On-farm water harvesting for rainfed agriculture development and food security in Tigray, Northern Ethiopia

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On-farm water harvesting for rainfed agriculture development and food security in Tigray, Northern Ethiopia:

Investigation of technical and socioeconomic issues

By Girmay Tesfay

July 2011

The Drylands Coordination Group (DCG) is an NGO-driven forum for exchange of practical experiences and knowledge on food security and natural resource management in the drylands of Africa. DCG facilitates this exchange of experiences between NGOs and research and policy-making institutions. The DCG activities, which are carried out by DCG members in Ethiopia, Eritrea, Mali and Sudan, aim to contribute to improved food security of vulnerable households and sustainable natural resource management in the drylands of Africa.

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ACRONYMS

BOPED	Bureau of Planning and Economic Development
BoWRD	Bureau of Water Resources Development
Co-SAERT	Commission for Sustainable Agriculture and Environmental Rehabilitation in Tigray
DCG	Drylands Coordination Group
GDP	Gross Domestic Product
GEO	Government of Ethiopia
MU	Mekelle University
NGO	Non-Governmental Organization
PREM	Poverty Reduction and Environmental Management
REST	Relief Society of Tigray
SSA	Sub-Saharan Africa

ABSTRACT

Rainfall in the semi-arid Ethiopian Highlands is characterized by erratic nature and dryspells during crop growing season is a critical problem in the rainfed production systems. Rainfed farming therefore needs to be supported by appropriate water harvesting technologies to mitigate the moisture stress during critical crop growth stage during the main season and to increase opportunities for irrigated horticultural production. With this aim, a wider scale of water harvesting technology dissemination program was carried out in these areas of Ethiopia since 2002/03. In Tigray region, on-farm level household ponds, larger communal ponds, and a series of ponds were the three types of water harvesting technologies promoted by the program since it initiation to store and utilize rain water/runoff. This research was conducted with the aim of evaluating the implementation of the program and its impacts thus far, and to identify the major technical and socio-economic constraints to the wider utilization of the on-farm level household ponds.

The on-farm household ponds were found not well adapted to the socio-economic environment and the utilization level of the ponds for the planned objectives was limited in the region. The implementation process was found deficient in popularizing the pond technologies among farmers and many technical problems were found to limit the wider utilization of the household ponds. The experience of farmers in irrigated farming, particularly with such small-scale water harvesting structures, is limited and farmers have attitude problems in accepting the technologies. Although, some model farmers were able to utilize the ponds in a beneficial way, the economic benefits for the large majority of the farmers were limited. However, detailed analysis of the case of model farmers show that acceptable economic returns are possible from pond technologies given that farmers are able to follow appropriate cropping patterns and irrigation techniques to improve water use efficiency.

It is recommended that the technologies should be disseminated in the region with a limited dependence of external support and in a more farmer participatory approach. The technology options should also be widened and these require more research for the generation of alternative technologies.

1. INTRODUCTION

1.1. BACKGROUND

Ensuring food security in areas with a high-population pressure and fragile resource conditions such as the semi-arid highlands of Ethiopia represents a great deal of challenge. One of the challenges is to alleviate the most limiting factors to crop production: moisture stress and soil fertility problems. The national policy on development and food-security and the research and extension support should therefore give due attention to these problems.

Increasing agricultural productivity in Ethiopia is a means both to improve the livelihoods of rural people and the sustainability of the economy. Rainfed farming in the country is the dominant agricultural production system and irrigation development is at a very low level. Rainfall in Ethiopia has erratic nature and the consequent moisture stress is a major limitation to raising agricultural production. There is also clear evidence that rainfall has been below average in Ethiopia since mid-1970s (Warren and Khogali, 1992). Variability of rainfall distribution in Ethiopia often results in dryspells during the growing season and ultimately leads to a wider gap in food supply. Declining length of the rainfall period and unpredictable occurrence of dryspells and droughts from year to year and within a growing season are therefore major limitations to the rainfed farming.

Lack of efficient water resources development and conservation systems suitable for small scale farmers is one of the major problems limiting the capacity of agriculture to meet its role in food security and overall development in the country. To face the challenges of increasing food production in the rainfed systems, improvement of the rainwater use efficiency is therefore inevitable. Water harvesting practices, although very ancient, seem a new opportunity in water resource development in the drylands of Ethiopia. The role of water harvesting is widely recognized these days as a means to increasing agricultural production, redressing environmental problems and alleviating poverty. Water harvesting is believed to increase sustainability of the vulnerable rainfed systems in Ethiopia. Thus, there is a need for research on the identification of traditional water harvesting systems and development of enhanced water harvesting and conservation systems for a sustainable solution to the problem of moisture stress in crop production.

Efficient utilization of surface water, in particular the seasonal rainfall and runoff, has to be at the heart of development efforts of the country. In line with this thinking, water harvesting has recently gained highest policy consideration. It is one of the main components of the food security strategy of the country and that of the Tigray region. It is becoming a subject of research and policy debate these days. Furthermore, the government has launched programs in many regions of the country to introduce new water harvesting technologies in the traditional farming systems both at household and communal levels.

Generally, rainwater and flood harvesting has the potential to increase the productivity of cropland by increasing the yields and by reducing the risk of crop failure. Nevertheless, rainwater management goes beyond construction of collecting structures. It includes careful use of the collected water and consideration of non-technical issues that influence the water management. The challenges in rainwater management are therefore related to both storage and efficient utilization of the collected water. Proper rainwater management requires development of appropriate rainwater storage and utilization technologies, policy reforms, infrastructural interventions and re-organization of the social structure of farming communities.

The research project, *'On-farm water harvesting for rainfed agricultural development and food security in Tigray: Investigation of technical and Socio-economic issues,'* was launched with the aim of conducting a technical and socio-economic assessment of the newly introduced water harvesting programs and technologies in the context of the Tigray region. Different research activities have been carried out to identify factors determining the performance of water harvesting ponds in the region. It also aimed to study the irrigation systems applied by farmers, address the problems of the technology, and assess the economics of on-farm rainwater harvesting practices. It aimed also to identify the socioeconomic and institutional constraints to sustainable use of rainwater harvesting systems in the region.

The project has been conducting technical monitoring and socioeconomic surveys from 2003 to 2005, and experimental works in 2004 and 2005 in different sites in the region. The technical monitoring work was conducted during a rain season with the focus on assessment of water storage potential and the physical conditions of household ponds. The socioeconomic surveys were conducted to assess the impact of pond technology on household economy, farmers' perceptions of the program, and identify the socioeconomic and institutional constraints to the utilization of ponds. The experimental works were conducted to identify efficient irrigation and agronomic practices and cropping patterns that can be applied by farmers to optimize the use of pond water.

1.2. THE SETTING

Ethiopia is one of the three most populous countries in sub-Saharan Africa with a population well over 70 million people. Most part of Ethiopia (63.5%) is dryland, and it is a home for large proportion of human and livestock populations. In the country, rainfed agriculture is the main source of subsistence and income for over 85% of the population. However, besides other complementing factors, the erratic nature of the rainfall is a major limitation to agricultural production and, as a consequence, a large mass of the population lives under absolute poverty (Hagos, 2003; Solomon, 2005).

Tigray is the northernmost region of Ethiopia bounded by Eritrea to the North, the Sudan to the West, and the Ethiopian regions of Amhara and Afar to the South and the East respectively. Figure 1 shows the location of Tigray region. The population of Tigray is over 4 million, with an average family size of five persons per household (Solomon, 2005). There is an estimated 825,678 rural households, of which 70% are male-headed and 30% female-headed (*ibid*, 2005).

In Tigray, agriculture contributes around 57% to the regional GDP, of which 36% is from crop production and about 17% and 4% is from livestock and forestry respectively (BOPED, 2004). The major production system in Tigray is a mixed crop-livestock system. The crop production is dominantly rainfed associated with small-scale livestock husbandry. The average land holding in the highlands of the region is less than a hectare (Pender *et al.*, 2002b; Pender and Gebremedhin, 2004). Major crops are sorghum, *Teff*, barley, finger millet, wheat, maize and pulses (BOPED, 2004).

