

# Feasibility Study of Rainwater Harvesting for Agriculture in the Caribbean Subregion



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## Acronyms and abbreviations

APUA	Antigua Public Utilities Authority
CARDI	Caribbean Agricultural Research & Development Institute
BADMC	Barbados Agricultural Development and Management Corporation
BWA	Barbados Water Authority
CARICOM	Caribbean Community
CDB	Caribbean Development Bank
CEHI	Caribbean Environmental Health Institute
CH	Centre Hill, Montserrat
DBMC	Dominica Banana Growers Association
DCA	Development Control Authority
DOWASCO	Dominica Water and Sewerage Company
EC	East Caribbean Dollar
FAO	Food and Agriculture Organization of the United Nations
IICA	Inter-American Institute for Cooperation on Agriculture
MOA	Ministry of Agriculture and Fisheries
MCW	Minister of Communication and Works
MWA	Montserrat Water Authority
NAWASA	National Water and Sewerage Authority
NRHP	National Rainwater Harvesting Programme, Grenada
NIDP	National Irrigation Development Plan
NIC	National Irrigation Commission Limited
RPPD	Rural Physical Planning Division
RWH	Rainwater Harvesting
RADA	Rural Agriculture Development Authority
WRA	Water Resources Authority
WRDMP	Water Resources Development Master Plan
WTO	World Trade Organization

## Executive Summary

Caribbean farmers experience annual droughts for five or more months of the year. The typical dry periods occur during the month of December through to April of the following year and can start as early as November and end as late as May. During this period, water scarcity in rainfed systems can be so severe as to force many of the farmers to cease planting.

According to CaFAN<sup>1</sup> there are at least 500 000 small farmers in the subregion, who are primarily rainfed. All of these farmers experience extremes in water scarcity at the farm level from time to time, resulting in loss of food production and other farm related livelihoods. Among these farmers are those whose production is critical to sustained national and subregional food security and to the reduction of household food insecurity, especially in poor rural communities.

The Food and Agriculture Organization has been working in partnership with CARICOM/COTED and other development partners in the subregion to improve national and household access to nutritious food. The focus is on improving all four pillars<sup>2</sup> of food security with emphasis on improved access and availability through higher levels of production at subregional and household levels. Indications are that there is good potential to achieve this goal by focusing on technologies to increase domestic production of fruits, vegetables, legumes and starch replacements.

Several reviews of small farm operations in the subregion reveal that inappropriate selection and improper use of technologies in food production systems are among the traditional constraints many farmers experience. Furthermore, increasingly risks associated with climate change and climate variability are pointing to the need to adopt a new or improved set of technologies suitable to small farming, which can produce measurable increases in production, over the long term.

Rainfall variability has emerged as one of the most challenging among climate change events for society in general. In this regard the lifestyles of different social groups can be negatively affected from time to time by excessive rainfall and extended drought, caused by rainfall variability. However the small farmer and the household are extremely vulnerable to these changes as the entire well being of the farming community is integrally linked with the capacity of these populations to access the right amounts of water at all times to ensure yields from the crop or livestock. Accordingly, during a period of drought the farmer must have adequate amounts of water in storage to meet the needs of the farm. An imperative for rainfed farming therefore, is that a technology or innovation to store water for later use when needed. A major concern of the subregion is the potential impact of extended droughts on rainfed systems of the more than 60 percent of small farmers who have no other source of water for the farm.

This study of the feasibility of rainwater harvesting for agriculture provides outputs that justify the promotion of the technology as a support tool to extend the duration of access to

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<sup>1</sup> Caribbean Farmers Association Network

<sup>2</sup> Availability, access, consumption and utilization.

water for irrigation on rainfed farms during the dry periods. Missions to six of the countries have provided good evidence that the capture and storage of rainwater runoff for later use is possible in quantities sufficient to significantly reduce risks of losing some or all of the harvest each year owing to soil water scarcity. Additional benefits would be derived from the reduction of risks associated with flooding and soil erosion during the increasingly high rainfall intensities being experienced in the subregion. Small and micro farmers, especially those growing crops on hillsides, could therefore experience double benefits from rainwater harvesting practices.

Ten patterns of rainwater harvesting are recommended either for improvements or for introduction in the subregion. The range of patterns is all-inclusive as they make provisions for the diversity of small and micro farmers in the subregion. Furthermore similarities in geology, topography and rainfall across the countries support good possibilities for successful replication. Significant differences exist in the amounts of rainwater which can be stored in respective countries. However analyses of runoff from design rainfall indicate that the entire space of each of the six countries visited is suitable to rainwater harvesting. This strongly suggests that all of the small farmers across the subregion, including backyard gardeners and other micro-farming communities are geographically positioned to participate in rainwater harvesting practices and to have water in storage for later use on the farm during dry periods.

The document provides the information necessary to assist in the design of or strengthen national programs to build individual farmer or community capacities in rainwater harvesting. Farmers need not have prior knowledge in the use of the technology. However Extension Officers will require the necessary inputs from among technical officers with an understanding of the statistical, physiological and technological processes involved. These include practices in evaluation of suitability of series rainfall data, probability analysis of series data and simple engineering works suited to catchment and storage requirements.

It is recommended that consideration be given to the role of policy and institutional support for rainwater harvesting, as well as studies to determine the environmental, social and economic benefits of the technology. In terms of the social dimensions the role of farmers' organization should be considered especially as this relates to access to training, capacity building and bulk purchasing of materials for inputs for catchments and storage. Furthermore, the potential increases from extended planting periods may require that small farmers adopt a cooperative approach to marketing and utilization of year round production.

## Acknowledgements

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## Foreword

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Water for agriculture has been and continues to be a major determinant in reliable domestic food production in the subregion. Where groundwater and surface water is available many farmers are benefitting from Government irrigation schemes. However in this subregion, the majority of small and micro farmers are characterized by small plots on hillsides where there is no access to groundwater or surface water. They are largely rainfed farmers but a few have limited access to potable water for irrigation. In nearly all situations potable water is either less available, more expensive or the use for agriculture is prohibited during the dry periods.

Against this background, rainfed farmers have traditionally avoided production planning that extends into the dry periods. Furthermore the strategy to intercept and store rainwater runoff at the level of the farm for future use has not been mainstreamed in farm management.

Since 2008, a collaborative effort between FAO and other partners in the sub region has created a greater awareness of the possibilities for on-farm rainwater harvesting for agriculture. The focus is on how best to manage rainwater runoff at the farm level, in amounts sufficient to maintain cropping or livestock systems, throughout the normal dry periods or in situations of extended droughts.

This document examines the reliability of annual rainfall patterns and other climatic conditions of six of the countries to provide adequate rainwater runoff to support sustainable farm activities. The proposals presented benefit from the volume of series annual rainfall data and related information of relevance to rainwater harvesting such as geology, soils, topography and the quantitative analyses on water scarcity, available in the countries. These data provided the basis for the type of rainwater harvesting systems recommended as well as the responsiveness of these systems to the different circumstances of the small rainfed farmers in the subregion.

## 1

### **Background**

Rainwater harvesting is the accumulation and storage of rainwater runoff for reuse before it reaches the aquifer. In agriculture this water can be used to grow crops and to support small livestock and inland fisheries production at the farm level, often without further treatment.

Rainwater harvested for agriculture is collected from many types of surfaces including roofs of dwelling houses and farm sheds, road surfaces, concrete surfaces and plastic surfaces including greenhouse coverings. Natural surfaces which serve as catchments include slopes and the trunks and canopies of trees. To understand this document, rainwater harvesting will also include the terminology storm water and so does not make a distinction between roof runoff and runoff collected from road side drains and other manmade surfaces, such as those mentioned above. It therefore includes catchment surfaces such as airports, playing fields, parks and natural impervious surfaces.

This study seeks to promote rainwater harvesting as a technology that could contribute to intensification and diversification in small and micro- farming in the subregion. The measurable achievements foreseen are improvements in yields from small and micro-farms through reliable access to water for irrigation, when necessary. Other achievements include the extension of the number of planting days through the application of water from cumulative storage. In this respect, rainwater harvesting for agriculture is an important risk reduction measure against water scarcity and its potential negative impact on livelihoods and food security in small farming communities.

The sum total of benefits from programmed rainwater harvesting is expected to be far reaching as the majority of Caribbean farmers are on hillsides, where there is no access to surface or groundwater. Others are in areas where it is not economically feasible to build public infrastructure to divert water from neighboring watersheds. Similarities in the topography, geology, meteorology and climatic conditions in the location of small and micro farms across the subregion, provide the opportunity to develop and disseminate a common subregional program framework to guide the implementation of national programs on rainwater harvesting. One approach could be to develop these programs using an agro-ecosystem approach which would also facilitate monitoring of the wider use of the technology on ecosystems impacted by runoff such as inland water bodies including rivers, ponds and swamps.

Among the favorable situations that exist is that much of the data required for rainwater harvesting system designs are readily available from national statistics and more recently from the advanced information system provided by Caribbean Institute of Meteorology and Hydrology (CIMH). What may be uncertain however, is the availability of the required technical capacity within the agriculture extension system and farmers' organizations to conduct the analyses to design rainwater harvesting systems. At this time most of this capacity rests within the water resources units, which are often not within the Ministries of Agriculture or the other institutions that interact with small farmers on a daily basis.

Appreciation of the benefits of rainwater harvesting for small and micro farmers is not new to the subregion. The study found that countries such as Jamaica, Dominica, Antigua and Barbuda and St Kitts Nevis have implemented public programs in rainwater harvesting for small farmers with varying levels of success. The study also revealed that traditionally some private entities including small farmers in Saint Lucia, Dominica, Grenada and Jamaica have occasionally engaged in activities to collect and store rainwater runoff for agriculture. Furthermore that Barbados, Jamaica and Antigua and Barbuda have good experiences in the application of micro-irrigation technology. In addition, appropriate technical advice and suppliers of micro-irrigation systems are available across most of the subregion. At least one country - Antigua and Barbuda, has integrated rural road construction programs with surface runoff and embankments for pond storage of rainwater

The rainwater harvesting practices reviewed vary across the public and private sectors and include the construction of earth structures for storage such as of mini dams, series dams and ponds, on-farm small storage tanks and the use of the range of catchment surfaces mentioned above. It was confirmed that properly managed rainwater harvesting can increase availability of on-farm water for irrigation during low rainfall and periodic droughts on farms two hectares and under. However, the demands for this technology are far beyond what has been achieved. This is evidenced by the photographs in this document of inefficient and tedious methods farmers are prepared to undertake to intercept and store water. Coupled with the need to widen the number of farmers using the technology, will be the increasing challenge of how to manage the water stored for optimum productivity, as variability of annual rainfall is expected to increase, with the likelihood of more extreme droughts.

The study provides us with important details on water scarcity and the opportunities for rainwater harvesting in each of the six countries. Rainfall data of all the countries reviewed shows that mean annual rainfall ranges from a low of 1 070mm in Antigua and Barbuda to a high of 4 445mm in Dominica. In all of the countries visited, rainfall distribution shows with two peaks<sup>3</sup> and is concentrated in relatively short showers, which create high rainwater runoff. Records of geographic distribution of annual rainfall show that in Antigua and Barbuda, one of the countries of the subregion, minimum annual rainfall is above 700mm. This amount exceeds the 300mm<sup>4</sup> annual rainfall required on sites where a rainwater harvesting system may be established. In addition the calculations of design rainfall have established reliable annual rainfall patterns and amounts with a 90 percent probability well above 300 mm annual rainfall. It is therefore, the conclusion of the study, that rainwater harvesting is feasible in all the countries visited. This conclusion could be extrapolated the general situation across the subregion, based on the similarities in climate, geology and topography.

In respect of water scarcity the situations of the countries reveal the following:

Jamaica: The estimated deficit for potable water is 400 million cubic meter annually, with rainfall peaks in April through June and August through November. The pattern varies significantly, making rainfall as a major source of water, unreliable for crop and livestock production. Water demand for irrigation is not available or sufficient in the dry season and occasionally in the normal wet season. This situation creates a threat to successful production cycles in many crops, especially for vegetables.

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<sup>3</sup> Rainfall may peak as early as April and a second peak from October to November

<sup>4</sup> FAO

Based on the proportional ownership of farms in Jamaica, an estimated two thirds<sup>5</sup> of the farmers, mostly those who farm on hillsides, would benefit from rainwater harvesting. Already rainwater harvesting projects including the building of mini-dams and on-farm small tanks have given promising results as a source of augmenting water for irrigation on these farms. However the demand is much higher than what is now provided.

Barbados: Water resources availability per capita is only 390 cubic meters, placing Barbados among the 10 most water scarce countries of the world. The daily deficit in water supply for domestic and agricultural purposes is estimated at over 45 454 cubic meters. Desalination provides about 13 percent of the domestic water and wells operated for agricultural irrigation provide 63 percent of the demand for agriculture. These wells are subject to salt intrusion during pumping in dry seasons. Rainfall is therefore an inadequate source of water for agriculture in Barbados, making irrigation essential. While rainwater harvesting will help to alleviate the situation among small and micro farmers, major challenges with water for agriculture will continue to exist and intensify unless there are efforts to improve storage of rainwater either from surface run off or the capture of groundwater.

Grenada (Carriacou and Petite Martinique): Records showed annual rainfall decreased by over 100 mm from 1 524 mm in 1978 to 1 422 mm in 1996, with consequent declines in the availability of water for domestic purposes and for agriculture. The current daily demand for water in Grenada is 54 600 cubic meters in the dry season while the maximum water yield is 31 800 cubic meters. This means that there is a 22 800 cubic meters gap between demand and supply.

There are significant arable areas in all of the three islands, where ground and surface water is not sufficient to meet demands. For example in Carriacou there are no permanent streams or rivers. Hence stream flow in the various ghauts and valley bottoms is short lived and occurs only during rainfall events. In Carriacou domestic water supply is 100 percent reliant on rainwater harvesting, leaving no source of water for irrigation. The limited surface and groundwater resources have placed significant restrictions on the development of irrigation schemes.

Antigua and Barbuda: Droughts occur every five to ten years in Antigua and Barbuda. When several low rainfall years occur consecutively, the country faces critical water shortages. In the period from 1983 through 1984, water had to be imported from neighboring countries. It is estimated that over 80 percent of domestic water demand is satisfied by desalination and farms are often irrigated from potable water. Accordingly, water scarcity has become a critical restriction for social and economic development in the country.

Dominica: Dominica has an abundance of surface water. However owing to the fact that geographic distribution is uneven, farming practices are heavily dependent on irrigation in the dry periods, which occur from February through June, as well as during the rainy season. More than 70 percent of the land resources are classified as unsuitable for agriculture, because of the risk of erosion. Within the limited arable lands are areas where there is no economical source of surface or groundwater available for irrigation. In addition the national thrust towards crop diversification in the last two decades is creating a higher demand for water for irrigation. Currently farmers in some of the agriculture regions of the country do

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<sup>5</sup> 120 000 small farmers from an estimated total of 180 000.



practice rainwater harvesting, often using traditional, indigenous approaches with inefficient and inadequate collection and storage when compared with improved practices.

Montserrat: Except for 20 percent of overflow from springs in Olevston Mountains all of the runoff water and water available from wells and springs in the country is harnessed into a piped water supply system to provide drinking water. There are concerns that the water now available from springs in Olevston Mountain may become unavailable as future demands for domestic water increase. Water for agriculture is therefore a major concern on the island.

Against this background the study recommended ten rainwater harvesting systems. These systems may be replicated in other parts of the subregion. The systems are best suited for on-farm rainwater harvesting for small farm operations which do not require major infrastructure developments. They are also meant for small farms where rainwater is used at the point of collection and storage.

The recommendations include practices such as extending roof runoff for domestic rainwater harvesting to include water for irrigation of backyard gardens and small farms around the home, mini roof runoff from sheds on the farm and from plastic roofs of greenhouses, building mini-dams on seasonal waterways including at road crossing, series dams on river courses, interception ditches on natural slopes and ponds for storage and the use of plastic as rainwater collection surface.

Where the opportunity exists, such as in Jamaica, improvement of in-stream storage to avoid diversion of surface water from major rivers is also recommended.

## 2

### **State of the critical factors for rainwater harvesting for agriculture**

**Introduction:** The details of the study provided important information on the feasibility of rainwater harvesting for agriculture in the Caribbean subregion. This information included the favorable location of the subregion in the sub-humid tropics, which provides climatic conditions, geology, topography, soils and rainfall patterns and distribution that allow interception and storage of runoff at economical costs.

In several locations, on farm topography and soil conditions create a situation in which the soil surface of the farm facilitates adequate rainwater collection efficiencies, with minimum modifications. In addition several artificial surfaces that facilitate collection of runoff are available. Many of the farm households are familiar with rainwater runoff practices for household use and to a lesser extent for agriculture. In at least two of the countries there is policy, legislation and incentive support for rainwater harvesting for household purposes. It was also observed that all of the countries visited have very good and accessible series rainfall data to facilitate site-specific analyses to determine design rainfall on or in close proximity to farms.

**Location:** The area of the subregion under consideration consists of thirteen island systems in the Caribbean Sea and three countries on the South America mainland. The study was conducted in six of the islands<sup>6</sup>. All of the islands are exposed to tropical hurricanes during the period June through October each year and two rainfall peaks with normal to extended droughts, sufficient to reduce food production and disrupt household water supply.

**Geology, soils and topography:** Most of the countries can be divided into four or more landforms including mountains, valleys, plateaus and coastal plains. Countries such as Barbados and Antigua and Barbuda are relatively flat with the highest peak in Barbados reaching just below 140 meters. On the other hand Dominica and Jamaica are mountainous countries with peaks in Jamaica reaching above 3 000 meters.

The islands vary in geology and soils. Jamaica has a backbone formed by peaks and plateaus running the length of the island, while Saint Lucia is well known for its peaks (the Pitons), which rise from sea level. In this way, the range of features include steep-sided mountains, highly karsted land, high plateaus, rolling hills and coastal plains sometimes with large interior valleys.

Except for Barbados, which has a non-volcanic soil, all the other countries in the study are of volcanic origins. At least three of the countries, Saint Lucia, Dominica and Montserrat have active volcanoes. Owing to the coralline nature of most of the soils in Barbados, percolation of water and subsequent discharge into subsurface water bodies is overland. In Jamaica there are several categories of soil formed from weathered limestone and calcareous shale. The soils of Grenada are dominated by 85 percent clay loams, 11 percent clays and three percent sandy loams. Generally the soils are mostly well drained and reasonably fertile. Due to the geology and topography of these island systems, sinkholes, caves, and disappearing streams are common features.

**Climate:** Overall annual temperatures range from between 24°C and 28°C with slightly lower temperatures prevailing at higher elevations, which can reach as low as 10°C in the peaks

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<sup>6</sup> Antigua and Barbuda, Dominica, Grenada, Jamaica, Grenada and Montserrat

of the Blue Mountains of Jamaica. Relative humidity levels are between 70 and 80 percent on average, year round. However climate can vary at country levels, for examples in Jamaica two types of climate are recognized. There is an upland tropical climate on the windward side of the mountains and a semiarid climate that predominates on the leeward side. Annual rainfall also varies among the countries and can be as low as 700 mm in parts of Antigua and Barbuda to a high in excess of 6 000 mm, in the highest elevations of Dominica and Jamaica.

Water demand and supply for water for agriculture: Rainfall is the primary source of water in the countries providing flow in the streams as surface water, direct recharge to the limestone and alluvium aquifers and indirect recharge to the aquifers through the streams, depending on the geology of the country. With respect to water resources, Jamaica has 33 watersheds and 10 basins with good potential for reliable annual ground and surface water. On mainland Grenada, there are 71 watersheds and in Carriacou there are 20 watersheds. The watersheds in Jamaica and Grenada are characterized by networks of permanent rivers. In the case of Jamaica, some of these flows are relatively large rivers with millions of liters of freshwater reaching the coastline every day. Dominica also has large amounts of groundwater and a dense network of rivers numbering over two hundred. However, in Jamaica and Dominica water resources are unevenly distributed across both countries. For example in Jamaica, most of the surface waters are in the north and northeastern end of the island. In both countries it would be uneconomical to convey water to the primary agricultural lands and in many cases the infrastructural work required could be damaging to the environment.

In Montserrat, the runoff water and water available from wells and springs is harnessed into a piped water supply system to provide drinking water. As a result over time there is a marked reduction in river flow compared with the recent past. There are no rivers which have water throughout the year, neither are there any natural lakes.

By contrast, Barbados and Antigua and Barbuda do not have access to large amounts of groundwater and Saint Lucia has no groundwater resource. In Antigua and Barbuda there are no permanent streams or rivers. However, it is normal that after heavy or prolonged rainfall, some sections of the larger streams may flow for periods of up to a few months. In these countries, all the major catchments are dammed at several points to retain stream flow. In addition to these freshwater resources, desalinated seawater is increasingly being used in Antigua and Barbuda and in Barbados to provide water for domestic and agricultural purposes.

All the countries store large amounts of water in reservoirs. While this water is intended for household purposes, some of it is used for irrigation on small and large farms. For example Antigua and Barbuda has 10 medium sized reservoirs and some 550 ponds and earth dams with a total design capacity of approximately seven million cubic meters of water. Of this total capacity, almost five million cubic meters are required for municipal water supplies, with some of the balance available for irrigation.

In most of the countries agriculture is the single largest user of water, accounting for amounts ranging from between 24 percent of total consumption in Barbados and 70 percent of total consumption in Jamaica. Wells across the subregion are operated under licenses issued to both private sector and public sector entities. In a few of the countries the wells are subject to excessive pumping and salt intrusion during the dry season, making it necessary to use potable water for irrigation.

