (ACORD’s ferrocement, COWESER’s ferrocement, URWA’s mortar jars, and CIDI’s tarpaulin tanks) funded the tanks through a grant of some kind which subsidized construction They required only a nominal “community contribution” from the beneficiaries, usually amounting to 10-25% of the total cost, usually paid as “in-kind” material contributions such as sand, large aggregates, or unskilled labor.

The second proposed reason is related to the first: a disconnect between the goals of those promoting technologies and a successful self-supply approach. The goals of ACORD, COWESER, and CIDI were all to build a certain number of tanks within a budget – not to create an environment with the proper technical knowledge for private initiative to continue. Only URWA had this second goal with their mortar jars, intending to create fully functional businesses with operating supply chains to continue, but again it is thought their high subsidies killed the initiative once URWA's involvement ended. Similarly, there is a disconnect between the goals of self supply, as described by RWSN, and the government of Uganda. Self supply wants users to take incremental steps toward sufficient water quantity and quality, encouraging private investment by seeing every small step as a good one. The government's approach is "all or nothing" – since they calculate the minimum volume necessary for a tank to provide sole-source access for an average household throughout the dry season to be 6,000 liters, they will not support any sizes smaller than that. That is antithetical to the idea of self supply, as well as being economically efficient (recall Thomas and Rees's 1999 economic analysis in Section 2.3).

The third proposed reason is failure to truly understand what products are worth investing in. URWA is actively promoting mortar jars, and they would appear to be a good value, certainly one of the least expensive built-in-place tank types. But the Rakai office of the Ministry of Water and Environment is of the opinion that mortar jars are not a good investment; they say the small size is a disadvantage, because the water is rapidly emptied from the tank during the dry season, and the intense sun then cracks the empty jars, rendering them useless after only one or two cycles of being filled and emptied. It is not known how widespread this phenomenon is but it should be determined – along with the strengths and weaknesses of every other tank type, before technologies are actively encouraged.

It should also be noted that a diversity of choices for storage options should result in more resiliency to disruptive changes in the future. A wide variety of rainwater storage options, in addition to boreholes, protected springs, and piped water systems may also contribute to building a society that can more readily adapt to changing climate.

4.4.3 Cost

The costs of all rainwater storage technologies, associated with their respective volumes, are shown in Table 4.17**.** Where more than one value for a particular brand or technology exists for the same volume, costs are averaged. This comparison assumes a perfectly competitive market, where consumers have free choice among all of the options. As shown in Section 4.4.1, at no point in Rakai District is this actually the case.

Table 4.17 Complete volume and price ranges of storage methods identified in this study

Volume (liters)	Brand-less chemical	SkyPlast	Premier	Rajol	Techino	Arsalan	VNPL	AfroPlast	Victoria Nile	Crestank/ Poly Fibre	55-gallon metal Drum	Corrugated Iron	PBG	Tarpaulin	ISSB	Ferro cement	Mortar Jars
60								17,500	18,125								
100			27,000				24,000			67,850							
120									26,375								
150										108,560							
208											80,000						
210	75,000	49,000															
220	40,000								46,870								
240	80,000																
250				80,000						122,130							
420																	152,000
500										203,550							
750										305,325							
1000						300,000				373,175							
1500					480,000					508,875							
2000										644,575		300,000					321,000
2500										780,275							
3000					1,050,000					915,975		350,000					498,000
4000												433,333				997,500	
5000																1,182,500	
6000												600,000	494,400			1,413,300	
7,000																1,499,175	
8000										2,374,750		776,666		336,000		1,665,350	
10,000										3,121,100		1,133,333			2,000,000	1,932,833	
12,000												1,300,000					
15,000												1,500,000		535,500	2,600,000		
16,000										5,457,500							
17,600														609,500			
20,000															3,100,000	3,146,900	
24,000										8,112,500							
25,000														1,166,000	3,400,000		
30,000																2,749,500	
40,000																3,536,850	
50,000																4,645,200	

Figure 4.7 shows the types of tanks offering storage volumes less than 1,000 liters, and the vertical bar shows the range of storage volumes each different type can offer. It should be remembered that the brand-less chemical drum, AfroPlast, VNPL, Rajol, SkyPlast, Premier, and Arsalan products are very weakly distributed compared to the much more dominant Victoria Nile brand, but they are presented here nonetheless.

