Food and Agriculture Organization
of the United Nations

Compendium on Rainwater Harvesting for Agriculture in the Caribbean Sub-region

Concepts, calculations and definitions for small, rain-fed farm systems

Food and Agriculture Organization of the United Nations

2014

Published by Food and Agriculture Organization of the United Nations (FAO) 2014

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Preface

The purpose of this document is to provide a practical tool to train and build human capacity in the Caribbean sub-region in the practice of rainwater harvesting. Application of rainwater harvesting techniques will produce measurable improvements in livelihood and household food security, generated by access to reliable water resources for irrigation.

The document is targeted to agricultural smallholders operating on two hectares of land or less, as well as backyard gardeners and school gardening projects. It describes simply, but carefully the relationships between plants, soil, water, climate and rainfall, and on-farm rainwater harvesting.

The document uses calculations and tables to explain the concepts, charts and drawings to illustrate them. Furthermore, both metric and imperial systems of measurement are used throughout to facilitate practical application of the knowledge gained by users. It includes important definitions and reference tables to provide added guidance to users. Additionally, each example of a rainwater-harvesting system is illustrated by the relevant drawings and/or photographs.

In a step-by-step approach to knowledge-building, the document addresses the following five areas: (a) design rainfall; (b) the catchment area and storage design; (c) reference crop evapotranspiration and crop water requirements; (d) managing effective rainfall and cumulative storage; and (e) rainwater harvesting systems suitable for the Caribbean sub-region.

Every effort has been made to keep the document farmer-friendly. However, there will be need for institutional support from national agricultural extension services, the Caribbean Agricultural Research and Development Institute (CARDI), agricultural engineering and irrigation units, and farmers' organizations to mobilize and motivate farmers to engage in rainwater harvesting, thus ensuring access to a reliable source of irrigation.

Introduction

The key to rainwater harvesting lies in assuring the availability of adequate quantities of water for crops during the planned growing season. A recent study[1] conducted by The Food and Agriculture Organization of the United Nations (FAO), in collaboration with Caribbean partners, confirmed that rainfall intensities and patterns of distribution across the Caribbean were suited to rainwater harvesting systems for agriculture. Furthermore, on-farm, cumulative annual storage of rainwater runoff can be sufficient to maintain small-scale production systems of many of the food crops grown throughout most of the annual dry periods.

Small farmers and planters of crops in greenhouses, backyard gardens, school gardens and family farms will find this document useful for increasing their income and improving household food security. The majority of such farm populations are rain-fed producers with no access to surface water or groundwater. Rainwater harvesting is, therefore, their sole alternative for accessing sustainable quantities of water to satisfy crop requirements during periods of drought.

The basic requirement of rainwater harvesting is sufficient storage at the site for the amount of rainwater that will be needed. Requirements for successful rainwater harvesting are, therefore, location specific, and incorporate climatic, geological, hydrological and meteorological conditions. Within these parameters, key specifications must be affirmed before a system can be designed.

System design is based on probability analysis of series rainfall data to determine the frequency of a certain annual rainfall pattern, calculation of reference crop evapotranspiration rates and crop water requirements at the cropping site, calculation of the amount of rainwater runoff, and of the pattern of cumulative annual storage.

There are important preconditions for design and management of the system, that include appropriate technical capacity of farmers and their service providers, soundness of data quality, ready access to professionals to provide simple engineering works for catchment and storage, and simple statistical analysis to determine reference crop evapotranspiration rates and water demand of the crops.

Central to successful rainwater harvesting is the adoption of good practices in planning and management of the limited water stored. Hence, another important precondition is familiarity with micro-irrigation practices, including how to manage soil water needs and rainfall.

Calculations on water demand and cumulative runoff have suggested that rainwater collected for well-planned areas of cultivation can be sufficient to extend planting seasons to at least 10 months of the year. In this respect, rainwater harvesting could be addressed under an innovative policy that would promote the technology as a core adaptation strategy for making water available for irrigation among small- and micro- farmers. The objective would be to establish the framework for the intensification of small-scale production areas under traditional rain-fed systems, coupled with community-based or farm-family-

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[1] Food and Agriculture Organization of the United Nations (FAO) (2008), *Feasibility Study on Rainwater Harvesting in the Caribbean Subregion*

oriented agro-processing modules. In return, these activities could help alleviate household food insecurity and increase farm income, especially among the poor.

In order to ensure sustainability, inputs to the suggested policy formulation and support framework would include assessments of economic and social factors as well as of the environmental impact of unregulated rainwater harvesting, especially on watersheds and surface flows.

Meanwhile, the present compendium can improve livelihoods, income and food security of households dependent on farm activities across the Caribbean.

CHAPTER 1

Defining Rainwater Harvesting for Agriculture

What is rainwater harvesting for agriculture?

Rainwater harvesting for agriculture is the collection, conveyance, storage, delivery and utilization of rainwater runoff for productive use, primarily in cropping systems. In practice, the delivery and utilization is at the point of collection on the farm.

Rainwater harvesting in the Caribbean is practiced primarily by small farmers. However, successful application of the technology is based both on empirical formulae derived from complex statistical calculations, and on an appreciation of the characteristics which define rainwater harvesting.

Rainwater harvesting for agriculture is the collection, conveyance, storage, delivery and utilization of rainwater runoff for productive use, primarily in food crop production. In practice the utilization is at the point of collection. Rainwater harvesting for agriculture includes the interactions and variability among climate, meteorology, hydrology and geology at local sites and in the crop characteristics.

Critical characteristics of rainwater harvesting for agriculture

1. The soil/plant/water relationships in rainwater harvesting for agriculture introduce a broader dimension not encountered in runoff water for household purposes. This results from the influence and variability of climate, meteorology, hydrology and geology at the farm site in the determination of crop water demand.

2. Meteorological considerations influence crop behaviour, yields and water demand. Soil water availability (infiltration rate, water-holding capacity, and depth) is influenced by geology. Hydrology is relevant in its applied form, especially the character of water in rainwater runoff rates, estimates of spillway requirements, and storage.

3. Soil/water/plant relationships, especially evapotranspiration rates at the farm, determine the adequacy and efficiency of management of the harvested quantities of rainwater runoff. Calculation of crop water demand requires, at least, a general appreciation of site characteristics such as the interaction between evapotranspiration and climate, particularly relative humidity, temperature and hours of sunshine.

4. Rainwater harvesting has a broader range of catchment surfaces than harvesting from rooftop runoff for household purpose. Natural slopes are of critical importance, as are artificial catchments such as the paved surfaces of roads, airports and highways, and even tree trunks. Natural catchments and storage present as much variability in surface area and rainwater collection efficiency. The management of natural slopes as catchment surfaces is singled out for treatment in the present document.

5. Agricultural extension officers need to be equipped to provide adequate rainwater harvesting services to small- and micro- farmers, as rainwater is usually the sole source of water during periods of low rainfall or drought.

Accordingly, relevant databases from observations on rainfall, climate[2] and crop behaviour in soil/plant/water relationships must provide information – in a timely manner – on the potential for rainwater runoff collection, forecast crop water demand, storage capacities required and the most suitable method(s) of harvesting rainwater.

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[2] An agro-ecosystem approach should be adopted at the country level.

CHAPTER 2

Design Rainfall

What is design rainfall?

Design rainfall for rainwater harvesting for agriculture is defined as *the total amount of annual rainfall received by the farm at which or above which the catchment area will provide sufficient rainwater runoff for harvesting and storage to supplement crop water requirements*. The objective is to have sufficient cumulative rainfall runoff stored to sustain the soil/crop water demand for planned crop development and yield. The process of affirmation that a certain volume of annual rainfall is a reliable estimate of design rainfall is based on the probability analysis of annual rainfall series data occurring with 90% frequency.

Design rainfall in rainwater harvesting for agriculture is the total amount of annual rainfall received by the farm at which, or above which, the catchment area will provide sufficient rainwater runoff for harvesting and storage to satisfy crop water requirements.

Why design rainfall for rainwater harvesting?

Annual rainfall can be highly variable and the distribution is often skewed. As a result, a certain volume of annual rainfall must be selected from rainfall series data to represent a reliable basis for collection and storage of rainwater runoff, in sufficient quantities to sustain annual production on the farm throughout the planned growing season.

Rainwater runoff differs from rainfall received by the farm during a rainfall event. Runoff is an additional amount which is collected during that same rainfall event, and stored to be used at a later date when rainfall is insufficient to satisfy crop water demand. After selecting the most reliable annual rainfall pattern and volume for the site at the farm, a production plan can be designed, adapted to the sum total of rainfall received by the farm plus the annual cumulative rainwater runoff in storage.

Selecting design rainfall for rainwater harvesting is perhaps the most challenging part of designing the rainwater harvesting system for agriculture. If the actual rainfall were below the design rainfall, the potential would exist for the additional water collected and stored to be insufficient, and plants could experience moisture stress, wilting, and even death when rainfall did not satisfy the water demand of the crop. Since most of the small- and micro- farmers in the Caribbean use rain-fed systems, with no access to other sources of water for their farms, the 90% reliability of the occurrence of that volume of design rainfall is the most critical determinant of success in the use of the technology.