Sprinkler and drip irrigation systems are widely used by farmers for vegetable, fruit and other horticultural crops. Some of the Governments offer rebate incentives for the use of highly efficient irrigation technologies in order to reduce the demand on the potable water supply, while others offer other types of incentives to encourage rainwater harvesting.

According to the study there are opportunities in all the countries to save water from improvements in irrigation practices. Efficiency of sprinklers can be further improved through a reduction in the numbers of overhead sprinklers and an increase in the use of micro irrigation systems that place water only where it is needed, around the roots of the plants. There is also good possibility to reduce large amounts of unaccounted for water through rehabilitation of the distribution systems and other management measures.

**Agriculture:** Agriculture accounts for between 0.06 percent and 31 percent of GDP across the countries, with only three of the countries accounting for more than 10 percent of national GDP. Traditionally countries of the subregion were agriculture economies but now most are either service oriented, mixed or transitioning to mixed economies. However, agriculture is important to rural livelihoods, employment, food security and to ecosystems stability of these fragile island systems. As a result, large areas of the land are still categorized as agricultural, even though to varying extent a high proportion of these lands is not under active production. The main crops grown are sugarcane, bananas, rice, and food crops including root crops, vegetables, vine fruits and grain legumes. Large agriculture areas are also dedicated to livestock production and smaller areas to freshwater fishponds and forestry.

With respect to livelihoods, the sector plays a significant role in rural communities, often as the only source of income for many households. Almost 90 percent of the farmers across the subregion are classified as small farmers, each household operating on less than two hectares of farmland. An estimated 60 percent do not have access to available water for irrigation and the only source of water for the farm is from rainfall. A large number of farms are located on hillsides and this increases the challenges to access water from irrigation schemes or from surface streams. Hence in a few countries, the numbers of farmers entirely dependent on direct rainfall are much higher than the average. Consequently, many of the small farms plan their production to coincide with the traditional rainy season. However variability in rainfall intensities and pattern caused by climate change, increasingly presents challenges from unexpected and extended drought situations. Accordingly many small farmers as well as farmers in general who have no access to irrigation schemes experience extended periods of drought resulting in loss of harvest.

**Institutions related to water management and irrigation:** All the countries in the subregion have some form of public or quasi -government institution, with special responsibility to manage water resources for household purposes and or for agriculture. To varying extents, these institutions are engaged in policy implementation, compliance or direct actions to manage, legislate, protect and control allocation and use of water resources in the countries. It is normal for the Ministries of Agriculture in the respective countries to share some of the responsibility for development and allocation of water for agriculture

Rainwater harvesting practices include tank storage of roof runoff for domestic supply and pond collection from natural catchments for irrigation. Some countries including Antigua and Barbuda and Barbados, have legislation in place governing rainwater harvesting for household use. Others such as Saint Lucia are considering policy and legislation for rainwater harvesting, also for household use. There were no reports of institutional arrangements or policy

and legislation to govern rainwater harvesting for agriculture. This is despite the fact that many farmers practice some form of rainwater harvesting for agriculture and that development agencies have provided technical assistance in rainwater harvesting in the subregion.

Challenges to water supply for agriculture: The key challenges to water supply identified by the study are as listed below.

- Due to topographic restrictions, it is difficult to supply water for areas in the hillsides and other mountainous areas to satisfy demands of agriculture and domestic purposes.
- Most of the farms with access to irrigation are the large and medium scale holdings which grow crops for export on the plains, while almost 90 percent of farms are small holdings growing food crops, with limited or no access to water except from rainfall events.
- Rainfall variability, the impact of drought conditions and the increasing risks and uncertainties from climate change are making it more challenging to plan for rainfed production systems based on rainfall events alone.
- Climate change is also affecting annual rainfall amounts. In Barbados data recorded since 1996 indicate a decrease of over 100 mm of rain moving from 1 524 mm in 1978 to 1 422 mm in 1996. This decline was accompanied by degradation of ground and surface water resources creating a further decrease in the availability of water supply, for both domestic and agriculture purposes.
- Where there is an abundance of surface water it is frequently unevenly distributed and or uneconomical to convey across watersheds. At the other end are those countries with no permanent rivers.
- Degradation of ground and surface water resources is causing a decrease in the availability of water for health and sanitation and greater uncertainties in the share of this water for agriculture. Furthermore in areas where groundwater is very deep, development of water resources for public supply is limited or completely absent.
- The cost of drilling wells in some areas and expansion of water supply infrastructure is prohibitive.
- Many surface storage facilities including reservoirs are shallow and exposed to high rates of evaporation from prevailing winds and high temperatures. Mini-dams, which are popular storage for water for agriculture, are often exposed to high rates of evapotranspiration. Most of these mini-dams dry up during the drought and do not provide reliable storage for agricultural use.
- Depending on the depth of drying out of the soils in the watersheds, considerable rainfall is often required before runoff and significant recharge takes place.

### 3

## Potential for rainwater harvesting for agriculture

Introduction: The key to rainwater harvesting is that the pattern and amounts of annual rainfall facilitate cumulative collection and storage of rainwater runoff necessary to meet crop water demand from supplementary water for irrigation, during extended droughts or low rainfall periods.

The study reviewed rainfall data in all the countries visited and analyzed series data from specific sites. These data confirmed that rainwater harvesting to reduce or prevent water scarcity in rainfed production systems is a feasible strategy for sustainable food production in small scale farming in the subregion. The analyses further confirmed that all of the agricultural areas in each of the countries received adequate rainfall in amounts and distribution to allow farmers to benefit from rainwater harvesting. This means that even in Antigua and Barbuda where annual rainfall in some areas is as low as 700 mm, the total amount of rainfall received justifies the establishment of physical infrastructure for rainwater harvesting.

Rainfall distribution and amounts: Typically seasonal variability is high, occurring in two peaks, one in May and June and the other in September and November, with most of the rainfall occurring in September and November. The annual dry season lasts from December to April, with slight variations across the countries. However, the pattern of rainfall can vary significantly from year to year making direct rainfall an unreliable major source of water for the farm. As a result, rainfed farmers experience water deficits and droughts across the subregion. This happens during the wet season as well as during normal and extended droughts. Nevertheless, rainwater harvesting is still a feasible option as the monthly rainfall averages analyzed in all the countries show that despite the monthly variability, rainfall is relatively concentrated and intense in the two short periods to favor high rainwater runoff, even with relatively low catchment surfaces.

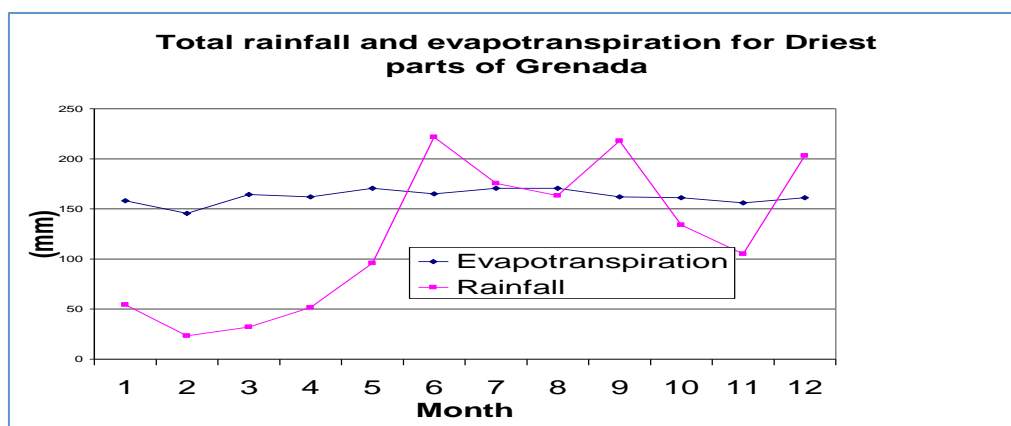
Demand for the technology: With respect to the demand for rainwater harvesting, it was observed that many farmers are already involved in self help methods to harvest rainwater runoff. The methods vary from crude harvesting from tree trunks to more modern approaches such as roof runoff. The general observation was that annually there are periods when average evapotranspiration is significantly higher than the average rainfall, making supplemental irrigation necessary for even moderate levels of production in rainfed systems. In order to sustain yields many farmers use potable water, which is expensive. Others pay high costs to transport water to the farm. For some farmers such as those on Montserrat, neither surface nor groundwater is available for irrigation. Harvesting of rainwater runoff has therefore emerged as the only option to meet supplementary water for irrigation.

Indications are that variability in rainfall and extended droughts are likely to continue with climate change, presenting more challenges to access water for small farms, especially those located on hillsides. While desalination has proved to be adequate source of water for household use in at least two of the countries visited, it is unlikely that this technology will be a consideration for agriculture because of the associated high cost of production compared with the small size and level of productivity of most of the farms.

Outlook for rainwater harvesting in the subregion: Despite the clear demand for the

technology, much of the rainwater harvesting for agriculture is still carried out using very traditional practices, leaving many gaps that could be improved through improvements in design and application. The successful adoption of the technology will require a discreet program approach to capacity building in aspects such as catchment surface and size and storage capacities for the respective farm or communal area. These considerations are necessary to assure reliability of the system to support crop production and to achieve optimum returns in the use of the technology.

Evapotranspiration rates can be very high in some of the countries where winds are steady and temperatures high. For example in Antigua and Barbuda even in the wetter zones, like Greencastle, evapotranspiration exceeds effective rainfall in eleven months of the year, resulting in vegetative growth being significantly constrained by lack of water in most years. This means that cropping sites and the crops must be carefully selected on the basis of design rainfall, cumulative runoff and reference crop evapotranspiration rates. Figure 1 below shows that even where drought conditions are less extreme, the impact of steady evapotranspiration rates can be significant. Based on the foregoing, success of the application of the technology will also require an appreciation for soil plant water relationships, among agriculture extension officers and lead farmers.



**Figure 1 - Total rainfall and extrapolation for driest part of Grenada**

The rainwater harvesting practices captured in the photographs shown in Figures 9 and 34 of the document are evidence of the resilience of small farmers to collect even the limited amounts of water from such crude methods. It is clear however, that the quantity of water collected using these methods is insufficient to maintain crop production for more than a short duration of the dry periods. In the absence of properly designed systems, rainwater harvesting from runoff will continue to be insufficient to satisfy farm needs for supplementary irrigation.

The study observed that fair numbers of small farmers have very good experiences in the use of high efficiency micro-irrigation systems. These include the use of sprinklers and micro-drip systems. These experiences are favorable pre-conditions for the adoption of rainwater harvesting. It was also observed that in most of the countries, there are adequate service providers in micro-irrigation systems. Extension personnel in the respective Ministries of Agriculture also had good knowledge of the management of micro-irrigation systems.

The study found however, that development of the technology has been hampered by relatively limited financial and technical support. As a result, the rainwater harvesting

practices have remained close to indigenous or ad-hoc activities at best, and are still not yet recognized as a strategic response to increase access to water for agriculture.



## 4

### **Recommendations for rainwater harvesting systems for agriculture in the Caribbean subregion**

Introduction: Rainwater harvesting technology is being adopted across the countries of the subregion using a wide range of practices. Country specific findings on these practices in Appendix 1 are strong indicators of the demand for the technology and the creativity of some farmers to collect and store runoff.

The recommendations proposed in this document include improvement of current and new rainwater harvesting systems, which if properly managed should increase access to water for irrigation throughout most of the dry periods. They represent a selection of best options for adoption of the technology based on topographical, geological and meteorological features of the six countries included in the study. Roof tops and natural and artificial slopes are the main types of catchment proposed, different types of dam systems are proposed to increase interception and storage of runoff water and micro-irrigation systems are recommended for increased efficiency in the use of stored water. The layouts of the different combinations of catchment, interception, collection and storage recommended for the subregion are described below. The information focuses on the main features of the physical structure and assumes that readers have basic knowledge of terminologies such as dams, ponds, conveyance and micro-irrigation systems.

#### 1. Build mini-dams on seasonal waterways to store rainwater

Mini-dams are proposed primarily for small farms located on hillsides. The storage capacity recommended for these small farms is in the range of 5 000 and 200 000 cubic meters. In situations where large numbers of farmers are concentrated in close proximity, the recommendation is that consideration be given to the establishment of demonstration sites to reduce the cost of farmer training programs and as a promotion tool for the practice.

Figure 2 illustrates the layout of the rainwater harvesting system for a mini-dam scheme. The main features of the system are the dam, storage facility, and the conveyance for water supply to the farm.

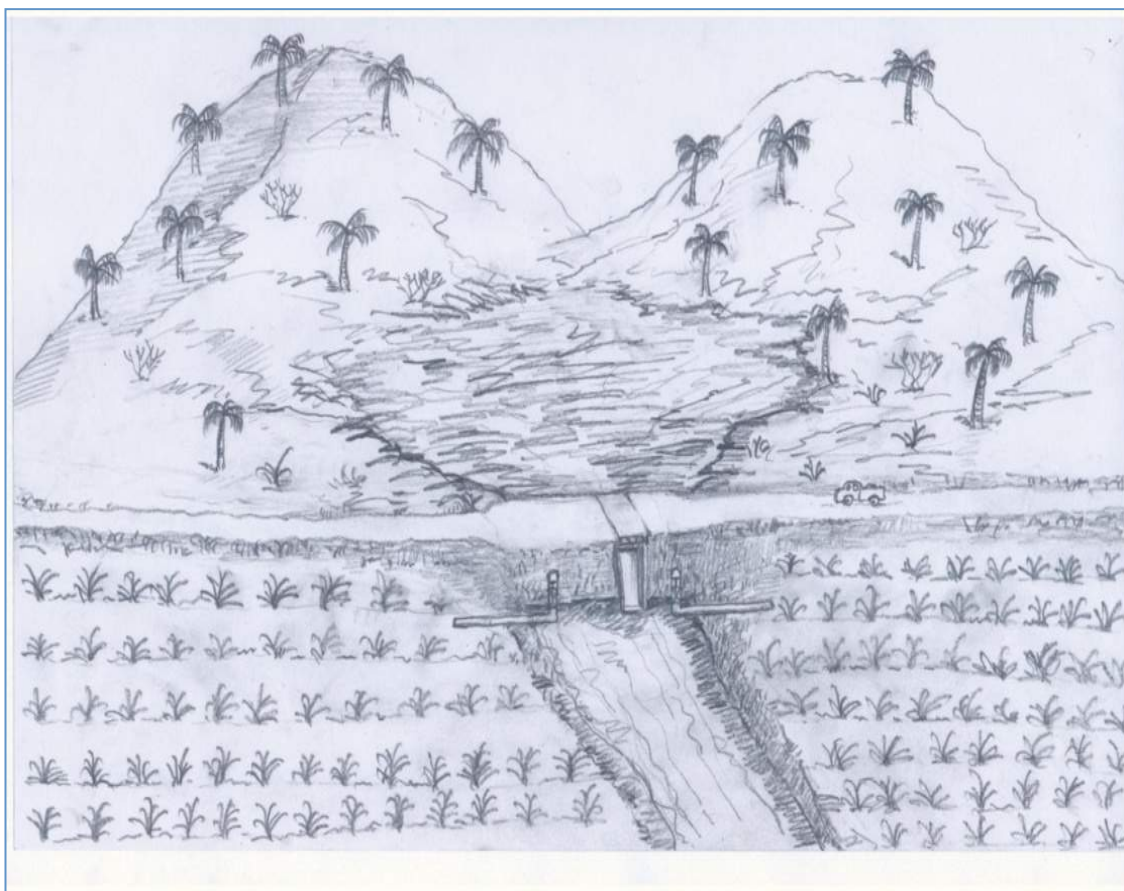
**Dam:** The dam may be constructed from earth, especially where clay soil is available. For those farmers who can afford to build a concrete structure this would be more desirable.

**Storage:** Storage for the harvested water should be a natural basin in the watercourse. It is recommended that a geological survey or other appropriate assessment is conducted to ensure there is no leakage in the storage basin.

**Water supply:** Gravity fed water supply is recommended where possible. The dam should therefore be positioned at a level, where water can be delivered by gravity flow.

**Irrigation system:** In most cases a regular pipeline will provide adequate conveyance from the reservoir to the farm, to supply a drip or micro sprinkler system.

The mini-dam system of rainwater harvesting is recommended for Jamaica, Barbados, Grenada, Dominica, Antigua and Barbuda and Montserrat.



**Figure 2 - Layout of mini-dam for rainwater harvesting**

**2. Road-cross dam for interception of runoff**

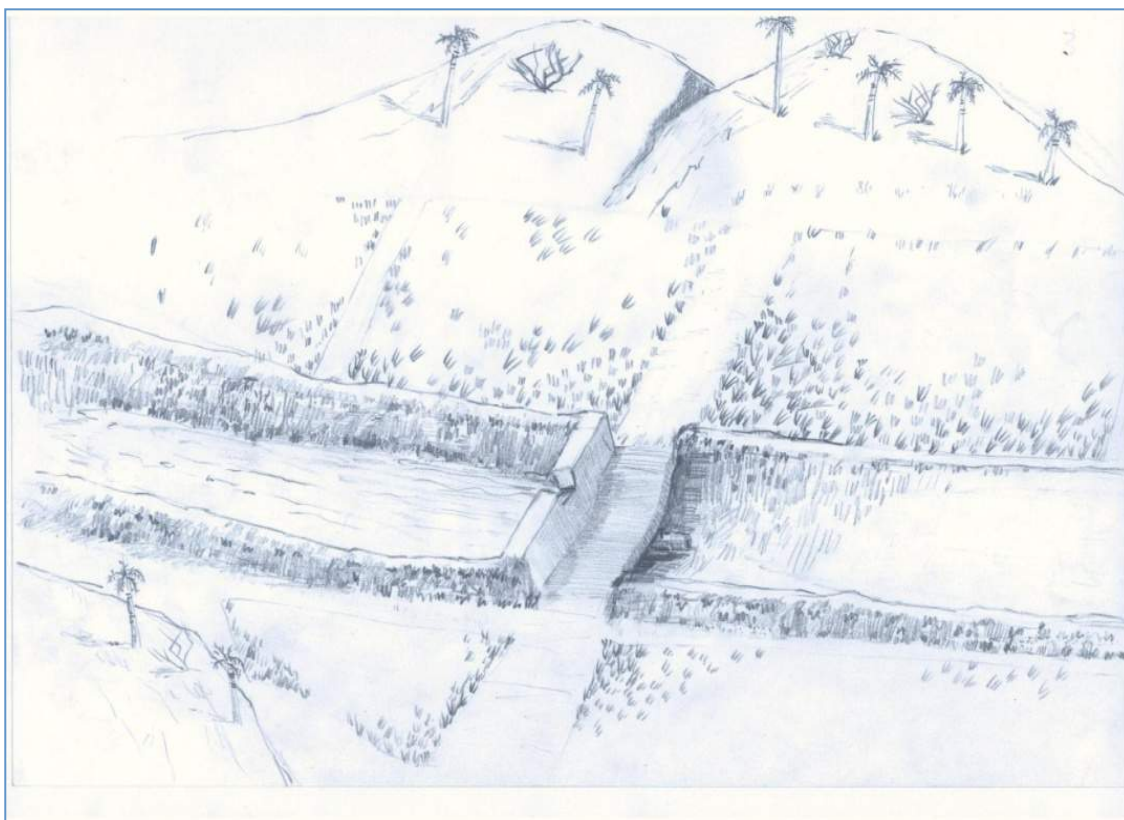
There are many places in the subregion where seasonal waterways cross rural roads or paths. The common structure to manage this situation is usually a bridge or culvert. In a few cases a concrete pavement is built across the road. The proposal is that the construction of the concrete pavement is modified to function as a dam or reservoir on the seasonal river-course. The main features of the layout of this system are illustrated in Figure 3.

**Road-cross dam:** This acts as a dam for water storage. Professional engineering assistance is necessary to design the structure in order to minimize the use of concrete, other input costs and to ensure that the dam is properly constructed.

**Storage:** Storage is provided in the natural temporary river-course, often of considerable volume. Mild excavation may be carried out in order to enlarge storage capacity.

**Water supply:** Based on the topography of the farm, delivery of water to the field may be by gravity flow or pumping. Drip or micro-sprinkler system is recommended for water use efficiency.

The road-cross dam is highly recommended for Barbados, where in many locations concrete pavements are built at points where seasonal waterways cross small rural roads or paths.