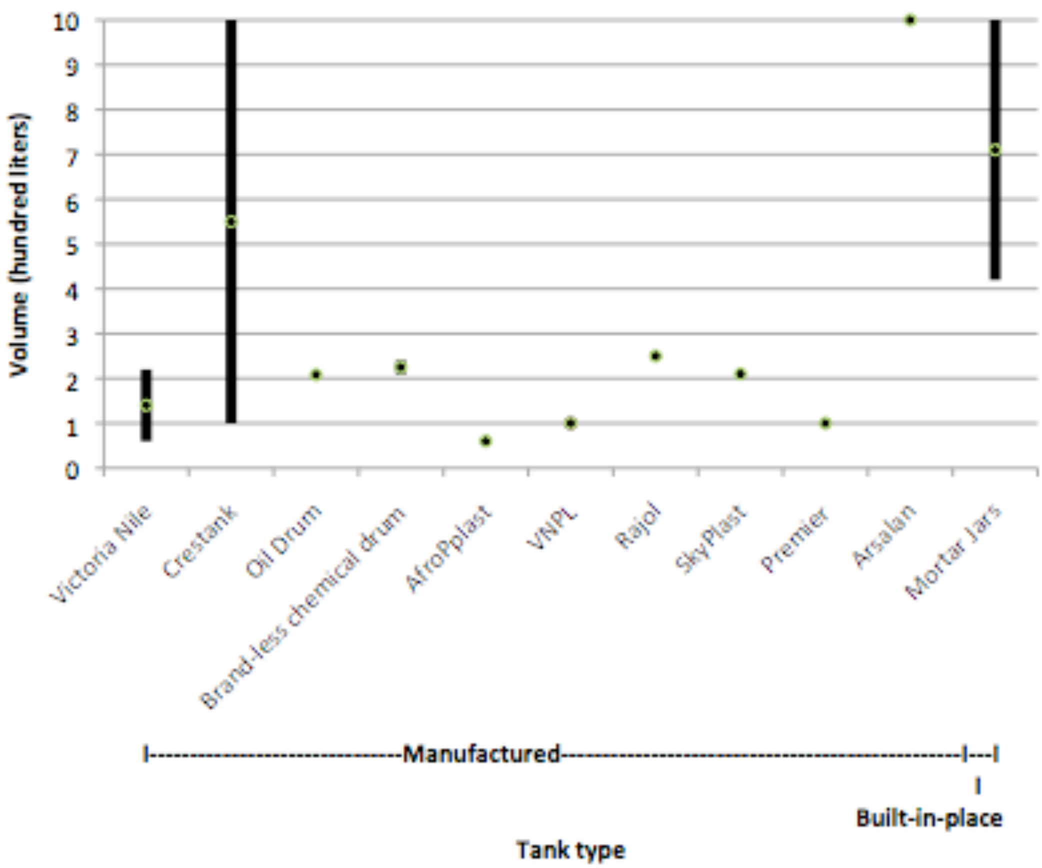

Figure 4.7 Volume ranges less than 1,000 liters by tank type. Black bars indicate volume range available for each tank type. Black points indicate tanks available only in one size, or a very small range.

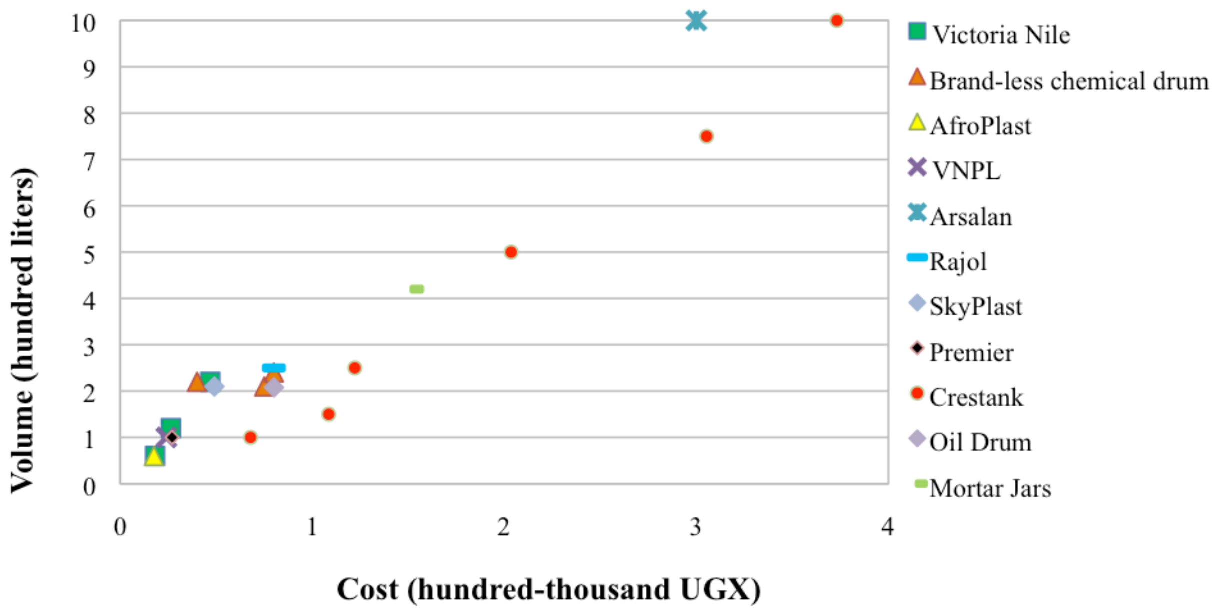

Figure 4.8 Volume versus cost for tanks less than 1,000 liters in volume.

Figure 4.8 shows each individual data point gathered for tank volume and price, for all tanks less than 1,000 liters in volume. Table 4.18 ranks each of these points by cost per unit volume, in increasing order. It is believed that the brand-less chemical drum ranked first is an outlier, since the costs vary so wildly among similar volumes (see Table 4.7 in Section 4.2.3 for more details). Disregarding this outlier, the Victoria Nile 220-liter plastic tank is the highest performer, leading the 120-liter Victoria Nile tank, the other small plastic tank brands, and the lowest priced built-in-place tank, the mortar jar. The most expensive tanks per unit volume are the 55-gallon metal drum and Crestanks offerings in the sub-1,000 liter range.

Table 4.18 Cost per unit volume ranking for tank volumes less than 1,000 liters.

Cost (UGX)/ Volume (liters)	Volume (liters)	Cost (UGX)	Brand
182	220	40,000	Brand-less chemical drum
213	220	46,870	Victoria Nile
220	120	26,375	Victoria Nile
233	210	49,000	SkyPlast
240	100	24,000	VNPL
270	100	27,000	Premier
292	60	17,500	AfroPlast
300	1,000	300,000	Arsalan
302	60	18,125	Victoria Nile
320	250	80,000	Rajol
333	240	80,000	Brand-less chemical drum
357	210	75,000	Brand-less chemical drum
362	420	152,000	Mortar jar
373	1,000	373,175	Crestank
377	208	78,333	55-gallon metal drum
407	750	305,325	Crestank
407	500	203,550	Crestank
489	250	122,130	Crestank
679	100	67,850	Crestank
724	150	108,560	Crestank