Tigray is one of the regions of Ethiopia which are highly vulnerable to recurrent drought and famine. The main rain season is during the months of June to September and in some areas of the region a short rain season occurs between January and March. Rainfall distribution in the region is characterized by high temporal and spatial variability, with annual precipitation ranging from 450 to 980 mm (Gebremedhin *et al.*, 2004). According to Belay (1996) the coefficient of variation in annual rainfall in Tigray is about 28%, which is much higher than the 8% national average in Ethiopia (cited in Hagos *et al.*, 1999). Araya *et al.* (2005) show even higher degree of rainfall variability in the region which ranges between 40 and 50%. Such high inter-annual and inter-season rainfall variation is a critical problem leading to water and food shortage (Cowater International Inc., 2003). Moisture deficiency is the most critical problem identified in the study of production systems in the region (Araya *et al.*, 2005). The Tigray Bureau of Agriculture (BoA) and Relief Society of Tigray (REST) (2002) have summarized the intensity of the problem of moisture stress in the region for four selected districts (See Table 1A).

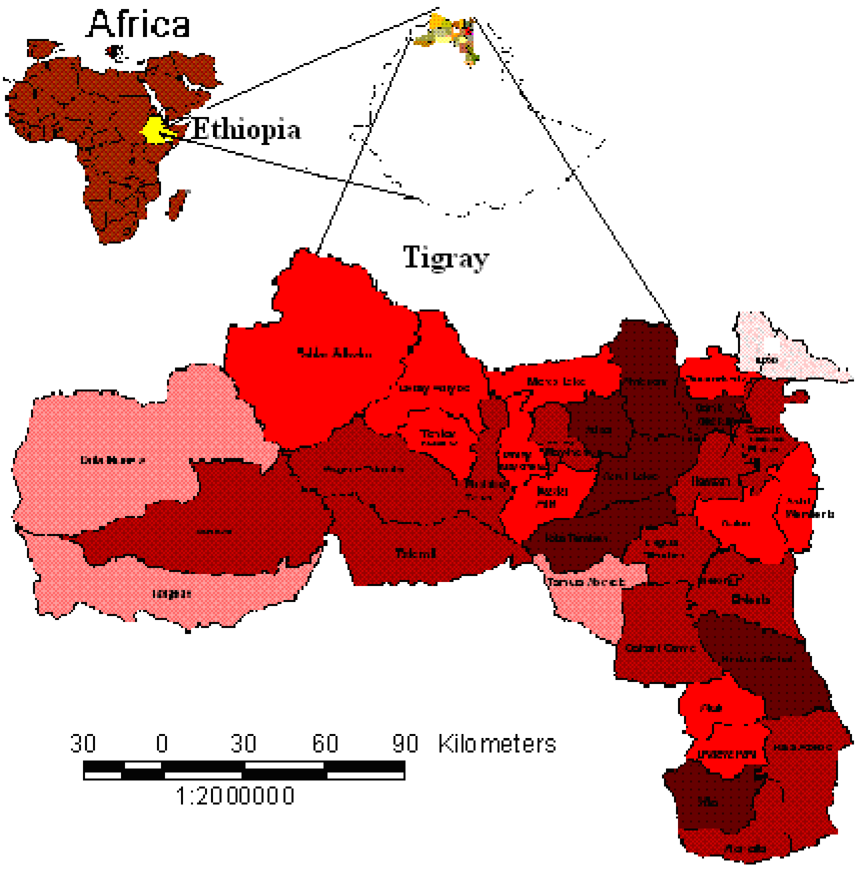

Figure 1. Location map of Tigray region, Ethiopia (Not for official use)

The regional food supply is below the food demand and it is dependent on external food aid. In the Tigray region, poverty is extremely high (Hagos, 2003) and recent reports show nearly 75% of the population is living below the absolute poverty line (BOPED, 2004). According to BOPED (2004), the average household level production in the region (which is 6.59 quintal) covers about 38% of the annual food demand of the average household. Only about 17% of households are self-sufficient (Hagos *et al.*, 1999). Improving their living conditions therefore requires development of the agricultural sector with inputs of technological and institutional innovations.

In addition to farming, rural households in Tigary are dependent on seasonal off-farm employment which is mainly during the dry season. Introduction of irrigation using water harvesting technologies therefore will have a direct impact on the labor allocation pattern of households.

1.3. THE NEED FOR RAINWATER HARVESTING IN TIGRAY

Large proportions of the world's poorest and malnourished people live in the rainfed areas of the tropics (World Bank, 1997). In sub-Saharan Africa over 60% of the population depends on rainfed subsistence economies accounting for 30-40 percent of the Gross Domestic Product of a country. Out of the total agricultural land in SSA 95% is under rainfed systems and irrigated land accounts only for 5% of the total. The success of agriculture in dryland areas depends largely on the availability and efficient use of water.

In most part of Tigray the total amount of annual rainfall ranges between 400 mm and 1000 mm. The distribution is uneven both temporally and spatially during the crop growth period. Critical moisture deficiency during the growing season is a major limitation to the realization of the maximum productivity of major cereals in the region. Thus, a way of minimizing the moisture stress during the production period is important in order for the region to achieve sufficient production. Water harvesting for supplementary irrigation has therefore become a new strategic approach to boost food security in drought prone areas of Ethiopia and Tigray in particular.

In this regard the government of Ethiopia, in particular the regional state of Tigray, has been working on reducing the effects of erratic and insufficient rainfall on the livelihoods of the farmers of the region through constructing water harvesting structures (GEO, 2002). In the region the Commission for Sustainable Agriculture and Environmental Rehabilitation in Tigray (Co-SAERT) was institutionalized to coordinate water resources development activities. The Commission's main aim was to build water-harvesting structures in the form of micro-dams to irrigate 50,000 hectares in the region. However, the plan faced many technical and socio-economic limitations and the achievements were limited. For instance, the potential of such practice was limited in terms of number of beneficiaries and technical possibilities. Therefore, there was a need for promoting innovative water harvesting and management technologies at farm level to properly utilize the scarce rainwater. Accordingly, in recent years a new initiative has been launched to introduce low-cost labor intensive water harvesting ponds in many districts of the region for supplementary irrigation. The overall purpose of such initiative by the government is to assure farmers at least one good harvest annually.

The techniques recently focused in the region's water resource development interventions are of two types, namely floodwater harvesting (i.e. run-off water conveyed to nearby pond for latter use) and shallow ground water development (i.e. wells dug up to few meters deep to extract ground water). The regional plan for the year 2002/03 was to build about 30,000 ponds in the neediest areas and this target was nearly achieved as planned in terms of construction. Moreover, the intention is to further scale up the practice all over the region for some years until significant coverage is achieved. Three types of ponds with different capacity were promoted in the region; namely individual household pond, communal ponds and a series of communal balancing ponds connected along flood stream. The capacity and system definition of the ponds is given in Table 1B (see annex 1). The ponds introduced at individual household level are intended to have a capacity of 200 m^3. The household ponds are constructed in a trapezoidal shape.

The main implementers and actively involved institutions are the Tigray Bureau of Agriculture (BoA), Bureau of Water Resources and Development (BoWRD), Relief Society of Tigray (REST) and other NGOs. Figure 2 is an illustration of the household level ponds promoted in Tigray.

Figure 2. Structure of household level ponds

The ponds introduced at community level are of two types as mentioned earlier. The first one is a small earthen dam with a half-moon shape and it is for collective use by community members. The second type, a series of ponds structure, is built on seasonal streams where by three or more large size ponds are constructed along a stream to form a system to capture flood water at different spots in the stream area. The communal ponds are planed to store between 1000 and 10000 meter cube of water (See annex part Table 1B). Illustration of each type of pond is given in Figure 3. The specific objectives of these communal ponds are not well known. However, farmers are utilizing them for watering livestock and households who have plots nearby are expected to form water users association to utilize the ponds for irrigation purpose. Financial support is provided through credit for households forming a water users association to utilize the communal ponds. However, the use of such communal ponds for irrigation purpose is limited thus far. One benefit of these communal ponds is also ground water recharge. These ponds do not have plastic lining. The construction of these ponds is machinery supported.