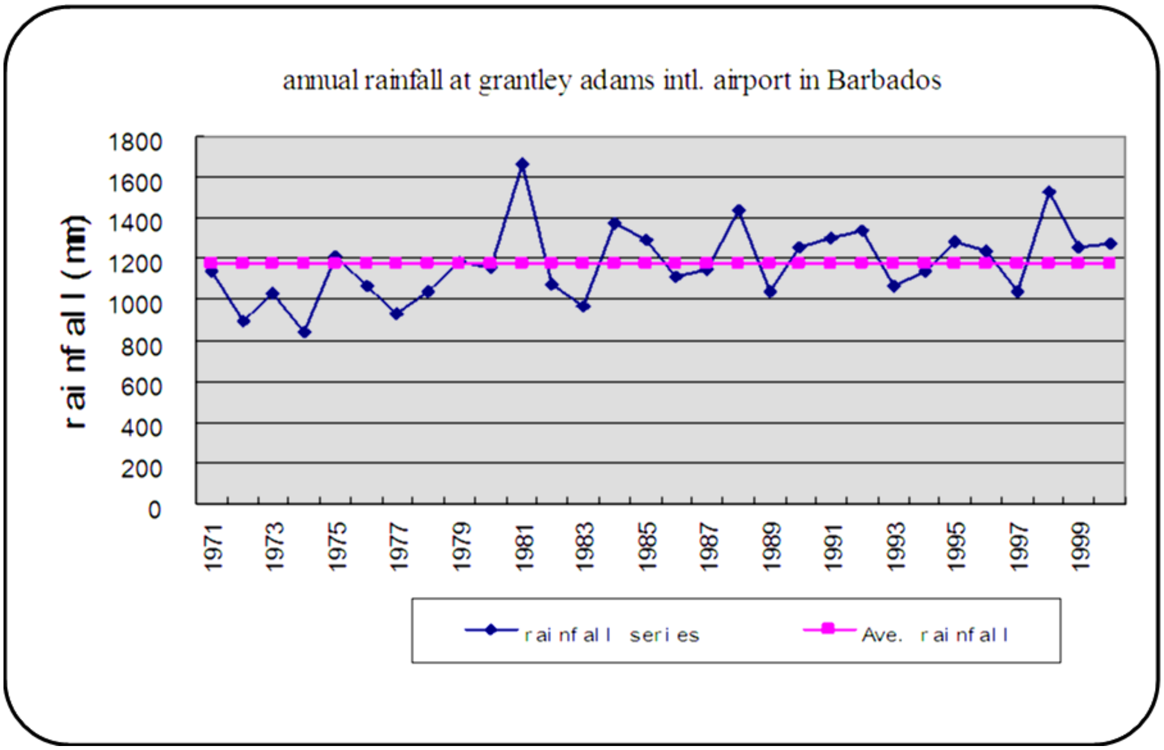
Calculating design rainfall

The calculation of design rainfall for a specific farm/cultivation or cropping site requires access to the series annual rainfall data that best represent the rainfall amount and distribution at the farm where the rainwater harvesting system is to be established**.** The graph of thirty-year series[3] rainfall data collected at Grantley Adams Airport in Barbados (see figure 1) is a good example of series rainfall from which to select and affirm design rainfall for agriculture. In terms of location-specific data, the rainfall data in figure 1 would be considered representative of farming areas around the Grantley Adams International Airport, such as Wilcox and Gibbons. The best data are always those that have been collected at, or closest to, the locality of the farm.

Data will be available normally from institutions such as the Ministry of Agriculture, weather stations managed by National Meteorological Offices and CARDI, from The Caribbean Institute for Meteorology and Hydrology (CIMH) website, schools of agriculture, or other public or private institutions with an interest in weather, as well as individuals with a well-managed rain gauge.

Design rainfall is determined by means of probability analysis. The following steps will assist in affirming design rainfall using the rainfall series data shown for Grantley Adams International Airport, Barbados in figure1.

Figure1. Thirty-year rainfall series data for Grantley Adams International Airport



Source: Grantley Adams International Airport Meteorological Station, Barbados

Step 1: Access the rainfall series data most representative of the farm where the rainwater harvesting system is to be sited. The 30-year rainfall series data, from the year 1971 to 2000, show that, on average, annual rainfall at Grantley Adams Airport was 1,177.94 mm. This is not the design rainfall.

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[3] Series data should be over at least 10 years, but preferred series would be closer to 20 years, with no missing data, unless the technical capacity existed to manage missing data.

Step 2: Use the empirical formula shown below to determine the probability of the frequency of each rainfall year volume in the series.

$$\boxed{P(\%)=\frac{m-0.375}{N+0.25}\times 100}$$

where *P* is frequency of rainfall in percentage or the probability %.

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

N is the number of years of the rainfall series.

The task is to identify the amount of rainfall that has occurred with 90% frequency. As design rainfall is the total amount of annual rainfall on which a farmer can plan for additional water for irrigation from harvested rainwater runoff, the 90% frequency is important. Using long-term rainfall series data increases the reliability of design rainfall affirmed. The 90% frequency target has been recommended for humid regions such as the Caribbean.

Step 3: The next steps (3-5) show how to develop a probability analysis table using the empirical formula given above. The data are the best estimates which could be read from the Barbados rainfall series data graph, and are an example of how to calculate design rainfall.

Step 4: Record all the observations of the rainfall series data, as shown in table 1.

Table 1: Annual rainfall series data for Grantley Adams International Airport, 1971-2000

Year	Rainfall mm	Year	Rainfall mm	Year	Rainfall mm	Year	Rainfall mm	Year	Rainfall mm
1971	1 243	1978	1 150	1985	1 453	1991	1 250	1997	1 500
1972	900	1979	1 147	1986	1 370	1992	1 080	1998	1 241
1973	1 062	1980	1 244	1987	1 145	1993	1 118	1999	1 380
1974	800	1981	1 147	1988	1401	1994	1 350	2000	1 250
1975	1 372	1982	1 650	1989	1 100	1995	1 300		
1976	1 149	1983	971	1990	1 455	1996	1 201		
1977	930	1984	1 390						

Source: Grantley Adams International Airport Meteorological Station, Barbados

Step 5: Rank the annual totals with the largest annual value as 1 and the lowest annual rainfall value as 30 and rearrange the data as shown in Table 2.

Use the empirical formulae given above to determine the probability that a certain annual amount of rainfall occurred with 90% frequency in the series data. The exercise can be done in Microsoft Excel or using a calculator.

The use of the formula is recommended for *N* = 10 to 100.[4]

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[4] Reining et al., (1989). This is one of several, similar formulae known to compute experimental probabilities.

Table 2 shows that the 90% probability (frequency) of a certain amount of rainfall being the most typical occurs in rainfall years 1983 and 1977.

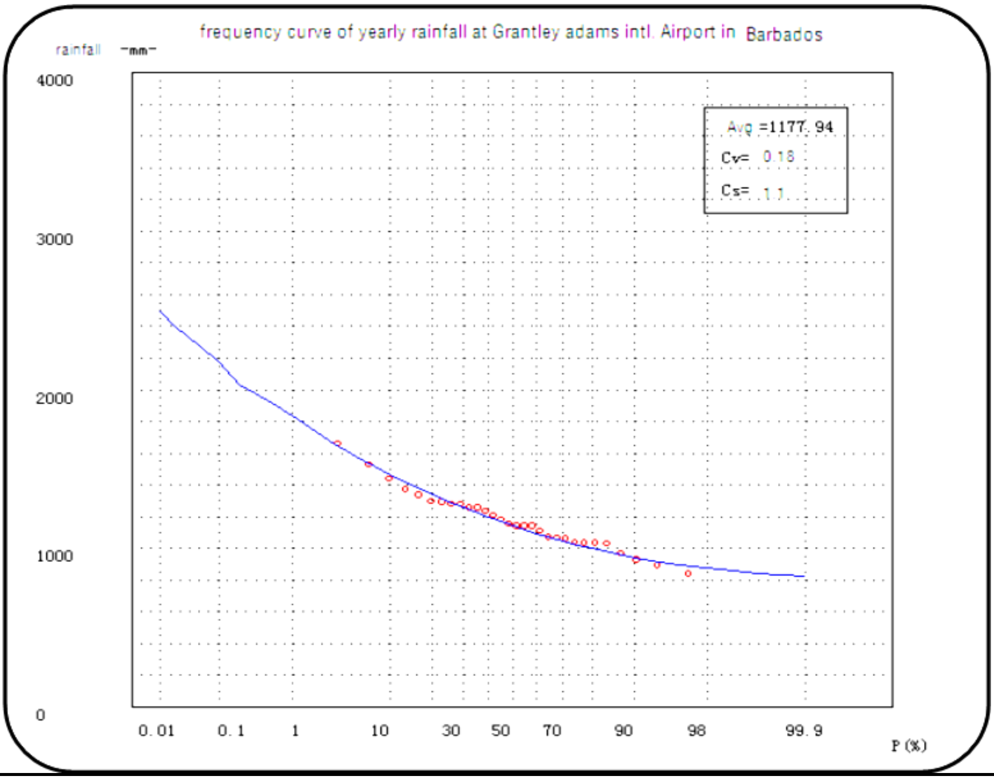
Table 2: Annual rainfall series data for Grantley Adams International Airport, 1971-2000

- Re-arranged according to rank and probability

Year	Rainfall	m	P	Year	Rainfall	m	P	Year	Rainfall	m	P
	mm		%		mm		%		mm		%
1982	1 650	1	2.06	1980	1 244	13	41.73	1992	1 080	24	78.09
1997	1 500	2	5.37	1971	1 243	14	45.04	1973	1 062	25	81.40
1990	1 455	3	8.67	1998	1 241	15	48.34	2000	1 260	26	84.71
1985	1 453	4	11.98	1996	1 201	16	51.65	1983	971	27	88.09
1988	1 401	5	15.28	1978	1 150	17	54.95	1977	930	28	91.32
1984	1 390	6	18.59	1976	1 149	18	58.26	1972	900	29	94.62
1999	1 380	7	21.90	1979	1 147	19	61.57	1974	800	30	97.93
1975	1 372	8	25.20	1981	1 147	20	64.87				
1986	1 370	9	28.51	1987	1 145	21	68.18				
1994	1 350	10	31.81	1993	1 118	22	71.48				
1995	1 300	11	35.12	1989	1 100	23	74.79				
1991	1 250	12	38.42								

Source: Author's calculations using data from table 1.

Figure 2: Frequency curve of annual rainfall at Grantley Adams Airport in Barbados, 1971-2000



Step 6: Use probability paper to plot a graph using the curve-fitting method. By this method, fit a curve or a line so that the distances of the observations above or below the curve are as close as possible to the line. Curve fitting and the use of probability paper provides an objective approach to finding the best line for many data points such as rainfall year series.

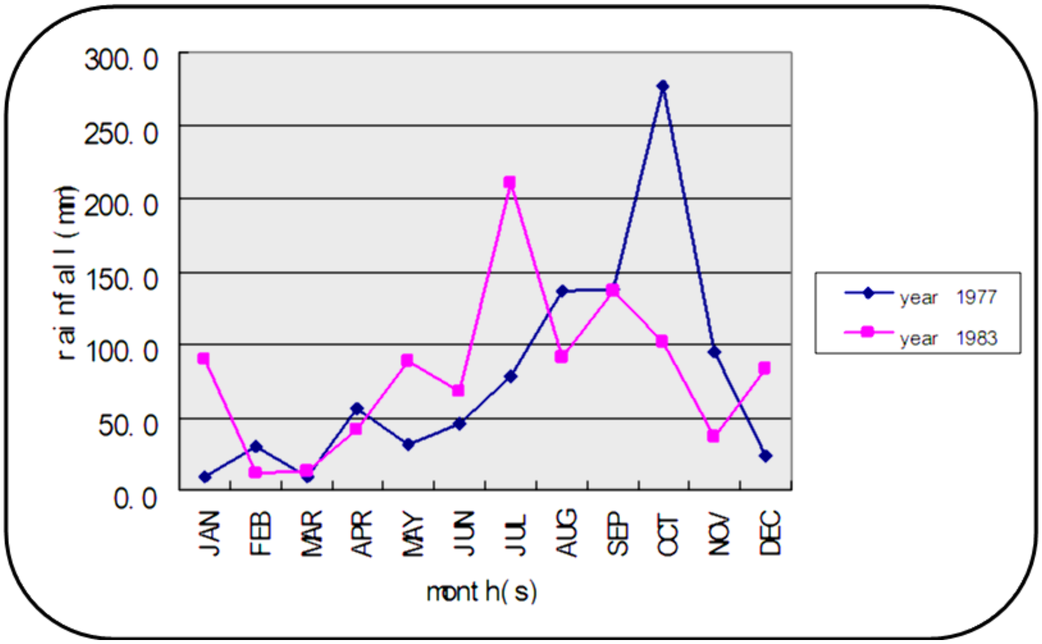
The frequency curve[5] for rainfall at Grantley Adams International Airport is shown to occur with 90% frequency at 943.2 mm.