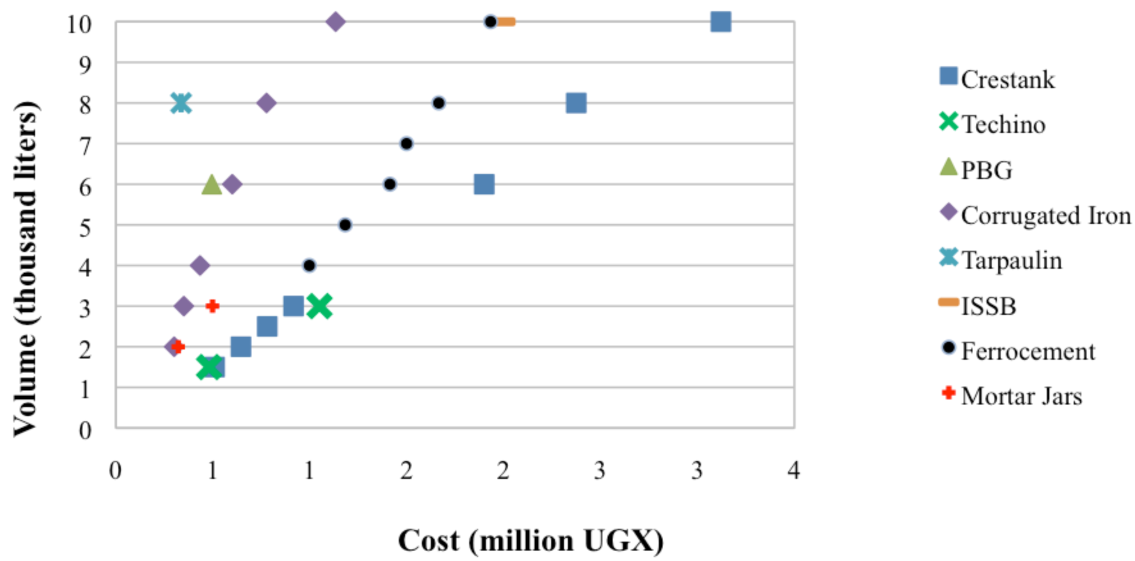

Figure 4.9 Volume versus cost for tanks between 1,000 and 10,000 liters in volume.

Figure 4.9 plots each individual data point of volume and cost for all tanks between 1,000 and 10,000 liters of storage. Figure 4.10 shows the range of storage for each tank type offering products in this range.

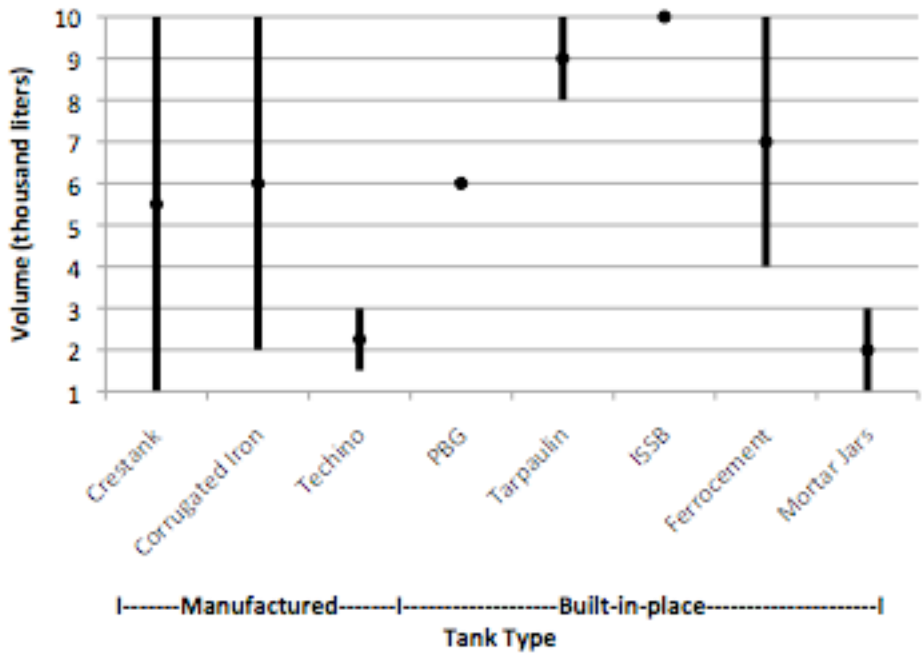

Figure 4.10 Volume ranges between 1,000 and 10,000 liters by tank type. Black bars indicate volume range available for each tank type. Black points indicate the average price within a range, as well as tanks available only in one size.

Table 4.19 shows the ranking of price per unit of storage volume for tanks between 1,000 and 10,000 liters. For this volume range, tarpaulin tanks appears to be good value (again measured by volume obtained per unit cost), followed by partially below ground ferrocement, corrugated iron tanks throughout the full volume range of 1,000 liters to 10,000 liters, and mortar jars at the low end of the volume spectrum. Crestank once again is the worst value, while ferrocement and ISSB are very evenly matched in between the very inexpensive tarpaulin and corrugated iron tanks on one end, and the very expensive Crestanks on the other.

Table 4.19 Cost per unit volume ranking for tank volumes between 1,000 and 10,000 liters.

Cost(UGX)/Volume(liters)	Volume(liters)	Cost(UGX)	Brand
42	8,000	336,000	Tarpaulin
82	6,000	494,400	PBG
97	8,000	776,666	Corrugated Iron
100	6,000	600,000	Corrugated Iron
108	4,000	433,333	Corrugated Iron
113	10,000	1,133,333	Corrugated Iron
117	3,000	350,000	Corrugated Iron
150	2,000	300,000	Corrugated Iron
161	2,000	321,000	Mortar jar
166	3,000	498,000	Mortar jar
193	10,000	1,932,833	Ferrocement
200	10,000	2,000,000	ISSB
208	8,000	1,665,350	Ferrocement
214	7,000	1,499,175	Ferrocement
236	6,000	1,413,300	Ferrocement
237	5,000	1,182,500	Ferrocement
249	4,000	997,500	Ferrocement
297	8,000	2,374,750	Crestank
305	3,000	915,975	Crestank
312	10,000	3,121,100	Crestank
312	2500	780,275	Crestank
317	6,000	1899800	Crestank
320	1,500	480,000	Techino
322	2,000	644,575	Crestank
339	1,500	508,875	Crestank
350	3,000	1,050,000	Techino

