RAINWATER HARVESTING SYSTEMS FOR COMMUNITIES IN DEVELOPING COUNTRIES

By:

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A REPORT

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This report "Rainwater Harvesting Systems for Communities in Developing Countries" is hereby approved in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE IN CIVIL ENGINEERING.

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Preface

This first part of this report was completed in December, 2004, prior to my departure for Peace Corps service. It was submitted in partial fulfillment of the requirements for the master's degree from the Master's International Program in Civil and Environmental Engineering at Michigan Technological University, pending corrections and a final chapter on my observations on rainwater harvesting in the country of service, which are now included.

In January 2005, I began twenty seven months of service with Peace Corps in Mali, West Africa, as a water and sanitation volunteer in a small rural town of four thousand people, with the hopes that I would be able to continue to build upon my research on rainwater harvesting methods in developing countries, specifically large scale rooftop catchments for potable water. After some preliminary observations, I decided to abandon rooftop catchments and focus on the more prevalent ground catchments found scattered throughout the central region of Segou, immediately after the rainy season.

One of the Peace Corps program goals for the water and sanitation sector focuses on year round access to water for potable, domestic and agricultural needs. Since virtually every family in the town I lived in had their own well and were already educated as to how to maintain their wells to keep the water potable, I focused on access to water for agricultural needs, assisting the local women's association in obtaining pumps for their garden activities. I also worked briefly with the regional fishing ministry. They specialize in implementing man-made ground catchments in local villages throughout the region for harvesting rainwater for fisheries. It was from working with them that I began to question the sustainability of this common and still popular approach to rainwater harvesting.

The focus of this paper is rainwater harvesting systems as observed in communities in developing countries, namely Mali. The goal is to apply the information presented here in the assessment of such systems where rainwater harvesting is a viable option. This report was completed in August 2007.

Acknowledgements

A heartfelt thanks to my Lord, to my family, to my friends for their support throughout the years, and to all of my professors for making this possible: Jim Mihelcic, Brian Barkdoll, Dave Watkins, Blair Orr, Tom Van Dam, Casey Huckins, Peg Gale, Alex Mayer, Dave Hand, and Chris Wojick. Thank you.

Abstract

Millions of people worldwide suffer from lack of water. The importance of water is well known. The problems facing water sources have been well documented. There are many factors that compromise quantity and quality of water supply sources in some developing countries.

It is found that rainwater harvesting, the collection of rain from surfaces upon which it falls, is a long-standing practice of many countries still used as a means for dealing with the water problems of today. Rain is harvested in many ways and is a vital supplementary source of water.

Can a focus on rainwater harvesting effectively solve some of the water availability issues faced by communities in developing countries? Is this age-old practice still acceptable by modern feasibility criteria?

This paper defines feasibility in terms of the physical, social, and technical environments of developing countries. More specifically, current water supplies, climate, available resources, cultural preferences, gender roles, community dynamics, supply and demand are defined and evaluated to determine the role each play in sustaining the practice of rainwater harvesting.

These criteria are applied mainly to the idea of ground catchments, a rainwater harvesting system common in Mali, West Africa. Previous research on general technical aspects of above ground roof catchment systems, and other considerations regarding such systems are listed in Appendix A.

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1. INTRODUCTION

Water is our most precious natural resource (Sustainable Earth Technologies, 1999). Its uses are innumerable and its importance cannot be overestimated. Its role ranges from domestic uses, agriculture, and industry to religious ceremonies, recreation, landscape decoration and even therapy. Water is basic to life.

Despite the obvious need for a sufficient, year-round water supply to sustain life, there is still a lack of water, much less clean water for many of the world's poor. The lack of water is bound to get worse. Estimates of the number of people without water put the number at about one-fifth of the world's population. For developing countries the number could be one-half, (Weatherall, 1999).

The problems that plague current water resources are numerous (Figure 1), but so are the possible solutions. This paper presents rainwater harvesting as "one of the most promising alternatives for supplying freshwater in the face of increasing water scarcity and escalating demand" (United Nations Environmental Programme, 1997). The objective is to support rainwater-harvesting systems in the developing world. A brief review on the history of rainwater harvesting and a feasibility assessment, the criteria of which are first defined and then applied to an example, are used to show the potential of such systems.

- Approximately thirty percent of the world uses groundwater and it is the primary supply of water in many non-urban settings. Over-use has resulted in a drop in water table levels and have made the cost of water rise. (Weatherall, 1999)

- Large amounts of contaminants are filtering into groundwaters (Weatherall, 1999). Other sources have been contaminated by fluoride, (naturally occurring) arsenic, or salt (in coastal areas) (Development Technology Unit, 1987). In Bangladesh, for example, arsenic has affected 18 million people already and millions more are susceptible (Weatherall, 1999).

- Surface waters are also being contaminated from industry, mining, and agriculture. In northern Mali, pesticides were found to have polluted the water, and in Mauritius, industrial and sewage pollution is threatening the livelihood of fishermen (Smith, 2002).

- It is difficult to transport infrastructure for water supply where terrain is mountainous or otherwise unleveled, as is the case, for example, in many islands (United Nations Environmental Program, 1997).

- Cost is a limiting factor to the implementation of high-tech systems in many developing countries (Development Technology Unit, 1987).

Figure 1 *Problems with current water resources*

2. BACKGROUND

Rainwater harvesting, henceforth RWH, is defined here as the collection of water from surfaces on which rain falls, and subsequent storage of this water for later use (Sustainable Earth Technologies, 1999). The practice of harvesting rainwater is an old tradition adopted in many parts of the world, as well as a new technology that is growing in popularity. Rooftop catchments and cistern storage have been used in the Caribbean, and in the Middle East, for over three hundred years (Global Applied Research Network, 2003). Rainwater is also harvested in large rural areas such as Honduras, Brazil, and Paraguay as an important source for domestic water supply (United Nations Environmental Programme, 1997). In Thailand, there is evidence of rainwater collection from roofs or gutters into jars (Prempridi and Chatuthasry, 1982). In Asia, the history of RWH dates back to the 10th Century (Global Development Research Center, 2002). It is also popular in rural Australia, parts of India, Africa and parts of the United States.

For more than a decade, accelerated interest in domestic RWH has lead to both the formation of national RWH associations and the expansion in RWH research worldwide (Global Applied Research Network, 2003). Water policies of developing countries often list RWH as a source of domestic supply. (International Rainwater Catchment Systems Association, 2004). Moreover, individuals and groups have developed many varieties of RWH systems for use (United Nations Environmental Programme, 1997). This technology has been adapted in arid and semi-arid areas (United Nations Environmental Programme, 1997), rural and urban areas, and can serve as a primary or supplementary water source. While there are some disadvantages to harvesting rainwater, (dependency on climatic patterns, storage capacity limitations, and contamination from poor collection and storage methods) these disadvantages can be avoided with proper planning and management. The flexibility and the many benefits (Figure 2) associated with rainwater harvesting make it a welcomed, widely accepted, and increasingly-promoted alternative for the water demands of today.

- Relieves demand and reduces reliance on underground sources, and surface waters.
- Avoids many surface-water pollutants (Texas Water Development Board, 1997)
- Cost effective: reduces water bills and running costs are low.
- Is a simple yet flexible technology. Local people can be trained to build, operate and maintain a RHW system.
- Does not depend on terrain, geology, or infrastructure management schemes (United Nations Environmental Program, 1997).
- Water can be delivered nearer or directly to the household, relieving the women and children from the burden of carrying it, saving time and energy (International Rainwater Catchment Systems Association, 2004).
- Can be used for agricultural purposes.
- Can be used for ground water replenishment.

Figure 2 *Benefits provided by rainwater harvesting systems.*

3. FEASIBILITY ASSESSMENT

There are three important questions that should be asked when undertaking any project in a developing country: Does the community need it? Does the community want it? And can it be done? For a rainwater harvesting system, these translate into assessment of the physical, social, and technical environments. Figure 3 shows in some detail how these factors are subsequently broken down for consideration. Some are interrelated.