Step 7: Note that a straight line could also fit from probability analysis.

Step 8: Use the series rainfall data to select the year most typical of the design rainfall in annual amount and monthly distribution. In the case of the Grantley Adams Airport data, the years 1977 and 1983 in the series data recorded actual annual rainfall of 929 mm and 971 mm, respectively (see figure 3). These years are closest to 943.2 mm and are taken as typical for design rainfall.

In most cases, one[6] year emerges as clearly typical of design rainfall. **In the example, the year 1977[7] can be selected as typical, and affirmed as the representative year for design rainfall, both because (a) the quantity of annual rainfall (929 mm) is closest to that of the design rainfall (943.2 mm), and (b) the amount of rainfall is indicative of the worst conditions to be expected in a dry season.** In such a case, the reliability of the rainwater runoff harvested, and on which the farm will depend, will be higher.

Figure 3: Monthly rainfall amounts of years typical of design rainfall.



Step 9: Note that table 2, on its own, provides a good indication of the quantity of annual rainfall that occurs with 90% frequency. In this example, the table also shows that the two years closest to a

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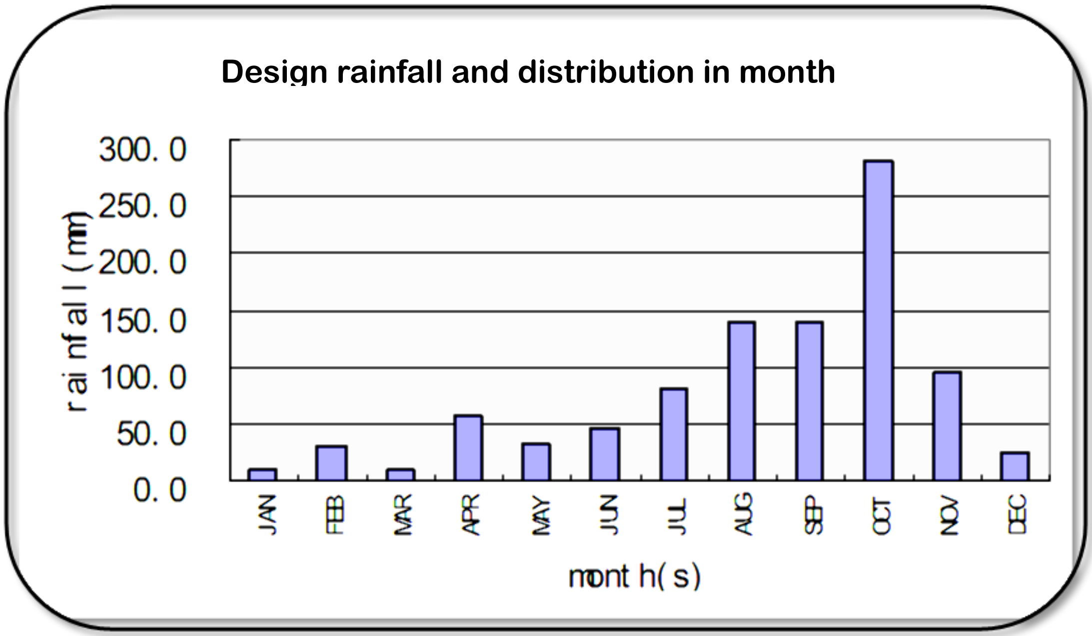
[5] This could also be a straight line.
[6] As many as three years may emerge as candidates.
[7] Note that the two years, 1977 and 1983, were already indicative in the probability analysis table.

90% probability are 1977 and 1983, with 930 mm and 971 mm annual rainfall, respectively. The annual rainfall closest to 90% frequency is also 1977 at 930 mm, only a slight difference.[8]

Step 10: Figure 4 displays the rainfall series data of the amounts and distribution[9] of monthly rainfall for 1977, the selected design rainfall year. **These are the annual rainfall amounts and distribution on which the plan to harvest and store rainwater runoff will be based, to ensure reliable access to water for irrigation during annual water scarcity.** Record the amounts in a table.

Figure 4: Monthly rainfall distribution of representative design rainfall year



1. Calculate the design rainfall for your farm or farming area by accessing rainfall series data from your agricultural extension officer. It is better that this should be done at one of your farmers' meetings.

2. Keep the information, as you will need it to work through the exercises in this document.

3. Remember that rainwater runoff can only be harvested during periods of rainfall and that, for greater reliability, the actual rainfall of the year selected is usually higher than the design rainfall.

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[8] The use of the probability paper is highly recommended for accuracy, but is not critical.

[9] A good indicator of the pattern of cumulative storage.

CHAPTER 3

Catchment Area and Storage Design for Rainwater Harvesting in Agriculture

The key factors that affect the amount of rainwater runoff that can be stored from design rainfall are

(a) Catchment surface and rainwater collection efficiency (RCE)
(b) Area of the catchment
(c) Conveyance and storage capacity.

What is the catchment in rainwater harvesting?

The catchment in rainwater harvesting for agriculture is the surface area which collects rainwater runoff for a particular farm. Unlike the catchment of a watershed, it is a localized surface area of specific size linked to a conveyance for the runoff and storage for the said farm. Typical catchment surfaces are rooftops of houses or farm sheds, plastic coverings on the ground or rooftop (greenhouses), paved surfaces of roadways and airports, and natural slopes.

Catchment surfaces vary in rainwater collection efficiency according to the type of surface, the area of the surface, the unevenness in the surface, and the degree and length of the slope. The practice of rainwater harvesting requires—at the minimum—good knowledge of the area of the catchment surface, and its efficiency in collecting rainwater runoff from a certain volume of annual rainfall (design rainfall).

What is rainwater collection efficiency?

The efficiency of the catchment surface in collecting runoff is described as the *rainwater collection efficiency* (RCE), and is based on observations of runoff from different types of surface during diverse rainfall events. RCE amounts in table 3 are those recommended in the FAO *Feasibility Study of rainwater harvesting for agriculture in the Caribbean subregion* (2008).

Table 3: Rainwater collection efficiency of different catchment materials

Material of catchment surface	Yearly rainwater collection efficiency of catchment surfaces with different volumes of annual rainfall *(Percentage)*		
	250 -500 mm	500 - 1 000 mm	1 000 - 1 500 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	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 (rice- like vegetation)	6-15	15-25	25-45

Source: FAO Feasibility Study of rainwater harvesting for agriculture in the Caribbean sub-region *(2008)*

Designing the area of the catchment

The following steps may be used to design the area of catchment surface required for the additional water to be collected from annual rainwater runoff, in order to satisfy annual crop water requirements during drought and water scarcity.

Step 1: The equation to apply is given below:

$$\boxed{A = \frac{W_d}{R_p \bullet RCE_y}}$$

where A is the area of catchment

W_d is the water demand in one year[10]

R_p is the rainfall of certain frequency p

RCE_y is the annual rainwater collection efficiency

How to calculate the area of the catchment

1.1 Given crop water requirements of 1000 mm for the total growing season for lettuce, design rainfall of 930 mm at 90% and collection efficiency of 0.90 (galvanized zinc), use the formula to determine the area of the catchment surface required for your area under crops (your cultivation).

(a) Crop water requirement for lettuce for the total growing season = 1000 mm[11] (W_d)

(b) Design rainfall = 930 mm annually at p = 90 % (R_p)

(c) Runoff collection efficiency = 0.9 (galvanized zinc or plastic roofing)

The ratio of the area (cultivated /cropped area) under crops on the farm to the catchment area is

$$\frac{\textbf{Catchment}}{\textbf{Cultivated area}} = \frac{\textbf{crop water requirement for total growing season} - \textbf{annual rainfall}}{\textbf{annual rainfall x RCE}}$$

$$= \frac{1000 - 930}{930 \text{ X } 0.9}$$

Area of catchment = .067: I = ratio of catchment to cultivated area

Assume cultivation of 100 m^2, area of catchment required = (100 m^2 x 0.067) = 6.7 m^2

Various rearrangements of the formula will provide measurements of water harvested and crop water requirements.

---

[10] Water demand for the crop for the year = crop water requirements (calculations will be shown later).

[11] See Appendix 2

How to calculate water harvested

Water harvested **= area of catchment x design rainfall x runoff coefficient**

2.1 Given a catchment with surface area of 100 m^2 (rooftop) with rainwater collection efficiency (RCE) 0.90 and design rainfall of 950 mm, what is the annual cumulative storage?

Step 1: Convert annual mm rainfall to metres = 950/1000 = 0.95 metres

Step 2: Water collected at .90 RCE[12] =100 m^2 x 0.95 m = 95 m^3 x 90/100

= 85.5 m^3 annual cumulative storage requirement.

To convert the annual cumulative storage to gallons, multiply by 220

= 220 x 85.5 m^3 = 18,810 gallons of water

To convert annual cumulative storage to litres, multiply by 1 000

= 85. 5 m^3 x 1 000 = 85 500 litres of water.

To convert annual cumulative storage to cubic feet, multiply by 35.47

= 85. 5m^3 x 35.47 = 3 032.7 ft^3 of water.

2.2 Given catchment with surface area of 144 ft^2 with rainwater collection efficiency (RCE) of 0.85 (plastic sheet) and design rainfall of 50 inches, what is the cumulative storage?

Step 1: Convert inches rainfall to feet = 50/12 = 4.1 ft.

Step 2: Convert to volumes (144 ft^2 x 4.1 ft) = 590.4 ft^3

Water harvested/collected = 590.4 ft^3 x RCE = 590.4 ft^3 x 0.85 = 501.84 ft^3

Volumes of water harvested by the catchment area may also be expressed in other units more familiar to the farmer using the conversion factors in Appendix 4.

Example: Use the conversions taken from Appendix 4 to convert the water harvested to acre/ ft. of water.

Water harvested = 501.84 ft^3

1 acre /ft. of water = 43,560 ft^3 (depth of water = 1 foot down the profile of 1 acre).

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[12] Volume = area x depth and expressed in cubic metres of water.