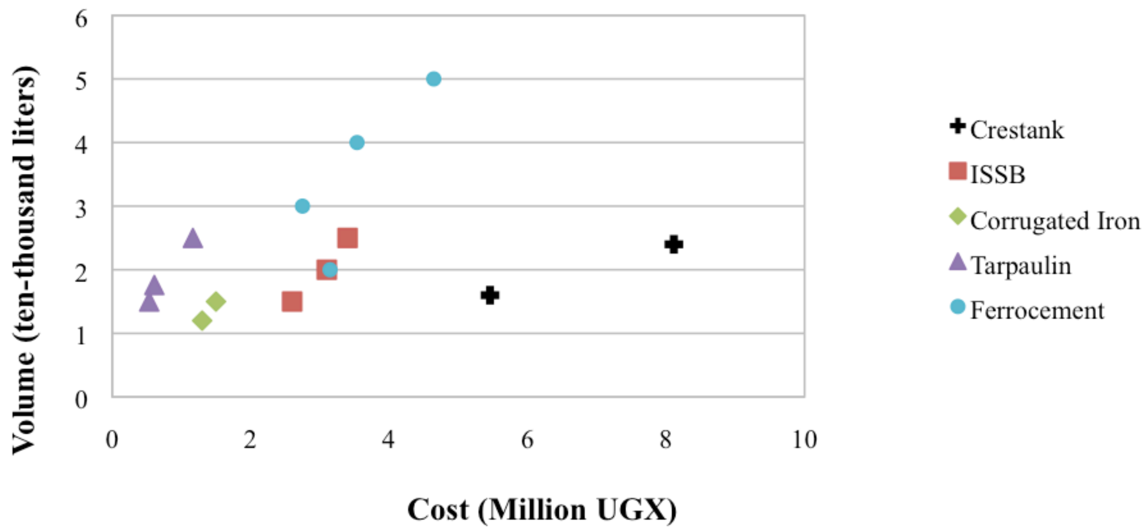

Figure 4.11 Volume versus cost for tanks greater than 10,000 liters in volume.

Figure 4.11 plots the volume and cost data points for tanks offering storage greater than 10,000 liters. Figure 4.12 shows the ranges of each of the 5 tank types with products in this range.

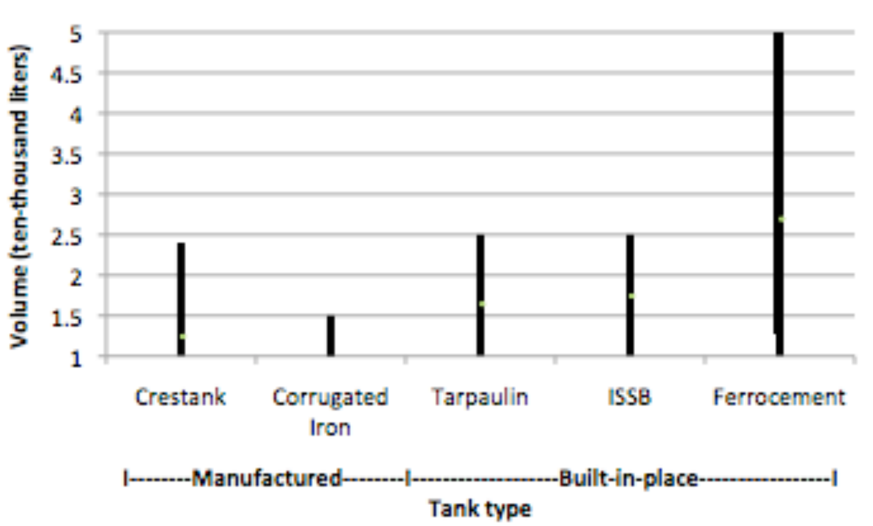

Figure 4.12 Volume ranges greater than 10,000 liters by tank type. Black bars indicate volume range available for each tank type.

The ranking in Table 4.20 shows that for very large tanks in excess of 10,000 liters, tarpaulin tanks once again offers the lowest cost per unit volume. Corrugated iron follows, ISSB and ferrocement bring up the middle of the range, and Crestank is priciest.

Table 4.20 Cost per unit volume ranking for tank volumes greater than 10,000 liters.

Cost(UGX)/Volume(liters)	Volume(liters)	Cost(UGX)	Brand
35	17,600	609,500	Tarpaulin
36	15,000	535,500	Tarpaulin
47	25,000	1,166,000	Tarpaulin
88	40,000	3,536,850	Ferrocement
92	30,000	2,749,500	Ferrocement
93	50,000	4,645,200	Ferrocement
100	15,000	1,500,000	Corrugated Iron
108	12,000	1,300,000	Corrugated Iron
136	25,000	3,400,000	ISSB
155	20,000	3,100,000	ISSB
157	20,000	3,146,900	Ferrocement
173	15,000	2,600,000	ISSB
338	24,000	8,112,500	Crestank
341	16,000	5,457,500	Crestank

Figures 4.13, 4.14, and 4.15 summarize the data provided in Tables 4.18, 4.19, and 4.20, respectively. This figure summarizes the cost of particular storage tanks based on the two types of tank characterization identified in this research for which costs were gathered. Shown on the three figures are the average cost (dot) and the price range (the dark bar). This presentation is made for each of the three volume ranges: 1) less than 1,000 liters (Figure 4.13), 2) between 1,000 and 10,000 liters (Figure 4.14), and 3) above 10,000 liters (Figure 4.15).