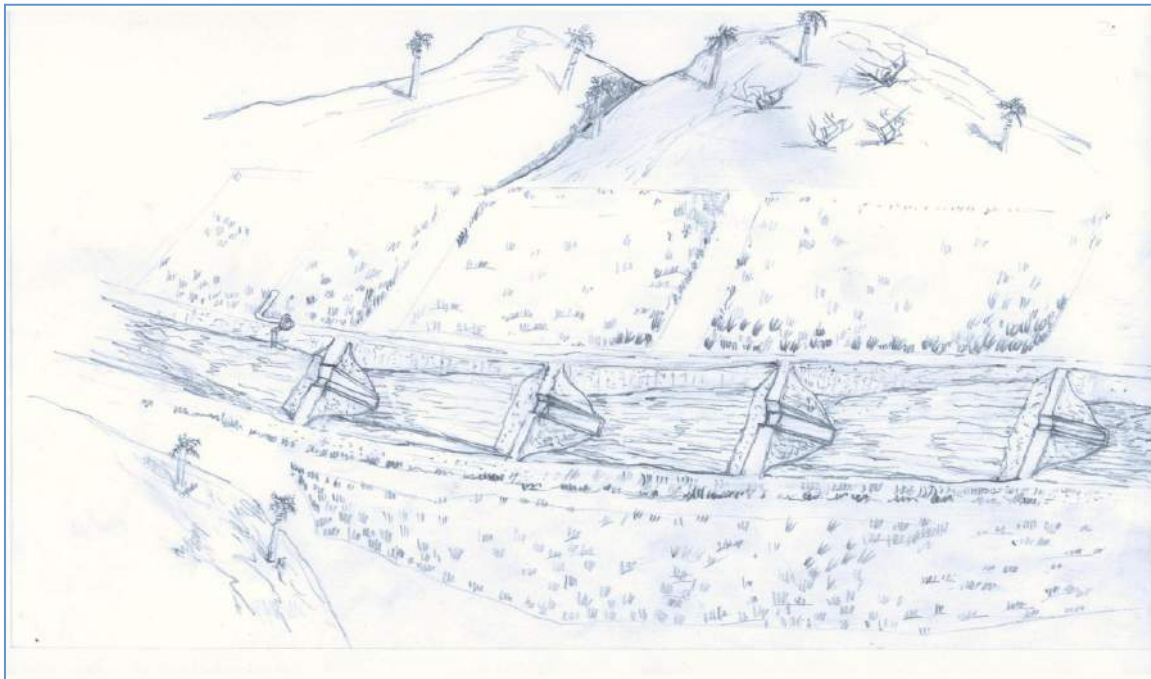


**Figure 3 - Layout of road-cross dam for rainwater harvesting**

3. Series dams on same river-course.

Series dams are recommended for areas where the structure is built on a river with substantial surrounding areas of submerged arable lands, as in the Central Plains of Antigua and Barbuda. The purpose of employing series dams is to reduce the amounts of surface area exposed to evaporation, when compared with a larger dam. The design of the dams normally requires light engineering inputs. Some guidelines for a suitable design of the storage structure for a series of small dams along a river are given below:

- Rivers with depth between 1.0 and 2.5 meters and width between three and ten meters will provide more than adequate natural space for storage of runoff in dam.
- Areas of the river with trees and other vegetation growing along the banks will be less exposed to loss of water from evaporation.
- Farms receiving the water supply for irrigation should be close to the banks of the river.
- The dam may be an earth or concrete structure depending on the geological structure and on availability of suitable clay soil. In the case where the best option is an earth-dam, a concrete or masonry overflow should be included.
- The series dam system will not facilitate water supply by gravity flow hence a pipeline pump system should be installed to supply water to the field.



**Figure 4 - Layout of series dams on same river course**

The layout of the series dam is illustrated in Figure 4 above. This system is highly recommended for the Central Plains of Antigua and Barbuda and is suitable for other arable areas across the subregion with similar topography.

#### 4. Rainwater harvesting from the natural slope

It is feasible to harvest rainwater runoff from natural slopes. These slopes must provide minimum rainwater collection efficiency of between 25 percent and 30 percent and function best where minimum rainfall received over the slope is over 1000 mm annually.

The layout of typical rainwater harvesting system from a natural slope is described below and shown in Figure 5.

**Catchment:** Measures to increase the collection efficiency from the bare surface of a natural slope may include compaction of the soil surface or other actions such the cleaning of the ground vegetation to facilitate increase runoff. It was observed that some farmers have also paved the surface of the natural slope as shown in the photograph below.

**Storage:** The storage area may be a natural or artificial pond or a concrete tank, according to the affordability and choice of the farmer. Where storage is in a pond there can be considerable loss of water from seepage if the structure is built with earth. Loss of water may be reduced or prevented by selecting an area with clay soil. Applying a sealing membrane may also prevent seepage, especially where the soil type has high infiltration rates. The natural pond may be modified to increase storage by placing a dam or a dike in the lowest position of the depression. Care should be taken to ensure that the modified structure is at a level where the height of the stored water is lower than the surrounding ground, thereby facilitating easier gravity flow through the conveyance and on to the farm. A sluice by the side of the dam will



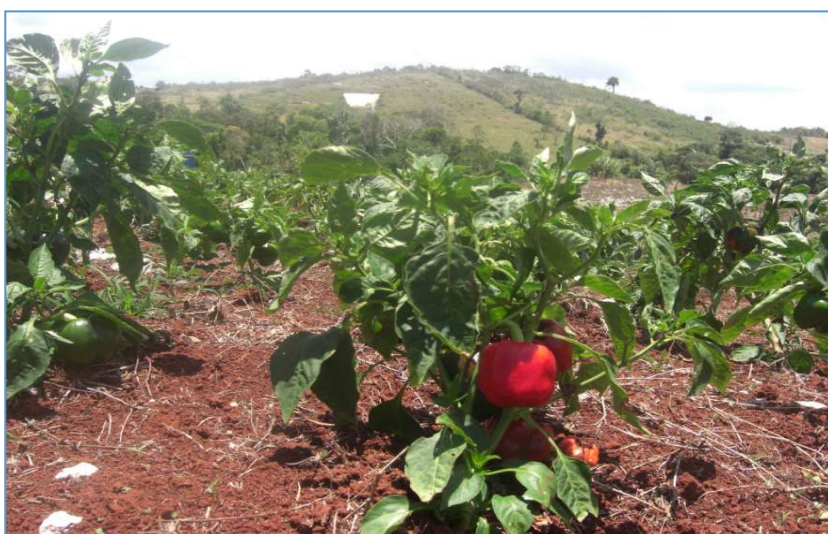
avoid spilling over the sides during a storm.

Water supply and irrigation: Gravity supply is recommended as this can reduce the operational cost of irrigation. Drip and micro-sprinkler are proposed as the ideal irrigation system.

Rainwater harvesting systems from natural slopes are recommended for Jamaica, Grenada, Dominica and Montserrat.



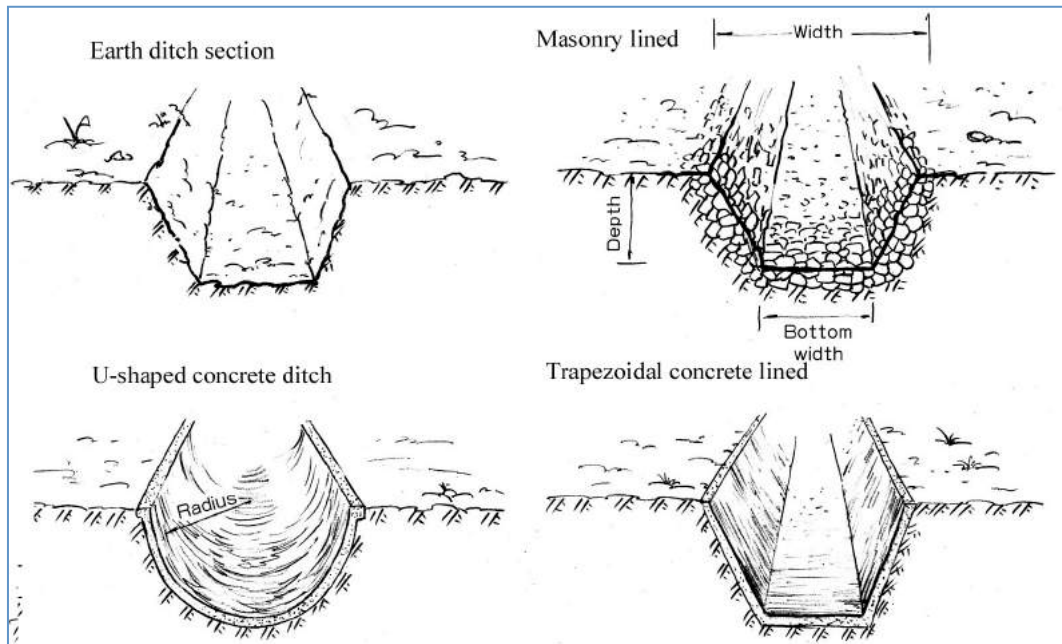
**Figure 5 - Layout of rainwater harvesting from natural slope**



Small hillside vegetable farm irrigated from runoff from paved natural slope (white spot) in the hill and stored in concrete tank

**Figure 6 - Representation of hillside farmer's layout for harvesting from slope in Jamaica**

Interception ditch and convey canal: Depending on the degree of the slope it may be necessary to build interception ditches and a convey canal at the lower position to regulate the flow into the storage facility. Figure 7 below illustrates the different types of interception ditch and convey canal which may be used.



**Figure 7 - Section of interception and collection canal**

#### 5. Rainwater harvesting from artificial slopes

Existing pavements and other similar forms of hard artificial surfaces can be made to function as catchments. These include surfaces of highways, airports and school playgrounds among others.

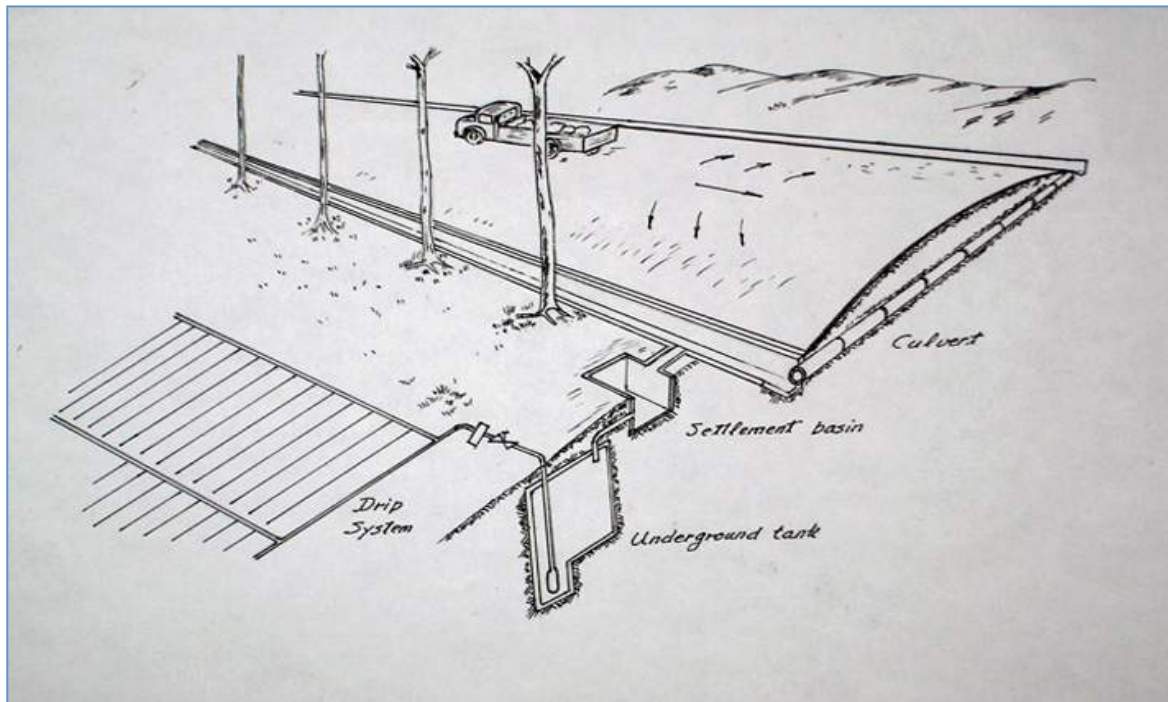
Artificial surfaces are highly impermeable with relatively higher rainwater collection efficiencies estimated at between 50 percent and 85 percent, when compared with bare natural slopes. The types of artificial surfaces recommended are often relatively low cost in terms of input, as they require minimum modifications to intercept rainwater runoff. The most common modifications required include the construction of one or more collection trench by the side of the catchment, installation of a gutter or the construction of a shallow ditch, immediately below the surface of the road.

Attention should be given to the correct placements of the tanks at the downstream of the decline. The volume capacity of the tanks should also be adequate to collect all the runoff from the area of catchment along the highway. Where there is no drainage ditch then it is necessary to build collection ditches. If there are already drainage ditches at the side of the highway the only other requirement is that an additional ditch is constructed to divert water out of these ditches, at certain points.

Among the different types of highway pavements, the concrete type is most ideal for good quality water. Asphalt paved highways are often contaminated with petroleum or other

types of chemical pollutants which can make the water runoff unhealthy for washing farm produce, though adequate for irrigation. An electric or diesel-pump is recommended where gravity flow is not possible.

The layout of the system from a highway is shown in Figure 8 below. These systems are recommended for Jamaica, Barbados and Montserrat and for consideration in other parts of the subregion where similar artificial surfaces exist.



**Figure 8 - Layout of the rainwater harvesting system by intercepting rainwater runoff from highway**

## 6. Rainwater harvesting from various types of rooftops.

6.1 Household rooftop rainwater harvesting for irrigation of backyard farms and gardens: The recommendation is that the current practice of rainwater harvesting for domestic water is extended to include water harvested for backyard cultivation. Calculations of annual rainfall in the driest parts of Antigua and Barbuda and in Montserrat confirm that annual cumulative storage will be adequate for household use and for irrigation, to sustain yields from vegetables and vine fruits for the farm household. The typical layout of rainwater harvesting from household rooftops for backyard (micro-farms) farming is described below and illustrated in Figure 9.

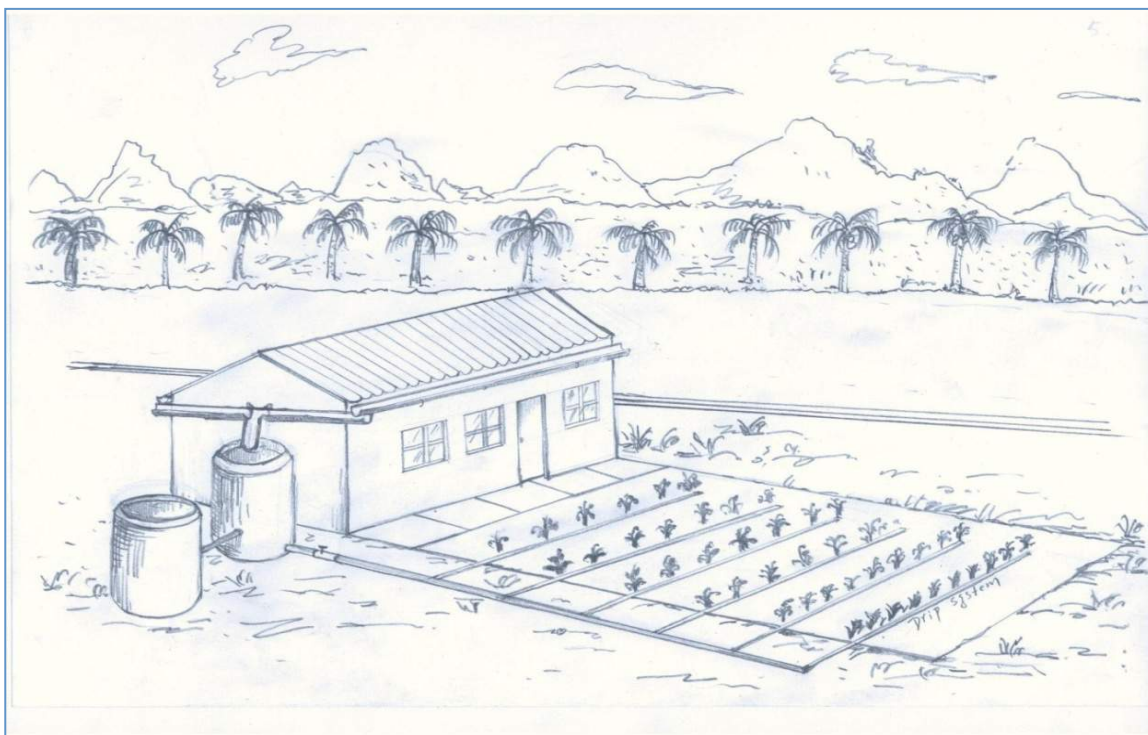
**Roof catchment:** Galvanized iron sheets provide roof surfaces with high rainwater collection efficiencies, usually in excess of 85 percent. Based on this level of efficiency households with an average roof area of 150 m<sup>2</sup> can harvest an estimated 240 m<sup>3</sup> of rainwater annually in the Antigua and Barbuda and in Montserrat. This quantity of water is usually more than is required for household use with the balance available for irrigation for the backyard crops.

**Rainwater conveyance system:** The regular guttering and pipes installed to collect and convey rainwater into storage for domestic purposes may also be used for runoff harvested for agriculture.



**Storage:** Storage may be in drums or concrete tanks positioned as shown below. The drums are readily available on the local market and are already used by householders for storage of domestic water. Concrete tanks are also suitable. Many are already in use and may be built underground or above ground depending of the availability of space around the house.

**Water supply and irrigation system:** In situations where the storage is underground, a pump should be installed to ensure reliable supply of water to the field. Storage above ground usually provides an opportunity to gravity feed water supply to the field. It is recommended that drip systems or micro-sprinklers be employed for efficient application of the limited water.



**Figure 9 - Layout of house rooftop rainwater runoff for backyard farm irrigation**

6.2 Mini roof rainwater harvesting for vegetable production: Mini roof water harvesting is suited to areas where the periods of water scarcity for the crop last on average less than eight weeks and where precipitation rates are high. This system is most suitable to small and micro-farms operated long distances from the home, where rainwater harvesting is the only alternative to access supplementary water for irrigation. As the amounts of water stored are usually small there are some conditions for adoption of the system including (a) the location of the farms should be in humid or semi-humid areas, with high precipitation (b) the periods of drought or water scarcity should be short (c) irrigation requirements should be for small sized farm and (d) micro irrigation system is the preferred method of water application. The layout of the system is illustrated in Figure 10 below.

**Roof catchment:** Assuming that galvanized iron sheets are the roof material of choice, the catchment will provide rainwater collection efficiency estimated at 85 percent. Accordingly a system with area of 10 m<sup>2</sup> of roof will harvest about 15 m<sup>3</sup><sup>7</sup> of rainwater on average annually.

**Conveyance system:** Guttering and pipes must be installed to collect and convey rainwater into storage.

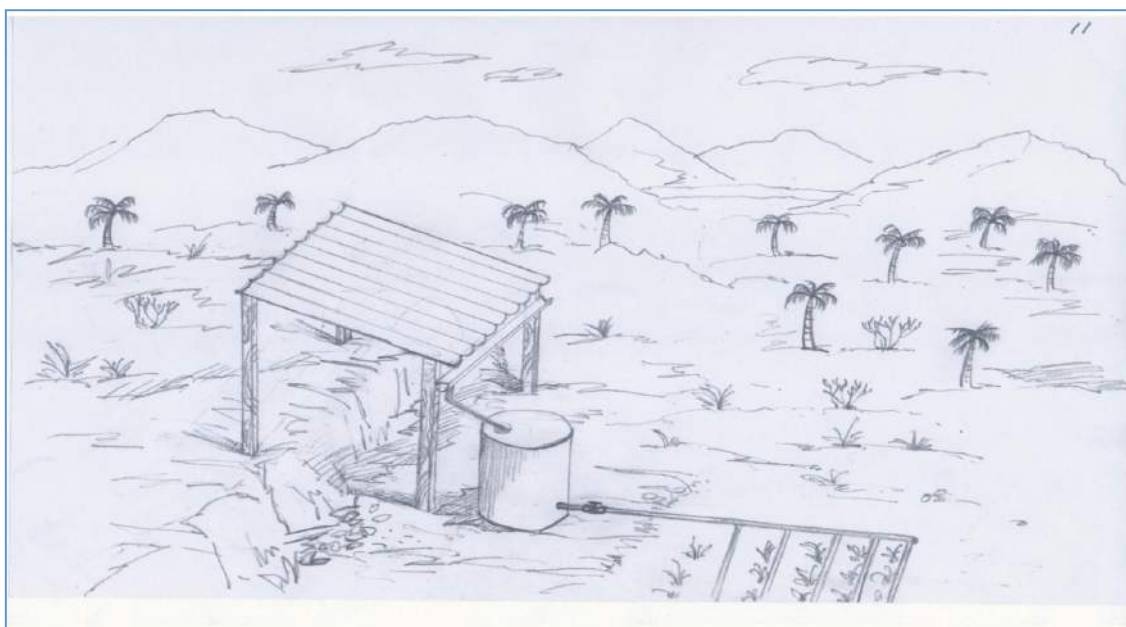
<sup>7</sup> Estimated design rainfall 1 760 mm



**Storage:** One or more drums may be placed inside the shed. In situations where the shed is also used for storage of agricultural tools or products, the drums should be placed outside of the shed (See Figure 10 below). Cheap plastic bags of appropriate sizes could also be set up outside the shed to collect water.

**Water supply:** The location of the system is best when positioned at a higher elevation, which is close enough to the farm to permit gravitational flow. Pumps are recommended but the farmer's ability to purchase should be a major factor in the determination of how water will be supplied to the farm.

**Irrigation:** Micro-drip and other similar systems are strongly recommended for high efficiency. However where this is not affordable to the farmer hand watering from a bucket, plant by plant with the nozzle held close to the roots is also acceptable.