Annual cumulative acre/ft of water from runoff = 501.84/43,560 = 0.012 acre/ft. [13]

1 acre/ft = 325,851 gallons

0.012 acre/ft = (325,851x 0.012) = 3,910 gallons

Dimensioning storage and management of annual cumulative storage

Planning for storage of rainwater runoff in rain-fed systems requires knowledge of annual cumulative storage, the pattern of storage, and the pattern of demand for the water stored. This section of the document is meant primarily to assist in calculating annual cumulative storage of the rainwater runoff from a certain annual rainfall at 90% frequency with known catchment surface area and RCE. It also provides guidance on how to manage cumulative storage through production planning, and to affirm dimensioning of the storage without losing water to spillage.

Tables 4 and 5 and figures 5 and 6 are examples of how to calculate annual cumulative storage.

Table 4: Example of calculation of cumulative runoff at design rainfall

- of 929.5 mm, catchment surface of 100 m^2 and rainwater collection efficiency (RCE) of 90 %

Month	**(a)** Monthly rainfall in mm	**(b)** Conversion to m =(a)/1000)	**(c)** m^3 water =(b) x $100m^2$	**(d)** Water runoff collected m^3 =RCE x (c)	**(e)** Cumulative runoff in m^3	**(f)** Cumulative runoff in gallons =(e) x 220	**(g)** Cumulative runoff in litres =(e) x1000
January	9.0	0.009.	0.9	0.81	0.81	178.2	810
February	28.0	0.028	2.8	2.7	3.51	534.6	3 510
March	8.60	0.0086	0.86	0.84	4.35	957.00	4 350
April	53.3	0.0533	5.33	5.09	9.44	2 076.8	9 440
May	34.7	0.0347	3.47	3.12	12.56	2 763.2	12 560
June	47.4	0.0474	4.74	4.27	16.83	3 702.6	16 830
July	75.4	0.0754	7.54	6.79	23.62	5 196.4	23 620
August	138.0	0.138	13.80	12.42	36.04	7 928.8	36 040
September	137.5	0.1375	13.75	12.37	48.41	10 650.2	48 410
October	275.8	0.2758	27.58	24.82	73.23	16 110.6	73 230
November	97.9	0.0979	9.79	8.81	82.04	18 128.0	82 040
December	24.5	0.0245	2.45	2.21	84.25	18 535.8	84 250

Source: Author's calculations

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[13] Estimated 523 square feet with water supplied 1 foot down the profile = reasonable backyard garden

Figure 5: Cumulative runoff storage requirement for design rainfall

- of 929.5 mm x catchment surface area of 100m^2 x 90% rainwater collection efficiency

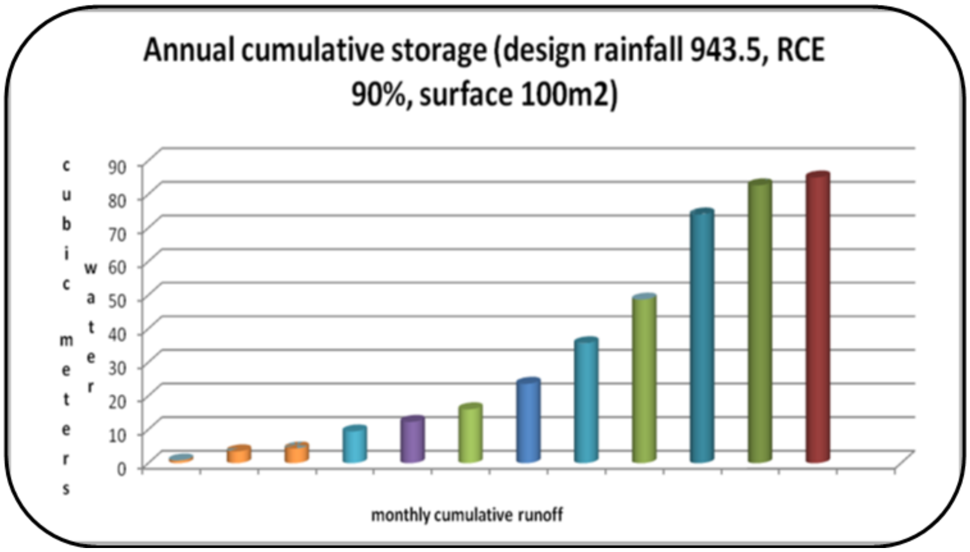

Table 5: Example of calculation of cumulative runoff at design rainfall

- of 1 999 mm,[14] catchment surface of 100 m^2 and rainwater collection efficiency (RCE) of 90%

Months	(a) Monthly rainfall in mm	(b) Conversion to m = (a)/1 000	(c) m^3 water = (b) x 100 m^2	(d) Water runoff collected m^3 = (RCE x (c))	(e) Cumulative runoff in m^3	(f) Cumulative runoff in gallons = (e) x 220
January	66.9	0.0669	6.69	6.02	6.02	1 324.4
February	100	0.1	10.0	9.0	15.02	3 304.4
March	81.8	0.818	81.8	7.66	22.38	4 923.6
April	113.4	0.1134	11.34	10.17	33.08	7 277.6
May	61.3	0.613	6.13	5.57	38.65	8 503
June	240.5	0.2405	24.05	21.6	60.25	13 255
July	167.7	0.1677	16.77	15.09	75.34	16 574.8
August	174.7	0.1747	17.47	15.72	91.06	20 033.2
September	239.9	0.2399	23.99	21.59	112.65	24 783.5
October	91.4	0.0914	9.14	8.23	120.88	26 593.6
November	475.9	0.4759	47.59	42.83	163.71	36 016.2
December	186.4	0.1864	18.64	16.78	180.49	39 707.8

Source: Author's calculations

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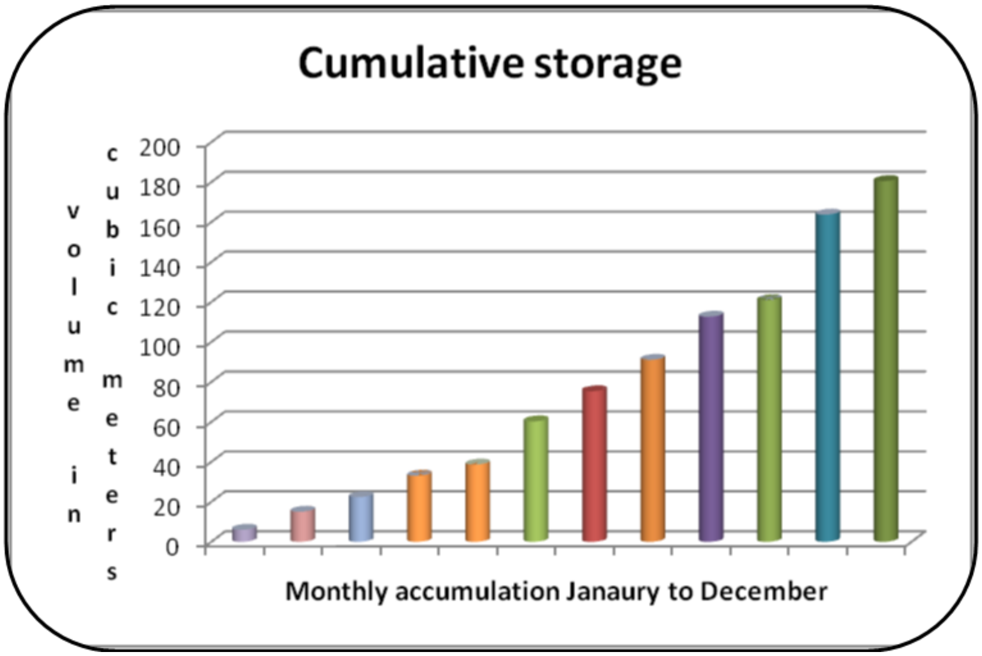
[14] Design rainfall for areas around Melville Hall Airport in Dominica

Figure 6: Cumulative storage requirement for design rainfall

- of 1 999 mm at catchment surface of 100 m^2 and 0.90 rainwater collection efficiency (RCE)



How to manage cumulative storage for optimal production planning

Knowledge of the maximum storage from design rainfall and the pattern of distribution is also the first step towards managing water storage, to (a) ensure that storage is adequate to satisfy additional demands after effective rainfall, and (b) optimize planting days and storage capacity.

Table 6 (using data from table 5) and table 7 (using data from table 4) show how to manage stored water and optimize storage capacity. Annual cumulative storage and use is linked to a specific catchment size and a specific plot size.

Two equations will assist in developing your own tables. The calculation of reference crop evapotranspiration rates and effective rainfall are given in Section 4 of the present document.

1. **Water demand = Reference crop evapotranspiration rate – effective rainfall**

2. **Cumulative balance = (Cumulative − ET0) + (Rainwater runoff − water demand)**

Table 6: First year of rainwater runoff storage, use and cumulative balance (surplus)[15]

Month	**(a)** **Rainfall** **(mm)**	**(b)** **Effective rainfall** **P_e = P0.8-25** **(P ≥ 75 mm)** **Pe = P 0.6-10** **(P ≤ 75 mm** **In 100 m^2 field** **(m^3)**	**(c)** **Water runoff collected** **(m^3)**	**(d)** **Cumulative storage from runoff** **(m^3)**	**(e)** **Water demand ET_0 − effective rainfall** **(m^3)**	**(f)** **Monthly totals** **(m^3)**	**(g)** **= d) - (e) + (c) - (e)** **Cumulative balance in storage** **(m^3)**
January	66.9	3.02	6.02	6.02	26.98	9.40	0
February	100.0	5.5	9.00	15.02	24.5	14.5	0
March	81.8	4.04	7.66	22.68	25.96	12.0	0
April	113.4	6.57	10.17	32.85	23.43	17.74	0
May	61.3	2.68	5.57	38.42	27.32	8.25	0
June	240.5	16.74	21.16	**60.02**	13.26	37.90	60.02 - 13.26 = 46.94
July	167.7	10.9	15.09	75.11	19.1	25.99	(46.94+15.09) -19.1 = 42.93
August	174.7	11.47	15.72	90.83	18.53	27.19	(42.93+15.72) -18.53= 40.12
September	239.9	16.9	21.59	112.42	13.10	38.49	(40.12 +21.59)- 13.10= 48.61
October	91.4	4.81	8.22	120.65	25.19	13.03	(48.61+8.22)- 25.19= 31.64
November	475.9	35.57	42.83	163.48	+5.57	78.40	31.64+42.83 =74.47
December	186.4	12.41	16.78	180.26	17.59	29.19	(74.47+16.78)- 17.59= 73.66

Source: Author's calculations

Note: Design rainfall is 1,999 mm with 90% frequency at surface area 100m^2 and RCE 0.90.
Reference crop evapotranspiration = 10 mm/day
Cultivation size = 100 m^2
Water demand/ crop water requirements = Reference crop evapotranspiration mm/day – Effective rainfall
= (10 mm/day x30 days ÷ 1000) x 200 m^2) − Effective rainfall
Cumulative balance in storage = (Cumulative – ET_0) + Rainwater runoff – Water demand
Green Sufficient water from storage and effective rainfall to meet water demand in the cropping system/cultivation of 100 m^2
Red Insufficient water from storage and effective rainfall to meet water demand in the cropping system/cultivation of 100 m^2
Recommended storage capacity = 120 cubic metres

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[15] Table does not take into consideration irrigation efficiency, expected to be more that .90 using micro-irrigation systems.