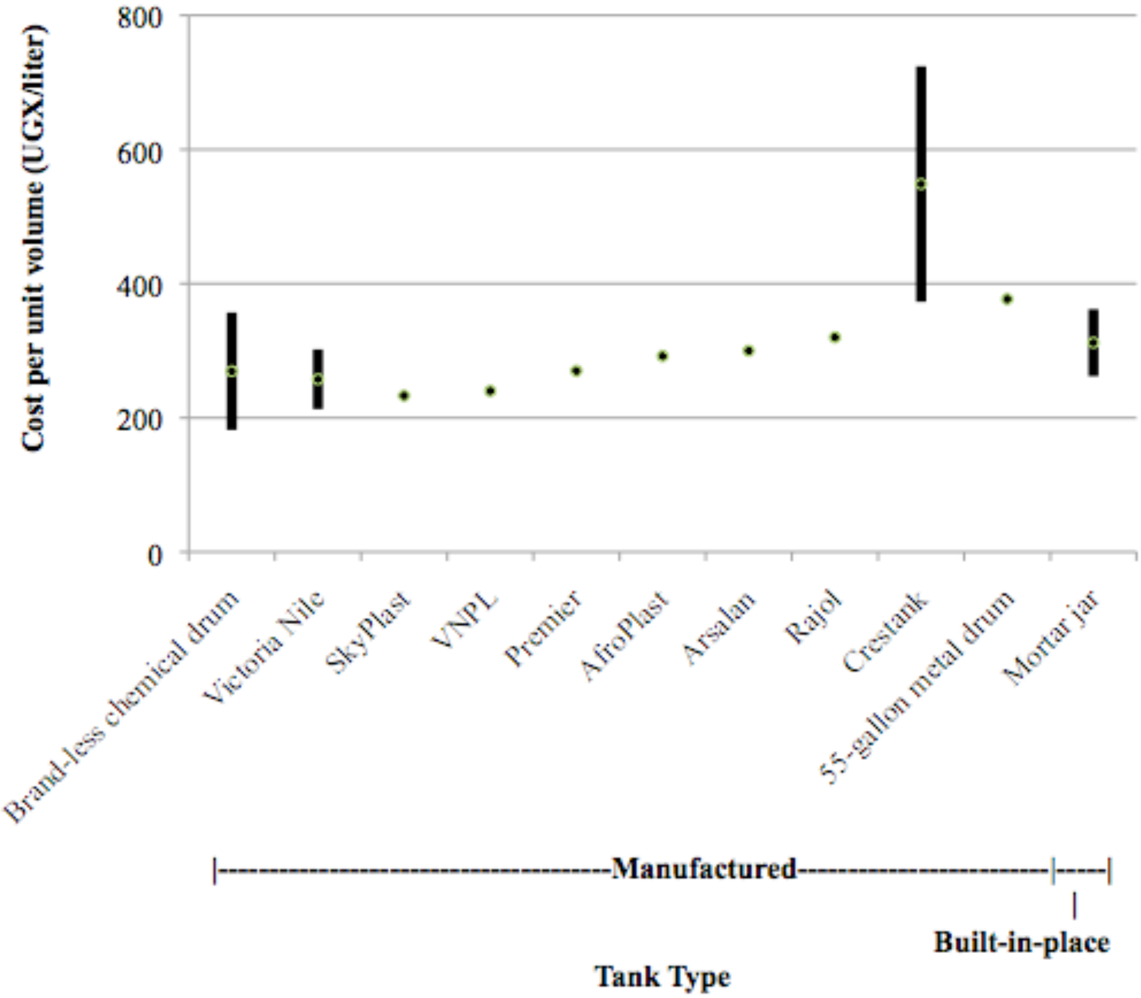

Figure 4.13 Range of costs per liter for tank volumes less than 1,000 liters.

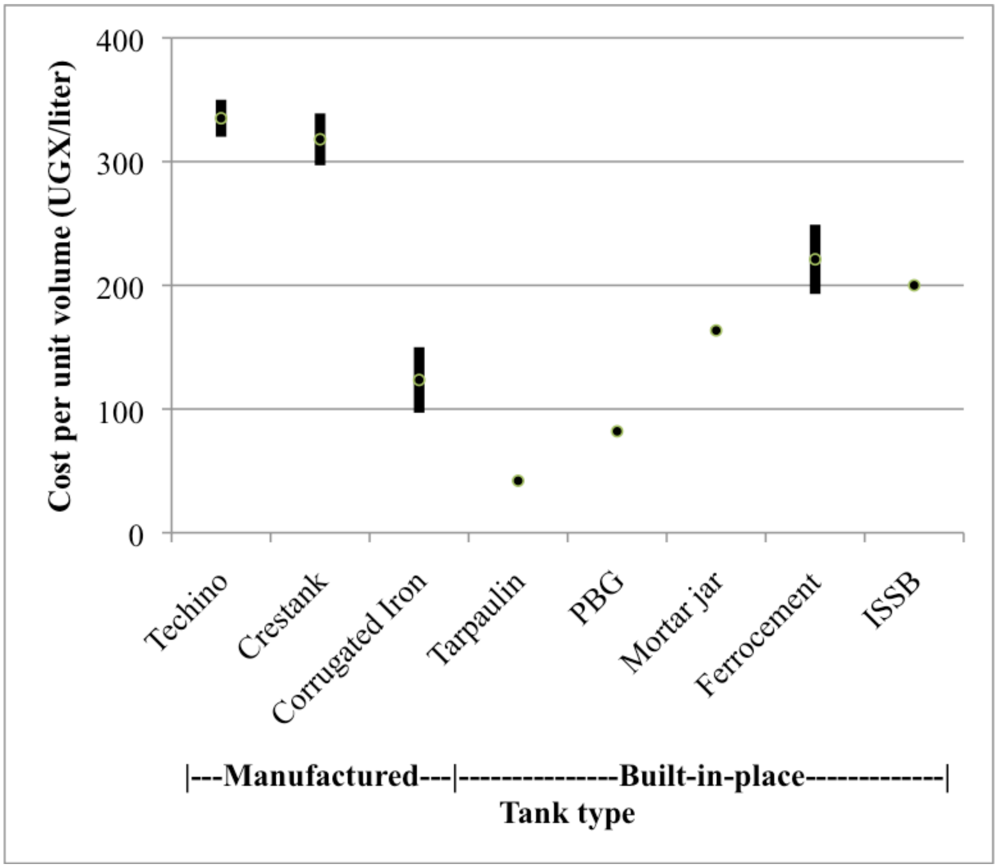

Figure 4.14 Range of costs per liter for tank volumes between 1,000 and 10,000 liters.