Figure 3. Structure of communal ponds

1.4. OBJECTIVES OF THE STUDY

Recognizing the fact that rainwater harvesting and management includes careful use of the collected water and consideration of non-technical issues that influence the water management, Mekelle University took the initiative to undertake technical and socioeconomic evaluation of the water harvesting programs together with the implementing organizations, particularly the Relief Society of Tigray. The improvement of the performance of water harvesting ponds requires a good knowledge of the technical and socioeconomic constraints in the context of the farming systems and social settings of the region. Taking the local experience into consideration, the management practices of the pond systems have to be adapted to the social and economic context.

The broader objective of the project was therefore to assess the technical and socioeconomic constraints to the wider utilization of household level water harvesting ponds and the economic contribution of the pond technology to household food-security. In this line the specific objectives of the project were

1. To identify planning and implementation problems of the program in Tigray region
2. To identify technical problems with the pond technology and suggest remedial solutions;
3. To assess the socioeconomic feasibility of the pond technology in the context of the regional farming systems;
4. To identify irrigation methods and cropping patterns for increased water use efficiency;
5. To evaluate contribution of ponds to the household economy and food security; and
6. To draw lessons and recommendations for policy

1.5. ORGANIZATION OF THE REPORT

The rest of the report is organized as follows. Section 2 is a brief introduction to the implementation of water harvesting programs in Tigray. In section 3, the conceptual framework is explained. In section 4, the research methodology is briefly explained and section 5 presents the findings on the status of utilization of water harvesting technologies and the factors that influence the level of utilization. In section six, a discussion is given on ways of enhancing the role of water harvesting technologies. Finally, in section 7, major conclusions and recommendations are outlined.

2. IMPLEMENTATION OF WATER HARVESTING PROGRAMS IN TIGRAY

Traditionally and through program support, water harvesting practices have been part of the farming systems of the dryland farming in Tigray. Farmers are familiar with flood diversion practices and many small-scale earthen dams have been constructed in Tigray through program support and local resource contributions.

Since 2002/03 a new approach is followed to widely introduce household level water harvesting ponds in Ethiopia. The program is widely implemented in Tigray region and REST, BoA and BoWR have jointly designed three types of ponds to be implemented at different agro-ecology. At household level, the annual target in the region was to construct around 30, 000 ponds.

In each district the Administration and the Rural Development offices were responsible for planning and implementation of the program at *Tabia* level with cooperation of the *Tabia Baito* and trained foremen. The construction of the ponds is program assisted and a group of 20 farmer-laborers are usually contracted with a gross pay of 20 quintals of grain and some money (about 500 *Birr*) to prepare one household pond. The construction includes digging of a trapezoidal shape pond and a silt trap pit, installing the plastic lining, covering the lining with a stone riprap and properly stabilizing the surrounding of the pond by reinforcing with a soil and stone. Where a plastic lining is not used the group is responsible to make compact the surface of the pond and covering it with a stone riprap. The team also is responsible for construction of channels to convey run-off water from nearby catchment or flood stream and a silt trap. The owner of the pond is responsible for management by fencing and regularly clearing silt inside the flood channels, silt trap and the pond structure.

The grain and financial support for implementation of the program is contributed by the Relief Society of Tigray (REST), a local NGO. The team is organized by the *Tabia Baito* as the program is part of the food-for-work program in the Region which is planned to link food aid with development activities. The regional Bureau of Agriculture and Natural Resources pays the trained foremen.

The implementation of the program is at its early stage and more research is required to evaluate the feasibility and economic performance of the water harvesting technologies. A number of research activities have been conducted through the financial support of the DCG Ethiopia, in collaboration with Mekelle University, since 2003/04 in Tigray to address relevant topics in regarding the implementation of the program and its impacts thus far. A number of field studies were carried out by staff of the Mekelle University with financial support of the MU-DCG water harvesting project. Besides the socioeconomic studies, technical investigations were carried out to identify ways to enhance the efficiency of water use (Araya *et al.*, 2005; *Tigabu et al., 2006*) and agronomic constraints in the production of horticultural crops (Wubetu and Dereje, 2005).

The research activities aimed to evaluate whether the actual implementation of the proposed ponds was as per their design specification; determine the important design factors that affect the performance of the ponds considering differences in biophysical, technical and socioeconomic parameters. The impact of these factors will be evaluated taking sample ponds from representative households in different agro-ecologies.

3. CONCEPTUAL FRAMEWORK

3.1. HISTORY OF RAINWATER HARVESTING PRACTICES

Rainwater harvesting is almost 4000 years old (Myers, 1975; cited in Pandey, 1991). It was begun in the Bronze Age when desert dwellers smoothed hillsides to increase runoff and built ditches to collect water and convey it to lower laying fields. There are methods of harvesting surface runoff that have a potential for application on farms and domestic use in arid and semi-arid regions. In semi-arid areas open-air hardened surface is used to collect rainwater and unoccupied land is used to establish rainwater catchment. Such practice is very common in the semi-arid regions of China, India and other desert areas of the world (Yuan *et al.*, 2002; Grewal *et al.*, 1989; Pandey, 1991). Historical records show that water harvesting has been practiced in Ethiopia for agricultural purpose since 560 BC (PREM, 2007). In recent history, the practice is more common in the lowlands of Ethiopia mainly for human and livestock watering.

3.2. ASSESSMENT OF PERFORMANCE OF WATER HARVESTING PONDS

One of the crucial factors in rainwater management is designing and constructing of efficient water storage structures. Adequacy of storage capacity of the ponds in relation to the anticipated irrigation consumption is influenced by catchment characteristics (land use or vegetation cover, soil type and depth, geological condition) and climatic factors (rainfall characteristics such as intensity and distribution, temperature, etc.). Besides, the amount of water stored will also be influenced by amount of sediment coming to it. Technically, the volume of water harvested and the retained amount over reasonable duration sufficient enough to support one cycle crop growth is one indicator of the performance of a water harvesting pond. The storage capacity of the ponds and the physical determinants need to be identified in order to address design and site selection problems.

3.3. WATER USE EFFICIENCY AND IRRIGATION SCHEDULING

Another equally important aspect that needs to be investigated in the assessment of the performance of water harvesting is the water use efficiency and irrigation scheduling. Despite its scarce nature, significant wastage of irrigation water is observed because of inefficient utilization methods and poor scheduling which leads to reduced water use efficiency (WUE) and economic returns from irrigation (Mintesinote, 2002).

The relationships between crop yields and water use are complicated. Yield depends on when and how much water is applied. In other words, the effect of water stress on the yield of a given crop depends on the growth stage during which the stress is imposed. The various crop development stages posses different sensitivities to moisture stress (Doorenbos and Kassam, 1979). Basic information on optimal scheduling of limited amounts of water to maximize crop yields is therefore essential if irrigation water is to be used most efficiently (Al-Kaisi *et al.*, 1997; Mintesinote, 2002).

One of the focuses of this project was to determine rational irrigation scheduling for selected major crops in the region with limited availability of water collected in ponds to obtain optimum yields and maximize profits (Araya et al., 2005; Tigabu et al., 2006). It aims to examine the effects of number and timing of supplementary irrigation applications on yield and to determine crop yield to water relations. Water sensitivity indices are verified at various growth stages. Based on these results, therefore, optimum irrigation schedules for maximum net profit for selected major crops in the study areas will be established.

3.4. ECONOMICS OF WATER HARVESTING

Many factors influence the selection of water harvesting systems and economic factors are among the commonly cited. The economics of alternative water harvesting systems have to be studied considering agro-ecological conditions and production systems. Furthermore, socioeconomic and policy research is needed to identify the socioeconomic and policy factors that may inhibit or favor adoption of more water harvesting technologies at household and farm levels.

Different approaches have been applied to evaluate the economics of rainwater harvesting techniques and utilization practices. One of the approaches is a simple average productivity calculation per unit of water harvested (e.g. Stewart, Musick and Dusek, 1983). This is common in economic evaluation of micro-dams and other water storage methods. Linear regression functions relating the effective available quantity of harvested water to yield of a given crop and income from that is used as an alternative approach (e.g. Mahendrarajah and Warr, 1991). Bioeconomic simulation techniques are applied to related weather conditions and economics of water harvesting (e.g. Pandey, 1991; Scrimgeour and Frasier, 1991). Commonly, cost-benefit analysis is used to determine the economic profitability considering the nature of the technologies and utilization practices (e.g. Oron *et al.*, 1983; Grewal *et al.*, 1989). The maximization of the net present value, of all benefits and cost streams throughout the effective life of the structure, is a common criterion used to assess economic viability. Depending on the context of the problems and data availability, one or a combination of these techniques may be utilized to evaluate the economics of the current rainwater harvesting practices and alternative technologies in Tigray.