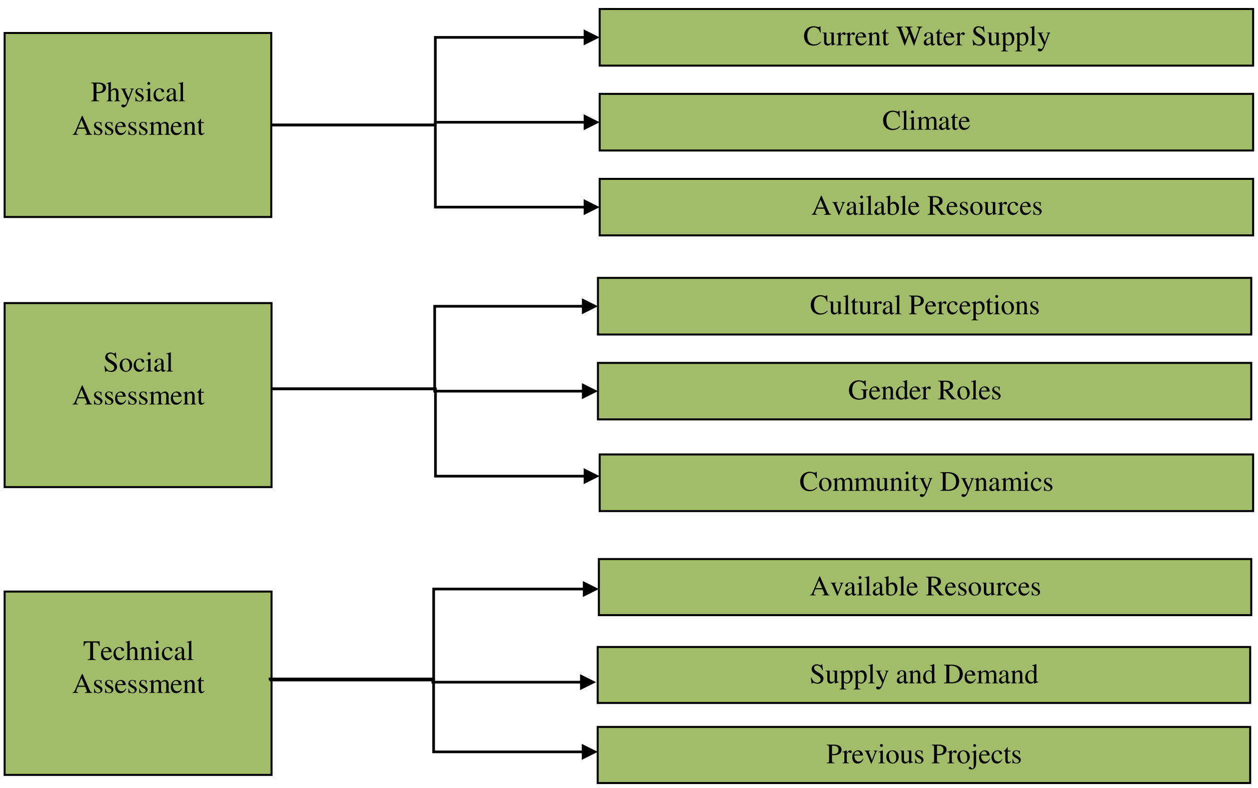

Figure 3 *Areas to address when evaluating feasibility of a RWH system.*

3.1 Physical Assessment

A physical assessment requires taking inventory of the current situation. For example, what sources of water currently exist? Are these sources for potable or non-potable uses? What are their conditions? Are they local? Are they accessible to the community? What is the quality of the water? Is it a reliable source, or is it available only in certain seasons or at certain times? Answers to these questions will begin to answer whether or not there is a need for a new or improved water supply. A public water supply, i.e. a well or a nearby river, may already be available. The quality and reliability of this water supply, and the preferences of the people must be taken into account. For the given location, does it rain and how often? Does the amount of rainfall per month or per season warrant the usefulness of a rainwater harvesting system? According to one source, the recommended minimum amount of rain required for a RWH system is 50mm per month for at least half the year (Development Technology Unit, 1987). Another source recommends 400mm per year (United Nations Environmental Programme, 1997). Rainfall data can be obtained from the World Meteorological Organization, from local weather bureaus, or by direct observation over a period of time. Asking the locals for this information will also give a general idea. An additional observation should be in regards to local building materials. For example, what kinds surfaces exist for catching rain? It should be noted that some types of materials are not suitable for RWH systems for potable uses. See Appendix A for more detail.

3.2 Social Assessment

Social assessment must begin with a definition of community and the identification of key persons. How many people exist in the community? Who are the real respected leaders of the community? The social assessment goes on to answer the why's of the physical assessment. For example, why is one source of water more preferred than another? Is a water source located in an area by choice or by circumstance? Why does a community not practice rainwater harvesting? Is there a real felt need for better water provision (United Nations Environmental Programme, 1997)? A community may have the need for an improved water supply, but there are several reasons the community may not be receptive to the idea of a RWH system. Depending on the kind of system presented, the technology may be above the education level of the community. There may be other priorities, depending on the season. It may not be considered an immediate need, or there may already be multiple sources of water, each with its own specified purpose. There may be traditional RWH systems already in place. Cultural perceptions and religious views regarding the use of water, as well as traditional preferences for its location, taste, smell or color are all important and to be taken into consideration. "Too often, non-community agencies (government, NGOs, and outside donors) will seek to implement a new technology without taking into account the cultural traditions and social roles of that community" (United Nations Environmental Programme, 1997). It is those very traditions and social roles that will determine the successful implementation and use of a rainwater harvesting system.

In many developing countries, women are primarily responsible for water, but decisions to undertake investments, such as installing a RWH system, are typically undertaken by men. Both sexes need to be included in any discussions regarding the implementation of a RWH system. Pacey and Cullis (1986) recommend forming community water groups to be responsible for the system. It is important to know the people, to be aware of their concerns, and to encourage their participation in every step of the process. It has been shown that the more a community is involved, the more potential for a successful project (United Nations Environmental Programme, 1997).

Other aspects regarding assessment of community dynamics include level of cohesion and communication, community politics and relations with surrounding communities, amount of enthusiasm (often evaluated in terms of willingness to contribute), and assistance from outside groups. These and likely other factors not mentioned here can positively or negatively affect a RWH system. For example, the identification of key persons can extend to outside groups, individuals in surrounding communities as well as those in regional government agencies or from NGOs who can provide resources or knowledge. Local community leaders must agree on the inclusion of such individuals or groups.

3.3 Technical Assessment

The technical assessment seeks to answer the question ‘Can it be done?’ by taking into consideration the resources required for the implementation of the system, by determining expected supply and demand for water based on gathered data, and, where applicable, by taking into consideration previously-attempted projects and their reception by the community.

Determining available resources will require taking inventory of local building materials and discussing with those involved which materials are necessary, which can be supplied by the local community, which must be brought from outside and the transportation options that exist. Available resources must also take into consideration the financial contribution of the community and that from outside sources. Human resources will include skills, training, management abilities as well as labor. A plan outlining future maintenance and safety requirements is key from the outset to ensure the sustainability of the system. A site assessment is also important as this determines the location of the water storage catchment or catchments and how the water will be supplied. Remember, rainwater harvesting can be done on a large scale or local to individual households.

Potential supply can be estimated based on the size or area of the surface catchments, and the amount of rainfall expected. More detail is given in the example in the next section.

Expected demand does not dictate how much rain will actually be collected, but it is a useful guide for calculating storage capacity. Demand is estimated based on: the intended uses for the water collected, the number of users, and the expected use of currently existing sources in light of a new water source. Intended uses can range from drinking and cooking to washing, cleaning, or gardening. The number of users as well as consumption patterns will vary depending on age, gender, or season. It may be best to estimate consumption patterns by household, since the women responsible for bringing water to the home generally have a set pattern and a set number of containers for collecting water. Where existing sources are available, or preferred, they may be used until the dry season, when the stored rainwater becomes the main or only source of water. Nevertheless, if the stored rainwater is nearer than a distant source, it may be used more frequently. In short, designing for demand may not be an easy task. It is better to overestimate than to underestimate. Table 1 provides an example of how demand can be estimated.

	USES:	Number of users	Amount used (gal/day)	Number of days	Totals
Adults	Bath	12	10	180	21,600
	Drink	12	3	180	6,480
	Cooking	6	6	180	6,480
Children	Bath	9	5	180	8,100
	Drink	9	2	180	3,240
	Cooking	0	0	180	0
Teens	Bath	5	10	180	9,000
	Drink	5	5	180	4,500
	Cooking	0	0	180	
Total Demand					59,400 gal or 225,000 liters

Table 1 *Calculations for estimating RWH storage needed.*

Demand is calculated for a community of 12 adults, 5 children and 9 teenagers. Intended uses are listed for each group. Columns listing number of users, amount used and number of days is multiplied to attain totals usage. Totals are then summed. 180 days represents a six-month period. Safety factors are not taken into account in this example.

Finally, a review of existing projects or previous efforts to implement water supply systems can contribute valuable knowledge and prevent past mistakes from reoccurring. A local community may not always volunteer such information. It is critical, in the case of existing projects, to know their owners and any contract or stipulations associated with them. This can prevent making changes in an area where changes are limited, not allowed, or not aligned with the original intentions of the project already there. Some knowledge of regional or country water policies may also be useful.

4. THE WATER CRISIS IN MALI

Mali is a country with an area of about 482,077 square miles (Bamako, the capital, is 97 square miles) with an estimated population of 13 million, mostly in the southern half of the country. Mali is landlocked with, Niger and Burkina Faso adjacent on the east, Algeria on the north, , Senegal and Mauritania on the west, and Cote D'Ivoire and Guinea on the south. See Figure 4. There are several plateaus to the south and southwest, and mostly flat plains in the north and central regions. The two main rivers that flow through it are the Senegal River and the Niger River. The Senegal flows northwest across Mali for about 420 miles towards the Atlantic. The Niger flows from northeast for 1,100 miles through Mali (Encyclopedia Britannica Online, 2007).