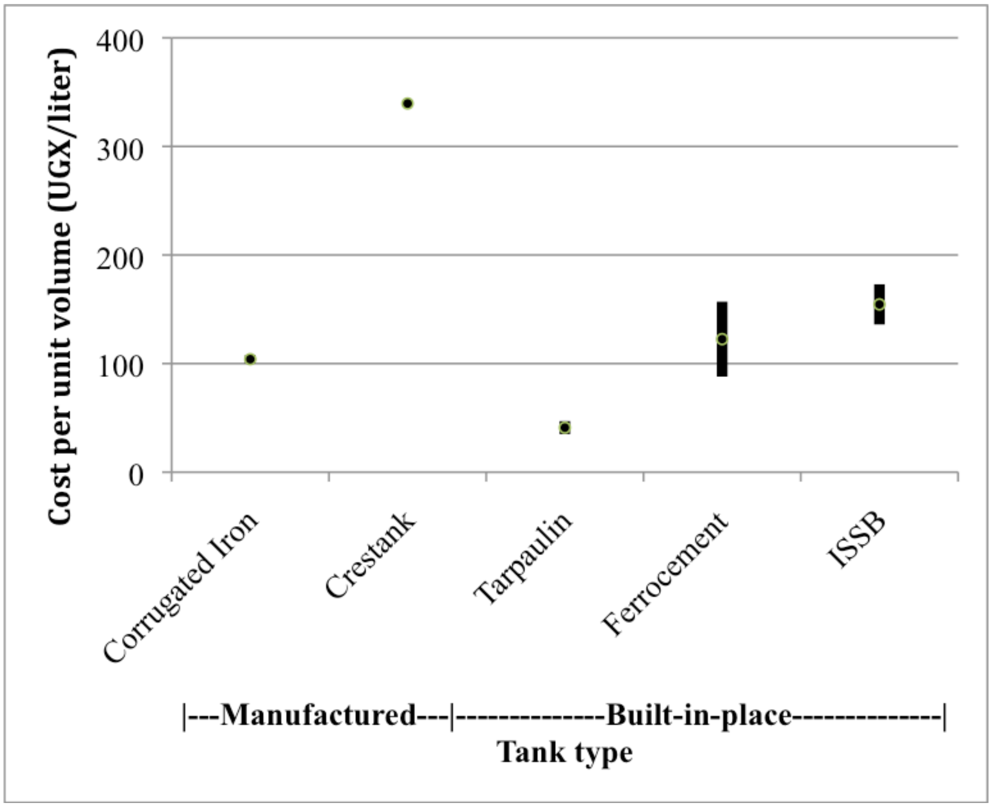

Figure 4.15 Range of costs per liter for tank volumes greater than 10,000 liters.

The results shown in Figures 4.13-4.15 support the third proposed reason for the lack of wide distribution of technology types that was discussed in Section 4.4.1. That is, there is a need to more deeply understand the factors users consider when decided to invest in rainwater storage. It would appear that cost is not the only factor. For example, metal oil drums are popular for rainwater storage, despite being nearly twice as expensive as the Victoria Nile 220-liter tank. The reason for this was not raised in the interviews for this research, but from personal experience the author suggests that this may be because of the perceived durability of the metal compared to plastic material. The metal might also be preferred because the added weight can act as a theft-deterrent. Likewise, corrugated iron tanks are not very popular, despite their relatively low price. Many people interviewed cited their tendency to leak, and rusting which can sometimes reduce the life of a tank to as little as three years.

As another example, Crestanks are very popular, especially at institutions such as schools hospitals, and government buildings, despite their already high price, additional cost necessary for a concrete base, and ease of puncture. In rural areas especially, it is widely reported (and observed by the author) that large plastic tanks, like Crestank and Poly Fibre, are disabled – often permanently – by neighbors and area residents piercing the tank to steal water. The reasons behind user's investment decisions merits further study, as it would assist in fostering an enabling environment for self supply.

Figure 4.16 (not to scale), similar to Figure 1.1, represents steps a user can take toward increasing their rainwater storage. The color transitions represent the costs and volumes where the next technology offers a lower cost per liter than the previous step. These points are determined by a simple linear interpolation between specific known tank sizes and costs. Note that some of these steps are only marginally beneficial; for example, a user should only invest in a corrugated iron tank if they want to spend more than 300,000 UGX but no more than 336,000. Outside of this narrow margin of costs, a user will achieve larger storage for their money with mortar jars or tarpaulin/PBG tanks on the lower and upper bounds respectively. Tarpaulin and PBG, as well as ferrocement and ISSB, are grouped together because they are priced similarly enough that users may want to choose either.

Figure 4.16 can be loosely related to the rainwater harvesting ladder presently previously in this thesis as Figure 2.3. The lower steps represent informal or opportunist rainwater harvesting situations, while the upper levels represent main-source, or in rare cases, sole-source utilization of rainwater harvesting. The middle ranges, depending on how water is withdrawn and the individual needs of the household, represent wet-season, potable, or adaptive rainwater harvesting.

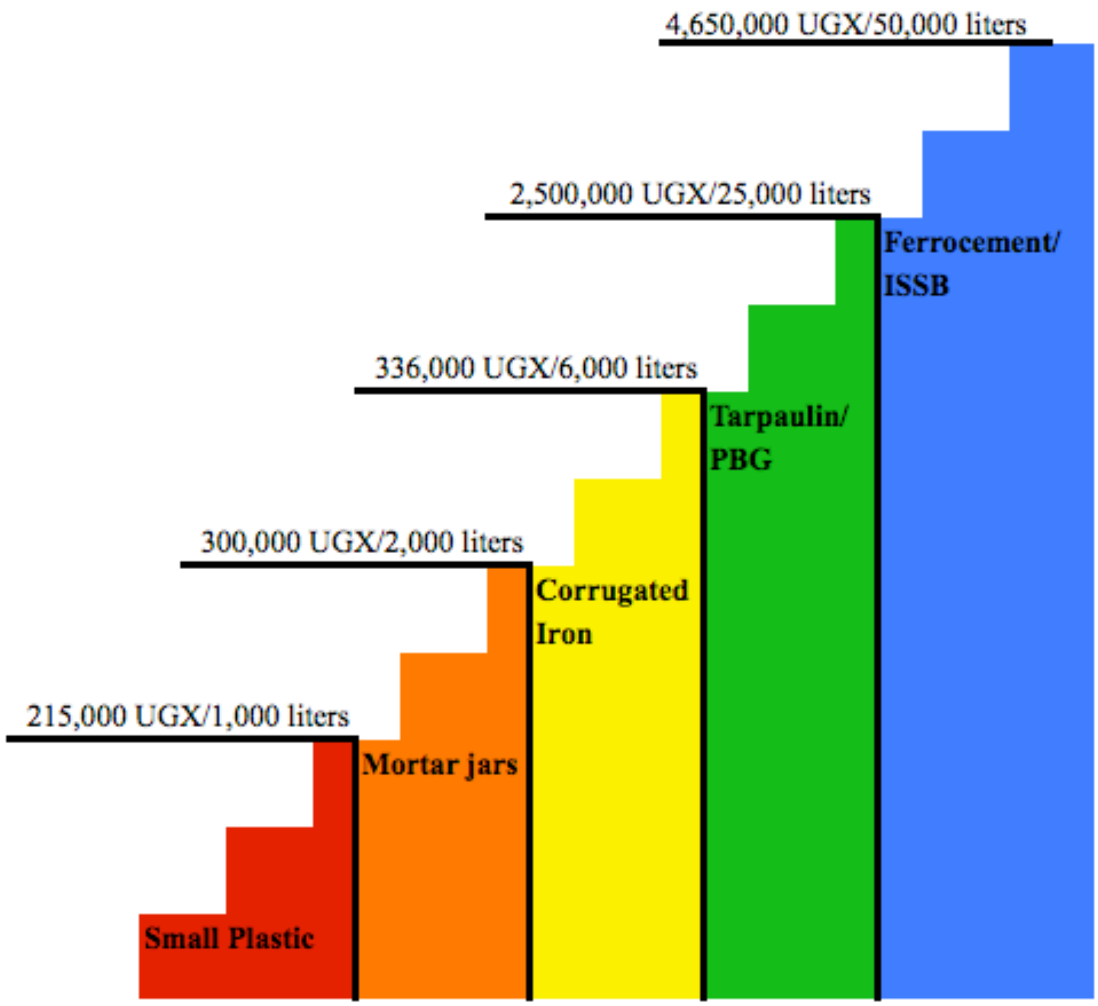

Figure 4.16 Incremental steps users can take to increase rainwater storage. Colors indicate which technology offers the lowest cost per liter of storage within a given volume range. PBG – Partially Below Ground Ferrocement tank. ISSB – Interlocking Stabilized Soil Brick tank.