3.5. DETERMINANTS OF TECHNICAL AND ECONOMIC FEASIBILITY AND ADOPTION OF RAINWATER HARVESTING TECHNOLOGIES

In broader terms water harvesting is a practice of efficient water management which requires effective technology, policy and institutional inputs (Oweis *et al.*, 1999). Many water harvesting and supplemental irrigation systems have failed, despite good techniques and design, because the social, economic, and management factors were inadequately integrated into the development of the system (Bazza and Tayaa, 1994; cited in Oweis *et al.*, 1999). Environmental factors do also play a part in the success of water harvesting technologies for rainfed agriculture development.

The success of the policy objectives of the promotion of water harvesting technologies depend very much on the successful adoption and use of the technology. Experience from other African countries show that successful transfer and utilization of ponds was very much dependent on the labor endowment of the household and its composition (Kronen, 1994).

The level of risk that farmers associate with the technology is a well known factor that influences their decision on whether or not to adopt the technology. Their risk bearing capacity, which is related to their resource endowment, matters in adoption decision. Farmers who are relatively risk averse may decide to take the technology slowly or may completely reject it. Program support for the acquisition of industrial products and provision of training may be important incentives for adoption.

Engagement in other off-farm activities may also lesson the use of ponds unless there is sufficient labor at household level to meet both farm and off-farm demand for labor. Off-farm involvement may have both positive and negative impacts in terms of the finalization of the construction of ponds and starting utilization. The positive impact may be associated with better capacity to use technologies for lifting water such as tridle-pump and better marketing of vegetables. The negative implication of off-farm involvement may be in relation to its impact on male labor availability for management of the pond structure such as fencing and clearing silt. Access to alternative irrigation sources may also enhance or limit the use of household ponds.

Other factors also determine the economic feasibility and widespread adoption of rainwater harvesting technologies and practices. Economic feasibility of water harvesting and supplementary irrigation systems is influenced by the probability of successful dry season second crop without irrigation and the seepage rate (Pandey, 1991). Other factors may be the type of construction materials used, the location of the storage structure, the form of water collection methods (roof or catchment), and the efficiency of water use. The usefulness of the harvested rainwater is enhanced when water saving and seepage preventive techniques are employed (Yuan *et al.,* 2002). In order to maximize the economic return from rainwater harvesting it is essential to select crops with a water requirement process that coincides with local rainfall events (*ibid*.) The level of cooperation among farmers in an area where there is a need for sharing of structure because of small land holding size is also an important factor in this regard. These and other factors, depending on the context of the area, influence the short-term profitability and long-term sustainability of rainwater harvesting technologies.

In general, the design of a water harvesting technology needs to consider both technical, such as rainfall, climate, soil and topographic conditions, and socioeconomic factors such as resource availability, household objectives and markets conditions. As studies in East Africa show, water harvesting technologies are successful when the rainfall is above average, i.e., rainfall above long-term mean with even distribution within a season (Hatibu *et al.*, 2005). The study therefore aims to identify the major factors playing a role in the technical and economic feasibility of ponds in Tigray.

4. RESEARCH METHODOLOGY

The study started in 2003 employing a variety of methods depending on the nature of the issues addressed. It was conducted in 9 districts taking one *Tabia* (sub-district) from each district. The districts and the *Tabias* were purposively selected in consultation with the stakeholders, primarily the Relief Society of Tigray (REST) and the respective district administration offices. The selection of study sites was done considering agro-ecological diversity, availability of alternative water harvesting systems, and logistics. From the selected *Tabias*, 7 to 10 households owning pond were randomly selected. In Atsibi-Wonberta district 15 households were included because the number of household ponds constructed in the district was proportionally higher compared to the other districts in 2002/2003. A total of 84 households were included in the sample. In each *Tabia*, two senior students of Mekelle University were assigned for three months, July to September, to do the data collection. The team of students is one each from Dryland Crop Sciences department and Land Resources Management and Environmental Protection department. This was as part of their Practical Attachment Program, which the University has been offering for students completing their third year study.

The data collection was done using structured questionnaire and recording formats for the field measurements. In the technical monitoring of water harvesting technologies, besides household ponds, at least one communal and one series of ponds from each *Tabia* were included depending on availability. The survey was repeated in 2004 using the same sample of households although some 8 households were omitted in the final analysis because they dropout in the second round. Detailed information on the location and number of households included in the survey is given in Table 1. In 2005, a separate survey was done to assess the status of utilization and economic impact of the household ponds including 73 out of the 84 sample households. The rest ten households were dropped for various reasons.

Table 1. Location and number of sample households in 2003 and 2004 surveys

Zone	Name of District	Name Tabia	Number of Household ponds
Southern	Hintalo Wajirat	Mai Nebri	7
	Raya Azebo	Tsiga'a/Genetia	10
Central	Dogua Tembien	Adi-Azmera	8
	Kolla Tembien	Begashika	7
	Were' Leke	Mai Kelawi	10
	Ahferom	Dibdibo/Endamariam	7
Eastern	Wukro	Genfel	10
	Hawzen	Selam	10
	Atsibi-Wonberta	Endamariam	15
Total			84

Source: Girmay *et al.* (2004)

The data collected in the two rounds of surveys relate to the household characteristics including family size and labor endowment, consumption habit, access to infrastructure and social services such as roads, markets, credit and extension institutions, experience on irrigation use, land endowment and potentially irrigable size using the pond, livestock ownership, and household's experience on rainfed and irrigated farming. The nature of the farming systems was also studied in terms of the diversity of crop and livestock production activities. Opinion of pond owners on the implementation process and their expectations and doubts on the future use and problems of the ponds were included. Besides, data on the physical features of the household pond in terms of size, construction inputs requirement and lining type, the location of the pond and the catchment, and the volume of water at regular interval was collected during the study months. Measurement of land taken for the construction of the household pond and potential area irrigable was done as well.

Similarly, for communal and series of ponds, data collected relate to village level features on water resources availability, land lost for construction of ponds, land use-land cover type of the catchment of pond, potentially irrigable land size, comparison of inconsistency in design and implementation of ponds, construction inputs and lining material type, water utilization systems and water level fluctuation and sedimentation records.

In 2005, an attempt was made to collect detailed information on the actual use of the ponds by households and the economic impact at household level. Respondents were asked questions on the total inputs and costs of pond construction, when they started to use the pond if used, their opinion on the size of the pond, area irrigated in the form supplementary and permanent garden by season and total production and utilization. Other opinion questions were related to why households have not used the ponds if not used; their opinion about the associated problems they encountered; their opinion about household pond technologies and how they are perceived in their respective community; their opinion on whether they want to construct additional ponds for themselves or other households in their village; and their opinion on impact on the work burden of women with the introduction of ponds.

One of the major limitations in dealing with a comprehensive economic impact analysis of the household ponds is the problem of getting reliable data. The effort made to get sufficient detailed production and input data from those households who have started utilizing ponds was not successful due to problem of record keeping. The recollected data are also incomplete because farmers were not able to give reliable estimate of size of land they irrigated in the form of supplementary irrigation, the labor input used for crop management, the level output from each crop type, and the volume of output sold and consumed at household level.