A case study by N'Djim (1998) states: lack of access and shifting population patterns cause water quality and quantity problems in Mali. In 1992 it was estimated that less than fifty percent of the people had clean water. The figure was even less in Gao and Timbuctu. In these regions there is more groundwater but a shortage of rainfall. Poor use of resources and rapid population growth add additional pressure on the environment and other resources indirectly affecting water supply. Poor water quality and seasonal availability, especially in the rural areas, leave room for improvement of the water supply. This section is an observational feasibility assessment of ground-level surface catchments in the region of Segou.

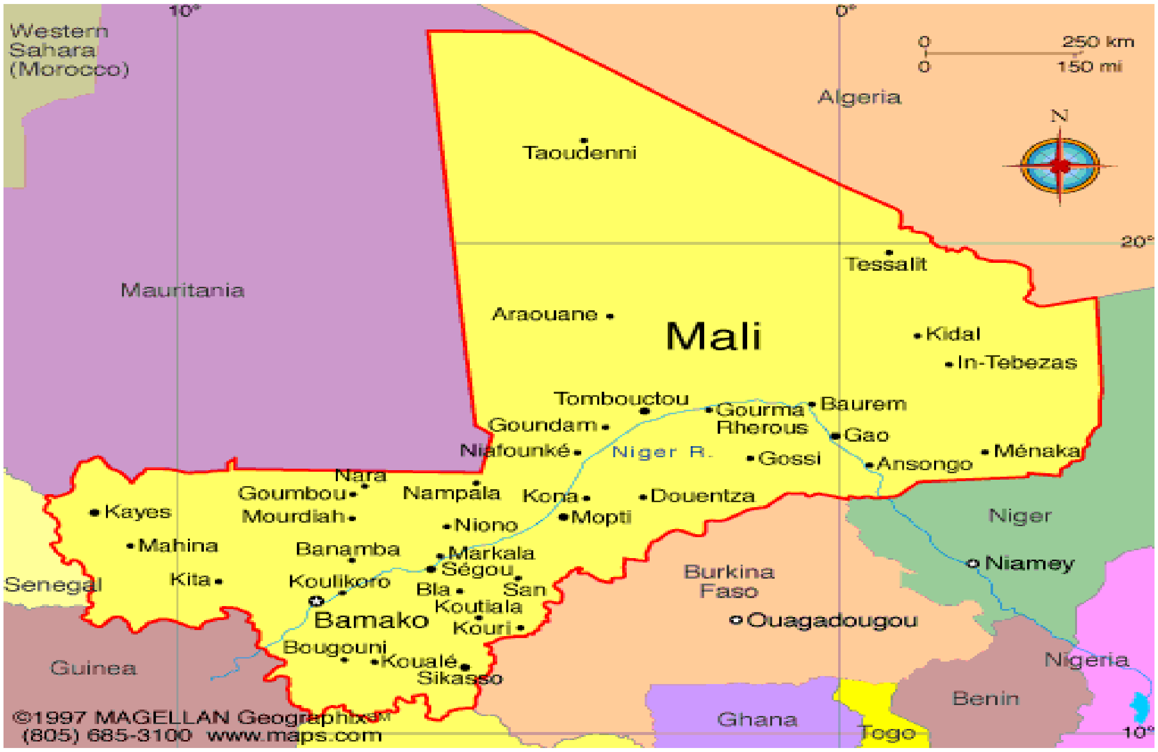

Figure 4 *Map of Mali, West Africa*

4.1 Physical Assessment

4.1.1 Climate

The seasons in Mali are described by a wet and dry season. The dry season lasts from November to June and exhibits low humidity, high temperatures, and the *alize* and *harmattan* winds. The *alize* blows from the northeast from December to February, bringing cooler temperatures averaging 77ºF. The *harmattan*, blowing from the east out of the Sahara, can cause daytime temperatures of up to 104ºF from March to June. The wet season, from June to October, varies between Mali's three climatic zones: the Sudanic, the Sahelian, and the desert zones. Annual rains of 20 to 55 inches at 75-86ºF characterize sudanic climate. The Sahel, bordering the Sahara, receives 8 to 20 inches annually, with temperatures averaging between 73 and 97° F. In the Sahara, temperatures range from 117 to nearly 140°F during the day (Encyclopedia Britannica Online, 2007).

The region of Segou falls into the Sudanic climate zone with rainfall averaging 16 to 76 inches the past three years, as shown in Figure 5. Areas further south receive relatively more abundant rainfall. Figure 5 shows a comparison between the normal cumulative rainfall between 2005 and 2006 where the region received more rain in 2006, in part because of reported efforts of cloud seeding by the government (data from ASECNA Meteo stationed in Segou). The impacts of these efforts are still being evaluated and the results are critical in a country where a large percentage of the population is heavily dependant on agriculture, subsistence farming, animal husbandry, and pastorialism, especially in the northern regions, for their livelihood.

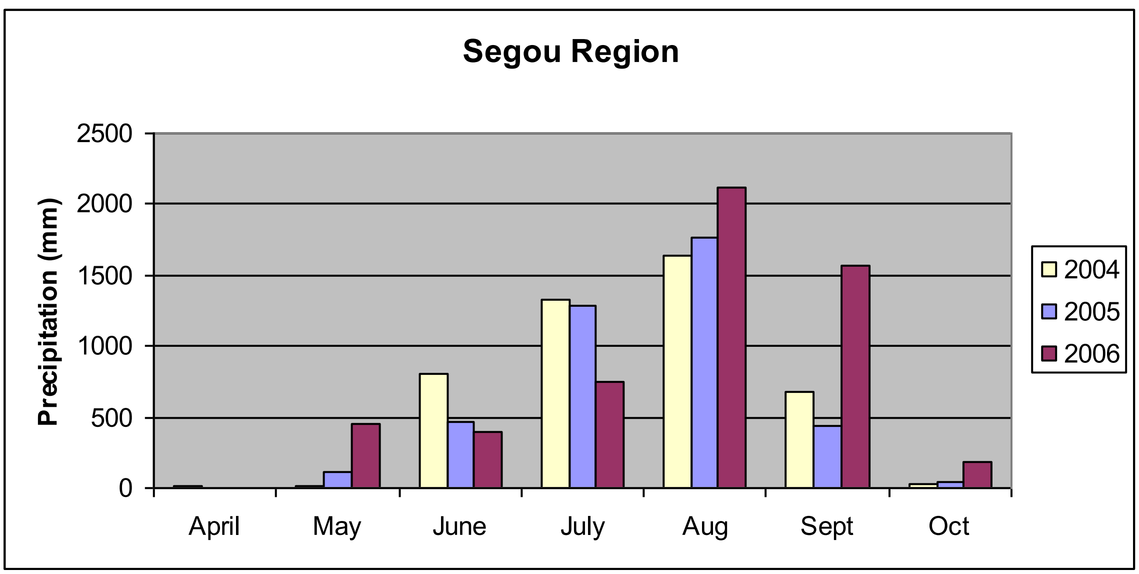

Figure 5 *Rainfall in the region of Segou*

4.1.2 Water Supply

Mali's sources of water include the perennial surface waters of the Niger and the Senegal rivers, non-perennial surface water, subterranean water, and rainwater. Subterranean includes traditional wells, and modern wells, not all of which have water available year round.

In the region of Segou, the Niger River is one of the main sources of water, spanning two to four kilometers wide with a reported depth (by locals) of one to three meters. It branches to several smaller canals, some leading to floodplains further inland. The river and the canals are maintained by a handful of dams such as the one shown in Figure 6(a). The most notable dam in the region is the Markala Bridge Dam, shown in Figure 6(b) and (c). It is known for its impressive size and unprecedented span. The Niger is popular in the city for gardening, for washing clothes, and for harvesting sand and fish. It is a means for transportation used by the local community whose homes are on the other side and for tourists wishing to view the waterside or travel to an upriver town. The waters of the Niger River are not considered potable. While a majority of the population is somewhat aware about the health hazards of drinking river water, some still do. Aside from the Niger and the city water supply, another source of water is wells, widely used by communities outside of the city. There are deep wells and shallow wells, the shallow wells ranging from seven to twenty feet deep. The depths of the deeper wells, some established with pumps, are guessed to be twenty feet and more.

Figure 6 *Examples of Dams in Mali*

(a) (top) Example of typical smaller dam in Mali, (b) (center) Markala Bridge Dam seen from afar, and (c) (bottom) close-up view of the Markala Bridge Dam

Most wells are in close proximity to the family or families using the water, often in the living area (concession) itself. In several villages visited, it was noted that even the public wells were never more than a few meters of walking distance away.