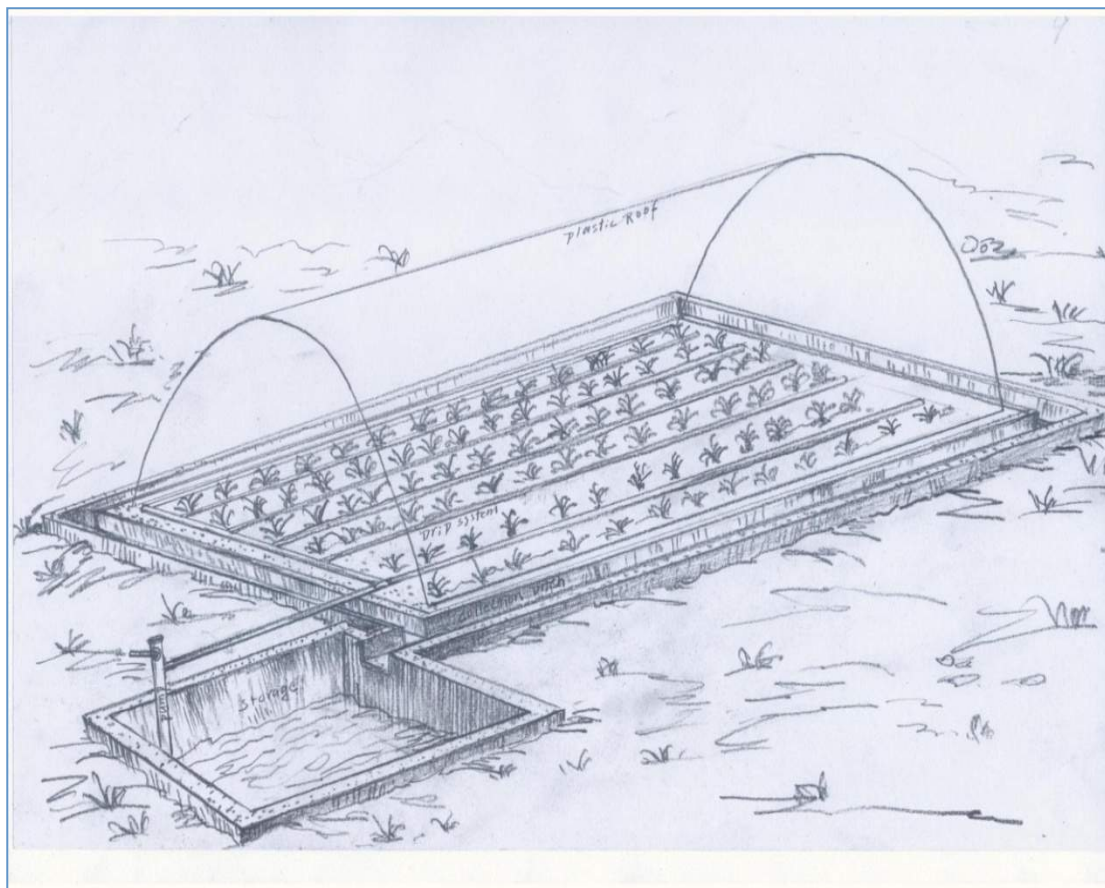
**Figure 10 - Layout of mini roof rainwater harvesting system for small vegetable garden**

The mini-roof system is recommended for Montserrat, Grenada, Jamaica and Dominica and other parts in the subregion with similar situations as described in this section.

**6.3 Rainwater harvesting system from plastic roof of greenhouse:** Plastic roofs of greenhouses used as catchments for rainwater runoff provide rainwater collection efficiencies of over 95 percent. Water collected from greenhouse roofs is also of high quality. The quantities collected are usually in volumes which are adequate to supply water for three to four harvests of greenhouse vegetables, when water is applied through micro-irrigation.

Rainwater harvesting from plastic roofing is very efficient when compared with some of the systems mentioned earlier in the document. For example a greenhouse with area 500 m<sup>2</sup> and design rainfall in excess of 1 500 mm could harvest about 900 m<sup>3</sup> of rainwater annually. Even in the drier locations, where annual rainfall is as low as 889 mm there is the potential to harvest 400 m<sup>3</sup> of water annually. This amount of cumulative storage will ensure sufficient supply to meet irrigation demands for crops inside of the greenhouse using drip system. Storage tanks should be built outside the greenhouse to avoid using space in the production area of the greenhouse. Supply of water to the greenhouse plants may be powered by electricity or hand-pressured pump.

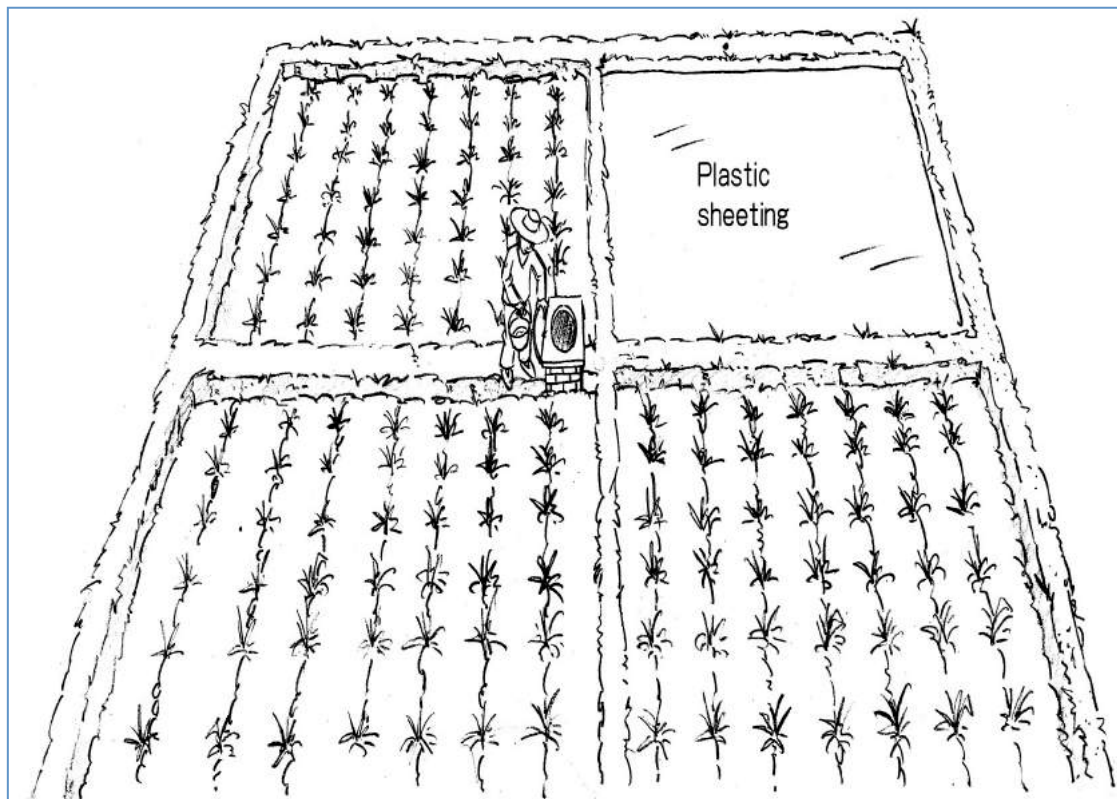
Figure 11 below shows the layout for rainwater harvesting from a greenhouse roof. The system is recommended for Barbados, Grenada, Dominica and Jamaica and any other country in the subregion with conditions that satisfy requirements for the practice.



**Figure 11 - Layout of rainwater harvesting system from greenhouse roof**

#### 7. Use of plastic sheeting as catchment for rainwater harvesting for irrigation

There are many locations in the countries where areas of fallow land ranging from between 200 m<sup>2</sup> and 300 m<sup>2</sup> or more exist. Moveable plastic or plastic mixed with cloth placed over the bare ground in these areas can function as catchment surfaces for harvesting rainwater. As with the greenhouse roof, the plastic transforms bare ground into high collection efficiency surfaces. One way in which the plastic could be used is to divide the farm into four quarters and to cover one of the quarters of bare ground with plastic film as shown in Figure 12. Each year another quarter of bare ground is covered with plastic film (thickness of 0.001 mm) to function as a catchment surface for the rest of the cropped field. In the following year another quarter of bare ground would be covered and a cycle is developed. Although each year the farmer will not reap a harvest from one quarter of land, the returns from the three quarters of irrigated land compensate for much more than the loss of production from the fallow land.



**Figure 12 - Layout of plastic sheeted field catchment**

## 5

### Designing rainwater harvesting systems for agriculture

Introduction: The goal of the rainwater harvesting system is to ensure there is adequate water in storage for irrigation during periods of water scarcity caused from normal or extended periods of drought. The technology is based on probability analysis of series rainfall data to determine the frequency of a certain annual rainfall pattern, the calculation of the amount of rainwater runoff from a known catchment area and the annual cumulative storage. Factors that affect the adequacy of the amounts of water stored are reference crop evapotranspiration rates at the cropping site and irrigation efficiencies. This section of the document focuses on the methodology to determine frequency of a certain rainfall pattern from series rainfall data. This certain rainfall pattern will be the design rainfall for the specific location associated with the series data.

Selection of design rainfall is the most challenging part of rainwater harvesting as the integrity of the entire system can be compromised if the rainfall frequency is not reliable. If annual rainfall is less than design rainfall, the water stored might not be sufficient to maintain the crops throughout the dry periods. On the other hand if design rainfall is in excess of expectations the amounts and intensities could damage the system and flood the crops.

The document adopts the application of an empirical formula endorsed by international bodies including FAO to determine the probability of the frequency of a certain rainfall pattern and amounts (see below). Relevant data for the analyses are borrowed from series data for Grantley Adams International Airport in Barbados.

Methodology to calculate the design rainfall: The design rainfall is defined as the total amount of rainfall and its distribution which can be reliably expected annually, thereby providing a basis for calculating how much rainwater runoff can be harvested annually. Design rainfall is calculated on a probability analysis of 90 percent frequency of a certain rainfall pattern selected from series data on annual rainfall.

The empirical formula adopted by the document is shown below:

$$P = \frac{m}{n + 1} * 100$$

Where

P is frequency of rainfall in percentage.

m is the rank order of rainfall series which sorted from the lowest to the highest.

n is the number of years of the rainfall series.

The thirty 30 years rainfall data (Figure 13) collected at Grantley Adams International Airport in Barbados is used to demonstrate how the design rainfall is determined.

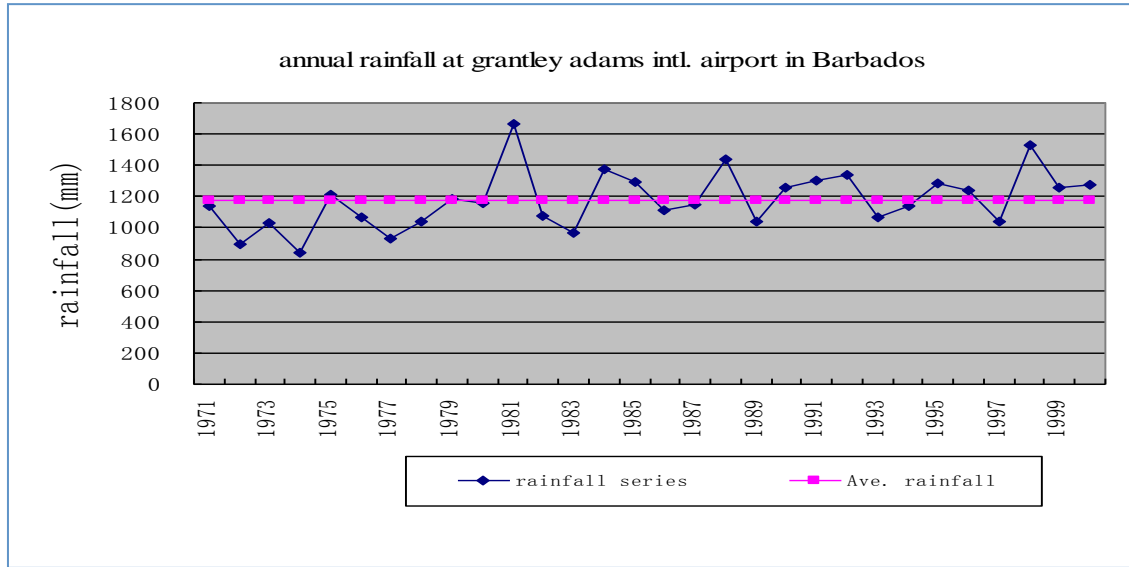


Figure 5 - The series data on annual rainfall at Grantley Adams International

According to Figure 13 average annual rainfall at Grantley Adams is in the range of between 800 mm and 1 700 mm. For a total of 14 years annual rainfall is more than average while for a total of 16 years annual rainfall is less than average. In the normal years the rainfall received on the farms in and around the Airport can mostly meet the agriculture production needs during the wet season. However, during the dry seasons farmers experience water scarcity, resulting in droughts and soil water deficits in the cropping system. Irrigation is therefore necessary for plant growth and crop production, especially in sensitive crops such as vegetables

The task is to determine the annual rainfall that can support reliable planning for rainwater runoff and storage, hence the coefficient of variation (Cv) and skewness coefficient (Cs) of the rainfall year selected (design rainfall) are also calculated.

The formula below may be used to determine the coefficient of variation and skewness coefficient of design rainfall.

$$Cv = \frac{1}{x_a} \sqrt{\frac{\sum_{i=1}^n (x_i - x_a)^2}{n-1}}$$

$$Cs = \frac{\sum_{i=1}^n (x_i - x_a)^3}{x_a^3 (n-1) Cv^3}$$

Where

Cv is the variation coefficient

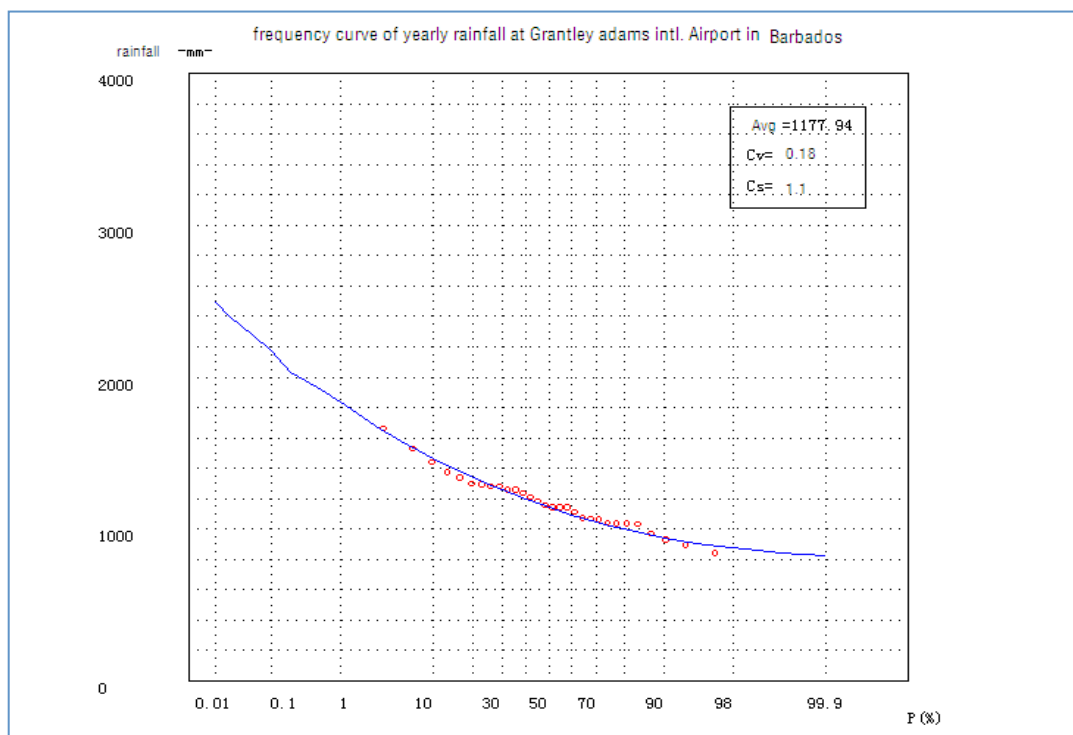
Cs the skewness coefficient,

$x_i$  is the yearly precipitation in the  $i$ th year, and

$x_a$  is the average yearly precipitation of the series.

$$x_a = \frac{x_1 + x_2 + \dots + x_i + \dots + x_n}{n}$$

In practice, the value of  $C_s$  is determined using the curve fitting method<sup>8</sup>. As a first step, all the actual yearly precipitation data are plotted against the empirical frequency on probability paper to derive a curve of the frequency distribution (Figure 14 below). The objective of this exercise is to find the annual rainfall with a frequency of 90 percent<sup>9</sup> using the empirical formulae



**Figure 14 - Frequency curve of annual rainfall at Grantley Adams in Barbados**

Using the frequency curve, the rainfall of varying frequency can be displayed as in Table 1 below. In this case, the annual rainfall of 943.2 mm satisfied the 90 percent frequency in the series rainfall data and is selected as design rainfall for Grantley Adams International Airport.

**Table 1 - Distribution of the design rainfall (mm) with frequency 90% - Grantley Adams International Airport**

Frequency (%)	1	2	5	10	20	50	75	90	95
Rainfall (mm)	1832.5	1726	1580	1462.3	1335.9	1139.8	1022.3	943.2	906.5

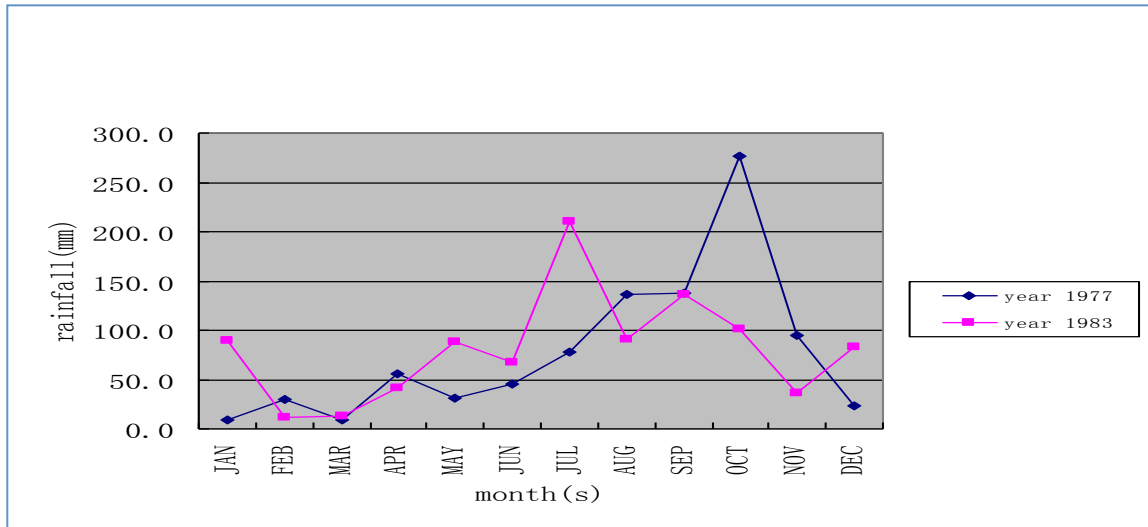
Based on the 30-year series rainfall data, 1977 and 1983, with annual rainfall of 929 mm and 971 mm, respectively emerge as most typical of design rainfall (Figure 15).

When both years are compared to the design rainfall (943.2 mm) the year 1977 with annual rainfall of 929 mm is selected, as it is closer to and slightly below the design rainfall (943.2 mm). With this selection the reliability of the irrigation system, which is dependent on the water supply

<sup>8</sup> The distribution of rainfall data follows the Pearson curve

<sup>9</sup> The 90% probability is recommended for design rainfall in humid regions.

from runoff, will be higher.



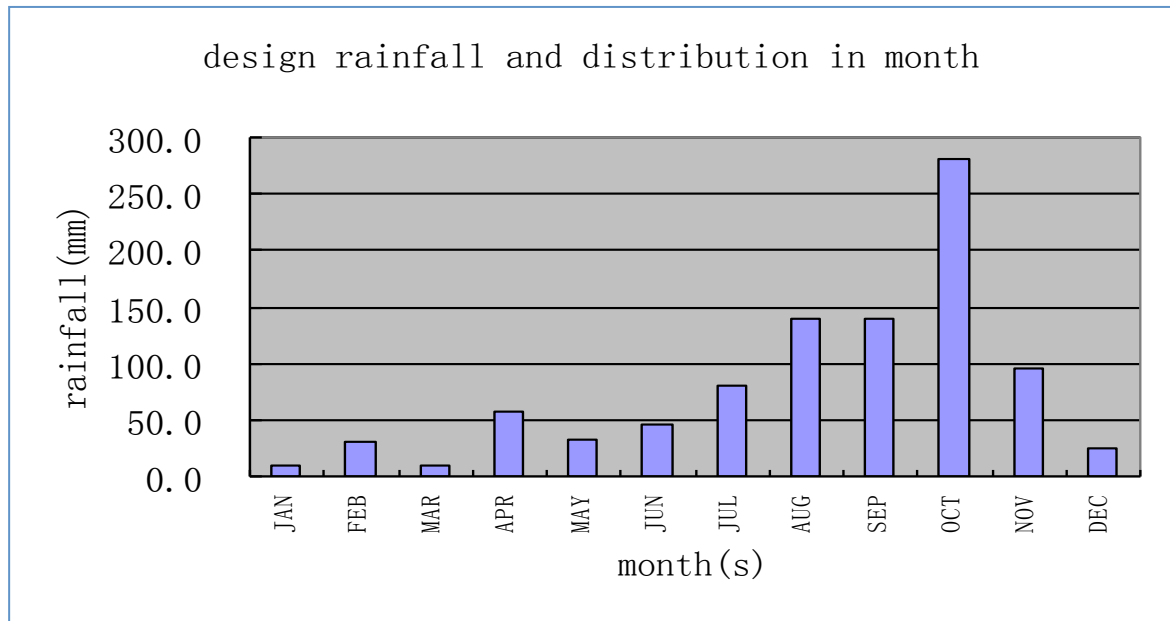
**Figure 15 - Rainfall of representative year with frequency 90% at Grantley Adams International Airport**

The monthly distribution of the representative year 1977 can be displayed as in Table 2 below and in Figure 16.