Table 7: First year use and annual cumulative balance (surplus) of rainfall runoff[16] without irrigation efficiency

Cumulative demand and supply at design rainfall 943.5 mm at 90% frequency and 90% rainwater collection efficiency (RCE)								
Month	(a) Rainfall (mm)	(b) Effective rainfall P_e = P 0.8-25 (P ≥ 75 mm) P_e = P 0.6-10 (P 75 mm) In 50 m^2 field (m^3)	(c) Water runoff collected (m^3)	(d) Total water availability (m^3)	(e) Water demand ET_0 – effective rainfall (m^3)	(f) Irrigation efficiency 90% (m^3)	(g) Cumulative storage from runoff (m^3)	(h) = (g)− (e) plus (c)−(e) Cumulative balance in storage (m^3)
January	9.0	0.45	0.81	1.26	7.37		0.81	0.81
February	30.0	1.5	2.7	4.20	8.58		3.5	3.5
March	9.30	0.45	0.84	1.29	9.63		4.34	4.34
April	56.5	2.82	5.09	7.91	7.26		9.43	2.17
May	31.7	1.58	2.85	4.43	8.50	9.44	12.28	2.84
June	41.4	2.07	3.73	5.80	8.01	8.90	16.01	7.11
July	79.4	3.97	7.15	11.12	6.11	6.78	23.60	8.81
August	139.0	6.95	12.51	19.46	3.13	3.47	35.67	18.42
September	139.5	6.96	12.55	19.51	3.12	3.46	48.22	27.85
October	281.9	14.09	25.37	39.46	0	0	73.59	29.38
November	97.9	4.89	8.81	13.70	5.99	6.65	82.40	33.10
December	24.5	1.23	2.34	3.57	8.85	9.8	84.74	26.59

Source: Author's calculations

Note: Cultivation size = 50 m^2

Water demand/ crop water requirements = Reference crop evapotranspiration mm/day − effective rainfall
= (6.72 mm/day x 30 days ÷ 1000) x 50 m^2 − effective rainfall

Cumulative balance in storage = (Cumulative – ET_0) + (Rainwater runoff – water demand)

Green Sufficient water from storage and effective rainfall to meet water demand in the cropping system/cultivation of 100 m^2
Red Insufficient water from storage and effective rainfall to meet water demand in the cropping system/cultivation of 100 m^2
Recommended storage capacity = 60 cubic metres

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[16] Table does not take into consideration irrigation efficiency, expected to be more that .90 using micro-irrigation systems.

How to measure volumes of water stored in a pond or mini-dam

The patterns of rainwater harvesting described later in the present document recommend the use of drums, tanks, ponds and mini-dams for storage of rainwater runoff. Drums and tanks carry specifications on volumes that do not change over time, whereas ponds and mini-dams may change shape and depth over time and, by extension, their volume storage capacity. Up-to-date knowledge of the capacity of your pond/mini-dam (in acres/ volume / in metric /imperial) is important.

A basic understanding is that, in any unit:

Volume = length x width x depth

- To determine the average depth in the pond in metres or feet, take depth soundings over the entire pond surface and find the simple average.
- To determine the volume of water in a rectangular pond in acre/ft, multiply the length by the width in feet, and divide by 43,560. The answer will be in acre/ft.
- To determine the volume of water in a rectangular pond in cubic metres, multiply the length by the width in metres and divide by 10,000 m^2. The answer will be in m^3/ hectare.
- To determine the volume of the pond in acre-feet, multiply the surface area in acres by the average depth in feet. The answer will be in acre-feet.
- To obtain the surface area of a circular pond in feet, measure the circumference of the pond and then square the number. To obtain the surface area in acres of water, divide the product by 547,390.
- To determine the volume of the pond in m^3 per hectare, multiply the surface area in hectares by average depth in metres. The answer will be in cubic metres per hectare.
- To determine the surface area of a pond with an irregular shape, use a global positioning system. Walk the perimeter of the pond, stopping at various locations and storing the way points where the pond changes shape. Then square the number, as above.

How to manage the variability in natural slope runoff

Small farmers on hilly slopes may face challenges with calculating rainwater collection efficiencies on natural slopes because of uneven surfaces, soil types or vegetation. In such situations, seek assistance in selecting the natural slope, as it will be necessary to carry out some observations (experiments) to determine the average rate of runoff, and how this varies from the recommended rainwater collection efficiency shown in table 1 of the present document.

The following steps provide guidance on one of the more reliable methods to be followed (see figure 7).

Step 1: Select a plot on the farm that is representative of the planned catchment area. Prevent water flowing into the plot—or the reverse—by placing metal sheets, or similar material, into soil at least 15 cm above the ground, as shown in figure 7. Install a rain gauge (see Appendix 4) inside, or near to, the plot. (The rain gauge needs to be on level ground).

Step 2: Place the conveyance (gutter or tube) at the lower end of the plot to collect the runoff. The conveyance should have a slope of not more than 2 % towards the collection tank. Ensure that the soil in the area of the conveyance is backfilled and compacted. The joint between the gutter or tube and the lower side of the plot should be built to allow the water to flow smoothly from the plot into the conveyance.

Step 3: Use regular plastic drums that are commonly used for rainwater collection, or any suitable type of container (measuring tank), for collection of the runoff. Position the container according to the position of the measuring tanks in the drawing below. The collection container should be suitably marked to allow measurement of changes in the level of the water. Keep the container covered to reduce surface evaporation or entry of rainfall into the collected water, as this will give false readings. Ensure that the container is large enough to collect all the runoff water.

Step 4: Each time it rains, record the rainfall amounts and measure the changes in water level in the tank. Take a number of daily readings, over several periods (seven-day intervals) and at different intensities, to determine how much rainwater is entering the measuring container from runoff. Compare with rainfall measured by the rain gauge to determine the percentage runoff down the slope. Check for silt at the bottom of the container. If this is the case, empty the container and clean regularly after measurement.

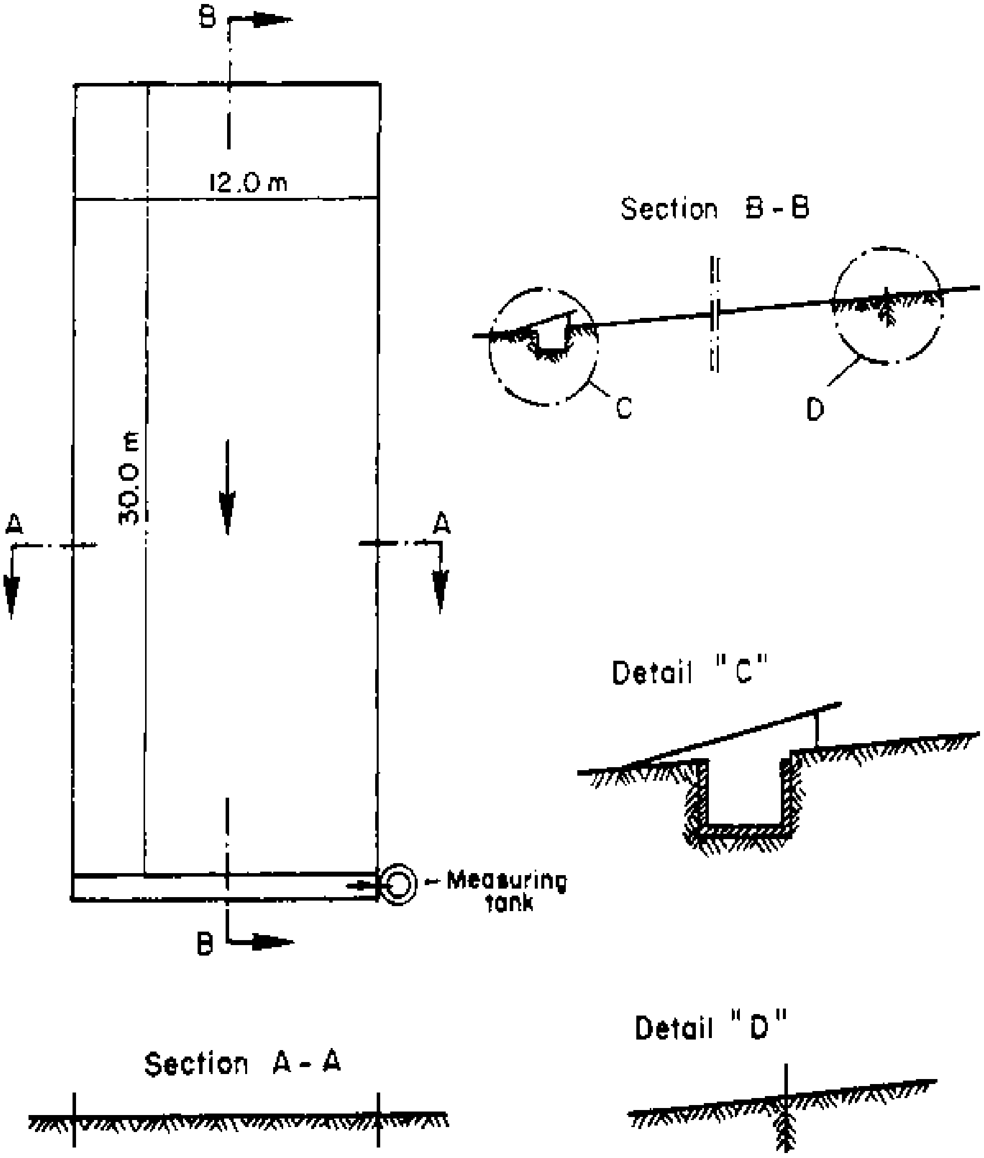
Step 5: Calculate the percentage rainwater runoff collected, from different rainfall amounts and intensities and over several observations, to determine the collection efficiency of the natural slope from different rainfall events. Take the average over several days and under different climatic conditions, especially daily temperature. Rainwater collection efficiency for natural slopes normally ranges from 0.3-0.5. Assistance should be sought from the engineering unit of the Ministry of Agriculture, or from CARDI, to determine any significant variability in natural slope and how this might affect storage volumes.