In both the city and in the towns and villages, reports of low water levels are often heard as the dry season begins in the months of March to July. Both ground water sources (wells) and surface waters suffer from the long dry season. It is, in most cases and for most water sources, a yearly occurrence. To cope, many villagers flock to the cities, gardening activities are suspended, and water is carted in from other sources.

Beginning as early as February and on until July, the land begins to dry and slowly becomes barren. Wells and major rivers fall to their lowest levels. In the region of Segou, some rain may fall as early as April, but these are often considered ‘mango’ rains, a few scattered showers for the sake of the mango trees. The real rainy season normally begins in June, peaking in August and September and is over in early November. Immediately after the rainy season however, natural depressions in the land and several man made depressions become filled with rainwater. These are noticeable in many villages and in fields along roads. The catchments, usually dug by local men, can range from one meter to two kilometers in length and width and be half a meter to three meters deep. Catchments continue to grow in number or in volume capacity, year after year, as the men return to these sites or create new sites excavating the earth for the manufacture of mud bricks (Figure 8) which are in turn used to build houses. The mud is also used for replastering homes in preparation for the rainy season. The soil’s clay content is such that it serves as a natural liner to the catchments. The water collected in these depressions is from runoff from the surrounding landscape (infiltration is slow) or from nearby tributaries and canals that overflow. It lasts from one month to five or six months, for the larger catchments. The distance between these sources and the village communities also vary, and can be as far as five kilometers. The water is not considered potable.

Regardless of the amount of rain, the supplemental water provided makes a significant contribution to the local water supply. For example, ground catchments alleviate demand on groundwater reserves (wells) for gardening and other domestic needs. Some women prefer to go to these sources when they become available rather than pump or pull water to carry to a wash area. Thousands of cattle, sheep and goats, the representative wealth of families, often stop to drink at these catchments. Table 2 lists other advantages of this type of rainwater harvesting.

Table 2 *Advantages of non-potable water use*

Water harvested in these catchments is usually for non-potable uses and play a vital role in ensuring the livelihood of many communities. ➢ Women go to these sources to perform household chores like washing pots, clothes, or bathing the children. ➢ In local villages, the water is necessary for the making of bricks, used in turn to build shelter. The water is also mixed with local clay for the resurfacing of homes in preparation for the rainy season. ➢ Community gardens often spring up near some of the larger natural depressions where lettuce, tomatoes, cucumbers, and melons, seasonal because of water shortages, are grown for food security and surplus is often sold for supplemental income. ➢ Cattle, sheep, and goats use these sources as their drinking water supply. Ducks and other birds also use these perennial waters as a source of food. ➢ In some cases, these depressions serve as fish farms, supplying a community with an alternate source of protein. ➢ They become a communal recreation area where the women gather to socialize as they wash and the children swim and play.

4.1.3 Resources

Most of the rural population in Mali live in thatched or mud homes in villages of 150 to 1000 inhabitants, or towns of up to 8000 inhabitants.

Roofing materials in the region of Segou include thatch (which can be from millet or sorghum stalks, or woven mats of dry grass, palm fronds or rice blades), mud (mixed with manure and rice or millet husks), or corrugated metal, popular in the city, and for those that can afford it in the villages. See figure 7.

Other locally available materials include wood and cement. Nevertheless, as previously stated, the natural earth or mud is the most preferred material for construction at the village level. Figure 8 shows mud bricks set out to dry near a catchment. Cement is reserved for official, externally sponsored projects like schools and health centers. Cement is also used to provide a strong support to gutters (perpendicular to the edge of the building) that drain water away from mud roofs. Cement is also used on floors but there is very fine clay that mimics cement in color and hardness that is used too. Wood is most often used at the local level when building roofs, fences, carts, and porches.

Land is another resource that is widely available. Most of the land is used for growing fields of millet, sorghum, and rice, and for grazing livestock.

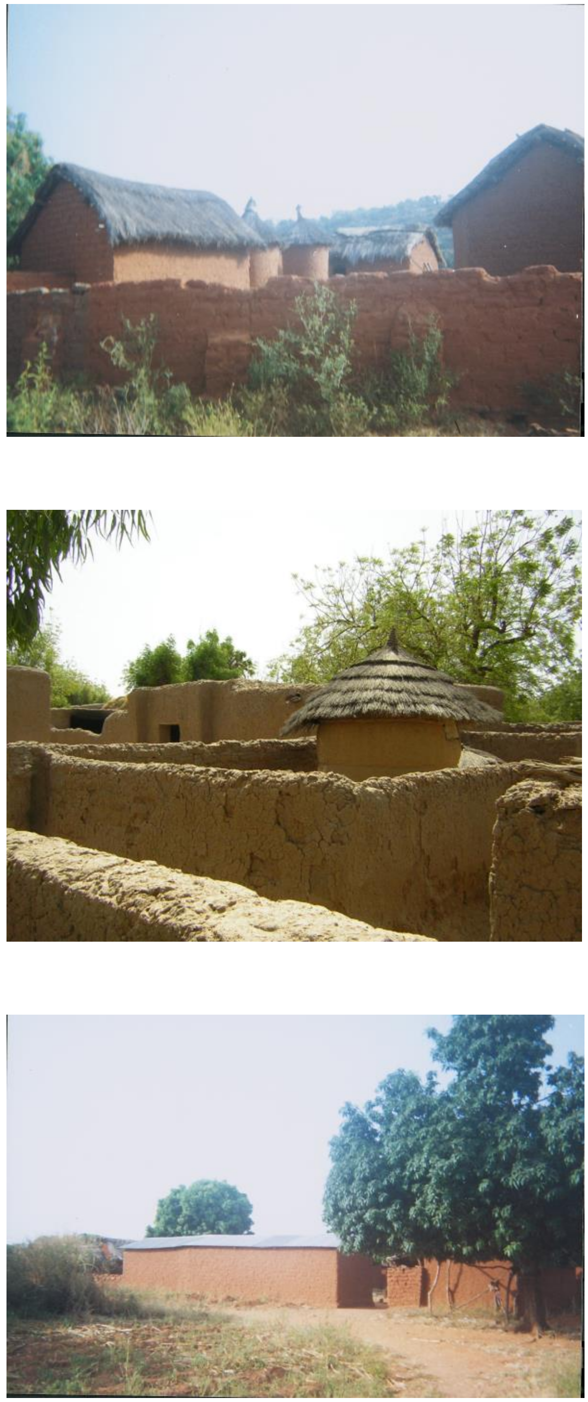

Figure 7 *Types of roofs in Mali*

(a) (top) Thatch (b) (center) Mud walls and Flat Mud roof (in the background), and (c) (bottom)Toll roof

4.2 Social Assessment

4.2.1 Cultural Perceptions

Lee and Visscher, 1990 state: "Roof catchment systems appear to have least potential (for rainwater harvesting) due to the predominance of mud roofs and long dry periods of up to eight months." Rainwater harvested from a mud or even a thatch roof is considered "dirty" by local standards because of the high turbidity from the organic matter in the mud or thatch. A long dry period suggests the need for a large catchment, a cost rural inhabitants with large families may not choose to support.

One theory on why rooftop rainwater harvesting has not been widely promoted or accepted has to do with it being a "new" technology. It is difficult for a community to support a project they do not understand or have not seen before. The risk is too great. Moreover, the idea to build a structure that houses water seems foreign, especially when those materials could be invested in other priorities. Rural inhabitants may encourage such ideas but not be inclined to support them, even if they agree to its importance and see the benefits. Another theory has to do with the method of promotion. Do men or women better promote technology? Is it better understood individually or in a group? Does it require repetitious learning sessions? No household rooftop RWH systems were noted in any of the many villages visited or in the city.

4.2.2 Gender Roles

In most communities observed, the establishment of a water source, the digging of a well or catchment, for example, is the responsibility of the men. The day-to-day responsibility of bringing water to the household from its source, the concession well or a nearby pump, is for the women. Women use buckets to bring this water to the household for drinking, cooking, bathing, and sometimes dish washing. Otherwise, dishes, especially the cooking ware, as well as clothes, and sometimes toddlers, are washed at the water source itself. In such cases the water source can be the concession well, a public pump, or a local ground catchment. Men will use large fifty-gallon drums to bring water to the house if there is construction or reparation work to be done. This water may be from a large ground catchment, a nearby stream, a locally installed pump and faucet, or any other source where water is available in abundance. The concession (most local) source of water (well water) is used as a last resort, as this is the main source for drinking water.

4.2.3 Community Dynamics

Excavations are common place. “Larger communal surface catchment systems show a great promise and can be used for the complete range of water needs if well managed” (Lee and Visscher, 1990). They are the ideal communal surface catchment system. Socially, they are widely accepted. Financially, it pays for itself as the bricks made from the excavated earth are personally used or sold to fellow villagers. Women use the water later collected in the catchments for gardening. Free ranging animals are able to quench their thirst. The entire community benefits from the larger communal surface catchment system.