**Table 2 - Distribution of the monthly design rainfall (mm) with frequency 90%**

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	9.0	30.9	9.3	56.5	31.7	46.4	79.4	139.0	139.5	281.3	96.2	24.2
Design yearly rainfall (mm)	943.2											





**Figure 6 - Distribution of design rainfall in month (mm) at Grantley Adams International Airport**

Catchment area and storage capacity: The adequacy of the catchment area and the storage capacity requires knowledge of the water demand, rainwater collection efficiency (RCE) of the catchment, the design rainfall and the irrigation system to be employed.

Owing to a lack of RCE data of the various materials used in the sub region, the RCE is recommended according to the practice in China and shown in Table 3 below.

**Table 3 - RCE of different catchment materials**

Material of catchment surface	Yearly RCE (%) with different annual precipitation		
	250-500 mm	500-1000 mm	1000-1500 mm
Concrete	75-85	75-90	80-90
Cement tile	65-80	70-85	80-90
Clay tile (machine made)	40-55	45-60	50-65
Clay tile (handmade)	30-40	35-45	45-60
Masonry in good condition	70-80	70-85	75-85
Asphalt paved road in good condition	70-80	70-85	75-85
Earth road, courtyard, threshing yard	15-30	25-40	35-55
Cement soil	40-55	45-60	50-65
Bare plastic film	85-92	85-92	85-92
Plastic film covered with sand/soil	30-50	35-55	40-60
Natural slope (rare vegetation)	8-15	15-30	30-50
Natural slope (nice vegetation)	6-15	15-25	25-45



The required area of catchment of a rainwater harvesting system may be calculated by using the following equation.

$$A = \frac{W_d}{R_p \cdot RCE_y}$$

Where,

A is the area of catchment,

$W_d$  is the water demand in one year,

$R_p$  is the rainfall of certain frequency p and,

$RCE_y$  is the annual rainwater collection efficiency.

Volume capacity of the storage may be determined using the equation below:

$$V = \frac{W}{F}$$

Where,

V is the volume,

W is the water supply amount and

F is a coefficient, which denotes the number of full-and-empty cycles of the tank in one year

## 6

### **Recommendations:**

On the basis of the study it is recommended that:

- Rainwater harvesting for agriculture is promoted and encouraged through policy and institutional support and discreet national programs implemented in all the countries of the subregion. It is further recommended that special consideration be given to farmers operating on hillsides. The program should be phased starting with the six countries in the study.
- National agriculture extension systems should include or be strengthened to build capacity among lead farmers and farmer's organizations in the selection of natural slopes for rainwater runoff collection and storage facilities. The poor quality of dam construction is a major concern and should be addressed as part of the extension services.
- The respective Ministries of Agriculture establish a program to map sites according to design rainfall as an input to the phased program for rainwater harvesting for agriculture. This should probably be done with an agro-ecosystem approach and maps should be easily accessed online or at the agriculture district offices.
- Technical cooperation programs be developed with subregional agencies such as CCCCC and CDB, the relevant development partners operating in the subregion and bilateral arrangements, to provide technical and financial support for rainwater harvesting for agriculture. It is further recommended that this program, with substantial development support, be integrated into the subregional program to alleviate household food insecurity and the declines in farm household incomes from agriculture.
- The communal approach to rainwater harvesting for agriculture, which is practiced in Dominica be further examined to determine value-added compared with individual approaches to the practice and that the common practice of rainwater harvesting for domestic water is extended to include water harvested for backyard food farms.
- At an early stage, issues such as encroachment on neighbors' rainwater runoff, ownership and rights to interception of runoff across adjacent farms be resolved either through social organizations or other regulatory mechanisms. .
- Ministries of Agriculture establish a baseline from which to monitor and evaluate the benefits of rainwater harvesting on small scale production including backyard farming as well as the impact of the practice on stream flow and other products and services of the watershed.
- Consideration should be given to the wide dissemination of this document and to the companion document Compendium on Rainwater Harvesting being developed, as a training tool on the establishment of reliable rainwater harvesting for agriculture. Both documents are farmer friendly and could serve as important tools for wider use in promoting rainwater harvesting in small and backyard food production systems.

## 7

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## **APPENDICES**

## **Appendix 1**

Country specific information relevant to feasibility of rainwater harvesting for agriculture

### **Antigua and Barbuda**

General information relevant to rainwater harvesting

**Location, geology and soils:** Antigua and Barbuda is located in the eastern arc of the Leeward Islands. The country is divided into three topographic zones: the mountainous southwest region, the relatively flat central plains and the rolling limestone hills and valleys in the north and east. The volcanic region in the southwest is composed of rising hard igneous rocks in the uplands and sedimentary material in the associated valleys. The central plains are composed of a mixture of agglomerates, tuffs, and conglomerates, together with some cherts and limestone, while the northeastern limestone region is composed of a mixture of hard limestone and softer marl deposits.

Soils are conveniently grouped into five broad categories according to depth and texture. These are described as (a) deep alluvial soils in the valley systems of the volcanic region, primarily sandy loams (b) deep kaolinitic clay soils of the central plain primarily heavy clays (c) shallow calcareous clay soils of the limestone areas in the north (d) deep calcareous soils, mostly in the eastern part of the limestone region and (e) the shallow soils of the mountainous volcanic region, mostly clay loams.

**Climate:** Antigua and Barbuda experiences a tropical maritime climate with little variation in daily or seasonal temperatures. Average monthly minimum temperatures range from between 22.4°C in February and 25.4°C in August, while monthly maximum temperatures range from between 27.9°C in February and 30.5°C in September. Relative humidity averages range from lows of 72 to 78 percent in mid afternoon to early morning highs of between 81 to 85 percent.

**Agriculture:** The sector provides an estimated four percent to GDP with the fisheries subsector providing 50 percent of total agriculture GDP. Major crop production activities are in vegetables and food crops and lesser quantities of vine and tree fruit. Farmers have taken advantage of irrigation and other technologies and a small core of medium sized farms are well developed. These farms can be considered highly efficient with mechanized production technologies and demonstrated potential to produce high quality food competitively. However, the sector continues to experience an inadequate supply of water for irrigation as well as a regular succession of severe droughts and destructive hurricanes in recent years. As a result, many farmers have not invested in much needed infrastructure or marketing systems.



Figure 17 - Map of Antigua and Barbuda

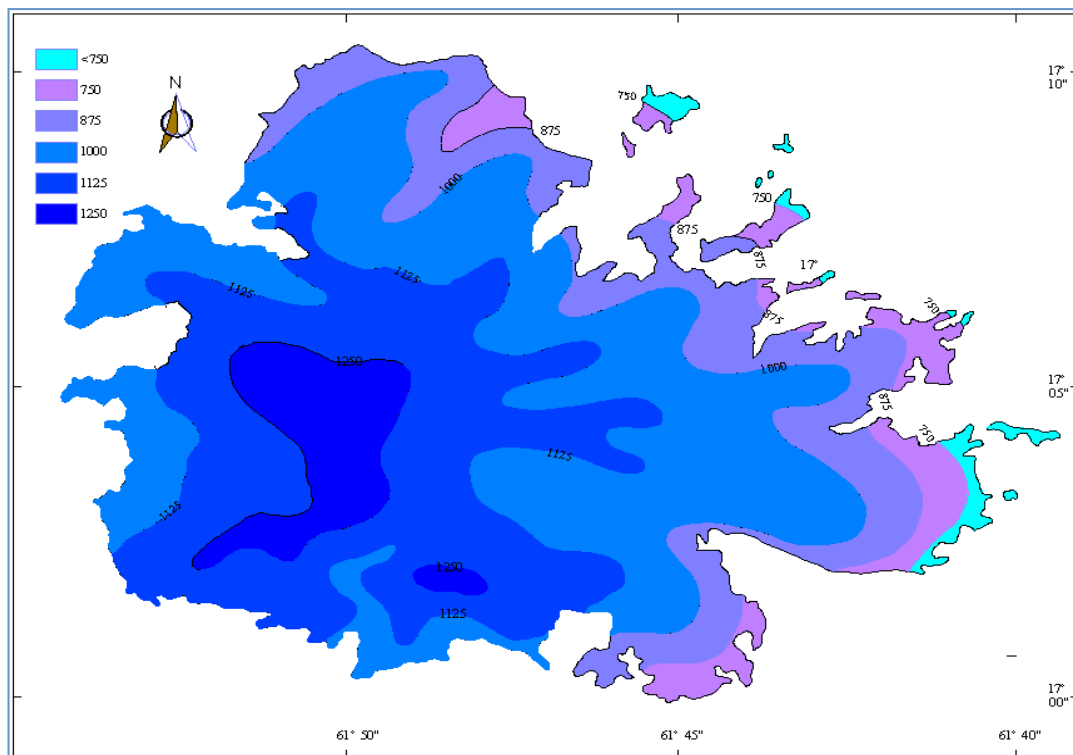
Water supply and management: In Antigua and Barbuda fresh water resources are found in three forms: surface storage, groundwater sources and domestic catchment in cisterns and storage containers. There are no permanent streams or rivers in Antigua and Barbuda. However, it is normal that after heavy or prolonged rainfall, some sections of the larger streams may flow for periods of up to a few months. All the major catchments are dammed at several points to retain stream flow. In addition to these freshwater resources, seawater is being increasingly used to provide water for domestic and agricultural use through desalination.

Most surface storage, including the largest reservoir at Potworks, is shallow and exposed to the prevailing trade winds. The constant wind and high temperatures result in high rates of evaporation loss from these storage systems, especially the mini-dams and ponds. Many of these dry up during the dry season of an average year and do not provide reliable storage for agricultural use. Depending on the depth of drying out of the soils in the watersheds, considerable rainfall is often required before runoff and significant recharge takes place. The majority of storage is located in the Central Plain where topography and soil conditions are favorable.

Rainfall: The geographic distribution of rainfall over Antigua, presented in Figure 18 below, shows that even in the drier areas located in the flatter eastern and northern regions, annual rainfall is still about 750 mm. This is a good indicator that the whole area of the island of Antigua is suitable to rainwater harvesting. The months of January through April are the driest period while September through November is considered wet season. These wet

months coincide with the period of active tropical waves and hurricanes. Barbuda, though drier than Antigua, with average annual rainfall ranging between 760 mm and 990 mm, is also very suitable for rainwater harvesting.

Notwithstanding the above, the use of rainwater harvesting will require careful planning in terms of catchment size and storage capacities. Evapotranspiration rates are quite high due to the steady winds and high temperatures and often exceed daily rainfall amounts. The monthly average ranges between a low of 87 mm in November with a peak of 143 mm in March. On average, even in the wetter zones like Greencastle, evapotranspiration exceeds effective rainfall in 11 months of the year, resulting in vegetative growth being significantly constrained by lack of water in most years. This means that rainwater harvesting will have to be implemented on carefully identified design rainfall, cumulative rainwater storage and reference crop evapotranspiration rates.



**Figure 18 - Geographic distribution of rainfall in Antigua and Barbuda**

Currently irrigation water is provided by a mixture of potable water taken from the desalinization system, surface supplies from reservoirs, mini-dams and ponds and in a few cases from private wells. When water is restricted, municipal needs are paramount and crop and livestock production systems suffer. No reliable figures are available for the current consumption of water for irrigation or the proportion obtained from municipal sources. However, if crop production were increased to meet the levels of importation of fresh vegetables, salad crops and vine fruit, annual demand for water for agriculture has been estimated at over one million cubic meters. At present, only a small percentage of farmers have access to water year round.



The Ministry of Agriculture, through its Soil and Water Conservation Division, has introduced programs to encourage investment in irrigation. The programs are aimed at providing assistance to construct mini-dams and ponds in key production areas to harvest rainwater. The experience so far has demonstrated great potential for rainwater harvesting for irrigation of high value agriculture. On the other hand, progress made in the wider use of the technology has been slow and restricted owing to weak capacity of existing rainwater harvesting infrastructure to meet the demands for water for irrigation.

It is widely accepted that new or improved measures to increase available water for irrigation are critical to assure agricultural development, since desalinated water is not suitable for irrigation and the quantities of ground and surface water are insufficient. Based on the review of the critical factors necessary for rainwater harvesting, the technology has emerged as a good option to source reliable and economic water for crop and livestock production.

Favorable conditions for collection of rainwater runoff: Annual rainfall in Antigua and Barbuda is low with high concentrations over short periods. This rainfall pattern facilitates rainwater runoff interception and storage for use later in the dry periods. The pattern of rainfall observed in Antigua and Barbuda and the features of the physical sites suggest that rainwater harvesting would be best managed through natural catchments and storage in min-dams and ponds. Owing to high evapotranspiration rates, the necessary considerations would include storage which reduces water loss from high surface evaporation rates. Micro-irrigation systems should also be the preferred choice as a further measure against water loss from evaporation.

All indications are that Antigua and Barbuda has good experience in the use of irrigation systems. Approximately 130 hectares of cultivated land is already equipped with high efficiency irrigation facility including sprinklers and micro-drip systems. Presumably a fair number of local farmers have developed adequate experience in the operation and management of sprinkler and drip irrigation systems, including relationships with suppliers and service providers of irrigation equipment.

Recommendations for rainwater harvesting for agriculture: All indications are that in Antigua and Barbuda water demands to satisfy development priorities and the increasing threats from rainfall variability, coupled with geology and soil conditions could worsen freshwater scarcity in the country. On the other hand, strategic management of rainfall events and rainwater runoff could prevent and mitigate some of the negative impact on food production systems, through rainwater harvesting practices. However, in view of the generally strong demand for water, the study foresees the need for a clear policy for water allocation for municipal uses and for agriculture

Against this background, the study recommends that the National Water Authority be given responsibility for policy, development planning and allocation of water resources including water harvested from rainfall runoff. These ideas are not new to Antigua and Barbuda and were first proposed as early as 2001<sup>10</sup>. The study further proposes additional water harvesting practices for Antigua and Barbuda to support the earlier recommendations in the document.

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<sup>10</sup> Integrating Management of Watersheds & Coastal Areas in Small Island Developing States of the Caribbean- Cooper and Bowen 2001

- Mini-dams already in existence across the country are evaluated on (a) technical adequacy of design and construction to correct the problems resulting in non-function of the dams after three years or less of operation (b) poor maintenance leading to failure of operation and (c) weaknesses on technical support for operation and maintenance.
- Consideration is given to the establishment of seasonal dams. These are normal mini-dams located at the narrow exit of a catchment or gorge of a seasonal river with suitable storage space of water. Depending on the topography of the land, it may be possible to situate the dam at a high elevation to supply water to the field by gravity.
- Rooftop harvesting of water for irrigation is recommended for all householders with backyard gardens in order to provide supplementary water for irrigation during dry periods. A typical house with adequate rooftop to function as catchment surface is shown below.



Typical backyard garden in Antigua and Barbuda Wilikies Community, St. Philip, Antigua

**Figure 19 - Backyard garden with no supplementary water from roof runoff**

## Barbados

General information relevant to rainwater harvesting for agriculture in Barbados

**Location, geology and soils:** The general location of Barbados is shown in Figure 20 below. The geology of the country is of non-volcanic origin and is predominantly composed of limestone-coral. Eighty five percent of the surface of the island consists of coralline limestone while the Scotland District contains outcroppings of oceanic formations at surface. Erosion is common to the country resulting in crop loss, landslides and washouts and falling rocks. Owing to the coralline nature of most of the soils in Barbados, percolation of water and subsequent discharge into subsurface water bodies is overland.

**Climate:** The overall annual temperature ranges from between 24°C and 28°C with slightly lower temperatures prevailing at the higher elevations. Humidity levels are between 71 percent and 76 percent year round. Rainfall occurs primarily between July and December with average of 1 422 mm.

**Agriculture:** The contribution of agriculture to Gross Domestic Product is estimated at US\$50M. With world food prices spiraling, Barbados is placing new emphasis on growing more of its food. Traditionally sugar has been the mainstay of agriculture. Non-sugar agriculture is primarily food crops, livestock and milk. However, except for milk and poultry, approximately 70 percent of food supply is from imports. Inadequate rainfall and water scarcity for agriculture have stymied the development of the sector and restricted its process of transformation from primarily sugar to more diversified farming in areas such as vegetables, cut-flower, fruits crops and livestock.

The current agriculture policy <sup>11</sup>includes initiatives to support greater food security from domestic production. These initiatives include modernization of agriculture through the application of greenhouse technology and irrigation.



Figure 20 - Map of Barbados

<sup>11</sup> Barbados Medium Term Plan 2008-2013

Water supply and management: Barbados' water resources availability per capita is 390 m<sup>3</sup>, putting it only slightly ahead of some of the desert nations and placing the country among the top 10 most water scarce countries in the world.

According to information provided by the Barbados Water Authority (BWA), daily water withdrawal is 150 000m<sup>3</sup>, mostly supplied from groundwater sources with 13 percent contributed by a desalination plant. During the dry season there are shortages in the potable water supply to some areas. The use of potable water for other non-essential purposes is prohibited island-wide.

Agriculture is the country's largest single water user accounting for 24 percent of total consumption. An amount of between 37 000 cubic meters and 55 000 cubic meters a day is licensed for agricultural use. The domestic sector comes a close second, at nearly 22 percent, while between 40 percent and 50 percent is unaccounted water. There is also growing evidence of deterioration in groundwater quality. In view of the competing demands on existing resources and mindful of extreme droughts in 1994 and 1995, there is a concerted effort to support an integrated approach to water management in the country.

Irrigation: The 1989 agriculture census recorded the actual irrigated area in Barbados as 1 000 hectares. According to information<sup>12</sup> provided by FAO, this was two-thirds of the potentially irrigable area of the country. There are 120 private wells which are mainly used for irrigation. Use of dams, springs, streams, roof catchments and road surface as catchments is limited. Reportedly between 61 percent and 64 percent of agricultural wells are subject to salt intrusion during dry season, owing to excessive pumping. As a result, the potable water supply is extensively used for irrigation purposes.

Sprinkler and drip irrigation systems are widely used. The Government offers rebate incentives for the use of highly efficient irrigation technologies to encourage farmers to reduce their dependence on the potable water supply. Two government operated irrigation schemes provide pressurized water supply for farmers. The main irrigated crops are tomatoes, cucumbers, hot peppers, sweet peppers, onion, carrot and beet. Other crops include citrus, bananas, plantains and cut flowers. There is very little wastewater reuse for irrigation and limited drainage work. None of the drainage work is linked to surface irrigation or a high water table.

According to the findings of the study there are many opportunities to save on water for irrigation. For example, sprinkler irrigation is still the most common form of modern irrigation. This system accounts for considerable loss of water from evaporation. It is also possible to reduce the large amount of unaccounted water in the distribution channels, through rehabilitation of pipelines and overall improvements in water management.

Institutions related to water management and irrigation: The main institutions are listed below.

- Barbados Water Authority (BWA) with responsibility for management, protection, controlled allocation and use of water resources. BWA supplies all potable water and also operates the Bridgetown Sewerage System. All abstractions from wells, streams and rivers must be approved and licensed by the BWA.

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<sup>12</sup> Agriculture Census 1989

- Ministry of Agriculture and Rural Development has responsibility for the development of irrigation. The associated activities are carried out by the Land and Water Use Unit of the Ministry of Agriculture, in cooperation with the Irrigation Unit of the Barbados Agricultural Development and Management Corporation. The latter operates and maintains two government-financed irrigation schemes.

Rainwater harvesting practices: Rainwater harvesting practices include tank storage of roof runoff for domestic supply and pond collection from natural catchment for irrigation. There is legislation that requires all new residences to have water storage facilities if the roof area or living area equals or exceeds 276.7 m<sup>2</sup> and there are similar requirements for all commercial buildings with a roof area of 92.9 m<sup>2</sup>. A rebate of US\$55.0 per cubic meter of installed tank capacity, up to the equivalent of 25 percent of the total roof area, is given as an incentive by Barbados Water Authority.

#### Potential for rainwater harvesting for agriculture in Barbados

Introduction: Rainfall is an inadequate source of water for further development of agriculture in Barbados unless access to surface and ground storage is improved. Currently rainfed production systems experience water scarcity in the dry season, to such an extent that it reduces production in most crops, especially vegetables.

The study identified areas where rainwater harvesting practices could improve water supply to satisfy requirements for crop and livestock production, as well as to alleviate urban flooding in selected sites. A listing of the sites where these practices could be established or reestablished is provided below:

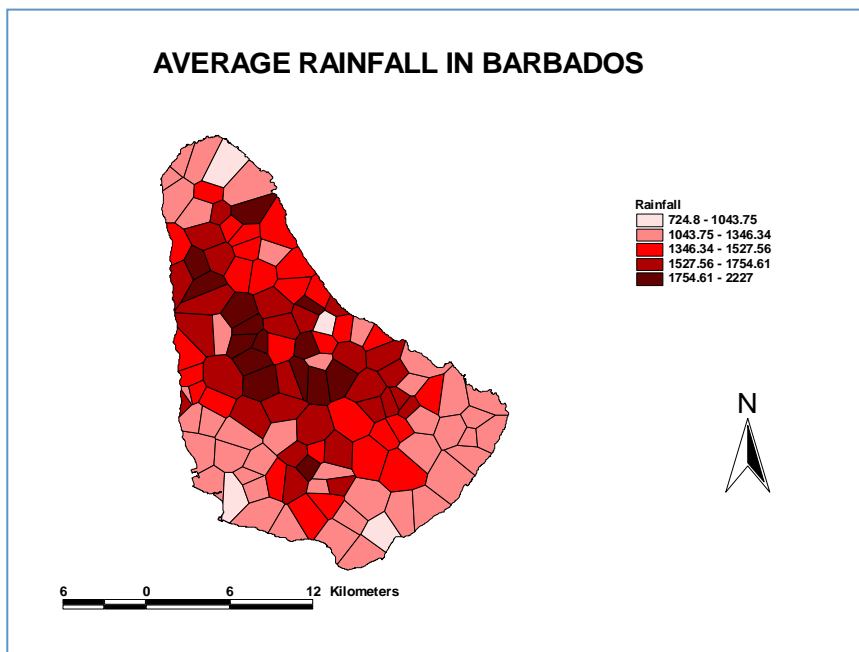
- Gibbons Boggs/Wilcox District: Forty-nine hectares of farm operated by 70 farmers are exposed to salt water intrusion in the wells during pumping in dry season. Seawater intrusion is a problem when the water table is low due to excessive pumping in the dry season. Rainwater harvesting in this area could reduce the dependency on water from wells.
- Spring Hall: This farm of size 182 hectares is operated by 22 farmers involved in vegetable and milk production. Water is supplied from two wells but the yield is not sufficient in dry season. The practice is not new to the area as in the past, a rainwater harvesting pilot project provided irrigation water for a nursery.
- Scotland District: This area is well known for its small rivers fed by spring sources and ephemeral streams that flow into the sea during rainfall events. During the dry season there are disruptions in the supply of potable water.
- River Plantation: This 141 hectare farmland is operated by 40 farmers with water sourced from springs, but these springs not sufficient for irrigation during dry season. The area also experiences flooding and drainage problems during the rainy season which could be alleviated through rainwater harvesting practices.
- Chicken Stop in Salter: This enterprise has a rooftop with a surface area of 1 096 m<sup>2</sup> which could serve as a catchment for runoff. Water collected and stored would be sufficient to provide all the supplementary water required for irrigation during the dry season.