Focused studies were also conducted to assess the economic potential of household ponds by selecting model farmers. In 2004, three model households were selected, one each from three zones of Tigray, namely Southern, Eastern and Central Zones (Table 2). The model households were selected in consultation with the district and *Tabia* administrators (Tesfay *et al.*, 2004). Similarly, sixteen model farmers were selected from Atsibi-Wonberta, Wukiro, and Mehonni and Yechila districts in 2005 to assess the economic potential of ponds considering alternative cropping patterns and the water use efficiency of the alternative cropping patterns (Araya *et al.*, 2005). The sites were purposively selected to represent the *Dega* (high altitude), *Weinageda* (middle altitude) and *Kolla* (low land) agroecologies. To identify the cropping pattern which has relatively better water use efficiency, Araya *et* al., (2005) have utilized relevant climatic, soil, and crop data from primary and secondary sources for the region and the study sites. Additional information regarding crop-water relations were taken from relevant literature sources (See Araya *et al.* (2005) for details). In the case of deficit irrigation experimentation, Tigabu *et al.* (2006) applied comparative analysis of the impact of different moisture stress conditions introduced at different growth stages of the indicator potato crop to measure the impact on yield. Their experiment was conducted under controlled irrigation system considering farmers irrigation practice one treatment and they followed a randomized complete block design (See Tigabu *et al.* (2006) for details).

Table 2. Name and location of model households studied in 2004

Name of model farmer	Zone	Name of District	Name Tabia	Village *(Kushet)*
Haile Fekade	Central	Ahferom	Endamariam	Mai Wezo
Dargie Teka	Southern	Raya Azebo	Genetia	Waekel
Asefa Gebru	Eastern	Atsibi-Wonberta	Hayelom	Men-Negede

Source: Tesfay *et al.* (2004)

5. FINDINGS

5.1. THE STATUS OF WATER HARVESTING PROGRAMS IN TIGRAY

To assess the implementation speed and organization of the program, the time of completion of construction of ponds is used as an indicator. Based on our survey results, out of the 73 household ponds included, for which their construction started in 2002/03, 95% of them were completed in the same year and the rest 5% were finalized in 2003/04. In 2005, 78% of households have started to use their ponds out of which 55% were since the production season immediately after the construction year (2002/03). For 20% of the household ponds utilization started in 2003/04 and for another 3% in 2004/05. Out of the total ponds put to use among sample households, 34% were used for supplementary irrigation of main season cereal crops. Supplementary irrigation is practiced mainly on crops growing around their homestead plots. Out of the total number of sample ponds only 16% have been developed into permanent gardens of vegetables and fruit trees. Most of the ponds utilized thus far are located around homestead area.

Another utilization status indicator is the level of development of the pond irrigation system. Where the pond is put in use, farmers have been planting a number of horticultural crops and fruit trees integrated with vegetables and/or as a fence. Commonly grown vegetables are green pepper, onion, tomato, lettuce, potato, garlic, cabbage, and Swiss chard in descending order of their extent. To a limited extent, farmers produce various spices integrated with vegetables. The common fruit trees are Guava, Mango, Orange, Papaya, Citron, and Lemon. Papaya, orange and guava are the dominant ones but in general farmers plant few fruit trees on their field plots. In some areas, ponds were recharged during short rain season and the incidence of floods. Other commercially important perennials planted by farmers are Gesho (Hoops) and *Chatt*. Many farmers have planted Eucalyptus trees as a woodlot or as a fence although it is not allowed for reasons of competition for water around irrigated systems.

Except in those developed into a permanent garden, the level of use for the others is irregular and economic impacts are difficult to quantify. For instance, in terms of area irrigated using supplementary systems the magnitude is small. In 2003 the average area irrigated, computed based on response of 12 households, is 217 meter squares with an average frequency of watering of 6 times. In 2004, for 24 households, the average area was 375 meter squares with an average frequency of watering of 13 times. However, the average area, of 25 households, declined to 215 meter squares in 2005 with an average frequency of watering of 10 times. The frequency of watering is computed based on the number of times that farmers applied water to their fields during a production season of 3 to 4 months when they feel that soil moisture is low. Given the small size of land irrigated, it would be important for the extension system to promote high value crops to benefit better returns from the limited water potential and irrigated area.

In terms of permanent garden development, for the 12 households, the average area, in meter squares, was 40 in 2003, 702 in 2004, and 710 in 2005 production years. The size of plots has shown remarkable increase in 2004 and 2005. In this system, plantation of vegetables or sowing of cereals starts in June/July during the main season and extends until March/April as far as water is available. Average economic benefits (in birr per production year), reported by 12 households with a permanent garden were 60 birr in 2003, 1580 birr in 2004 and 398 birr in 2005. The range is variable, between 60 Birr in 2003 and over 8000 Birr, the highest being for a household in southern zone who was cultivating 0.25 hectare using a pond which was modified by the household in terms of size and with a cement lining (cost of cement used 2000 Birr). Although qualitatively, some 42 pond owners acknowledge the positive contributions of ponds in improving availability of vegetables for own consumption and as a source of cash for women and the household in general.

(a) (b)

Figure 4. Examples of household ponds developed as vegetable gardens
(a) Owned by a model farmer by the name Dargie Teka in Raya Azebo district Genetia *Tabia* and *kushet Waekel*; and (b) a second example of household pond

However, the economic impacts of utilization of the household and the communal ponds in the study sites were not promising at present. It is important therefore to understand the reasons for a low level of utilization of household ponds in the region and draw lessons for improved program design and policy support. A number of factors were identified as possible reasons for the poor performance of the water harvesting program in Tigray. In relation to the utilization of household ponds, the important factors are discussed in what follows categorized as household characteristics, and technical, economic, and institutional factors.

5.2. HOUSEHOLD CHARACTERISTICS

The human dimension need due consideration to understand the impact of the social context in the wide-scale adoption of water harvesting technologies. Household specific factors identified in this regard were related to resource endowment and, knowledge and experience in irrigation and horticultural crop production of household heads.

Farmer’s resource endowment was one of the specific household features that influence the utilization of ponds. In general, farmers with small rainfed holding were found to show better utilization of ponds. In the Alamata and Mohonni districts of the southern Tigray the utilization of ponds was better among households with relatively smaller rainfed farmland holding and better labor endowment. The similar pattern was visible in the eastern and the central zones of Tigray.

Households were able to utilize their excess labor by growing vegetables and planting fruit trees, which was otherwise wasted or under utilized during the dry season because of limited employment opportunities. For instance, study of model households show that between 30 and 60 person-days equivalent of labor was used for management of vegetables and marketing depending on the choice of vegetable mix and actual capacity of the pond (Tesfay *et al.*, 2004). Therefore, availability of labor during the dry season matters for utilization of ponds. Most of the households who started to utilize their ponds were having 2 to 4 adult labor. Availability of child labor (age 10-15) was associated positively with actual use of the ponds. The major labor demanding activity is lifting water from the pond and water crops. Because of labor shortage farmers prefer to flood the fields rather than applying it in a more regulated form around the root zone of the plant.

Another major factor found to influence the motivation and effort of farmers in utilizing the ponds was the experience of farm households in irrigated farming. Farmers with a good experience in irrigated farming have good understanding of the economic potential and the management practices needed for developing vegetable gardens. Some farmers have shown a good effort in refilling the ponds after they utilized the water for supplementary irrigation of main season crops during dryspells by pumping water from near by sources and diverting flood. A good mix of vegetables and rational use of the small-irrigated plot was clearly visible among households with irrigation experience. Farmers with less experience opt for planting vegetable that require low intensity of management such as green pepper or cereals such as maize and barley. In the study sites, farmers with experience in irrigated farming was found limited and for most of the pond owners it was a new practice (Wubetu and Dereje, 2005). Proximity to market was also linked with a better economic return as household close to the market were able to grow a wide range of vegetables while those located far from the market were limited to green pepper and some spices.

5.3. TECHNICAL ISSUES

A number of technical problems were identified in relation to the implementation of the program and the actual use of the water harvesting technologies. These problems were found to have effect on the storage capacity of the ponds and utilization of collected water which determines in general the success of the intervention. The major ones are discussed as follows.

Mismatch between design specification and constructed ponds

In actual practice the constructed ponds were variable in terms of size and shape, construction and lining materials used (stone wall, compact soil, and polythene sheet), and topographic and land use condition of the location and catchment area of the ponds. These physical differences, combined with the diversities in socioeconomic features of the households and the communities, will have implications to the design of more appropriate technology. Although, some of the deviations of the actual from the design specification could be a result of adjustment to fit to the physical and the social circumstances of the areas, others are related to problems in the implementation process that should be corrected in the future. For instance, delay in the supply of plastic lining and poor coordination of the contraction team was the reason for some of the problems in the actual implementation.