From a regional and national perspective, “There is a pressing and well recognized need in Mali to develop resources such as water harvesting for agricultural purposes. In the opinion of government authorities, the main problems facing the rural areas of Mali are land degradation and the inability to produce sufficient food for a growing population or for cash-crop export. As such, over the last five years, natural depressions have become a focus of attention. Introduced water harvesting projects such as 'Amenagement de bas-fonds' programs designed to increase their water holding potential for livestock watering, gardening, and rice cultivation are being implemented through the building of dams and barrages" (Lee and Visscher, 1990).

The question of whether or not the community wants this kind of rainwater harvesting system is positively answered because the community automatically takes ownership of these catchments in all of its life stages. Community input is there, technology selection is theirs, risks for social conflict are minimized, management capacity is built in, labor is willingly provided, financing is minimal, potential for women's involvement is greater, and support from outside partners is available. This technology is replicable and sustainable. Increasing community involvement in such a project is facilitated by familiarity with this kind of rainwater harvesting system.

Figure 8 *Brick making near a catchment*

4.3 Technical Assessment

4.3.1 Projects

While existing natural depressions are beneficial, most are too small or too shallow to harvest enough water to last more than three to four months of usage. Temperatures as high as 104 degrees, hot winds, and winds storms all accelerate the evaporation of these sources and many are completely dry before the peak of hot season.

The Ministry of Fishing in the region of Segou, in collaboration with the Development Funds Program for the Sahel or Programme Fonds de Development en Zone du Sahel (FODESA), have been aggressively promoting large scale catchment areas for the purpose of fish farming throughout the region. Figures 9 – 11 exhibit some of their work. In addition, Figure 12 shows a catchment in progress by the development group Engineers-Without-Borders.

Figure 9 *FODESA, Regional Association of Segou*

Sahelian Areas Development Funds Program financed this "lake management" project in the village of Sagabougou.

Figure 10 *Village of Sagabugu Catchment's reinforced water entrance ramp*

Figure 11 *The Kamian Catchment excavation in progress (100m by 80m by 1.5m)*

Figure 12 *A recently dug catchment by an Engineering Without Borders group*

4.3.2 Resources

Smaller catchments require picks, shovels, carts, wheelbarrows, drums and manual labor by both human and animals. Existing catchments are usually made wider when there is still water in them. When those levels drop such that water can no longer be harvested, then the mud that remains is harvested for use, thereby deepening the catchment.

In the excavation of large catchments, an earth mover is usually preferred. Many communities however cannot afford the cost without outside assistance. The cost of a funded project can be in the millions of dollars. This figure takes into account the renting of the equipment (earth mover), the fuel it requires, payment to its operator, the cost per cubic meter of earth moved, as well as the salary and living expenses of the project supervisor, per diem costs for other supporting managers, and other costs of cement and gravel that are brought in for the construction of necessary reinforced entrance ramps.

4.3.3 Supply and Demand

One example is a 12,000m^3 area, excavated for the local community of Kamian. Water collected is limited by the dimensions of the excavated area, and not by expected supply. Expected supply of water can be estimated by looking at the average rainfall in the Kamian Basin area for the previous three years, shown in Figure 5 to be about 669mm per year. Taking into account that the excavated area where the water will be stored is itself a catchment (a surface upon which rain falls) apart from the natural contributing drainage area, Equation 1 (Appendix A) becomes

$$\text{Supply} = (\text{Rainfall} * \text{Coefficient} * \text{Excavated Water Storage Area}) + (\text{Rainfall} * \text{Coefficient} * \text{Drainage Area})$$

The coefficient, in this case a coefficient of loss, is a factor of evaporation, infiltration, and seepage and may vary in the two areas depending on soil compaction, vegetation, and other factors. The coefficient of loss is a measure of system efficiency in terms of retaining all captured water. If it is assumed the losses are the same for both areas, the equation can essentially be written as

$$\text{Supply} = \text{Rainfall} * (1 - C) * (\text{Area 1} + \text{Area 2}).$$

We can use this equation to determine how large the drainage area (or surrounding floodplain) needs to be in order to fill the excavated catchment. Using the figures from the Kamian excavation, the drainage area would need to be about 17, 625 square meters to fill the newly excavated catchment. (See Table 3) As previously mentioned, land is widely available, making surface areas surrounding excavated ground catchments equally available, even in areas where the land is farmed. Moreover, catchments are usually dug in places where water tends to pool naturally or where there is a pre-existing depression in the land. The Ministry of Fishing has a more rigorous process of evaluation, but the end result is the same: the water drains into and not away from the catchment.

Table 3 *Calculation of Surface Area Requirement for Kamian Basin*

Expected Supply = volume of storage catchment =100m x 80m x 1.5m = 12,000m^3

Rainfall = 669mm = 0.669m

Estimated Coefficient of Loss C = 0.30, (1-C = 1-.3 = .7)

Rearranging Equation 1, Surface Area can be found using the following equation:

Drainage Surface Area = Supply / (Rainfall * (1- C)) - Storage Area

Drainage Surface Area = 12,000 / (0.669 * 0.7) – (100m x 80m) = 25,624.6m^2 – 8,000m^2

Surface Area = 17,624.6m^2

To calculate demand, it is important to consider all the watering needs of the community. The women use the catchment water for washing pots and clothes as well as for gardening. The men use it for making bricks or preparing plaster for their homes. It is also used as drinking water for cattle, sheep, and goats. Fish, frogs, ducks, other bird species, and children also play, eat or live in these waters but they will not be considered in the following calculations. Assuming the water is carted away for use, what is the demand? How many people will the filled Kamian catchment support for the eight months (240 days) until the next rainy season? Table 4 is an estimated calculation of demand with figures based on observations from living in Mali. It is assumed one household = 10 persons and each household has two cows, four sheep, four goats, (each animal capable of drinking five gallons a day) and one plot in the community garden. Assuming every household will need about 500 bricks for home or wall reparations, the water requirement for just one household for a period of eight months is 8 x 14m^3, or 112m^3. For the village of Kamian, if the population is 1000 persons (or 100 households), then the total demand is 11,204.8 m^3 of water, and can be satisfied by the expected supply.

Table 4 *Calculation of demand with figures based on observations from living in Mali*

	Gallons / month	m^3 / month
Dishes: 10 gal / household / day	300	1.13562
Laundry: 100 gal / household / 15 days	200	0.75708
Garden: 50 gal / 100m^2 plot /day	1500	5.6781
Livestock: 50 gal / day	1500	5.6781
Bricks: 50 gal/ week for 125 bricks	200	.75,708
Totals	3700	14.00598

5 OTHER CONSIDERATIONS

There are some major concerns that should be taken into consideration when designing a ground catchment. Ground catchments are an open source of water. Their catchment area is the land surrounding the catchment itself. Some areas are full of organic matter and fecal matter from livestock and humans too. For example, if a catchment is in a field where cattle roam, there can be a high level of bacteria in the water. If the catchment is on the edge of a town where runoff drains in its direction, then all grey water from unsealed soakpits and even loose debris will find their way into the catchment. As such, placement of the catchment is important. The fishing committee, if one exists, the water and sanitation committee, or a responsible village committee needs to oversee the removal of debris and the general cleanliness of the water. Many women will rinse their cooking wares with potable water after scrubbing with catchment water but care should still be taken to educate villagers against adverse side effects of ingesting non-potable water.

Besides the issue of sanitation, an open water source will attract rodents and insects, especially mosquitoes. It will also attract various bird species, frogs, and livestock. How do they impact on the environmental balance of the water source? How do they impact the community?

An open water source will suffer from effects of wind and sun. In some cases, water lilies or other types of marine plant life grow over the surface of the water but not so extensively as to cover the entire surface. Affects of these plants on the evaporation rate of the water have not been studied. One question that has been asked is why not make the catchments deeper but minimize the surface area in order to minimize evaporation? One answer is that many areas cannot be deeper that 1.5 to 2 meters because of cost and because that is the limiting depth where rock begins. It is more difficult to excavate rock than earth, by hand or with a machine. Moreover, deeper waters are a safety hazards for children that swim in the water. In one known case, a fence was put around a 1.5-meter deep catchment for safety.

As mentioned, is that it is not necessary that there be a financial cost involved in the construction of a ground catchment. But if the idea is presented as if coming from the outside, ie a development worker, then more than likely, the project becomes viewed as an opportunity for monetary or other material advancement. Understandably, although the work being done is to the benefit of the community, the labor is difficult and the conditions can be harsh. The needs of the laborers (ie for shade, water, or a good lunch) should not be neglected. No one should work for free.

Finally, if evaluated using the McConville Matrix, a more sophisticated evaluation tool that combines five life cycle stages and the five factors of sustainability, RWH catchments of this type can potentially score 80/100 when evaluated in the given categories. See Appendix D.

6. CONCLUSIONS

The methods of assessment expressed in this report were used to assess the feasibility and sustainability of rainwater harvesting catchments found in the central region of Mali. The questions "Does the community need it? Does the community want it? And can it be done?" were answered by looking at the physical, social, and technical environments of the catchments.