Figure 4.16 is based solely on the factors of cost and volume of storage, which are certainly not the only factors users consider when weighing an investment. For example, expected life of the tank is one prominent omission. It is considered beyond the scope of this study, but it is a dimension of understanding with regard to rainwater harvesting that could be the basis for future study. Furthermore, it is known that water quality degrades with increasing time of storage and water temperature (Schafer, 2010). In addition, Schafer also observed that there was a statistical difference in the microbial water quality between polyethylene, fiberglass and cement water storage tanks as measured by *E. Coli* counts ($p = 0.082$). This increases the health risk posed to household residents associated with possible microbial growth in the stored water. This understanding is not reflected in Figure 4.16, but also needs to be studied further. For example, PBG tanks may lessen risk because they would maintain a cooler water temperature because they are constructed below ground.

Figure 4.16 also does not present the scenario where a user can progress incrementally from the bottom of the diagram to the top. That is, because the figure depicts different technologies the different technological steps may not build on one another. For example, when an individual steps from a small plastic tank to a mortar jar, the previous storage remains but an entirely new investment is being made, starting from scratch. This is not to say, however, that rainwater harvesting cannot be manufactured and subsequently installed in a more incrementable form like the process of upgrading a well that was previously shown in Figure 1.1. This could require that the storage tank is designed and manufactured to have a greater modularity so storage volume could be readily increased on an incremental basis. Table 4.21 thus shows the potential for modularity for each of the tank technologies.

Table 4.21 Ranking of tank technologies by ability to be modular.

Tank Type	Description of Modular Ability
ISSB	**Easily Modular:** Because the bricks are interlocking, additional layers can be added on at a later time, if the roof is removable, such as metal sheets on a wood framework.
Small Plastic 55-Gallon Metal Drum Mortar Jar Corrugated Iron Crestank/Poly Fibre Ferrocement	**Moderately Modular:** A modular installation would require a new tank connected in series, which from top to bottom is increasingly difficult due to footprint limitations.
PBG Tarpaulin	**Modular with difficulty:** A modular installation would require a new tank, which requires new excavation.

ISSB tanks are the only technology that have the potential to increase the storage of one tank over time, due to the interlocking nature of the building material. The only limitation would be the risk of leaks due to greater water pressure if the tank height became excessive. However, there is no reason that a 5,000-liter tank could not double in size if incremental additions were accounted for from the beginning. The second category of tanks listed in Table 4.21 for their modularity are incrementable with a little more effort, requiring two or more tanks to be connected in series. The third category is rated as being more difficult to increase storage incrementally because of the need for excavation.

CHAPTER 5: CONCLUSIONS & RECOMMENDATIONS FOR FUTURE RESEARCH

5.1 Conclusions

The objectives of this study were 1) to present a comprehensive collection of rainwater storage options in Uganda and 2) demonstrate the geographical disparities in the distribution of those options, in order to assist the self-supply concept in providing households with reliable, safe, and sustainable water supplies.

The first hypothesis is that Uganda has a wide variety of rainwater storage methods and technologies. This study identified 11 separate technologies in use: Clay pots, pots and basins, brick masonry tanks, plastic tanks, 55-gallon metal drums, corrugated iron tanks, mortar jars, tarpaulin tanks, ferrocement tanks, partially below ground ferrocement tanks, and interlocking stabilized soil brick tanks.

The second hypothesis is that manufactured rainwater storage products are well distributed and marketed. This study found 31 hardware stores selling smaller plastic tanks spread across nine towns in Rakai District, as well as two national distributors of larger plastic tanks. In addition, 55-gallon metal drums are available for purchase, and corrugated iron tanks are actively manufactured and distributed.

The third hypothesis is that built-in-place tanks are not well distributed, and that there are major gaps between areas where people have real choice for rainwater storage options. This study found that of the five types of viable built-in-place tanks identified, eight sub-counties have no access to any of them, eight have access to one, and only four can choose between two of the five technologies.

With regard to costs, it was found that for tanks with storage volume less than 1,000 liters, costs ranged from 182 to 724 UGX/liter. For volumes between 1,000 and 10,000 liters, costs ranged between 42 and 350 UGX/liter. Above 10,000 liters of storage, tanks ranged from 35 to 341 UGX/liter. Figure 4.16 showed the incremental steps a user can take to increase their storage: up to a 215,000 UGX investment, small plastic tanks offer the lowest cost per liter. Between 215,000 and 300,000 UGX, mortar jars are least expensive per liter. Corrugated iron tanks have a narrow advantage between 300,000 and 336,000 liters, above which PBG and tarpaulin tanks offer the lowest cost per liter up to their largest capacity (as documented in this research) of 25,000 liters. Ferrocement and ISSB tanks occupy the high end of the storage range.

5.2 Recommendations for Future Research

Figure 5.1 presents a conceptual framework for considering future research with rainwater harvesting and self supply. The research presented in this thesis is limited to the left-side box labeled technology. It provides information related to what storage technologies exist, where they are available, and what they cost on a unit volume basis. The second area that is important to perform research on is uptake of the specific technologies. That is, investigations need to be performed not only on which technologies are available, but also on which are being used and why, and for what purpose. The third area that requires further research is related to how to evaluate the usage of a particular technology and assign it a level of service. This could be related to the rainwater harvesting ladder presented previously in Figure 2.3 and should consider variables such as the water quality and expected life of the specific tank technology. Several specific items related to these aims are discussed below.