- Pig Farm/Barnwell Farms Ltd: This farm requires 68m<sup>3</sup> of water daily to meet the demands of the pig farm. Most of the water is used for washing the pig sheds at an estimated US\$36 000 annually.
- Holetown: This coastal town experiences frequent floods and drainage problems during the rainy season. Rainwater harvesting interventions could reduce the amount of water flowing to the sea through modification of selected infrastructure to function as catchments.
- Rainfall: Mean annual average rainfall of Barbados is 1 422 mm. The geographic distribution of rainfall over Barbados is represented in Figure 21, which shows that even in the drier coastal areas, annual rainfall is still as high as 724 mm. In this regard, the entire country is suitable to rainwater harvesting. There are other strong indicators that rainwater harvesting is feasible in Barbados. These include (a) the rainfall pattern, intensity and concentration suited to collection and storage and (b) the existing natural catchment is favourable to collect rainwater runoff.

Barbados also has fairly good experience with the application of advanced irrigation technology such as micro irrigation systems. These capacities are favourable pre-conditions for embarking on a program in rainwater harvesting for agriculture.

Rainwater harvesting for agriculture in Barbados: In addition to the recommendations made earlier, the following are important considerations for improvements in rainwater harvesting in Barbados.

- In some parts of Barbados, ponds have been used for rainwater harvesting to supply irrigation water for large scale farms during dry months and to buffer flood pressure in peak rain season. Two potential sites proposed as priority for application of the pond system are:



**Figure 21- Geographic distribution of rainfall in Barbados**

1. Spring Hall and River Plantation: These sites are described in detail in the previous section. The proposal is to build storage ponds for rainwater runoff from natural catchments.

2. Holetown: This area experiences floods and drainage problems in the rainy season. The proposal is to build ponds to intercept rainwater runoff from the upper area of the natural catchment. This measure will also help to buffer or prevent runoff from this area entering the town.

- Road-cross dams are recommended for the two sites below.

1. Chicken Stop in Salter: It is proposed that rainfall runoff from the rooftop of the chicken shed is intercepted and stored to supply irrigation water for the two acre farm surrounding the building.

2. Pig Farm/Barnwell Farms Ltd: It is proposed to store rainwater from the roof of the pig pens as a supplementary source of water for washing the floor of the pig pen and to satisfy the daily requirement of 68 m<sup>3</sup>

- Rainwater harvesting from roof runoff of greenhouses.

There are a number of well-established commercial size greenhouses concentrated on the same site. Good examples are the operations at Hydrogrow Farms Inc. in St Thomas and the greenhouses established on the grounds of the Ministry of Agriculture and Rural Development. These extensive areas of plastic roofs in the same location could be used to harvest a fairly large amount of good quality water for greenhouse irrigation. There are also other greenhouses established across the country for backyard gardening from which rainwater could be harvested from roof runoff. Based on the rainfall analysis,<sup>13</sup> a greenhouse with area 500 m<sup>2</sup> could annually harvest about 680 m<sup>3</sup> of rainwater. Even in the driest areas where annual rainfall is 724 mm there is the potential to harvest 340 m<sup>3</sup><sup>14</sup> annually; an amount that will ensure sufficient supply of irrigation water for the greenhouse crops using a drip system.

Other methods for improvement of rainwater harvesting in Barbados: Other recommendations for Barbados include the following:

1. Application of an integrated water resources management approach, by combining the surface, ground and rainwater as one package for securing sustainable water supply for social and economic development of Barbados.
2. Increase the application of the drip irrigation system to decrease water loss from evaporation during sprinkler irrigation.
3. Recharge the groundwater by building properly designed ponds and dams and by recharging wells to avoid runoff flowing into the sea.
4. Widen the use of plastic mulch in order to conserve soil moisture.

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<sup>13</sup> Estimated design rainfall 950 mm annually.

<sup>14</sup> Applying the same area of greenhouse roof



## Dominica

### General information relevant to rainwater harvesting for agriculture

**Location, geology and soils:** The Commonwealth of Dominica (Dominica) lies between the French islands of Guadalupe and Mari-Galante to the north and Martinique to the south. The country is characterized by very a rugged and steep terrain which extends from the center to the south. The topography is also characterized by a large number of ridges and deep narrow river valleys. Flatter areas are restricted to the coastal areas of the northeast and center of the island. The geology is of volcanic nature with coral limestone areas being almost nonexistent and restricted to small outcrops and uplifted areas on the west coast. Soils reflect the volcanic origin of the country and are classified into eight major groups: Hydrogenic soils, Protosols, Young Soils, Allophanoid Clay Soils, Kandoid Clay Soils, Smectoid Clay Soils, Unstable Soils and "Other Clay" Soils. The soils are generally readily erodible since they tend to be unconsolidated and friable.

**Climate:** Dominica has a mild climate, particularly during the cool months from December through March. Summer temperatures reach an average of 32°C with winter temperatures being not much lower, the average high being anywhere from between 29°C and 30°C. The dry season is from February to May, and the rainy season is from June to October. This is also the most likely period for hurricanes. Rainfall varies, being especially heavy in the mountainous interior. Average annual coastal rainfall varies between 1 500 and 3 700 millimeters.

**Agriculture:** Only about one-quarter of the island is suitable for cultivation owing to the rugged terrain. Currently there is a strong focus on crop diversification and intensification for exports as well as for national food security. Some of the measures applied include the introduction and development of improved germplasm, seedling nurseries and application of irrigation.

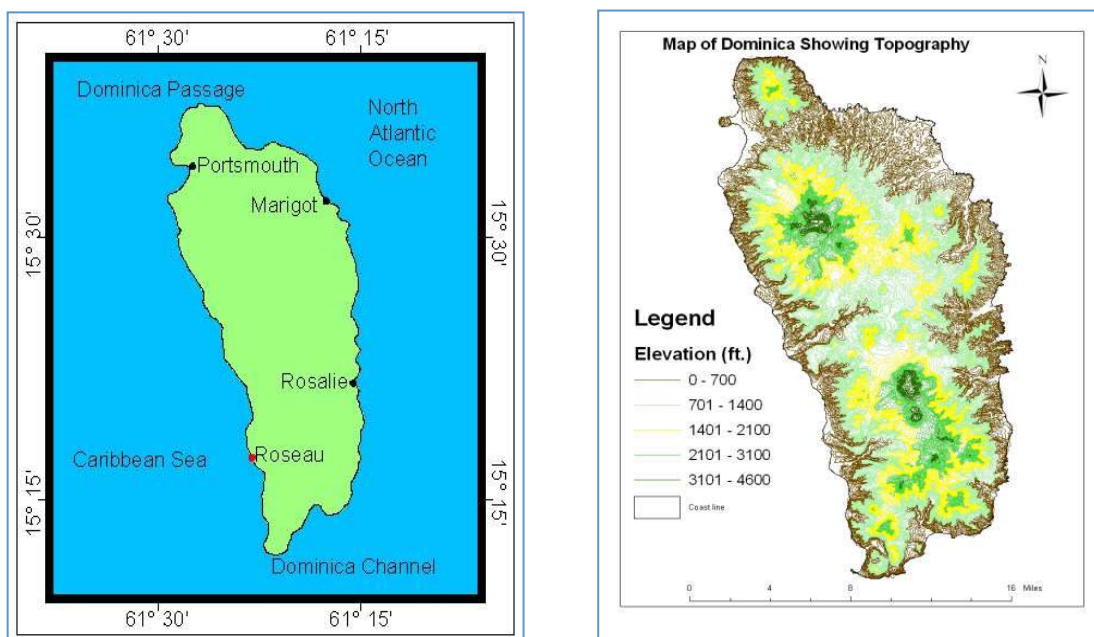


Figure 22 - Location and Topography maps of Dominica

Water supply and management: Dominica has seven major watersheds located mainly in the central region of the island on both the windward and leeward sides. Three smaller watersheds are located in the north of the island. Most of the catchment areas are under active cultivation. The total annual production from all currently used water sources is estimated at 16.6 million m<sup>3</sup>. It is estimated that an additional four million m<sup>3</sup> are needed to serve the whole population adequately. There are no demand figures of commercial or industrial uses.

There is considerable potential for irrigated agriculture in Dominica, but irrigation schemes are at an early stage. There are only small systems fed by surface water. Farmers use these systems to grow vegetables such as watermelons, carrots, tomatoes, cabbages among others. Indications are that most farms experience serious drought and could benefit from irrigation.

Main institutions for water management: The Dominica Water and Sewerage Company (DOWASCO) is the sole organization responsible for the management of the water resources in the country. DOWASCO has an exclusive license, to abstract and utilize the water resources of the country. It is charged with the development of water resources including research, data collection, projection and maintenance and development of new sources. Other institutions or individuals wishing to distribute water must do so under a sub-license from DOWASCO, although DOWASCO has no obligation to develop or provide water for agriculture.

Potential for rainwater harvesting for agriculture: No economical surface or groundwater resources are available for irrigation in Dominica despite the abundance of surface water. As a result some of the farmers in areas such as Warner struggle to truck water to their farms during the dry season. Others harvest rainwater using traditional methods to sustain vegetable production in areas such as Morne Prosper. Some farmers harvest rainfall from roofs or from large concrete pavements. At times there is a communal approach for domestic water supply as in one case at in Giraudel.

Despite the above, water is not scarce in Dominica. The problem is that the water resources are not distributed evenly. In some of the key arable areas like Warner and Morne Prosper, there is no available surface or groundwater. For these and similar locations rainwater harvesting is proposed as the solution for supplementary irrigation during dry seasons

The practice of rainwater harvesting to meet domestic water supply is common to areas such as Giraudel and Woodford Hill. However, rainwater harvesting for irrigation is still conducted using very traditional practices, leaving many gaps that could be corrected through improvements in the technology and infrastructure. The photographs in Figure 23 show some of the practices which still exist among farmers. These simple practices have allowed farmers to grow vegetables during dry periods. However rainwater harvesting methods are inefficient and limited. Hence the farmers' capacity to continue through extended dry periods is constrained.



Figure 23 - Rainwater harvesting practices on the farm in Dominica

Rainfall: The geographic distribution of rainfall over Dominica shown in Figure 24 below is a good indicator that even in the driest parts of the country rainwater harvesting is feasible. For example, in the drier parts of the western coastal areas average rainfall is estimated at 2 540 mm<sup>15</sup>. In addition the rainfall is concentrated over relatively short period, which facilitates high runoff for collection. Furthermore, with such high rainfall amounts there is no reason to construct large artificial catchments. In this respect, rainwater harvesting should be affordable to most farmers. Also many farmers already have some experience with high efficiency irrigation technology such as sprinkler and micro-drip systems. This experience is a favorable pre-condition for rainwater harvesting, as this method of irrigation improves efficiency in water use.

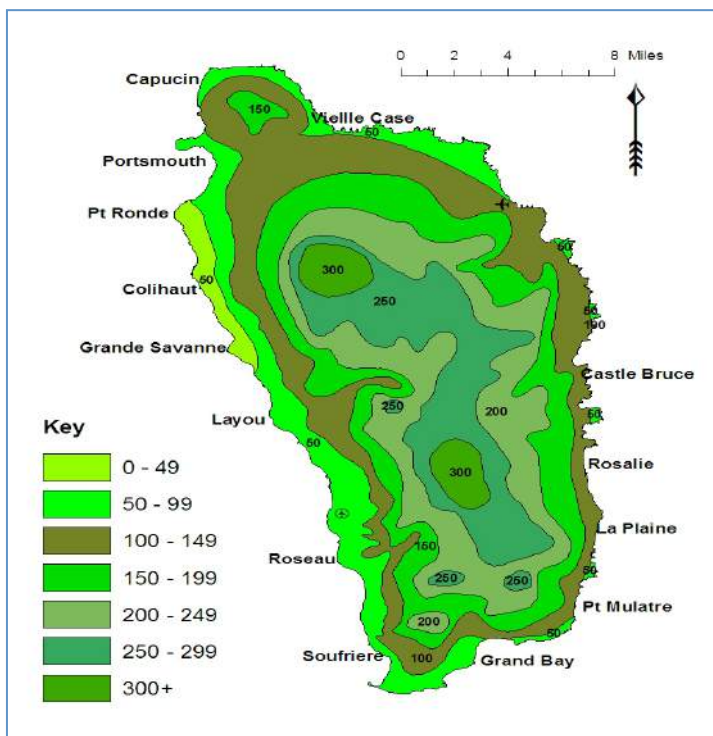


Figure 24 - Geographic distribution of rainfall in Dominica

<sup>15</sup> Rainfall recorded in inches: one inch = 25.4mm

Recommendations for rainwater harvesting: Six patterns of rainwater harvesting already recommended in the document should be evaluated for the following sites:

- Mini-roof water harvesting in the Morne Prosper plateau area where there is mainly vegetable production and where irrigation is necessary for those sensitive vegetables for periods of not more than four weeks of dry season.
- Mini-dams on seasonal waterways are recommended to supply water for a total of about 120 hectares of farms on arable lands in Warner as well as in selected areas in Woodford Hill.
- Ponds in Warner, Morne Prosper and Woodford Hill but not exclusively.
- Selections of other sites according to the rainwater harvesting system and the site specifications.

## Grenada

### General information of relevance to rainwater harvesting

**Location, geology and soils:** The location of Grenada is shown in Figure 25 below. The country is mostly volcanic being composed of andesite lava, pyroclastic rocks and basalt. Limestone deposits occur in isolated outcrops. Along the northwest coast and in some valleys are alluvial deposits in the lower corners of streams and rivers. The soils of Grenada are dominated by clay loams with lesser amounts of clays and sandy loams. Soils are mostly well drained and reasonably fertile providing considerable potential for productive cropping.

**Climate:** The climate is marked by a dry season from January through May and a wet season from June to December. Annual rainfall ranges from between 1 524 mm and 5 080 mm with an average of 2 350 mm. The three islands lie in the humid tropical zone within the Atlantic northeast trade wind belt. Owing to their relatively low elevation, Carriacou and Petit Martinique are significantly drier than the mainland, with average annual rainfall of 1 000 mm. Annual average temperatures range between 28°C and 33°C. However, temperatures in the mountainous interior can dip to as low as 20°C during the winter months.



Figure 25 - Map of Grenada, Carriacou and Petit Martinique

**Agriculture:** Agriculture provides an estimated seven percent of GDP and contributes eight percent to employment. The sector plays a significant role in the livelihoods of rural communities, often as their lone source of income. Average farm size is about one hectare and 60 percent of all farms are less than 0.4 hectare in size. Most are rainfed and experience the negative effects of normal or extended periods of drought. Small-scale irrigation systems managed by some of these farmers are highly dependent on potable water system.





Irrigation development is also restricted by limitations of the suppliers of irrigation equipment such as sprinklers and pumps. Replacement parts have to be ordered from abroad, frequently resulting in lengthy delivery time, leading to highly variable crop yields and sometimes crop losses.

Institutional arrangements for water management: The main institution is the National Water Sewerage Authority (NAWASA), with responsibility for management and development of the water resources. NAWASA's mandate is to execute the water related policies of the Government through (a) the provision of water supplies, conservation, augmentation, distribution and proper use of water resources including preservation and protection of catchment areas and (b) the treatment and disposal of sewage and other effluents.

According to the legislation, NAWASA is responsible for the provision of water for all shareholders including agricultural, industrial and commercial purposes. However in practice, the water supply for agriculture including the related investment and development is undertaken by Ministry of Agriculture. Significant amounts of arable land are located in areas where there is no available water source, either from surface or groundwater. This is especially so on Carriacou and in Mardigras and Shambord on mainland Grenada. Carriacou has no permanent streams or rivers.

Stream flow in the various ghauts and valley bottoms is short lived, occurring only during rainfall and for short periods after rainfall occurs. Mardigras, Shambord and other similar areas in mainland Grenada have no surface or groundwater for extraction. Where small amounts may be available this is not sufficient to meet demands of irrigation. Farmers intercept and store limited runoff for agriculture using low technologies such as that shown below.



**Figure 27 - Rainwater storage on small farm on Carriacou, Grenada**



Rainfall: The geographic distribution of rainfall shown below in Figure 28 reveals lowest annual rainfall to be around 1000 mm. This amount is well above the 300 mm annual rainfall requirement for rainwater harvesting, established by FAO. Rainfall is concentrated over relatively short period from June to November, which facilitates the creation of high runoff including from natural slopes. This means that rainwater harvesting in the country can be successful, even with low cost catchment surfaces provided by natural slopes.

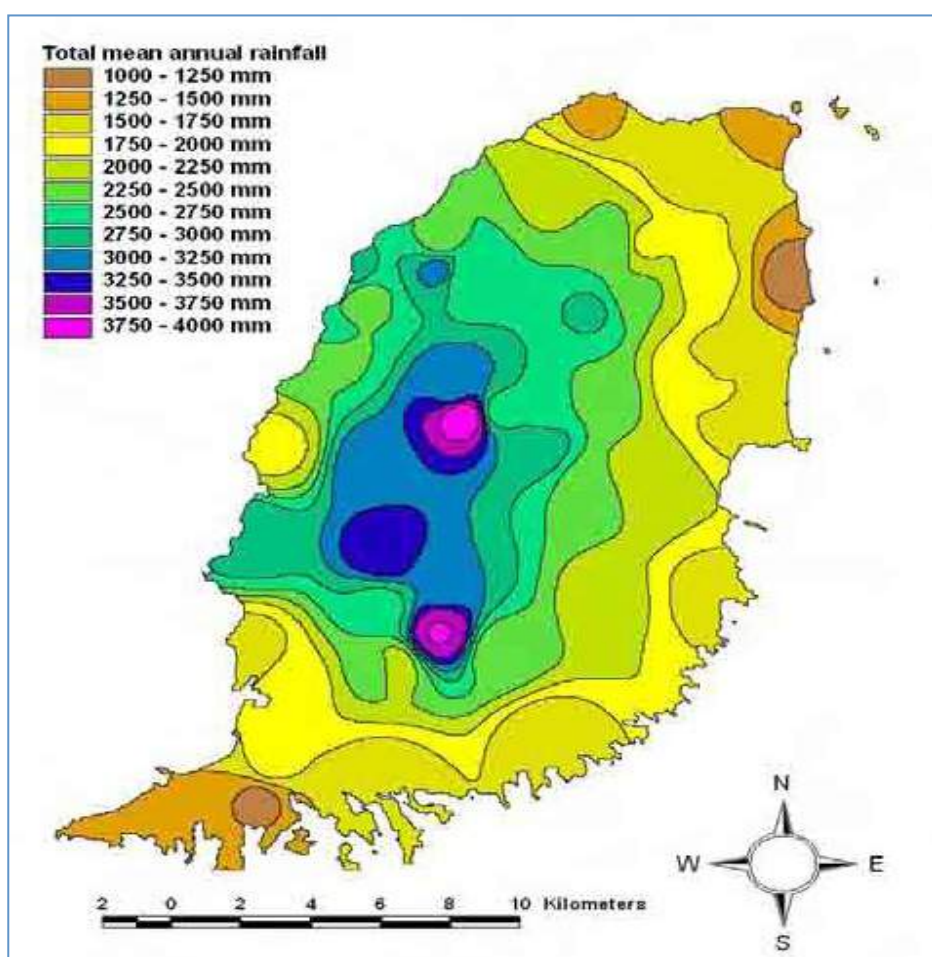


Figure 28 - Geographic distribution of rainfall on mainland Grenada

Recommendations for rainwater harvesting: In addition to the recommendations made earlier in the document, the following is also proposed for Grenada:

- Priority is given to building mini-dams in areas with an abundance of seasonal surface water. Thirteen such areas were identified in a 2001 FAO Study<sup>16</sup>. The 2001 FAO Study concluded that available runoff at 30 percent withdrawals will supply enough water for irrigation of nine of the sites. The other four sites require in-stream storage of rainwater. Mini dams are proposed for these sites because of the relatively large size of the farms to be irrigated. The study verified several potential locations suitable for building the mini-dams or ponds with volumes of between 10 000 m<sup>3</sup> and 500 000 m<sup>3</sup>.