The physical assessment showed that although many sources of water exist, villages still rely greatly on supplemental rainwater harvested in local ground catchments. Rooftop systems are not popular, but the ground catchments are ideal for non-potable uses such as gardening.

Socially, it is an appropriate technology, highly accepted by the local communities as shown in their initiative to dig these catchments without outside assistance. The fact that the government supports and is involved in implementing large scale catchments also underlines their sustainability. Both men and women use the water collected. There could be more collaboration between men and women when it comes to choosing where to place a catchment. For example, the women ideally want a catchment nearer to sites good for gardening whereas it is not certain what method the men use when choosing where to dig.

Ground catchments are not technically complicated to build, once a site assessment has been done. If done locally on a small scale, the cost is minimal. A local community can also construct a large-scale catchment but this would be done in yearly increments. For a large catchment to be built in a short amount of time, an earth-mover is necessary, but extremely expensive. Nevertheless, the building materials and the land required are available to design a catchment to meet the demands of most rural communities.

Unfortunately, ground catchments are an open water source and will breed mosquitoes and attract other water loving insects and rodents unless an appropriate intervention can be found. This is a major disadvantage in an area where malaria is a serious health concern. Moreover, the water should be restricted to non-potable uses only.

Altogether, upheld is the theory that rainwater harvesting using ground catchments is a sustainable approach with great potential to fully supply the demand for water for non-potable uses in Mali. This method of water harvesting could be the answer to water shortage problems around Mali.

7 FUTURE WORK

Listed below are other ideas for research that could be done to support current work being done in the research of ground catchments as a sustainable method of harvesting rainwater:

- Determine how waterways in the region connect.
- Review existing local methods of assessment, ie Ministry of Fishing.
- Assess how well newly plowed catchments hold water.
- Assess how long it takes for the soil particles to even out into an effective natural liner whereby infiltration is minimized, and compare before and after infiltration rates in newly plowed catchments.
- Assess how long water in these deeper, larger catchments last.
- Determine if water quantity is sufficient for the year-long watering needs of crops (for ground catchments near gardens).
- Include an economic assessment in light of physical, social, and technical standpoint.
- Research methods to reduce evaporation.
- Research methods to eliminate mosquito breeding.
- Research animal impacts on water quality.
- Determine how coefficient of loss changes over season of use.

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APPENDIX A : TECHNICAL AND OTHER ASPECTS OF A ROOFTOP RWH SYSTEM

TECHNICAL ASPECTS

This section describes the technical components for a rooftop rainwater harvesting system. See Figure A1. The main components are the roof, gutters and downspouts, roof washer and the tank.

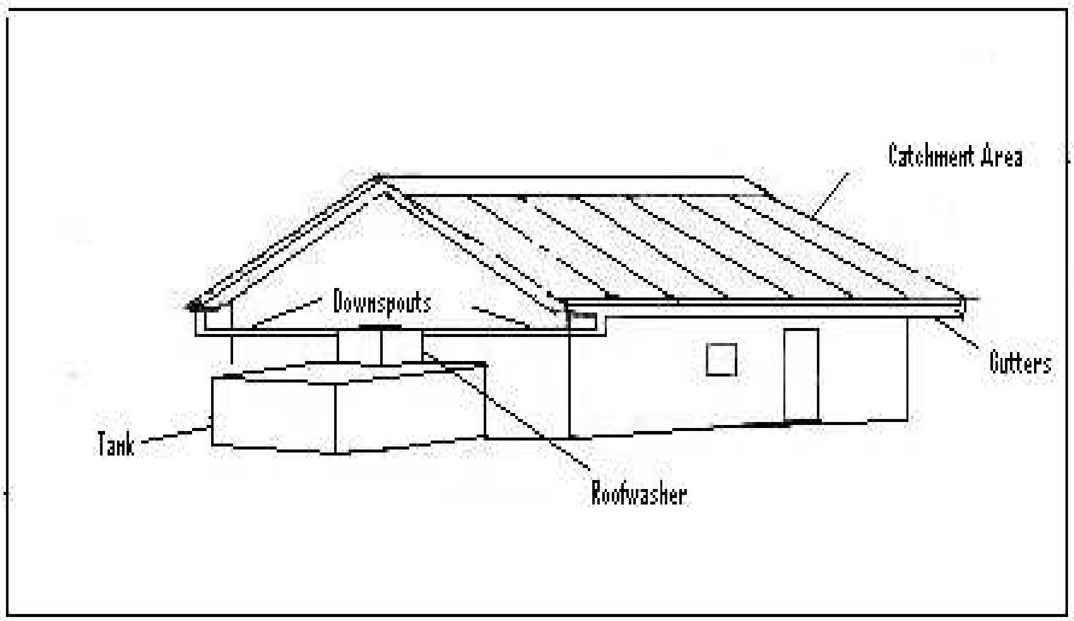

Figure A1 *RWH Scheme Components (Adapted from United Nations Environmental Programme Sourcebook, 1997).*

Roof

The roof or collection area, also termed catchment or capture area, is the surface upon which the rain falls. Actual construction of a surface is not within the scope of this report; it is assumed a surface already exists. Surfaces should be sturdy, durable, impermeable, and non-toxic. In many cases, the roofs of buildings are used, or a separate collection surface is built next to or above the water storage tank (Mogensen, 2000). The main concern is the roofing material, as this can have a direct impact on quality of the water and health of the users, if the water is to be for potable uses. Metal surfaces like galvanized iron are most often used and considered to be safe (non-toxic) for RWH systems. Sloped surfaces work best for maintenance, especially in terms of avoiding pools of water and dirt and algae build up which can affect the quality of the water.

Supply of rain can be calculated using Equation 1 (from Gould and Nissen-Peterson, 1999):

$$\textit{Supply} = \textit{Rainfall} * \textit{Coefficient} * \textit{Roof Area} \qquad (1)$$

To determine expected supply where rain data is not yet known, rainfall can be the mean annual rainfall in millimeters of previous years. Roof area is easily measured by determining the area of space it covers, keeping in mind that the collection surface is limited to the area of roof that is guttered (Texas Water Development Board, 1997). Be careful to keep the units consistent. One inch of rain on one square foot of area can yield 0.62 gallons (or approximately 600gal per 1000ft^2 area).

The runoff coefficient is used to determine efficiency of the system by taking into account the losses from the collection surface. Recommended values of 0.8 - 0.85 are often used for the runoff coefficient, however, it may be as high as 0.9 or as low as 0.24, depending on the surface material and other factors which may reduce the efficiency (Gould and Nissen-Peterson, 1999). These factors include evaporation, clogging, leakage, infiltration, overspill, and retention. A smooth, clean, impervious surface yields better water quality and greater quantity (Texas Water Development Board, 1997). The runoff coefficient is also a measure of the performance of the gutters and downspouts, as this is where most system losses tend to occur (Gould and Nissen-Peterson, 1999).

Gutters and Downspouts

Gutters and downspouts are the conveyance system, or the link between the roof surface and where the water will be stored. They serve to channel the water to the storage tank as it falls off the edge of the roof. There are very simple systems that do not require a conveyance system, but for larger systems, it is usually a critical component. Often, the construction or installation of the conveyance system is the weakest link in a rainwater harvesting system (Gould and Nissen-Peterson, 1999), and a poor conveyance system may result in high losses, poor overall system efficiency, and contamination of the water. Gutters are generally fixed on or along the edges of the collection area and must be properly sized, sloped and installed to maximize the quantity of harvested rain (Texas Water Development Board, 1997). They can take on a variety of shapes, but most often they are rectangular, semicircular, or folded into a V-shape from pliable metal sheets. When installing directly to the side of the roof, the front of the gutter should be slightly lower than the inside face so that water drains away from the side of the building. Gutters should be well supported (at least every 3 feet) so that they do not collapse under a full load of water. To prevent blockage by leaves and other debris, screens should be used along the entire length. As with the collection surface, the material for the gutter should not pose a health hazard. Most gutters are aluminum and galvanized steel (Texas Water Development Board, 1997). Plain galvanized iron sheets are also used. In developing countries, PVC pipes are sometimes used, halving them to achieve the semicircular shape, and bamboo poles can be used if available in sufficient quantity. The downspout, usually the same material as the gutters, connects the gutters to the storage tank. Downspouts should be well supported and large enough to accommodate maximum flows. There may be more than one downspout for a system. There should be a leaf screen at the top of the downspout as well.

Roof Washer

The purpose of a roof washer or "first flush" is to wash or flush away the first few gallons of water that come off the roof when it starts to rain. This water, especially after dry periods, typically has the highest accumulation of contaminants collected on the roof. A rule of thumb is to allow for at least ten gallons of water for every 1000 square feet of collection area (Texas Water Development Board, 1997). It should be simple and easy to operate. The rest of the water can then be directed to the storage compartment. If the water is for non-potable uses, this step is not necessary. However, it is beneficial for overall system maintenance, as it prevents sediment build up and contamination in the tank. First flush runoff should be diverted to where it will not pool or cause problems.