Small catchment area

Smallness of a catchment area is found as one of the technical problems in relation to site selection. Some ponds are constructed with a potential catchment area which is not sufficient to generate enough runoff to fill the maximum capacity of the pond. Some ponds are located on sites not suitable to harvest run-off and are only dependent on direct capturing of rain water (Araya *et al.*, 2005). A related problem is the construction of ponds on plots which do not have sufficient irrigable area. Therefore, pond site selection needs to consider a catchment area to cropped area ratio to determine location of ponds considering common cropping practices.

Distance of the pond from residence

Location of the pond relative to the residence is one of the factors found to explain the utilization of ponds (Tesfay *et al.*, 2004). When we see the distribution of sample household ponds by location, 67% are around homestead and 33% on field plots. Out of the 72 pond owners who gave valid response, 84% believe the location is suitable and 16% said the location is wrong. Farmers' criteria were distance from homestead, good catchments for collecting water, and availability of sufficient command area. Homestead location is preferred as far as the command and the catchment areas are sufficient. Another reason favoring homestead location is its closeness for management and guarding of vegetables. Smallness of the command and/or the catchment areas is cited by some whose ponds are located in their field plots which should be dealt during site selection. For the ponds located in suitable sites 70% were put to use and 30% are not utilized thus far.

It is clearly observable that most ponds located around the homestead and with good volume of water collected (which have favorable catchment area), are properly developed into a home/ kitchen/ garden with a good mix of vegetables and fruit trees growing. The finding on utilization ponds show that 65% of the ponds utilized are located around homestead area and 35% on field plots (Tesfay and Girmay, 2005). Ponds located on far crop fields are the least utilized. Ponds located far from homestead are found to be less likely used for vegetable and fruit growing. Ponds in far locations are utilized, like in the case of Atsbi area, for supplementary irrigation of main season crops during dryspells. These ponds were emptied using pumps and there was limited water left at the end of the rainy season.

Around Wukro, those with a limited amount of water were used for watering few fruit trees planted on the surrounding. However, the survival rate of fruit trees plant in far plots was extremely low (nearly zero) and it seems that such planting is only to show their attempt rather than a sustained effort. Proximity of the pond to the household residence was one of the factors that determine the level of management provided for vegetable crops and the daily supervision of the plots (Araya *et al.*, 2005). Farmers were more inclined to use the water for supplementing main season crops rather than developing a vegetable garden. The economic potential of the ponds located in far plots is not promising as it can be observed from the widespread underutilization and neglect by many farmers. In the study sites of Eastern and Southern Tigray, the location of the pond with respect to the residence seems to be the dominant factor that explains the level of utilization.

Agroecological conditions

The influence of agroecological conditions is twofold. In one respect, a lot of ponds do not collect sufficient water in areas where rainfall was very low towards the end of the main rain. As we have noticed from our research areas, many ponds do not contain sufficient water two to three months after September. This was visible around December in places such as Raya

Azebo, Mohonni, Adigudem, Atsbi-Wonberta, Wukro, Negash, and Adi Ahferom. The second agroecological problem, in the peak highlands such as Atsbi area in Eastern Tigray, is frost. Even if the ponds store sufficient water to irrigate one crop cycle, farmers usually wait until the frost problem is over around February/March which by then the available water is not sufficient to grow vegetables. Thus, delayed start on planting is one reason for the inefficient utilization of the pond water.

Mismatch between capacity of ponds and irrigable land size
Water stored in the pond is of limited volume and the irrigated area need to be adjusted in a proportional manner considering a cropping pattern. In actual practice, most farmers possess a large potentially irrigable land and the limited water is rather used to practice deficit irrigation. This is found to limit the performance of the pond technology and farmers need to follow recommended cropping patterns on an optimal irrigable land size (Araya *et al.*, 2005). However, Tigabu *et al.* (2006) show that water use efficiency from a pond system may be improved through planned deficit irrigation techniques. Careful planning of the timing of water application with the critical growth stages of the plant may increase the rational use of water and economic returns of the scarce pond water.

Water collection is done after the second or third flood so as to obtain cleaner water for two reasons. The first reason is that the pond water is used for additional domestic use. This is particularly true for ponds located nearby the homestead. The second reason is to minimize the silt problem which is perceived by farmers to be higher in the first few flood events. This implies the need for a technical solution in the design of the pond silt trap to reduce both problems and increase the chance of collecting water from the first few rainfall events.

High level of water seepage, even on ponds with a plastic lining, is significant limitation to the storage capacity of household ponds (Araya *et al.*, 2005) and this aggravates the problem of water shortage. Due to siltation problems, many farmers found the ponds to contain insufficient water which last only till December (Tesfay *et al.*, 2004). In such a situation farmers find it difficult to depend on pond water to plant vegetables and some look for alternative sources to refill the pond. In areas where additional water sources are available for refilling ponds during dry season, ponds are effectively used by farmers as a temporary storage and help establish permanent gardens. To adjust with water shortage, farmers start growing vegetables immediately after the first rain and use the land as a permanent garden.

On average, water loss due to seepage was estimated upto 13% and another 20% is lost due to evaporation (Araya *et al.*, 2005). Thus, in order to manage the loss of water, the design of the pond should be improved and damages to the plastic lining should be minimized during construction. To assess the effect of increased water availability on crop productivity, the relationship between water-stress and yield need to be established for indicator crops.

5.4. ECONOMIC ASSESSMENT

Study of model households from different sites of the region shows that when timely use of the pond technology is made, households are able to drive visible economic benefits (Tesfay *et al.*, 2004; Araya *et al.*, 2005). Although, the management levels applied to vegetables and other cash crops is limited, the economic return from household garden is reasonable. The model households are found self-sufficient for their consumption and are able to generate some cash from sale of vegetables. However, at regional scale, the level of utilization is low and the economic contribution of the on-farm water harvesting program is insignificant compared to the scale of public investment.

Similarly, the findings of a study of sixteen model household ponds in different agro-ecologies in Tigray show that the technology is economically feasible when efficient use of water is made by using appropriate cropping patterns (Araya *et al.*, 2005). According to Araya *et al.* (2005) the potential economic benefit from pond technology was found very much dependent on the type crop choice and irrigation scheduling. Comparison of water use efficiency of the current irrigation practices of model farmers in Wukiro and Mehonni areas show that the maximum efficiency (measured in Kg/M^3) achieved in these areas is below what is taken as a standard in the literature (Table 3).

Table 3. Water use efficiency (WUE) comparisons of crops grown by model farmers in Wukiro and Mehonni areas

Crop type	Wukiro		Mehonni		Literature
	Yield (kg/ha)	WUE (Kg/M^3)	Yield (kg/ha)	WUE (Kg/M^3)	WUE (Kg/M^3)
Tomato	20000	3.3 – 4.7	20000	3.3 – 4.7	10 – 12
G. pepper	10000	1.8 – 2.5	10000	1.6 – 2.4	1.5 – 3
Garlic	10000	1.5 – 2.2 bulb	-	-	8 – 10 bulb
Onion	12000	1.8 – 2.6 bulb	12000	2.4 – 3.4 bulb	8 – 10 bulb
Spices	1000	0.3 – 0.5	-	-	
Maize	3000	0.5 – 0.8	-	-	0.8 – 1.6
Sunflower	1500	0.3 – 0.4	-	-	0.3 – 0.5
Orange	12000	0.7 – 1 fruit	-	-	2 – 5 fruit
Papaya	-	-	78000	5.7 – 1.8	
Sweet potato	-	-	12000	2.3 – 3.3	

Source: Araya *et al.* (2005)

Araya *et al.* (2005) also show acceptable Net Present Value (NPV) and Internal Rate of Return (IRR) for the pond technologies for model farmers. Their computation is done assuming 8% discount rate; 7 years of service life for the ponds; a 2000 birr construction cost; and a maintenance cost of 5% of the initial investment cost. However, their findings show that the economic return for the green pepper and fruits trees mixed cropping pattern in Mehonni area was negative (Table 4). This affirms the need to adapt the pond technologies to the specific features of a site and a household. One problem with the economic analysis conducted by Araya *et al.* (2005) is that the initial cost of construction is underestimated compared to the value of grain and the cash paid for the team of farm-laborers who contract to prepare the ponds. Besides if we consider the cost of other material inputs such as the plastic lining, the cost should be much higher than what is assumed in their analysis. Therefore, the larger IRR value in some of the cases could be due to such problems in their assumption.