<sup>16</sup> Project TCP/GRN/0066

- Four sites are proposed in the first phase of a program for rainwater harvesting by building mini-dams on seasonal waterways.
  1. Shambord in Grenada, consisting of 121 hectares of arable land, with insufficient ground and surface water for irrigation in dry season.
  2. Mardigras in Grenada consisting of 20 hectares of arable land which has no surface water and is totally reliant on rainwater harvesting for irrigation.
  3. Dumfries in Carriacou, with 20 hectares of arable land owned by the Government, but sub-divided to farmers with an average of 0.75 hectares per family.
  4. Prospect in Carriacou, almost six hectares of arable land, including a seedling nursery.
- Ponds are proposed for areas such as Mardigras and Shambord as well as many other similar areas on the three islands.

## Jamaica

General information relevant to rainwater harvesting in Jamaica

Location, geology and soils: The location of Jamaica is shown in Figure 29 below. The topography of the country displays a highland interior, surrounded by flat coastal plains. Important features include steep-sided mountains, highly karsted land, high plateaus, rolling hills and coastal plains with large interior valleys. There are three land forms described as (a) interior mountain ranges (b) dissected limestone plateaus and hills and (c) coastal plains and interior valleys. Limestone plateau covers two thirds of the country.



Figure 29 - Map of Jamaica

Sinkholes, caves and caverns, disappearing streams, hummocky<sup>17</sup> hills, and terra rosa soils in the valleys are distinguishing features of the karst landscape. Soils are classified into several categories which reflect differences in geology. Upland Plateau Soils, Alluvial Soils and Highland Soils are the main types.

Climate: Two types of climate occur in Jamaica. An upland tropical climate prevails on the windward side of the mountains and a semiarid climate predominates on the leeward side. Rainfall is heaviest from May through October, with peaks in these two months. The average rainfall is 1 924 mm per year. Where the higher elevations of the John Crow Mountains and the Blue Mountains receive rain from moisture-laden winds, rainfall exceeds 5 080 mm per year. Since the southwestern half of the country lies in the rain shadow of the mountains, this

<sup>17</sup> Hummocky terrain is characterized by rolling hills of crests and troughs across a relatively flat landscape.

area has a semiarid climate and receives less than 762 mm of rainfall annually. Temperatures are fairly constant throughout the year averaging between 25°C and 30°C in the lowlands and 15°C and 22°C at higher elevations. Temperatures may dip to below 10°C at the peaks of the Blue Mountains.

**Agriculture:** Jamaica has a total area of 1.1 million hectares of which 270 000 hectares are cultivated. Agriculture accounts on average for eight percent of GDP and 12 percent of export earnings. The sector employs 25 percent of the country's labor force. Nearly two-thirds of the farmers are classified as small farmers, each operating on less than two hectares of land. Traditionally the large farms are located on the plains while the small farms are on the hillsides. The potential irrigable area of Jamaica is 90 000 hectares of which 25 000 hectares are irrigated.

**Water supply and management:** Rainfall is the primary source of water in the island providing flow in the streams as surface water, direct recharge to the limestone and alluvium aquifers and indirect recharge to the aquifers through the streams. There are 10 basins with potential for reliable ground and surface water. In summary these basins are the north draining basins<sup>18</sup> which contribute 56 percent and 48 percent of the national annual average yield, respectively. The Blue Mountain (North) Basin alone contributes 29 percent of the total annual average yield and 52 percent of the total reliable surface yield.

Of the total annual reliable yield of 4 088.5 Mm<sup>3</sup>, 80 percent is from the limestone aquifer, and 16 percent and four percent respectively, from surface water runoff and the alluvial aquifer. About 20 percent of the annual reliable yield of 3 276 Mm<sup>3</sup> from the limestone aquifer is developed through wells, mainly in the Rio Cobre and Rio Minho Basins. In the other basins, the water is generally available as base flow and is exploited through run-off-river developments. Currently agriculture accounts for 60 percent of the current water demand. Projections made in 1996 estimated that annual demand could more than double by the year 2015.

**Challenges to water supply for agriculture:** The challenges to water supply identified by the study include (a) large numbers of farmers operating on hillsides who cannot be easily reached through irrigation schemes (b) degradation of ground and surface water resources causing a decrease in the availability of potable water for supply and (c) the prohibitive cost of drilling wells in some areas and expansion of water supply infrastructure.

**Main institutions for water management and irrigation:** The main institutions for water management and irrigation are shown below:

- National Irrigation Commission Limited (NIC) with powers to assume full management and control of the main irrigation schemes.
- Water Resources Authority (WRA) with responsibility for management, protection, and allocation and use of all the water resources. The WRA maintains a hydrological database and provides data, information, and technical assistance to government and non-government institutions.

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<sup>18</sup> Blue Mountain Basins

- Rural Agriculture Development Authority (RADA) with responsibility for agricultural extension service for rural development. The range of services includes provision of training, information, marketing support, and technical support for small-scale irrigation schemes development.

Public programs include a Small Farm Tank Project managed and financed by the Ministry of Agriculture specifically for agriculture. Under the program farmers obtained 50 percent of the cost for construction of 10 000 gallon tanks on a grant basis and the remaining 50 percent was provided as a loan repayable over 10 years at an annual interest rate of six percent. A total of 5 673 tanks were built over a period of seven years. Further grant funds financed the construction of another 1 708 tanks and loan funds from the Caribbean Development Bank provided continuity in the construction of additional small farm tanks for small scale farmers.

The study found however, that development of the technology is hampered by the relatively limited financial and technical support. As a result the rainwater harvesting practices have remained close to indigenous or ad-hoc activities. Furthermore, rainwater harvesting is still not recognized as a strategic response to increase access to water for agriculture.

Rainfall variability: Monthly rainfall averages provided in Figure 30 below show two definite rainfall peaks. Despite the monthly variability, rainfall is relatively concentrated and intense in these two short periods and favors high rainwater runoff.

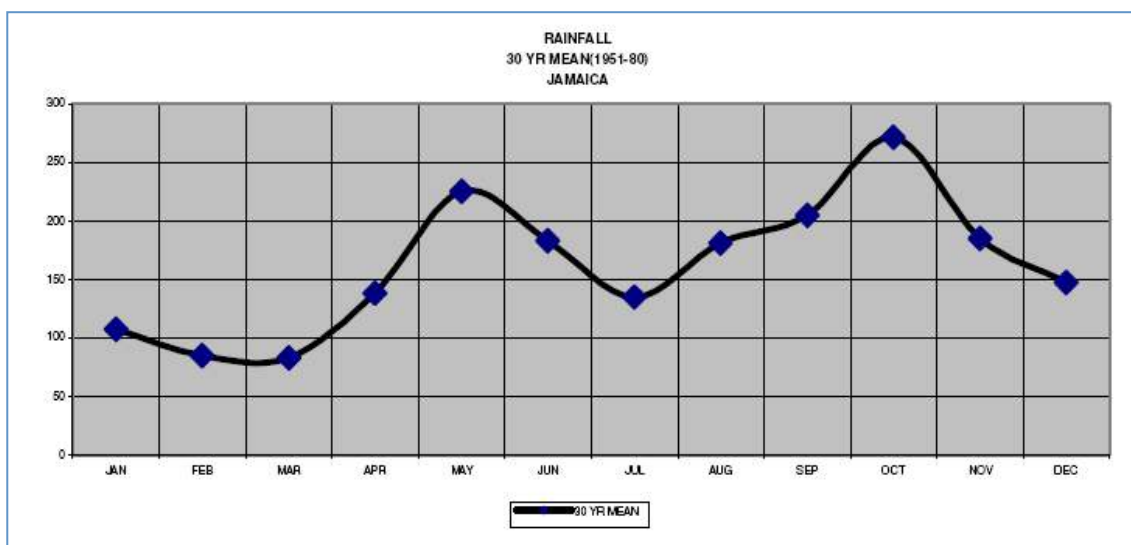


Figure 30 - Average monthly distribution of rainfall in Jamaica

Geographic distribution of rainfall over Jamaica is represented in Figure 31. The pattern and rainfall averages show that even in the drier coastal areas to the south-east and south-central parts of the country, annual rainfall is in the range of 1 000 mm; an indication that the entire island is suitable to rainwater harvesting.

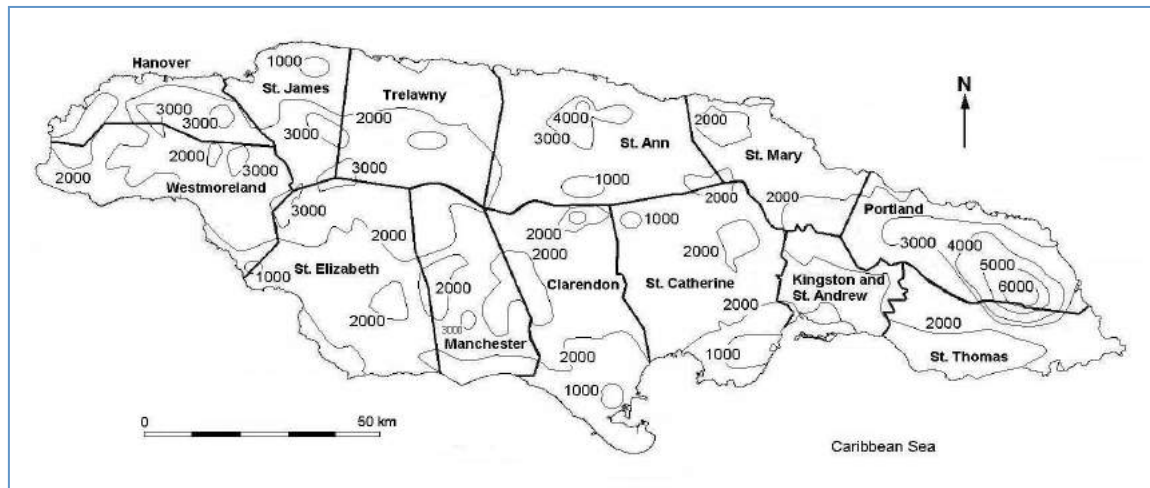


Figure 31 - Geographic distribution of rainfall in Jamaica

#### Improvement of in-stream storage and recharge of groundwater

Jamaica has an abundance of precipitation, providing surface water, direct recharge to the limestone and alluvium aquifers and indirect recharge to the aquifers through the streams. Due to uneven distribution, including periods of high rainfall intensity, much of this water flows into sea. While in-stream storage and recharge of groundwater are not normal considerations in rainwater harvesting systems for agriculture, these measures could provide opportunities to increase water for large-scale agriculture in Jamaica. The document therefore provides some information on measures that could be adopted to increase water for agriculture while releasing water for other development priorities.

The measures recommended for improvements of in stream storage and recharge capacity are as follows:

- Improvements through diversion of surface water: Based on the National Irrigation Development Plan (NIDP) data, most of the domestic and irrigation water demands are in the parishes of St. Andrew, St. Catherine and Clarendon. Currently groundwater from St. Catherine and surface water from the Yallahs River is diverted to meet the domestic demands of the Kingston metropolitan area. The recommendation is that water from the Wag Water River in St. Catherine is diverted to support a storage reservoir for the Kingston Metropolitan area. This would remove the need to divert water from the Yallahs River to support water for the Kingston Metropolitan area, thereby releasing water to be used for irrigation in St. Thomas.
- Construction of dams: A number of dams were examined in the parishes of St. Catherine and Clarendon. These include unfinished micro dams planned by the Ministry of Agriculture. It is recommended that the unfinished dams are completed after proper assessment and evaluation. Two new dam sites are proposed in Thomas River, where there is good potential for accommodating a storage reservoir.
- Recharge of groundwater: Three potential recharge sites are also recommended in the St. Catherine and the Clarendon plains. Two of these are in the lower Rio Cobre Basin with potential to store annual amounts of 30 Mm<sup>3</sup> and one in mid-Clarendon at Rhymesbury with potential annual storage of 11 Mm<sup>3</sup>.



## Montserrat

General information relevant to rainwater harvesting for agriculture

**Location, geology and soils:** The location of Montserrat is shown in Figure 32 below. Recent volcanic activity, including explosive eruptions has resulted in many rivers buried beneath several meters of ash and rock. The country is relatively young with likely origin less than 50 million years. Montserrat is divided into three geologic zones: Bugby Hole in the southwestern portion, Silver Hills in the central area and the Soufrière and South Soufrière Hills in the south. The soils are primarily volcanic in origin, comprised largely of clay and sandy loam. Much of the coastline is made up of high cliffs, with only a handful of dark sandy beaches.



Figure 32 - Map of Montserrat

**Climate:** The climate is mildly tropical, with temperatures ranging between 24°C and 30°C. The higher temperatures are experienced during the months of August and September, with January and February being the cooler months. Average annual rainfall is 1143 mm. Heaviest rainfall is experienced between September and January. Low humidity and constant cooling breezes maintain a pleasant climate year round.

**Agriculture:** The number of farmers decreased significantly as a result of the volcano. Presently there are only about 70 active farmers working on an estimated 54 hectares of land. Agriculture's contribution to total GDP was less than four percent in 2007<sup>19</sup> as the sector continues to be adversely affected by both the effects of volcanic activity and drought conditions that normally occur during the first six months of the year.

The Government of Montserrat has directed its policy towards achieving self-sufficiency in certain foods and meat products in an effort to reduce the high dependency on food imports, with accompanying high outflows of foreign currency. One of the measures is to provide a package which includes land for farmers and access to irrigation.

<sup>19</sup> CDB Annual Economic Review 2007



Water supply and management: Montserrat has numerous watersheds, draining into ghauts, rivers, and streams that empty into the sea from along the entire coastline. In the north, the watercourses tend to be wider and fall from gently sloping and eroded hills. Progressing southward, the watercourses are deeper and emerge from more rugged peaks.

Currently the water supply comes exclusively from a network of springs in the Centre Hills, which are in general adequately recharged by rain. There are nine springs available for extraction and distribution. Water is primarily gravity-fed through pipes into a network of 18 tank reservoirs located around the country. Approximately 400 000 cubic meters is extracted each month from these sources. An estimated 80 percent is allocated for use in the domestic supply system.

Depending on supply and demand, the remaining 20 percent overflows into ghauts. A minimal amount is "unaccounted for", through loss through leaks, evaporation, percolation and other pathways. The major recharge areas for these springs are in the Centre Hills. These springs range from between five meters and eight meters or deeper and the amount of recharge is dependent on gravity, soil type, and rainfall amounts.

Runoff water and water available from wells and springs have been harnessed into a piped water supply system to provide potable water. Consequently, there is currently, a marked reduction in river flow compared with the recent past. There are no rivers which have water throughout the year and there are no natural lakes. Figure 33 below shows monthly production by the major springs<sup>20</sup>.

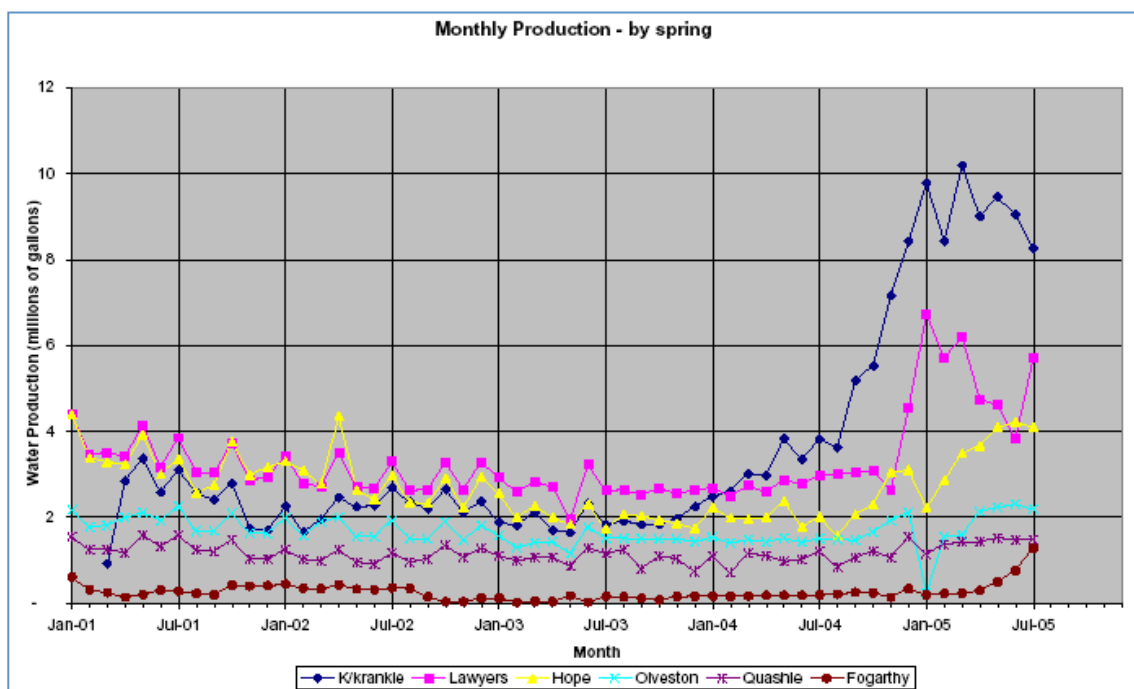


Figure 33 - Monthly Water Production from springs in Montserrat

<sup>20</sup> Montserrat Centre Hill, Socioeconomic Assessment Report.

Potential for rainwater harvesting in Montserrat: Annual average evapotranspiration is significantly higher than the annual average rainfall in Montserrat, making irrigation necessary for sustained yields and even moderate levels of production. Except for 20 percent of overflow from Olevston Mountain, the runoff water and available water sourced from springs and wells is diverted into the domestic water supply system. Currently this overflow is not being managed for use in agriculture or for future domestic demands and could easily be brought into production for irrigation, with the installation of pumping systems and other necessary equipment.

In order to sustain yields in dry season, farmers frequently use potable water for irrigation of cash crops. This is an expensive source of water as farmers often pay as high as US\$7.49 for four cubic meters of water. At such a high cost for water, the farmer can only expect a low return from farming activities. Furthermore, there are uncertainties associated with this source of water for agriculture as it is expected that demand for water for domestic supply will increase with future development and create a crisis in water for agriculture. As there is neither surface water nor groundwater available to meet the irrigation demands, rainwater harvesting has emerged as the only approach to supply irrigation over the longer term.

Rainfall: The amounts and distribution pattern of rainfall indicate that Montserrat is suitable for rainwater harvesting. Records of more than 90 years of series rainfall data show that even in the driest year annual rainfall was 972 mm. The records also show that rainfall is concentrated and occurs over a relatively short period, often in rainstorms. This pattern facilitates runoff and collection of relatively large amounts of water. Accordingly, natural catchments are being proposed as the collection field in Montserrat. This will help save on the cost of building artificial catchment areas.

Experience with high efficiency irrigation facility: High efficiency irrigation is well known in Montserrat. The Ministry of Agriculture has assisted some of the farmers to purchase irrigation equipment such as sprinkler and micro-drip systems. It was also observed during the study that many of these farmers displayed good knowledge and practices in the operation of sprinkler and drip irrigation system.

3. Recommendations for rainwater harvesting: In addition to the recommendations made earlier the following is proposed for Montserrat:

- Rainwater harvesting from rooftops is recommended for the estimated 300 households operating backyard gardens of the size 0.55 hectares and under. This would support some 30 hectares of backyard gardens in the country with potential for significant improvements in household food security.
- Roof catchment from galvanized zinc is popular among those householders who practice rainwater harvesting. Galvanized zinc has a high collection efficiency. In combination with the high rainfall in the wet season, households with average area of 160 m<sup>2</sup> of roof can harvest up to 250 m<sup>3</sup> of rainwater runoff annually. This quantity of water is sufficient to provide water from storage for irrigation of a normal backyard garden.



**Figure 34 - Rainwater harvesting practices in Montserrat**

- Mini-dams on seasonal waterways are recommended for about 20 hectares of farms on arable land in Blakes Mountain.
- Measures are taken to provide services in technical designs and access to other necessary inputs to avoid or reduce leakage in the mini-dams already built by the Ministry of Agriculture.
- Ponds are recommended for Olevston Mountain, where there is potential to develop 16 hectares of land for farming. The recommendation is to enlarge the existing pond or to build more ponds. Another option would be to install a solar-pump to lift the overflow from natural springs to this pond as backup water resources for irrigation. This option should however, be approached with caution as it is likely that with development, this overflow might not be available in the future.
- Rainwater harvesting from the natural slope is recommended for Central Hill. This is an area of high rainfall with natural slopes - a combination which compensates for the lower collection efficiency of natural slopes. These slopes are also sufficiently gentle not to require interception ditches and channels.
- The runway of the Gerald Airport is a large area with a highly impermeable surface providing good catchment or runoff. All the runoff from the airport should be stored to irrigate farms around the airport during the dry season. This new water supply will augment storage in the existing small pond in order to increase the total amount of available water for supplementary irrigation to sufficient levels to satisfy the water requirements of the 32 hectares of farmland around the airport. Larger cement-block lined tanks could also be placed along the runway to provide storage.