There are a number of first flush devices and several simple techniques which allow for this. The simplest way is to manually move the down pipe away from the tank inlet and manually replace it when water looks relatively cleaner, after the first flush has run out. Another idea is to use a second vertical pipe to intercept runoff before it reaches the downspout to the storage tank. This second pipe should have a volume that corresponds to the 10 gallon per 1000 square feet parameter. After the pipe filling, the remaining water can flow to the storage container. Rather than wasting this first flush, it can be used for non-potable needs such as irrigation (Texas Water Development Board, 1997).

Tank

The tank is where the water conveyed from the collection surface is stored. The concept of a water tank is fairly common in many developing countries, and there is already a wealth of resources and guides for tank construction. In some countries, tanks may even be commercially available. As with the collection surface, the tank can be built in a variety of shapes and sizes depending on budget, need, and available resources. Storage tanks may be inside or separate from a building. They can be built above ground, below ground, or somewhere in between. Above ground tanks are more accessible for drawing water, and easier to maintain. They also avoid the costs of excavation. Below ground storage areas benefit from cooler year-round ground temperatures (Texas Water Development Board, 1997), and they do not necessarily take up space needed for farming. They are, however, more susceptible to underground contamination or seawater intrusion (in coastal areas), and leaks may not be easy to find. Battery tanks (interconnected tanks) made of pottery, ferro-cement, or polyethylene, are also an alternative (Global Development Research Center, 2002).

Materials

Some necessary qualities of tanks are durability, and watertightness. The inside surface should be smooth and clean. In addition, it should be non-toxic (Texas Water Development Board, 1997). The materials chosen for the construction of a rainwater tank will depend on locally- available materials, their affordability, and environmental conditions.

Table A1 *Examples of advantages and disadvantages associated with materials used in the implementation of rainwater tanks (Cunliffe, 1998)*

MATERIAL	ADVANTAGES	DISADVANTAGES
CONCRETE/MASONRY		
Monolithic/Poured-in-Place (Reinforced Concrete)	• Durable, long lasting • Above / below ground • Can decrease corrosiveness • of rainwater (allows dissolution • of calcium carbonate from walls • and floors)	• Subject to cracks and leaks • Subject to underground stresses (especially in clay soils) • Not portable / heavy
Concrete Block	• Durable	• Difficult to maintain • Not portable / heavy
Ferro-cement (steel mortar composite)	• Portable • Durable • Flexible in design • Easy repairs	• May require more maintenance • Subject to cracks and leaks
Stone	• Durable • Keeps water cool	• Difficult to maintain • Not portable / heavy
PLASTICS		
Garbage Cans (20-50 gallon)	• Inexpensive	• Use only new cans
Fiberglass	• Alterable • Moveable / portable	• Degradable • Needs interior coating • Sensitive to sunlight
Polyethylene/ Polypropylene	• Above/below ground • Alterable (can have many openings) • Moveable / portable • Long life expectancy (25yrs) • More durable than fiberglass • Smooth interior, easy to clean • Large storage capacity	• Degradable • Not suitable for outdoor use (requires exterior coating /enclosure /UV inhibitor) • Must be FDA approved
Liners, other plastics	• Used to line concrete tanks • Used to repair leaks	• Needs support • May be sensitive to light
METALS		
Steel Drums (55 gallon) / Galvanized Steel Tanks	• Durable • Lightweight • Portable • Alterable	• Subject to corrosion and rust • May require liner/coating • Verify prior use for toxics • Fluctuating pH may release zinc • May contain lead
WOOD		
Redwood / Cypress / Douglass Fir?	• Durable • No resins • Resistant to insects and decay • Efficient Insulator • Life expectancy 50-75 years	• Expensive
Plywood		• Requires liner

Sizing

Technical aspects of storage tanks that follow will focus on above-ground tanks. There are several methods for determining the optimal size of a water tank. One method is based on capturing the maximum supply of rain possible for a given roof size. For example, a roof of $200m^2$ in an area with an annual rainfall of 1000mm yields about 156kL (Cunliffe, 1998). The tank size would be 156kL plus a factor of safety. Another method may be more demand-oriented. Some countries have long dry spells and only a few days of heavy rain, so storage capacity may be larger. In developing countries however, where a large storage area is needed, cost is often a limiting factor. Consequently, a third method for choosing tank size depends on costs, resources, and construction methods (Pacey and Cullis, 1986). Cunliffe (1998) of the National Environmental Health Forum gives the following equation for calculating tank size:

$$V_t = V_{t-1} + (Runoff - Demand) \qquad (2)$$

V_t is the theoretical volume of water remaining in the tank at the end of each month. A negative V_t means demand is greater than supply. V_{t-1} is the volume of water left in the tank from the previous month, starting with an empty tank.

Runoff in Equation (2) is the same as Supply in Equation (1). Demand can be estimated on a month-by-month basis, or averaged for simpler calculations. Calculations are performed iteratively with various tank sizes until V_t is greater than zero (or until demand is met every month) at the end of every month. Table A2 provides example calculations.

Table A2 *Runoff calculation example*

	V_t (m^3)	V_{t-1} (m^3)	Rainfall (m)	Runoff (m^3)	Demand (m^3)
January	0	0	0	0	0
February	0	0	0	0	0
March	17.5	0	0.25	40	22.5
April	35	17.5	0.25	40	22.5
May	60.5	35	0.3	48	22.5
June	78	60.5	0.25	40	22.5
July	79.5	78	0.15	24	22.5
August	73	79.5	0.1	16	22.5
September	58.5	73	0.05	8	22.5
October	58.5	58.5	0	0	0
November	58.5	58.5	0	0	0
December	58.5	58.5	0	0	0

Runoff is calculated for a 200m² roof area, with a given rainfall pattern as shown. Demand is assumed constant for seven months out of the year. (It is also assumed another source is in use for the other five months so that the harvested rainwater is not needed.) V_{t-1} *is mirrored from the previous month's* V_t. V_t *is calculated using Equation (2). The largest* V_t *represents the required tank size. This tank size allows all the water to be captured but is larger than necessary. Optimal tank size depends on objective.*

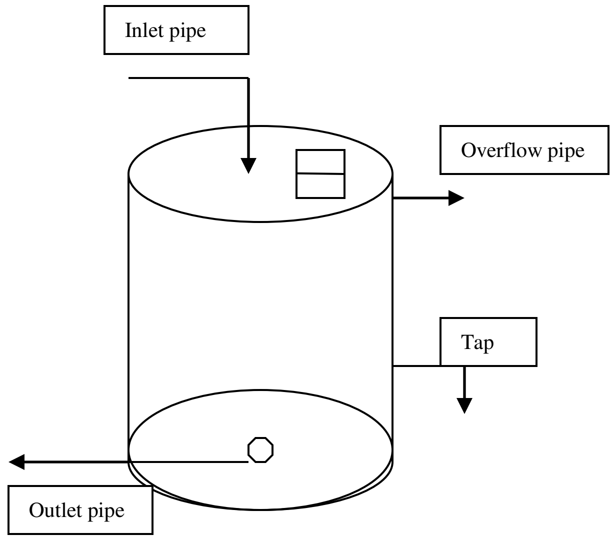

Figure A2 *Tank inlets and outlets*

Design

A tank should be well enclosed, except for the inlets and outlets (Figure A2) and a manhole for cleaning. The inlet to the tank, normally at the top of the tank, is directly connected to the downspout (or roof washer if applicable). It should be detachable for bypassing and maintenance. Avoid upward bends in it to prevent pooling areas. (This goes for gutters and downspouts as well.) When designing the inlet to the tank, consideration should be given to using other sources to fill the tank. In some cases, more than one inlet may be desired or the overflow may serve as an inlet. The overflow pipe is recommended (for aeration) even if the tank never fills to overflow. It can also act as a link to another tank.

The tap or water valve is normally some distance up from the base of the tank. This creates a mass of "dead water" below the point of the tap. This space can also be used for sediment, flushed out through the outlet pipe.

An outlet pipe facilitates cleaning, especially of sediments that may deposit at the bottom of the tank. Some tanks have a sloped bottom to allow an extra pocket for sediments, while others may have baffles creating a separate sediment chamber. The baffles can also act to dissipate pressure from incoming waters, minimizing disturbance of sediments.

Additional features can include a spillway to prevent pooling near the tank, a device to indicate the amount of water in tank, a safety (lock) on the tap, and a second tank (also facilitates cleaning) (United Nations Environmental Programme, 1997).

OTHER CONSIDERATIONS

Harvested rainwater, though more reliable than some alternative sources, can become unsafe for potable uses. The three main sources of concern are 1) unsafe materials in the construction of the system, 2) debris that accumulates on the collection surface area and washes into the tank, and 3) access for insects and animals into the tank.