From a model farmer's analysis, Tesfay *et al.* (2004) show that the pond technology is not financially profitable if annualized cost of construction is imputed in analysis. For model farmers the net return for water and annualized cost of pond construction ranges between 138 and 1500 Birr. This shows that the pond technology may require some subsidy in order to be financially sound for the individual households. However, such subsidy may not be socially feasible given the fact that most agricultural subsidies are removed due to the structural adjustment policy. The current way of linking implementation of the water harvesting program with the food aid programs is the only feasible way as far as the external support exists. However, researchers and policy makers should look for more self-sustaining approaches to promote water harvesting practices in the region.

Table 4. Economic analysis of household ponds of Model farmers in Tigray

Crop pattern	Decision criteria	Wukiro	Mehonni*	Remark
1 (Tomato, g. pepper, garlic)	B/C	1.48	-	40% tomato
	IRR	0.48	-	
	NPV (Birr)	1,339.21	-	
2 (tomato, g. pepper, spices)	B/C	1.79	-	50% tomato
	IRR	0.34	-	
	NPV	2,233.89	-	
3 (tomato, g. pepper, garlic, spices)	B/C	1.34	-	30% tomato
	IRR	0.20	-	
	NPV	943.18	-	
4 (green pepper and fruit trees)	B/C		0.98	60% g. pepper
	IRR		0.07	
	NPV		-45.80	

Source: Araya *et al.* (2005)

Note: B/C = benefit cost ratio; IRR= Internal rate of return and NPV= Net Present Value; * for crop patterns 1 to 3, the results of the economic analyses were similar for both sites.

One fact that needs to be acknowledged here is the lack of information on the economic benefits of ponds derived from use of water for supplementary irrigation of main season crops during dryspells. However, the extent of use was limited among farmers as findings from survey of sample households in different sites indicate (Tesfay *et al.*, 2004). Therefore, the limited contribution of ponds at regional level is also due to limited use of the ponds for supplementary irrigation. The current economic benefits are low also because of the longer time required for fruit trees to mature and yield. The off-site economic implication of water harvesting technologies need to be considered in the future as the on-site effect alone might not justify program intervention in this area.

5.5. INSTITUTIONAL ISSUES

Introduction of water harvesting practices in a given locality is expected to involve institutional interactions among users. The main cases encountered in the study sites are discussed in this section. For instance, refilling ponds from alternative water sources is practiced by farmers in some areas. However, farmers sharing the alternative water sources show resistance to allow pond owners to replenish their ponds during dry season indicating the need for integrating such a practice into wider water management system in a given locality.

Catchment areas for most household ponds are mainly farmlands, which may be their own or that of neighbors (Figure 5). In the case of neighbor’s farmland, there is a potential problem in relation to runoff collection and management of catchment area to minimize sedimentation of ponds. If farmers owning the plots in the catchments increase flood harvesting, it may lead to conflict of interest which ultimately affects the sustainability of the pond technology. From the current setting, the interaction among farmers owning pond and those who own the plots forming the catchment-area would be important factor in the success of the pond systems. The way ponds are constructed currently shows higher degree of interaction. This has to be considered in the future as one of the site selection criteria. Concerned households should negotiate in order to create positive interaction.

The traditionally practiced free grazing of livestock on farmlands after harvest of main crops during the dry season is one problem in the use of ponds located on field plots in the development of vegetable garden. Livestock from neighboring households may damage the vegetable and the pond structure when they are free to roam around the field plots. It is also a source of conflict among households owning the ponds and those owning the livestock.

Figure 5. Example of a household pond with farmlands as a catchment area

5.6. ON-FARM PONDS IN THE EYE OF FARMERS

The process of selection of households to be included in the program was evaluated based on the opinion of farmers. Although most households were selected based on consultation and with their agreement, there were others who were included without their will. Farmers who did not volunteer complained about the decision to include them in the program forcefully. The reasons that non-volunteering households mentioned for lack of interest were that 1) they were not convinced about the potential benefits, 2) they do not have sufficient resource to utilize the water, particularly labor resources, and 3) the loss of land taken by the pond structure (Tesfay *et al.*, 2004). It is therefore important to consider the concerns raised by farmers and include households who volunteer to participate. The reason for forced inclusion of households was related to meeting a target quota per village so that the regional plan could be met. This kind of approach has proved futile in other extension interventions in the past and it should serve as a lesson for current and future interventions. The program should be on voluntary basis without any imposition which otherwise would prove failure in the end.

Selection of specific sites for the ponds was mainly done based on technical criteria and significant number of households were unhappy with the selected sites (Tesfay *et al.*, 2004). The problems cited for their dissatisfaction were related to the type of farmland occupied by and distance of the pond.

Beyond the economic reasons, farmers in the hot lowland areas of southern Tigray oppose the pond technologies because of aggravated malaria problem (Tesfay *et al.*, 2004; Araya *et al.*, 2005; PREM, 2007). Because of the hot climate and open pond system with no cover, it is creating a favorable environment for mosquitoes to breed. Designing a low cost cover for the large surface area of the pond may help to minimize the problem. Improving the health extension system to address the malaria problem is necessary.

Farmers were asked a number of opinion questions regarding some physical features of the technology to assess their perceptions of its significance. Of the sample households, 58% accept the size of the pond as good/acceptable and 38% evaluate it as large (27 households). Only 4% of respondents said it was small. In relation to the sufficiency of collected water for one full cycle of production, based on their own knowledge of crop water use and the soil type of the plot they irrigate, 57 % of households rated it as insufficient, 36% just enough and about 7% as amply sufficient. Although, most rated the physical size as good, the collected water is found insufficient by most. This may be due to the frequently raised problem of high seepage even from ponds with a plastic lining. Asked about the possibility of using the pond for domestic use and livestock watering, 63% households said it can not be sufficient even at full storage capacity. However, many of households use it for both domestic purpose and livestock watering. The most frequently cited reason for not utilizing the ponds was insufficient water and the other reasons were distance from homestead and labor shortage. Additional reasons were incompleteness of physical work and damages on the plastic lining. Some 10% households abandoned to use their ponds after using for one or two seasons. The main reasons for the abandonment of utilization of the ponds by households were water shortage and problems of theft and damage to crops.

Asked about whether they want to construct additional pond, 63% households were not in favor while 32% were willing to contract a second one. The reasons for not wanting to have a second are related to shortage of land, poor utilization of the existing one and resource problems. The need for alternative water source for livestock and domestic use, and expanding irrigation capacity were the reasons mentioned by households who were in favor of constructing a second pond.

Farmers were also asked to list the major concerns that community members raise in their respective communities in relation to the introduction of ponds. The main ones were related to wastage of land created by the structure and the dug out soil, accident of people and livestock drowning, and the poor distribution, high cost and damage of plastic lining. In the southern mid-highlands of Tigray, such a Mehonni district, people have worries about spread of malaria associated with pond. In the region the problem of malaria is high with more than half of the population being at risk of getting the disease (PREM, 2007). Three households encountered accident of drowning livestock and one household reported a family member. Some are reluctant to accept the technology because they hold negative attitudes on the effectiveness of such a small-scale technology to address critical problems of food shortage. This is also related with lack of experience in irrigated farming and horticultural crops.

In relation to the need for expanding the program in their community, 85% of respondents were in support of it for reasons that it helps to expand irrigation farming, reach other households who do not own ponds yet, and improve availability of water for other uses such as livestock watering. The remaining said it is not necessary to expand the pond technology stating that the existing ones are enough in number and not properly utilized thus. Respondents also suggest for improving the design and construction materials such as replacing the plastic lining with cement and reducing the land taken by the structure.

Few cases of conflict were also mentioned by respondent households over competitive use of small catchment areas that serve two or more ponds. There were problems of sharing water and some damages on fruit trees and vegetables due to free livestock grazing.