## Appendix 2

### Design Rainfall for Selected countries in the Subregion

#### Green Castle Antigua and Barbuda

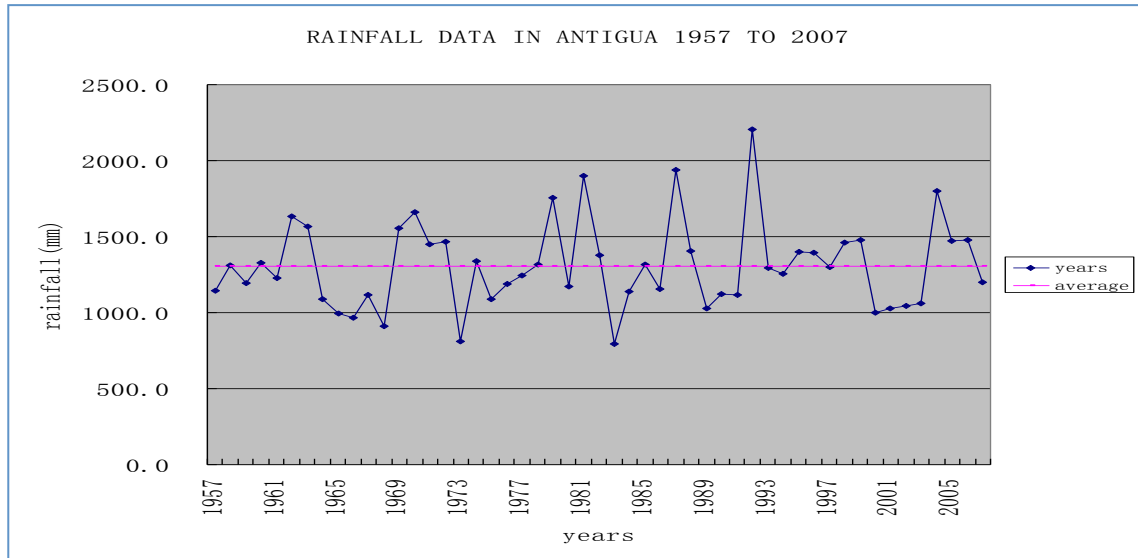


Figure 35 - Rainfall Series data at Green Castle, Antigua and Barbuda

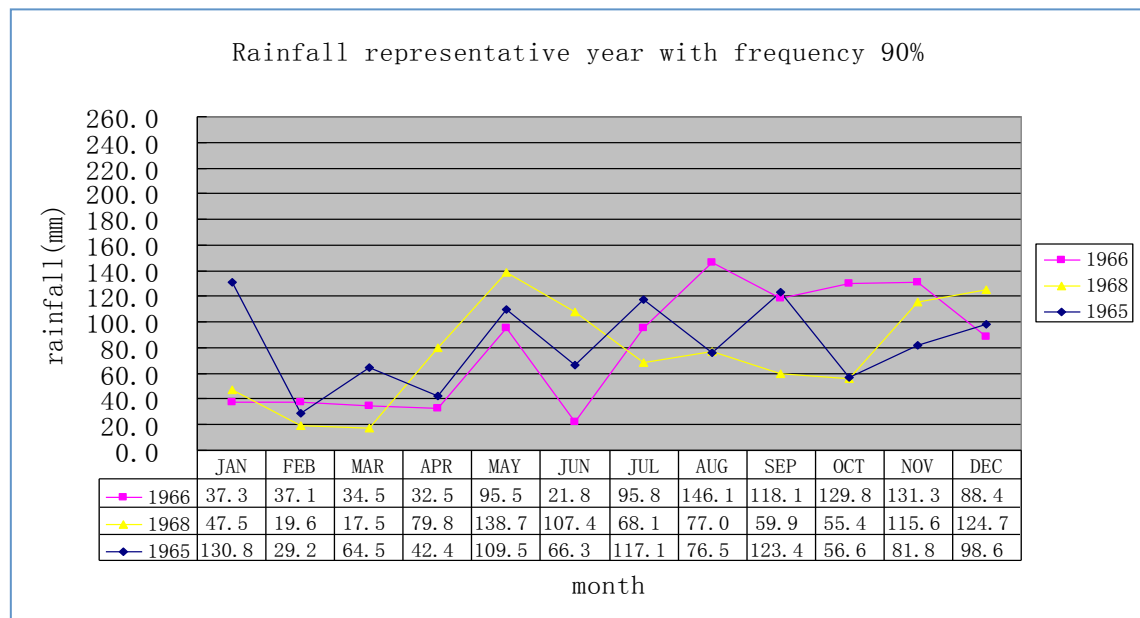


Figure 36 - Representative years typical of design rainfall at Green Castle, Antigua and Barbuda

## Melville Hall Dominica

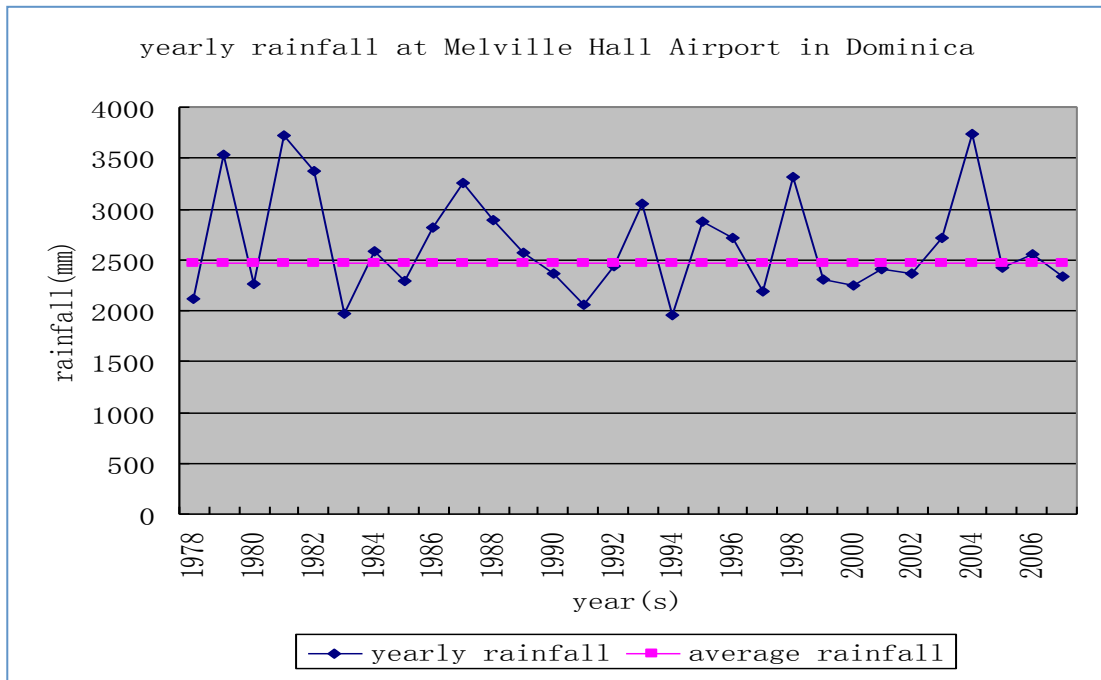


Figure 37 - Rainfall series data at Melville Hall, Dominica

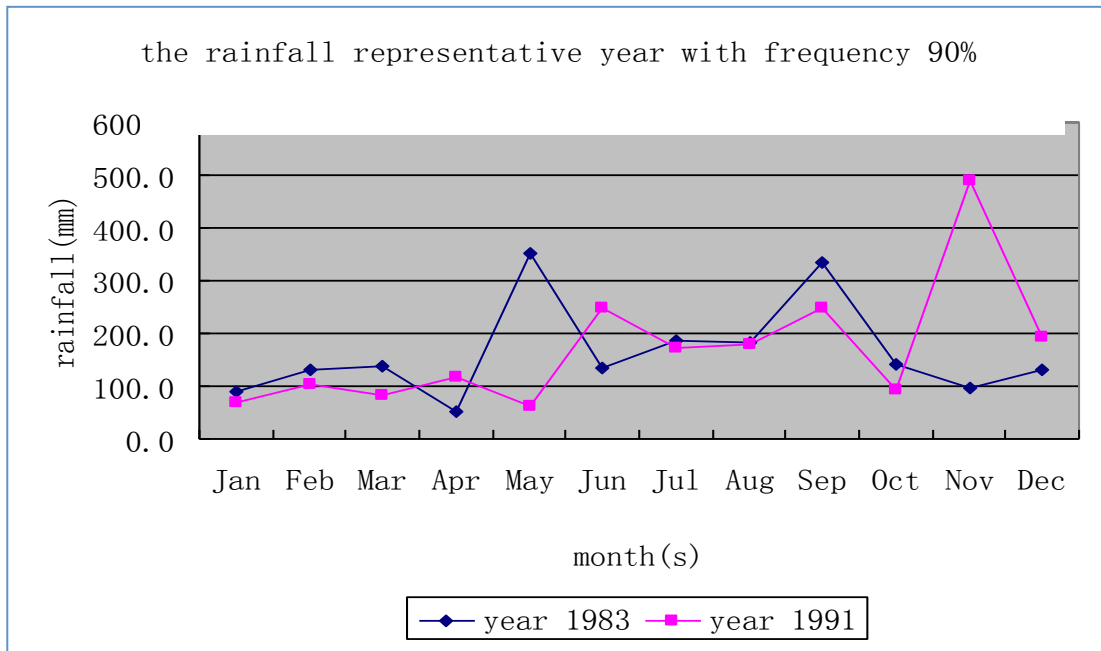


Figure 38 - Representative years typical of design rainfall at Melville Hall, Dominica

## Mt Horne Cocoa Grenada

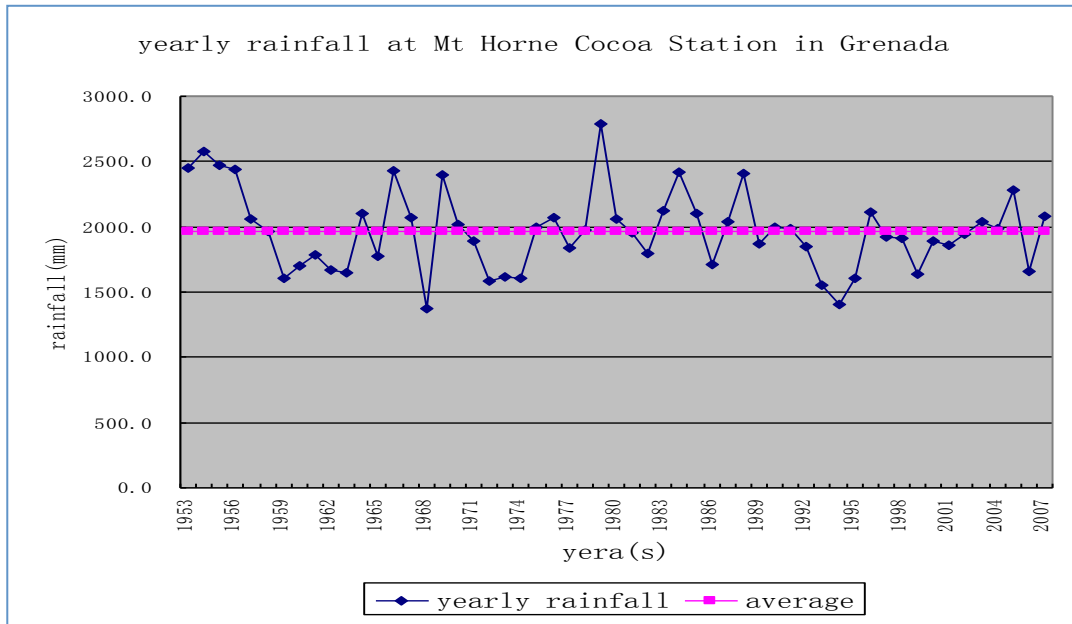


Figure 39 - Rainfall series data for Mt Horne Cocoa, Grenada

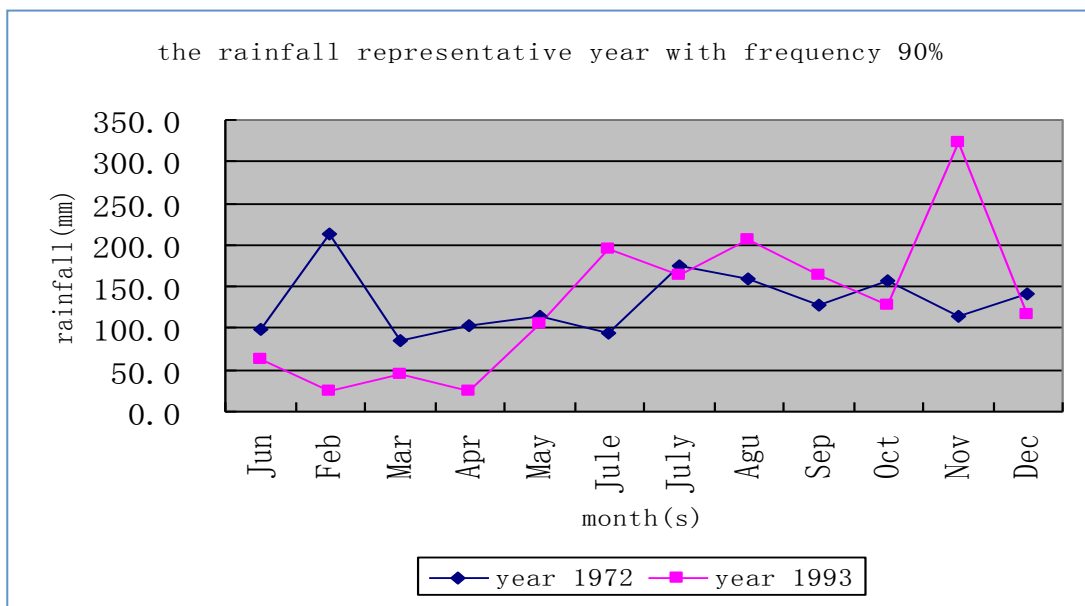


Figure 40 - Representative year with frequency 90% - Mt. Horne Cocoa, Grenada

Grove, Montserrat

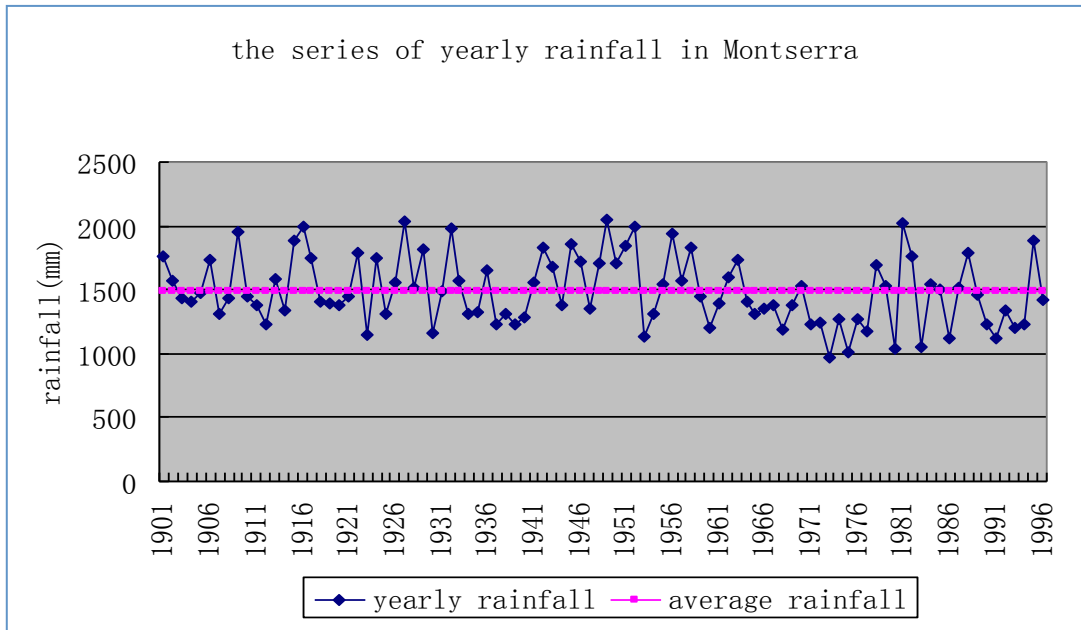


Figure 41 - Rainfall series data at Grove, Montserrat

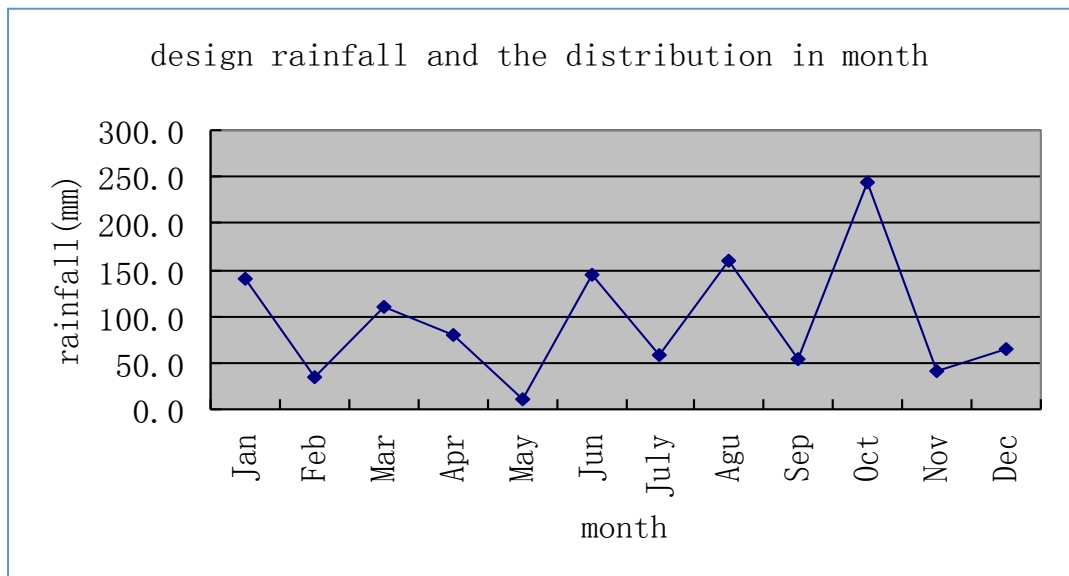
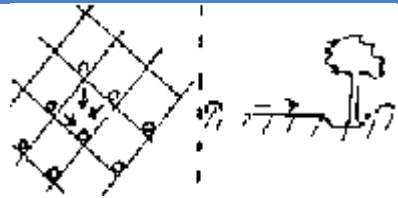
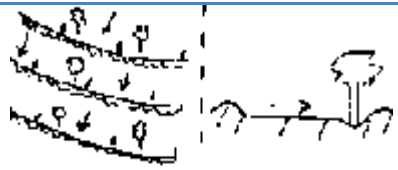
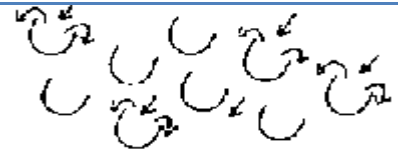
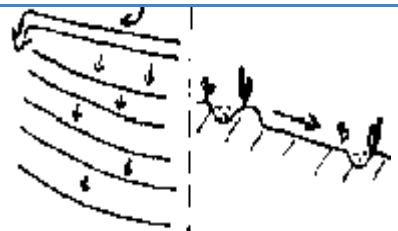

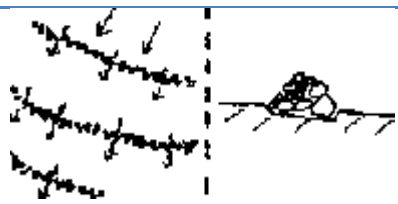




Figure 42 - Design rainfall at Grove, Montserrat

## Annex - 3 Chart of main runoff farming techniques

Techniques	Classification	Main Uses	Description	Where Appropriate	Limitations	Layout
Negarim micro catchments  (Negarim mean in Hebrew-Runoff)	micro catchment (short slope catchment) technique	trees & grass	Closed grid of diamond shapes or open-ended "V" s formed by small earth ridges, with infiltration pits	For tree planting in situations where land is uneven or only a few tree are planted	Not easily mechanized therefore limited to small scale. Not easy to cultivate between tree lines	
contour bunds	micro catchment (short slope catchment) technique	trees & grass	Earth bunds on contour spaced at 5-10 meters apart with furrow upslope and cross-ties	For tree planting on a large scale especially when mechanized	Not suitable for uneven terrain	
semi circular bunds	micro catchment (short slope catchment) technique	rangeland & fodder(also trees)	Semi-circular shaped earth bunds with tips on contour. In a series with bunds in staggered formation	Useful for grass reseeding, fodder or tree planting in degraded rangeland	Cannot be mechanized, require hand labour	
contour ridges	Micro-catchment (short slope catchment) technique	crops	Small earth ridges on contour at 1.5m -5m apart with furrow upslope and cross-ties Uncultivated catchment between ridges	For crop production especially where soil fertile and easy to work	Requires good technique of land preparation and planting	



Trapezoidal bunds	external catchment (long slope catchment) technique	crops	Trapezoidal shaped earth bunds capturing runoff from external catchment and overflowing around wingtips	Widely suitable (in a variety of designs) for crop production in arid and semi-arid areas	Labour-intensive and uneven depth of runoff within plot.	
contour stone bunds	external catchment (long slope catchment) technique	crops	Small stone bunds constructed on the contour at spacing of 15-35 meters apart slowing and filtering runoff	Versatile system for crop production in a wide variety of situations. Easily constructed by resource-poor farmers	Only possible where abundant loose stone available	
permeable rock dams	floodwater farming technique	crops	Long low rock dams across valleys slowing and spreading floodwater as well as healing gullies	Suitable for situation where gently sloping valleys are becoming gullies and better water spreading is required	Very site-specific and needs considerable stone as well as provision of transport	
water spreading bunds	floodwater farming technique	crops & rangeland	Earth bunds set at a gradient, with a "dogleg" shape, spreading diverted floodwater	For arid areas where water is diverted from watercourse onto crop or fodder block	Does not impound much water and maintenance high in early stages after construction	

Source:<sup>1</sup> [www.fao.org/docrep/U3160E/u3160e05.html](http://www.fao.org/docrep/U3160E/u3160e05.html)

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