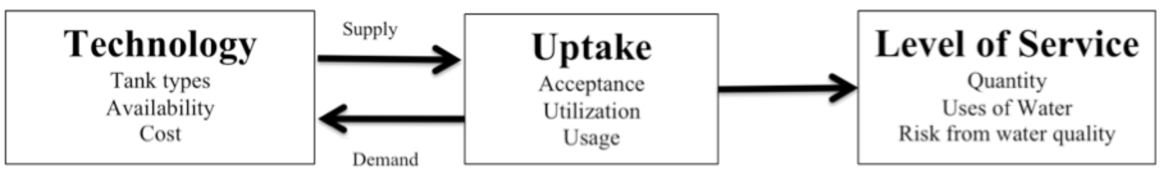

Figure 5.1 Conceptual framework for considering future research of rainwater harvesting and self supply.

1) There appears to be a prestige difference between methods of water storage, which may account for a household's apparent willingness to pay more for a particular tank type. For example, one household was observed where the owners had constructed a 10,000 liter tarpaulin tank at a cost of 300,000 UGX entirely out of pocket – but also built a ferrocement tank of the same volume, costing 2,000,000 UGX. (The government had subsidized that tank by 75%, but even with a family contribution of 500,000 UGX the second tank was significantly more expensive). The author suspects that the perceived increase in prestige of owning the ferrocement tank, compared to the tarpaulin tank, accounts for the willingness to pay an additional 200,000 UGX out of pocket for the same volume of storage with another technology. The same tendency has been observed by

ACORD in its hesitancy to adopt partially underground tanks – though they are also significantly cheaper. It seems that people want the prestige of a visible above ground tank located in their compound. This phenomenon should be more fully investigated. A study could build on the storage methods in this thesis by studying users of varying income levels in Rakai District or elsewhere to determine how they perceive different technologies and what a particular technology or size is worth to them. A starting point for determining willingness to pay could be a comprehensive analysis of the various rainwater harvesting construction programs, and the "community contribution" that households were expected to pay as their share of construction costs.

2) There is a discrepancy between the stated outcomes of self supply and the current policy of the Uganda Ministry of Water. The perspective of self supply is that every step, however small, toward self-sufficiency in terms of water volume and quantity for a household is positive. The Ministry however appears to have an "all or nothing" approach. That is, they do not appears to be willing to consider storage approaches with volumes less than 6,000 liters because they have concluded this is the minimum volume required for an average family to meet their water needs through the dry season. While this may indeed be the case, self supply could allow a family to first meet 10% of their water needs through the dry season and then increase that to 50% in the future. In contrast, the Ministry's policy results in ignoring the many options which may be more affordable to families in need of water. Furthermore, the Ministry's policy is in effect a mandate that rainwater harvesting not be utilized in the types of schemes where it has been shown to be most economically efficient; small tanks, cycled frequently, intended to

supplement but not supplant a households water supply (Thomas and Rees, 1999). This points to the importance of considering and aspect of social sustainability (i.e., political cohesion) that 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 (McConville and Mihelcic, 2007).

3) Another area that needs to be researched is how to effectively bolster the private sector by translating work in development engineering into new businesses and markets that offer more comprehensive water supply solutions. One question to then study would be how can Ugandans be provided with the marketing, accounting, and management skills to develop a thriving private sector that can assist families meet their water needs?

4) This research was explicitly focused on water quantity and possibilities for storage associated with rainwater harvesting. The different storage methods were not critically analyzed or assessed for effectiveness, or expected life of the tank. For example, some reports indicate that the mortar jars, while an inexpensive option for storing low volumes of water, may dry out and crack because they are emptied quickly during the dry season. Obviously there is overlap here with the earlier observation made that there appears to be some barriers between self supply and the Ministry of Water's current policy that would require research so they are better understood and resolved. The author believes that every method of storage available to a household could benefit from more detailed study of their performance in the field. For example, corrugated iron tanks are widely perceived

to rust and leak quickly – do they in fact do so? The mortar jars have been widely promoted by the URWA – is it really the case that most of them crack because of long periods of emptiness? What proportion of ferrocement tanks leak? And if any of these problems are demonstrated scientifically, what steps can be taken to rectify the issues, or should some of these technologies be abandoned?

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APPENDIX 1: PERMISSIONS

Greetings,

You are welcome to use the figures, but please reference them to the document.

Thanks!

Kerstin

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-----Original Message-----
From: Jonathan Blanchard [mailto:jblancha@mail.usf.edu]
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Hi Kerstin,
I'm back in the USA, working on writing my thesis. I want to use several figures from RWSN publications in my thesis and need to get permission to do so. In particular, I want to use Figures 1, and 3 and the table indicating how self supply contributes to the MDG's from "An Introduction to Self Supply: Putting the User First". I also want to use Box 1and Table 1 from "Self Supply: A Fresh Approach to Water for Rural Populations" , Box 1 from "Integrating a New Approach: The Example of Self Supply", and Box 3 from "Accelerating Self Supply: A Case Study from Uganda". Dr. Sutton is the author of many of these reports- should I contact her directly (and if so, can you give me her email address? I can't find it on the RWSN website) or is there another person at RWSn who can authorize me to use the figures? I may want some other figures as well, but at this stage of my writing that's what I'm planning to use. Thanks!
Jonathan Blanchard

Figure A1 Permission to use figures from RWSN publications

APPENDIX 2: VISUAL REPRESENTATION OF SEVERAL OF THE WATER STORAGE TANK TECHNOLOGIES DISCUSSED IN THIS RESEARCH

	
Ferrocement tank.	Large plastic tank.
	
Interlocking Stabilized Soil Block tank.	Informal rainwater harvesting with pots and basins under the edge of a roof.
	
Small plastic tank.	55-gallon metal drums, here being used for distillation of waragi, a local beverage.

Figure B1 Pictures of various tank technologies. Pictures by Jonathan Blanchard.

ABOUT THE AUTHOR

Jonathan Blanchard was born and raised in Madison, WI. He received his B.S. in Civil and Environmental Engineering at the University of Wisconsin-Madison in 2008. He was extensively involved in Engineers Without Borders, which led him to the Masters International Program in Civil Engineering at the University of South Florida. In 2011, he completed 2 years of Peace Corps service in Uganda, where he started and managed a business building rainwater tanks out of Interlocking Stabilized Soil Bricks. He married his wife Elizabeth in November of 2011 shortly after his return from Uganda, and they live in Madison, WI.