5.7. ISSUES IN DIVERSIFICATION TO HORTICULTURAL SYSTEMS

Water stored in the ponds is not efficiently used due to lack of proper irrigation application and/or mismanagement (Araya *et al.*, 2005). The pond technology is not accompanied with specific recommendations on irrigation agronomy and horticultural crop management. The practice of supplementary irrigation is not psychologically appealing to farmers who are from the culture of rainfed farming. The capacity of the pond is perceived as insignificant for irrigating cereals under field system. The extension system needs to address this attitudal problem in order to facilitate the adoption of the pond technology.

The recently emerging irrigated horticultural systems in the region are low input type and the maximum potential from irrigated systems may not be realized. Given the risky nature of the system, the model farmers studied in the socioeconomic survey (Tesfay *et al.*, 2004; Tesfay and Girmay, 2005) use low levels or not at all of external inputs such as fertilizer. Introduction of cash crops is also a new experience for most farmers (Wubetu and Dereje, 2005). However, it is a well-recognized fact that water and fertilizer use shows a large degree of complementarity under irrigation system. Use of poor quality vegetable seeds was a cause for low productivity mentioned by farmers which implies the need for improved supply system of quality seeds and seedlings. For fruit trees such as papaya the composition of male and female was difficult to understand for majority farmers and mostly the established plants were found male. This requires some understanding of the fruit reproductive biology which is not familiar to most farmers (Wubetu and Dereje, 2005). Better economic returns were realized by farmers when they develop an integrated garden with diversity of vegetables and spices (Tesfay *et al.*, 2004).

5.8. GENDER ISSUES

Assessment of differential impacts of program interventions by gender is of major concern in project evaluation. Whether a project has a negative or positive impact by gender has to be evaluated in order to understand the role of the project in changing the status of women and the benefits they realize. In relation to the water harvesting project, the gender dimension deserves careful consideration. Therefore, this aspect has been dealt with in relation to the research activities carried out to assess the socioeconomic impact of the project.

The positive impacts of the pond technology on women are related to access to cash from selling of vegetables and spices and improved availability of vegetables that minimizes women's burden in fulfilling home consumption needs. However, the development of home or kitchen garden was found to increase their work burden as women were mostly responsible for the management of the garden and marketing of the products. This requires improving the irrigation systems to reduce the labor demand and by supplying other facilities that minimize women's burden in household activities.

6. ENHANCING ROLE OF WATER HARVESTING PONDS

The role water harvesting ponds is wide. The availability of a functional pond at household level increases the diversity of diet, provides some level of employment to less marketable labor, and improves cash access to women of the household as marketing of vegetables is done by them. Children are also able to generate some cash for their schooling by selling vegetables from their home garden. However, the current role of the pond technologies is below policy expectations.

To enhance the role of on-farm pond technology for food production and income generation, a strong research and extension support is necessary. The technology requires a regular follow-up and improvement in design and suitable agronomic practices are needed to improve water use efficiency. Currently, farmers are utilizing a surface irrigation system, mostly furrow system, which has low irrigation efficiency and better techniques are required to achieve higher efficiency of the limited pond capacity (Araya *et al.*, 2005). Improved horticultural systems are needed to increase the productivity of water and the return for other inputs used in production such as labor. Farmers should get training on management of soils and nursery, seed and seedling selection for vegetables and fruits, and post-harvest handling of vegetable produce (Wubetu and Dereje, 2005). Seed and seedling supply systems need to be established to promote the use of ponds for horticultural development.

The use of the ponds for supplementary irrigation is low although the main aim of the program was to counteract problems of moisture stress during dryspells in the main production season. Many farmers lack the right attitude in this regard and downplay its significance. This is a major problem in promoting the technology for supplementary irrigation. Although one of the problems in relation to low use is the difficulty in lifting water to irrigate large plots, the availability of tridle-pump is an opportunity to solve the problem. Therefore, the wide dissemination of tridle-pumps at an affordable price should be the focus of the policy support for the development rainfed farming through water harvesting intervention.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. RELEVANCE OF PONDS IN TIGRAY AND FACTORS DETERMINING ACTUAL USE

Tigray is a region characterized by semi-arid ecology. Moisture stress or general water shortage is one of the critical problems in the production system of the region. Water harvesting practices therefore are relevant for the growth of agriculture in the region. Water harvesting techniques may play an important role in the use of scarce water resources, by retaining surface water and storing it for production purposes. These technologies may play important roles in the efficient use of the scarce water resources in the region. However, the new household ponds are found less widely utilized by farmers relative to the scale of introduction of the technologies. The level of utilization of communal ponds and the series of ponds is also below expectations.

Factors positively linked with the limited actual utilization of the household pond are the experience of households in irrigated farming, proximity to market centers of the household, availability of alternative water sources to replenish pond water during dry season, and good availability of labor and relatively small rainfed farmland holding of the household. The pattern of rainfall during the main rain also determines the volume of water collected and its availability for dry season irrigation. This implies the need for targeted approach considering the factors that condition the wide-scale adoption of the ponds. It is important to refine the policy objectives of the water harvesting programs and increase the technology options for farmers to choose based on their suitability to their circumstance.

7.2. LIMITATIONS OF THE PROGRAM

The major limitations of the water harvesting program in the context of the study region are outlined as follows:

1. Lower impact in terms of the primary objectives of the program. The development of supplementary irrigation system is limited and the focus of farmers is more on development of gardens for vegetable production.

2. The program offers limited technological options. The choice of structural design for the ponds should be wider than the one choice that is offered now by the program. The design of water harvesting pond is not suitable for efficient collection and use of water. Rather, the focus of design is on structural stability of the pond. Other alternative technologies should be included to increase the choice for farmers.

3. The program is dependent on imported industrial items such as the plastic lining and alternative local materials should be promoted.

4. The purpose of communal ponds is not clear and the extent of their dissemination is low. This needs to be thought out in future plans of the program.

5. The program lacks good integration with other development activities such as the livestock package and other food security programs. It lacks also integration with other water resource development programs in the region.

6. The program is promoted in a top-down approach and with a significant material support from the government. Such an approach may not be sustainable given the intermittent nature of government resources and its non-participatory nature. Thus, the roles of the individual households, the community, the non-governmental organizations and the state need to be clarified based on the principles of participatory development. The extent of external support should be limited and households should be encouraged to make voluntary contributions for the program.

7. The program lacks flexibility in planning and implementation and is dependent on gross quota systems to meet a targeted number of households without due consideration to the demand side.

7.3. RECOMMENDATIONS

In light of the findings of the study and the limitations of the program identified thus far, the following recommendations are forwarded for policy consideration:

- Improve the planning approach into more participatory and demand-driven so as to gain real support of the rural households. Voluntary and genuine support of local communities during planning is need for successful implementation of the program.

- Improve the organization of the implementation process to timely finalize the pond construction as delay in the supply of industrial products has been mentioned as one of the limitations.

- Adopt a flexible approach in both planning and implementation of the program considering local context: avoid quota system which is based on administrative boundaries; adapting technology to local conditions and encouraging farmers' innovative designs based on their indigenous knowledge of runoff utilization and rainwater harvesting.

- Improve the extension support system to popularize the technology and improve its adoption by farmers through voluntary means. The program should be promoted with a package of information on the successful diversification to horticultural production and use of alternative water sources.

- The extent of program support should not displace the role of the beneficiaries and should be designed to bring a lasting behavioral change in terms of adoption of the technology by farmers.

- Further investigation is needed to better include all possible impacts (positive and negative) that could follow the introduction of water harvesting technologies and to come up with a comprehensive evaluation of the technology.

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9. ANNEX

Table 1A. Intensity of rainfall deficit for crop production from August to October

District	Water deficit in mm	Deficit in % of required
Enderta and Wejerat-Hintalo	212	55
Wukro	266	62
Axum	253	54
Inda-selassie	138	29

Source: REST (2002)

Table 1B. Pond capacity and system definition

System definitions	Individual households pond		Communal ponds	Communal balancing ponds connected with individual ponds
Capacity	200 M^3	300 M^3	1,000-10,000 M^3	1,000-10,000 M^3
Regime (s)	Unimodal high rainfall	Bimodal high rainfall	Unimodal low rainfall Bimodal low rainfall Bimodal influenced	Unimodal low rainfall Bimodal low rainfall Bimodal influenced

Source: Cowater International Inc (2003)

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