Materials

The type of material used throughout the system is critical to water quality. Making sure materials used are not dangerous to health can prevent health hazards. Many roof and tank coatings, paints, and sealants contain toxic substances that can contaminate the tank water (Cunliffe, 1998). Table A3 lists common roofing materials and associated health concerns. Lead should never be used in any part of the system, including the gutters, pipes, faucets, taps, valves and other fittings.

Roof Contaminants

Substances that can build up on a roof or in a gutter (especially during the dry period) and be washed into the tank include wind blown dust particles, tree litter, and insect, bird, lizard, or other small mammal excrements. Studies have found organic matter to be a primary source of bacteria in the tank (Cunliffe, 1998), and excrements contain a variety of disease-causing organisms, all of which can lead to health problems. Pooling areas on the roof or within the gutters can store sediment, biofilms, and stagnant water, which can act as bacteria and mosquito breeding grounds. Nearby coal or wood-burning fireplaces and stoves may also contribute contaminants such as ash particles which contain heavy metals, organic particles and other substances that may be hazardous to health (Taraba, et al., 1990).

The use of a filter can improve water quality by filtering out dirt, debris, and microbes that bypass the screens and the first flush system. A filter is a container or chamber (or bucket) filled with filter media such as coarse sand, charcoal, coconut fiber, pebbles, gravel or layers of cloth. The unit bottom should be perforated, to allow for the passage of water. A very simple and inexpensive method is to use a small fabric sack over the feed pipe where water enters the storage tank (Global Development Research Center, 2002).

Other preventive measures for protecting the quality of the water and the health of the users include periodically trimming overhanging tree branches away from roof top and removing dirt, leaves, and debris from roof tops and gutters.

Table A3.*Health Hazards associated with various roofing materials (Cunliffe, 1998).*

MATERIAL		HAZARDS
Organic	Straw, Grass, Palm Leaves, Bamboo, Mud, Clay, Slate, Thatch	• Attracts rodents and insects • Yields contamination • Adds color to water
Wood	Shingles	• Not for potable uses if chemically treated
Concrete Masonry	Cement, Concrete, Tiles	• colored tiles will oxidize and color to the water • may require non-toxic coating/liner
Other	Asphalt, Asbestos	• Asphalt contributes grit • Asphalt requires pre-filtering of water
	Fibro-cement Fiberglass Shingles Plastic Liner / Sheet Cloth	• Asbestos fibers are dangerous to health, especially when inhaled during handling/construction • Not a known risk in drinking water • Not recommended for use
		• Plastic liner may degrade in high temperatures
Paints and Coatings	Lead-based Paint (or paints with lead or zinc) Acrylic Paint Bitumen-based materials (tar)	• Lead is toxic to health • Triggered by acidity • Will leach dissolved chemicals including detergents in first few run-offs. • May add unpleasant taste to water • Not for potable uses
Metals:	Iron, Tin, Lead –Based metals Galvanized Steel	• Galvanized roofing is a source of zinc • Iron may rust and leach into tank, but is not considered a significant health hazard.

Access

A tank that is poorly designed, or one that does not incorporate safety features, is an open invitation to disease vectors such as mosquitoes, roaches and other water-loving critters. A water tank can easily become a breeding ground for mosquitoes. Mosquitoes are responsible for many illnesses including malaria, dengue fever, encephalitis, and yellow fever. Their eggs can pass through some filters when considering that filters have to be large enough to allow sufficient water through without excessive headloss. Mosquitoes must be kept out of the tank. A fine screen, filter, or a piece of cloth securely fastened over the mouth of the inlets and outlets can keep mosquitoes that develop inside from going out. Frequent inspections, crack repairs, and annual cleaning are important components of a maintenance program.

Other factors that can affect water quality are sunlight and floods. Sunlight should not be permitted to enter the tank as this will cause algae to grow, which in turn can hide and feed other micro organisms in the tank. Flood levels higher than the entrance of RWH tank can contaminate the stored water (Development Technology Unit, 1987). This is especially a concern when below ground storages are used to store the water.

Rain is naturally slightly acidic (pH 5.6), and can be more so if the system is located in a highly industrialized area. The acidity may react with metals in the system and cause leaching. Aluminum, for example, is inert unless in contact with acidic water. High calcium levels observed in ferro-cement tanks may offset acidity (Gould and Nissen-Peterson, 1999).

Health risks are minimized when proper precautions are taken. A good system design should incorporate preventive measures against contamination. If the water's intended use is for irrigation or other non-potable uses, there is little or no need for preventive measures. Otherwise, steps should be taken to protect the health of those who drink it.

Monitoring and Treatment

Standard household treatments such as boiling, solar disinfection or chlorination are effective for treating stored water (Development Technology Unit, 1987). One method of ensuring high water quality is the fill the tank and then seal it for about a month. (Development Technology Unit, 1987).

Systematic monitoring and treatment is seldom possible in developing countries (Gould and Nissen-Peterson 1999), where the quantity of water available is often given higher value than quality (Shaw, 1999). Care should be taken to avoid epidemics (Shaw, 1999). Quality can be measured based on its effect on the health of the community. It is to be noted, however, that there are very few examples of poor water quality in RWH schemes (Global Development Research Center, 2002). Bird feces has not proven to be a cause of contamination. (Global Development Research Center, 2002). Microbiological contamination for harvested rainwater (measured by levels of E.Coli.) falls in the WHO water quality standards "'low risk" category (Development Technology Unit, 1987). Tests have yielded values of under *5* fecal coliform per 100mL (Development Technology Unit, 1987).

APPENDIX B : ROOFTOP RAINWATER HARVESTING EXAMPLE CALCULATIONS

The following guidelines for potable water supply are offered by N'Djim and Nissen-Peterson, 1998:

- 20 liters per person per day in rural areas,
- 41 liters per person per day in semi-urban areas, and
- 50 liters per person per day in urban areas.

Using the minimum of 20 liters (0.02 m^3) per person per day, for a village of 150 inhabitants, demand can be estimated in Table B1 as follows:

Table B1. *Demand estimate.*

Number of users	Amount used (m^3/day)	Number of days	Total Water Use (m^3)
150	0.02	30	(150*0.02*30) = 90

	Vt (m^3)	Vt-1 (m^3)	Rainfall (m)	Runoff (m^3)	Demand (m^3)
Wet Season					
June	85.34	0.00	0.1171	85.34	0
July	236.71	85.34	0.2077	151.37	0
August	410.53	236.71	0.2385	173.82	0
September	533.26	410.53	0.1684	122.73	0
October	573.78	533.26	0.0556	40.52	0
Dry Season					
November	484.08	573.78	0.0004	0.29	90
December	394.08	484.08	0.0000	0.00	90
January	304.15	394.08	0.0001	0.07	90
February	214.15	304.15	0.0000	0.00	90
March	126.99	214.15	0.0039	2.84	90
April	48.29	126.99	0.0155	11.30	90
May	0.63	48.29	0.0581	42.34	90

The next challenge is to determine how much roof area will be necessary to meet this demand. In Table B1, we assume demand exists only for the dry months. Equation 1 is used to calculate supply (runoff). Rainfall values from Figure A2 are used along with a coefficient of 0.8, corresponding to a corrugated metal roof. To determine the roof area required to meet demand, a random value has to be substituted such that V_t is not negative. From Equation (2), $V_t = V_{t-1} + (Supply - Demand)$. A negative V_t means supply does not meet demand. To correct this, roof area or efficiency must be increased. Rainfall, unfortunately, can not be engineered. A roof area of 911 square meters was found to exactly meet this requirement, as shown in Table B1, allowing some water to be left in the tank at the end of the dry season. The minimum tank size therefore should be the maximum V_t, and this does not include a safety factor.

An alternative is to have more than one RWH system in the village. This would reduce the demand on any one tank. For example, for a third of the demand, storage volume required would be about 200 cubic meters, requiring a minimum roof area of about 305 square meters, as shown in Table B1.

These estimates are, of course, purely theoretical. In the field, there are many factors, previously mentioned, which can affect the actual demand and supply and the optimal sizing of the tank, such as cost. It is important to remember that the design of a rainwater harvesting system can be flexible. The main components include safe materials, an efficient conveyance system, and a protected storage compartment. Water quality is maintained by regular inspection and cleaning of the system, and by securing all access points against mosquitoes and other disease vectors.

APPENDIX C : PHOTO GALLERY

Figure C1. *View of the Niger River in February*

Figure C2. *Niger River Continued*

Figure C3. *Niger River Continued*

Figure C4. *Author near a tributary/canal of the Niger River*

Figure C5. *Example of a man-made rainwater harvesting catchment*

Figure C6. *Example of rwh catchment*

Figure C7. *Natural depression*

Figure C8. *Example of water flora*

Figure C9. *Example of what the dry earth looks like in Mali*

APPENDIX D : THE MCCONVILLE MATRIX

Table 3: Sustainability Assessment Matrix. The matrix dimensions show five life stages and five factors of sustainability.

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

Figure D1. *Applying Life Cycle Thinking to International Water and Sanitation Development Projects 2006, (Reprinted with permission from the author).*