Several farmers working in the same farming area might be able to use the information gathered from the same plot to select similar suitable catchment sites for their own farms. The standard layout of the experimental runoff plot, taken from Siegert (1978) and shown in figure 7 below, will assist in the selection of the most suitable natural slope for the farm. This needs to be done only when there is evidence of unevenness in the natural slope such as, areas of ponded water.

Important facts about natural slopes

(a) Steep slopes collect more runoff than gentle slopes.
(b) The quantity of runoff decreases with increasing slope length.
(c) The volume of runoff per unit of area increases with the decreasing size of the catchment, i.e. the larger the size of the catchment, the larger the time of concentration and the smaller the runoff efficiency.

Figure 7: Layout of plot for measuring variability in rainwater collection efficiency (RCE) on natural slope



Source: Adopted from Siegert (1978)

CHAPTER 4

Evapotranspiration (ET), Climate and Reference Crop Evapotranspiration (ET_0)

Evapotranspiration is the sum total of soil water lost through soil surface evaporation and transpiration by plants. The evapotranspiration rate at the crop site is the main determinant of the adequacy of design rainfall[17] and, by extension, rainwater runoff to provide water for annual crop water demands on the farm. Evapotranspiration rates are influenced by crop cover and climate. In extreme conditions of soil water scarcity, evapotranspiration rates can be reduced.

Evapotranspiration is the sum total of soil water lost through soil surface evaporation and transpiration by plants. The process is influenced by climate, primarily relative humidity, number of sunshine hours, temperature and wind speed.
The amount of water lost from evapotranspiration is equal to the amount of water for which the soil must be compensated, either by rainfall or from stored rainwater runoff (irrigation).

When the climatic conditions are integrated with evapotranspiration rates, a reference crop evapotranspiration rate can be determined for a particular farm under conditions of optimum water management. This methodology, which involves the integration of climate, is known as the FAO Penman-Monteith method, and is universally accepted as the standard for determining reference crop evapotranspiration. The methodology obviates the need to determine crop evapotranspiration rates for different crop types and different stages of growth where climate conditions are the same and management practices are optimal.

Evapotranspiration

Cropped areas lose water vapour into the atmosphere from the soil surface and from plant surface areas through small pores in leaves and stems called stomata. Transpiration is a necessary process in plants that allows a constant pull on a stream of water molecules and nutrients from the soil through the plant system. Plants need this constant stream of water and nutrients to grow well and produce good yields. Some of this water is lost to the atmosphere in the form of water vapour. Transpiration stream is the term used to describe this constant pull on water from the soil to the point where it leaves the plant in the form of water vapour. The combined process of evaporation from soil surfaces and transpiration (vaporization of water) at plant surfaces is termed evapotranspiration.

In drought situations, or when there is water scarcity, soil water becomes increasingly unavailable to plants. Growth is adversely affected, crop yields are low and, in extreme cases, there is no yield. Evidence of low water in the soil is drooping or temporary wilting of leaves and of the plant itself. The plant will eventually die when the water availability is so low that the plant wilts permanently.

Plant development is best – and yields are highest – when the amount of water in the soil is optimal for plant growth. This soil water level is usually between 70% - 100% of field capacity. Field capacity is the maximum amount of water the soil will hold (100%) after percolation down the profile following a heavy rainfall event.[18] The purpose of rainwater harvesting is to make sure that, in rain-fed systems, the farm always has enough water in storage to keep (by adding water to the soil) the soil water close to, at least, 70% of field capacity.

Climatic factors can increase evapotranspiration rates, especially in hot, dry periods. When this happens,

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[17] Selected annual rainfall
[18] Soils reach capacity about 24-48 hours after intense rainfall. However, this varies with the soil type

the deficit between soil water status and field capacity increases over time, and can reach the wilting point for drought-sensitive crops within a short time. Because of this, it is important that the farmer has knowledge, or at least an appreciation, of the effect of evapotranspiration rates on soil water requirements in a cropped field, especially as irrigation water from rainwater harvesting is limited and should be used wisely.

You can make your own wet bulb by simply covering a regular thermometer with moistened cotton or cloth. The dry bulb is just another regular thermometer

What is relative humidity?

Relative humidity is a key variable in rainwater harvesting for agriculture. The term describes the state of the water-holding capacity of the atmosphere, as influenced by wind speed, sunshine hours and temperature and rainfall. Facts to note are, as follows:

(a) When relative humidity is low, evapotranspiration increases. As the soil continues to release more water to the plants, there is the potential for plant/soil water stress to develop if soil water is not returned to a level that releases this tension. Plants do not grow and produce a harvest very well under water stress.

(b) When relative humidity is very high, evapotranspiration is reduced, as the moisture in the atmosphere is closer to saturation.

(c) Moderately-high relative humidity is around 60% - 70%, and this state is most beneficial to plants, as plant water status is ideal for growth and development. Plants are usually turgid and leaves are in the best physical and physiological state for growing and producing a harvest.

(d) Normally, relative humidity is high in the mornings, at a minimum in the early afternoon and low in the mid-late afternoon, at which time evapotranspiration rates are highest, as the total water-holding capacity of the atmosphere increases.

(e) Based on the above, relative humidity is a good indicator of whether or not the potential exists for plants to be under moisture stress, especially during droughts or periods of low rainfall.

How to measure relative humidity

The common instrument for measuring relative humidity is the psychrometer (see figure 8 below). This instrument uses the difference in readings between two thermometers, one having a wet bulb and the other having a dry bulb, to measure the moisture content of the air. When the air is saturated (100 % humidity), the bulbs have the same temperature. When the air is less than saturated, the moisture around the wet bulb evaporates, cooling the wet bulb until it is cooled to the temperature where the concentration of water vapour in the air would saturate air at that temperature. This moisture level is the relative humidity.

Follow the instructions below to measure the relative humidity using a wet and a dry bulb.

- Wet the cotton wick covering the wet bulb with room-temperature water.
  Twirl the sling psychrometer for about 10-20 seconds and then take readings (in ° Celsius) from both thermometers, and record the results. Wet-bulb temperatures should be read first, and as quickly as possible, for highest accuracy. Delays in reading may cause error.

- Use the relative humidity chart shown in Appendix 4 to determine the relative humidity of the air. The numbers in the centre of the chart represent relative humidity in percentages.

- In the example shown, the dry-bulb temperature is 22 °C and the wet-bulb temperature is 16 °C. The difference between the two readings is 6 °C.

- Find the relative humidity with dry bulb on the y-axis and the difference between the wet and dry bulbs on the x-axis. The number where the two meet on the chart is the relative humidity, expressed as a percentage. In this case, the relative humidity is 53%, which is considered low-to-moderate, compared to the more favorable 70%, for the best situation for favourable evapotranspiration rates.

Figure 8: Sling psychrometer

- with wet bulb on the left and handle for twirling the thermometers

What is reference crop evapotranspiration?

The rate of evapotranspiration from a large area covered by grass 8-15 cm tall which is growing actively, completely covering the ground, and not short of water supply, is defined as the reference crop evapotranspiration rate.

The present document adopts the FAO Penman-Monteith method (1999) as the standard for determining reference crop evapotranspiration rates. This practice employs the integration of climatic conditions and the use of a hypothetical crop, to facilitate the process of elimination of crop-specific changes encountered with potential evapotranspiration methods. In other words, there is no need to apply the crop coefficient Kc to estimate actual crop evapotranspiration (ETc).

Based on the Penman-Monteith method, the International Commission on Irrigation and Drainage and the FAO Expert Consultation on Revision of FAO Methodologies for Crop Water Requirements have recommended that the equation19 below be the standard for estimating ETo. Internationally accepted, the method also recommends that, for ease of use across many regions, the grass reference evaporation concept be the model adopted.

Calculating reference crop evapotranspiration rate ET_o

The formula to be applied is shown below:

Reference crop evapotranspiration (ET_o) = ET = Kpan x Epan

where ET_o = reference crop evapotranspiration
K_{pan} = pan coefficient
E_{pan} = pan evaporation

The calculation involves the three steps shown below.

(a) Measurement of daily pan evaporation rate E_{pan}.
(b) Integrating climate to find the pan coefficient K_{pan}
(c) Calculating reference crop evapotranspiration ET_o

Measurement of daily pan evaporation rate E_{pan}

The method employs a Class A pan to determine pan evaporation, and a pan factor based on climatic conditions to determine reference crop evapotranspiration.

(a) **Specifications for the proper use of a Class A evaporation pan**: Daily water loss in millimetres from a Class A evaporation pan is recorded. The assumption[20] is that surface water loss by evaporation from the Class A evaporation pan is equal to water vapour loss by evapotranspiration from a grass plot 8-15 cm in height, well-watered and -managed for optimum growth, when a pan coefficient (K_{pan}) is applied. In this method, the reference crop evapotranspiration rate is influenced ultimately by the climate. To suit the methodology, the area of the reference grass should be about

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[19] FAO-Penman Paper No. 56 Penman Monteith Equation (FAO-56 PM).
http://www.fao.org/docrep/X0490E/X0490E00.htm

[20] The assumption is based on complex statistical analyses which may be researched on the FAO website

two hectares and not more than 1000 mm from the pan. Also, the plot should be on the windward side of the pan. These specifications provide the standard for the correlations between climate and evapotranspiration and the pan coefficient.

The Class A evaporation pan (see figure 9 below) is cylindrical, with a diameter of 1.2065 metres and a depth of 250 mm. Carefully rest the pan on a level wooden base about 15 cm above the ground. The pan is fitted with a fixed-point gauge and measuring tube at the centre of a cylindrical stilling well. The measuring tube is divided into 20 equal divisions, each of which is equivalent to 0.2 mm of water in the pan. Examine the Class A pan carefully to identify all of its features.

Do not try to make your own Class A pan. These pans are made with special specifications relevant to the calculations in the measurement of pan evaporation rates.

Evaporation is measured daily in millimetres and recorded as an average (mm/day) water loss. A seven-day average is considered reasonable, but the intervals may be less under extreme conditions of moisture loss. The evaporation pan must be protected from animals, birds and small children who might disturb the water in the pan. However, the protective method used should not impede evaporation of water from the pan.

(b) How to take pan measurements: On the first day of measurement, ensure that the water level in the pan is at the reference point (5 cm below the edge of the pan). At the end of 24 hours, normally set for 7 am under Caribbean conditions, the water level in the pan is restored by the following process: Using the measuring tube, fill the pan again, exactly to the reference point, and note the amount of water added. The total amount of water added is the evaporation in the last 24 hours. Any rainfall recorded during the 24 hours by the rain gauge in close proximity to the pan should be added to the total reading.

As the water in the pan and the reference grass (see diagram below) will not react in the same way to climatic conditions, the special coefficient (K_{pan}) has to be applied. The FAO Penman-Monteith method provides an internationally-accepted set of values for the pan coefficient (shown in Appendix 2). As indicated earlier, the application of the FAO Penman-Monteith pan coefficient makes it unnecessary to calculate crop evapotranspiration rates for different crops or stages of development under the same climatic and optimal soil water management conditions.

Based on the above, this document recommends that national agricultural extension systems consider establishing reference crop evapotranspiration rates for clearly-defined agro-ecosystems or smaller agro-climatic zones. The grass reference would be especially suited to food crops cultivated under rainwater harvesting systems, such as vegetables, crop legumes, vine fruits and root crops.

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Figure 9: Class A evaporation pan

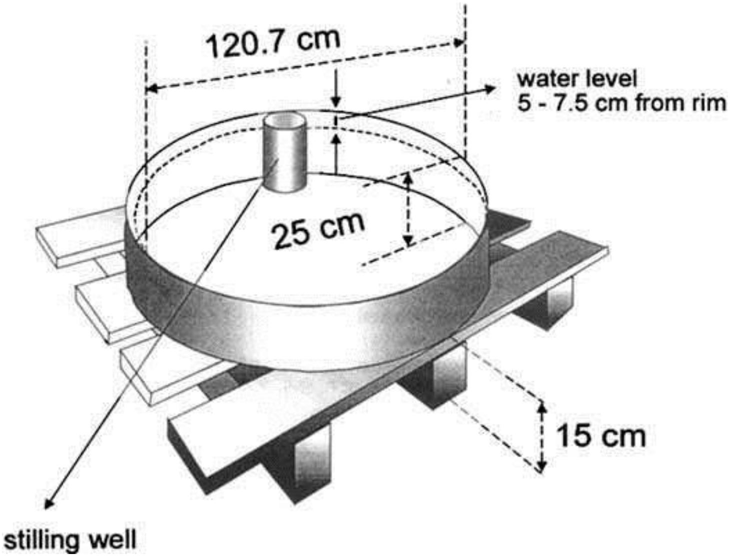
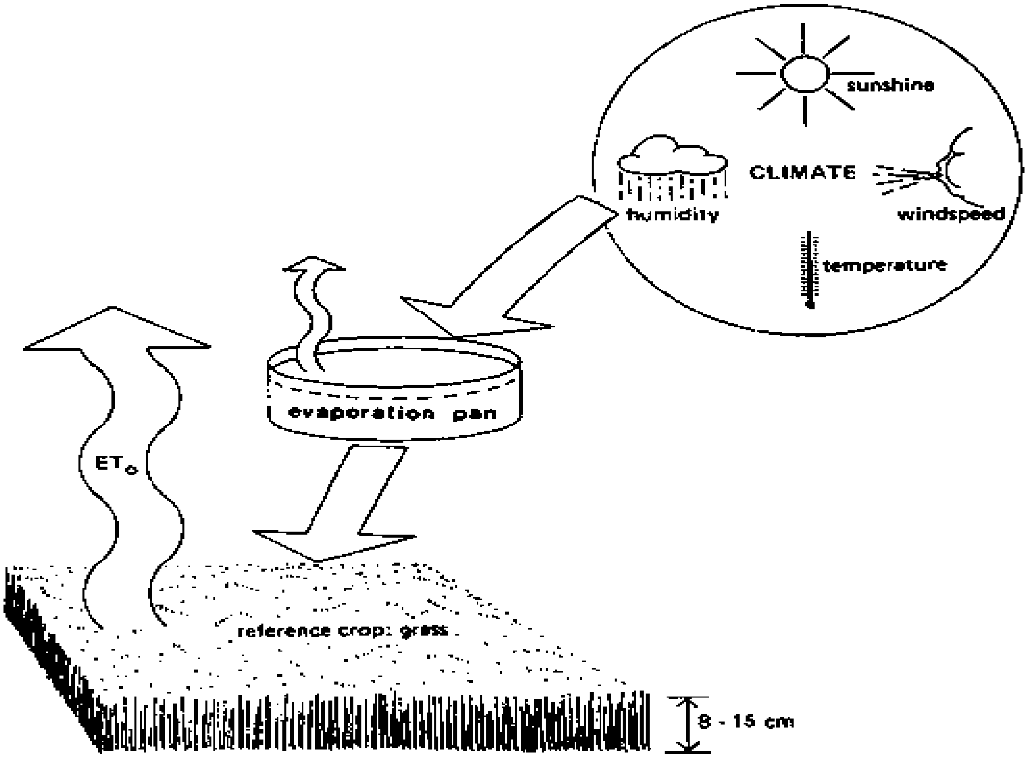


Figure 10: Reference crop evapotranspiration concept



Source: Adopted from FAO (1999)

(a) Calculation of pan evaporation rate (E_{pan})

Example of calculation to determine (E_{pan}).

Water depth in pan on day 1 = 150 mm
Water depth in pan on day 2 = 140 mm (after 24 hours)
Rainfall during 24 hours = 0 mm
Pan evaporation rate E_{pan} = 150 -140
= 10 mm/day

Should there be rainfall during the 24 hours, the evapotranspiration rate will have to be corrected accordingly:

Example where rainfall event occurs

E_{pan} = 165 – 152
= 13 mm /day

Assume total rainfall of 4 mm during the 24-hour period.

Then E_{pan} = 165 − 152 + 4
= 17 mm/day

(b) Calculation of K_{pan}

For the purposes of the exercise, assume that the following climatic conditions fit those under which E_{pan} was measured: Relative humidity at 70%; wind speed at less than 2 miles; reference plot not more than 1000 m[21] away on the windward side of the pan.

Now, use the FAO Penman-Monteith Tables[22] in Appendix 2 to find K_{pan}.

Based on the Table, the value of K_{pan} is 0.85.

(c) Calculation of crop reference evapotranspiration ET_o

Table 8: Evapotranspiration (ET_o) from pan evaporation using the FAO Penman-Monteith method

Given the daily evaporation data for the first week of October for a Class A pan installed in a green area surrounded by short irrigated grass: 7.2, 8.5, 7.6, 7.5, 8.6, 7.8, and 8.1. mm /day. In that period, the mean wind speed was 2 m/s and the daily mean relative humidity 70%. Determine the 7-day average reference crop evapotranspiration.			
Pan is installed on a green surface:			
Pan is surrounded by irrigated grass:	Fetch[23] $_{max}$ =	1000	m
Wind speed is light:	u <	2	m/s
Relative humidity is high:	RH $_{mean}$ >	70	%
From Appendix 4	K_p =	0 .85	-
	E_{pan} = (7.2 + 8.5 + 7.6 + 7.5 + 8.6 + 7.8 + 8.1)/7 =	7.9	mm/day
	ET_o = 0.85 (7.9) =	6.72.	mm/day

---

[21] Distance of reference plot from pan = Fetch in Table 6 above

[22] See Appendix 4.

[23] Reference vegetation (irrigated grass) not more than 1000 m away from pan on windward side of pan

The 7-day average of the reference crop evapotranspiration is 6.72 mm/day

Source: Adapted from FAO Natural Resources Management Division (1999)

How much irrigation water is required?

Based on the Penman-Monteith method, properly conducted, the ET_o rate is irrespective of crop type.

Based on the earlier definitions, crop water demand = reference crop evaporation rates.

The final decision on the water required from storage on a daily, or monthly, basis, or at whatever interval, is determined by two factors of equal importance: the irrigation system being used, and the effective rainfall at the cropping site.

Irrigation efficiency and water requirement formula

Irrigation efficiency is the fraction (%) of the water delivered which is actually available to the root system of the crops. In general, drip irrigation is the most efficient, with values that range from 0.85 to 0.95 (i.e. 85% - 95% efficiency). Micro-irrigation systems, including bubblers, range from 0.50-0.70. Hand watering, using buckets or small containers, is habitual practice in the Caribbean. While there are no established values for this method, water that is applied carefully to the roots and not to the canopies (leaves) can be as efficient in delivery.

Crop water requirement = Evapotranspiration [ET_o] ÷ irrigation system efficiency

Example:

Cumulative 7-day reference ET_o = 7 x 6.72 = 47.04 mm (see table 8)
Drip irrigation efficiency = 0.90
Amount of water required based on irrigation delivery = (47.04 ÷ 0.90)
= 52.26 mm / 7 days

Since water is supplied in volume from storage, convert to volumes of water required by the crop site

Assume area under cultivation = 100 m^2
Convert mm water to m water = 52.23 mm ÷ 1000 mm = 0.05226 m
Volume of water required = area of cultivation x crop water = 100 m^2 x 0.05226= = 5.23 m^3
If your water is stored in gallons = 220 x 5.23 m^3 = 1 150.60 gallons of water every 7 days
If your water is stored in litres = 5 230.0 litres every 7 days

Based on the above, storage for a well-managed backyard garden would need to provide an estimated 5.23 m^3 (or 1150.0 gallons, or 5230.0 litres) of water every 7 days, when there is no rainfall.

How to manage rainfall events and water requirements

Water requirement = Irrigation = ET_0 − effective rainfall ÷ irrigation system efficiency

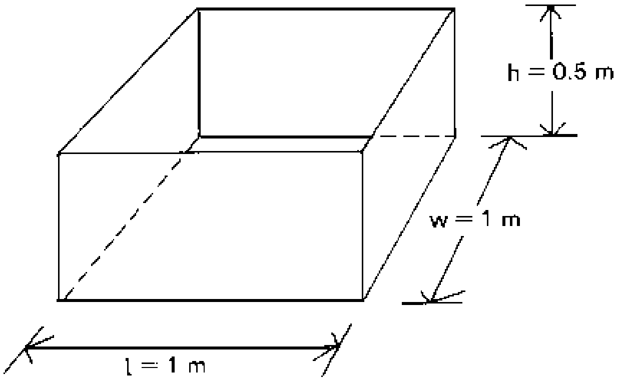
(a) Amount of rainfall and effective rainfall

The term *effective rainfall* is used to define the fraction of the total amount of rainwater useful for meeting the water demand of the crop.

The diagram below adopted from FAO *Irrigation and Management: Irrigation water needs Paper 3* provides a simple explanation of the way effective rainfall is measured.

Imagine that the open square container below is placed horizontally on an open area on the farm.

Figure 11: Container placed in field to simulate water depth following rainfall event



Note the measurements of the container: I metre wide and I metre in length, and a height of 0.5 metres. For the purposes of the exercise, continue to use the data from above. Assume that there are rainfall events during a period of seven days, and total water collected in the container is at a depth of 40.0 mm

The volume of water collected in the pan

= length (m) x width (m) x depth (mm) of the water collected

= 1 m x 1 m x 40/1000 mm

= 0.04 cubic metres of water

The cultivation surrounding the container would also have received a uniform water depth of 40 mm. However, as explained above, not all of the rainfall received by the field will be available to the plant. Some of this water will be lost through evaporation, through surface runoff, and through infiltration into the soil. Some of the water that infiltrates the soil percolates below the root zone, while the rest remains around the root zone.

Water held between soil particles around the root zone is the only part of the rainwater that is available to the plant. Effectively, this fraction of the rainfall is all the water that the plant can use from the particular rainfall event. This is effective rainfall.

Formula to determine effective rainfall (P_e)

This document adopts the two formulæ provided by FAO[24] to estimate the fraction of the total rainfall which the plant can use. These formulæ can be applied in areas with a maximum slope of 4% - 5% and so are still suitable to the circumstances of hillside farmers.

P_e = 0.8 P - 25 if P is more than 75 mm/month

P_e = 0.6 P - 10 if P is less than 75 mm/month

ET_0 = total evapotranspiration rates

= 47.04 mm/7 days

where P = rainfall for the month (mm/month)

P_e = effective rainfall (mm/month)

Note that P_e is always equal to or larger than zero.

(a) Calculation to determine effective rainfall

Assume rainfall = 40.0 mm over the 7-day period

= estimated 160 mm/ month[25]

P_e = 0.8 P – 25 = 0.8 x 40 -25 = 7.0 mm

Effective rainfall is 7.0 mm

(b) Calculation of water requirements (irrigation water) with rainfall

Et_0 = total evapotranspiration rates over 7 days = 47.04 mm

Water requirement = Irrigation = (47.04 00 mm - 7 mm) = 40.04 mm

Water requirement at irrigation efficiency 0.90 (drip) = 40.04 ÷0.90 = 44.48 mm

Assume area of cultivation is $100 m^2$

Water required from storage = (44.48 mm ÷ 1000 mm) x $100 m^2$

= 4.45 cubic metres every 7 days

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[24] *Irrigation water management: Irrigation water needs* Paper 3, FAO Natural Resources Management and Environment Department (NRMED)

[25] Estimated as normal for Dominica during the rainy months.

If water is stored in gallons = 4.45 x 220 gallons

= 978.56 gallons every 7 days

If water is stored in litres = 4.45 x 1000 litres

= 4 450 litres every 7 days

Calculation when rainfall in inches and irrigation is micro-spray

ET_0 over 7 days = 47.04 .0 mm

Rainfall recorded = 1.5 inches over 7 days.

Area under cultivation = 100 m^2

Irrigation efficiency = 0.65 (micro spray)

Rainfall recorded = 1.5 inches = 1.5 x 25.4 mm [26]

= 38.1 mm over 7 days

Effective rainfall P_e = 0.8P − 25 = 5.48 mm over 7 days

Water required = ET_o − effective rainfall = 47.04 − 5.48 = 41.56 mm

Irrigation efficiency using micro-sprinkler = 0.65

Water required = (41.56 ÷ 0.65) = 63.94 [27] mm

Volume required from storage = area of cultivated field x 63.94 mm /1000

= 100m^2 x (63.94 mm /1000)

= 6.39 m^3/7days

Test your knowledge

In the space below, test your knowledge of conversions. Convert 1.83 m^3 water to:

Cubic ft of water			
Gallons of water			
Quarts of water			

---

[26] 1 inch is equal to 25.4 mm

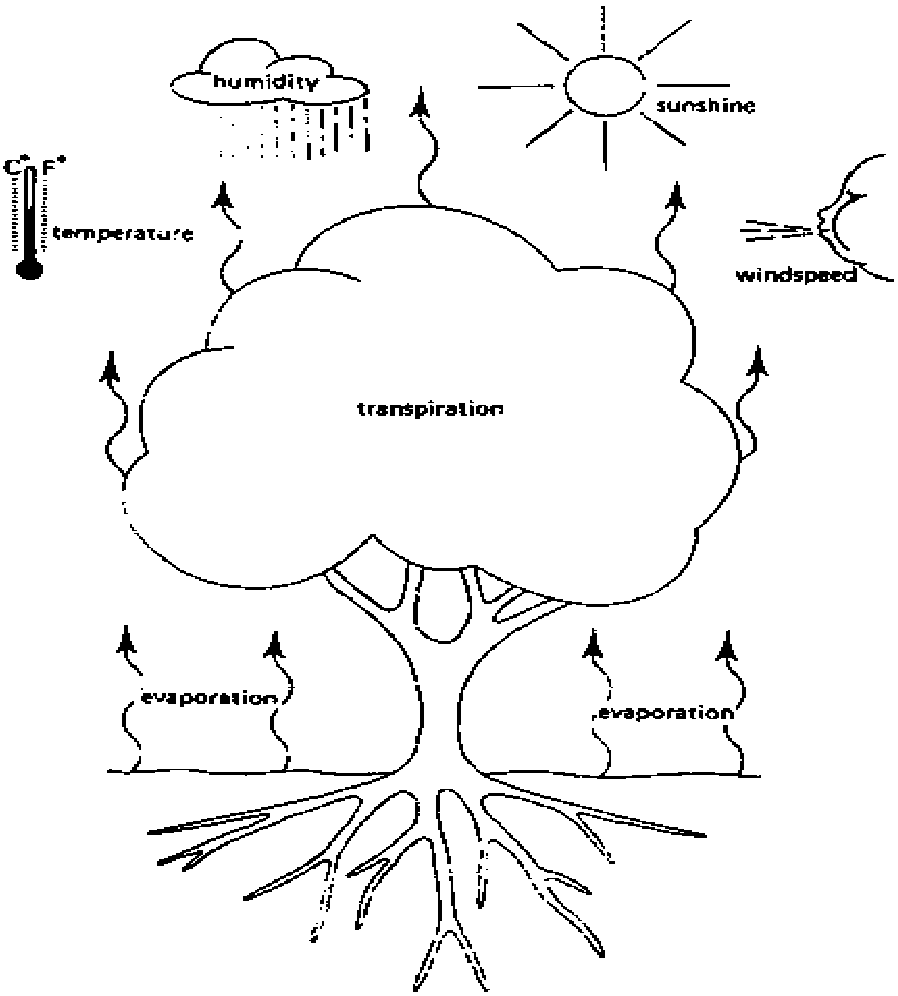
[27] Note lower level of efficiency of sprinkler system.

Litres of water			
Acre/ft of water			

As experience is gained, you will be able to judge whether or not to add less than the 100% water requirement.

If insufficient water is added, plants could wilt, production would be affected negatively, and plants could die even. If too much water is added, the excess simply will run off or percolate down the soil profile, and valuable—although limited—quantities of water will be lost Furthermore, the potential benefits of planned-for annual cumulative water will not be realized, and annual planting and harvest plans could be compromised. Likewise, the expected contribution and outcome of the selected design rainfall would be less. In other words, the rainwater harvesting system would not serve its purpose of sustaining crop yields in the rain-fed system for part, or all, of the dry period.

Figure 12: Diagram showing the interrelationship between climate and evapotranspiration rates



Source: FAO

Conduct the following knowledge test

- ***Select the design rainfall***
- ***Characterize catchment type***
- ***Calculate catchment area /cultivation ratio***
- ***Calculate annual cumulative storage***
- ***Manage potential variability in catchment on a natural slope***
- ***Calculate reference crop evapotranspiration using the FAO Penman-Monteith method***
- ***Calculate water requirements from reference crop evapotranspiration***
- ***Calculate water requirement from storage, based on irrigation system efficiency***
- ***Calculate water requirements from storage when there are rainfall events***
- ***Determine the optimum size of your plot /cultivation of vegetables, based on annual cumulative storage***
- **Convert water requirements from your storage using different units of measurement.**

CHAPTER 5

Choosing the Irrigation Method for Rainwater Harvesting

Usually, as the amount of stored rainwater is limited, highly-efficient irrigation methods have to be employed. Normally, micro-irrigation systems are recommended for rainwater harvesting.

- Micro-irrigation systems: This family of irrigation systems delivers water through small devices in the form of spray, mist, sprinkle, bubble or drip. Micro-irrigation systems are the most suitable, as they deliver water at the soil surface very close to the plants, or below the soil surface directly into the area of the root zone.

- The drip system is the most efficient, delivering in excess of 90% of the water directly to the plant, as droplets above the surface or below the surface.

- Micro-sprinklers deliver water either in spray or mist form, and are best when used for vegetables, flowers, crop legumes and some fruit trees. The efficiency of the micro-sprinkler varies from 50% - 70 %.

- Bubbler systems are also popular for water efficiency. Bubblers apply water from the emitters directly to the root zone of the plant. The flow rate of the bubble sprinkler can be changed from full flow to trickle by turning the nozzle, and can range from anywhere between 10 litres and 135 litres per hour (2.5 gallons – 35 gallons). Rates should be lowered if the water begins to pool.

- Manually operated pipe irrigation is also used.

- Watering cans are also popular among micro-farmers and, especially, with women operating backyard gardens, and nursery workers. Watering cans can be efficient if the nozzle is held close to the root of the plants and not sprayed over the leaves, as is the common practice.

Since layout and design of the irrigation system depends on the specific topographical conditions, it is not possible to provide detailed designs but only to suggest some general features. Some general recommendations for layout and design of irrigation systems for small- and micro- farms are given below:

- Semi-stationary or movable system for micro-irrigation system
- Main pipe in the semi-stationary system is fixed and usually buried underground while the laterals with the emitters are moved from field to field.
- The entire movable system, including the pump and pivot (valve, meter, filter, and chemical container) must be movable.
- Use the screen type filter for small micro-irrigation systems.
- Depending on the topographical conditions, the necessary water pressure for the micro-irrigation system can be produced by gravity, once the difference in level is more than 10 metres.

Rainwater harvesting systems

Bubbler irrigation system –highly efficient

Drip irrigation in greenhouse

Micro spray in tomatoes in Saint Lucia

Drip irrigation in straw in field Saint Lucia

Source: Ministry of Agriculture –Saint Lucia

Hand watering in nursery in Saint Lucia

Small farmer in Montserrat hand watering

Micro spray in greenhouse

Micro sprinklers in the field

Source: Ministry of Agriculture –Saint Lucia

CHAPTER 6

Physical Structures of Rainwater Harvesting Systems

The basic structure of the rainwater harvesting system consists of the water catchment, conveyance, and storage and supply systems to the field.

(**a) Catchment and surfaces** may be natural or artificial slopes (rooftops, roadways, airport strips, hillsides, tree trunks and canopies, greenhouse roofs and plastic-covered ground surfaces in the cropped field). Catchment and surface systems must be of known area and rainwater collection efficiency.

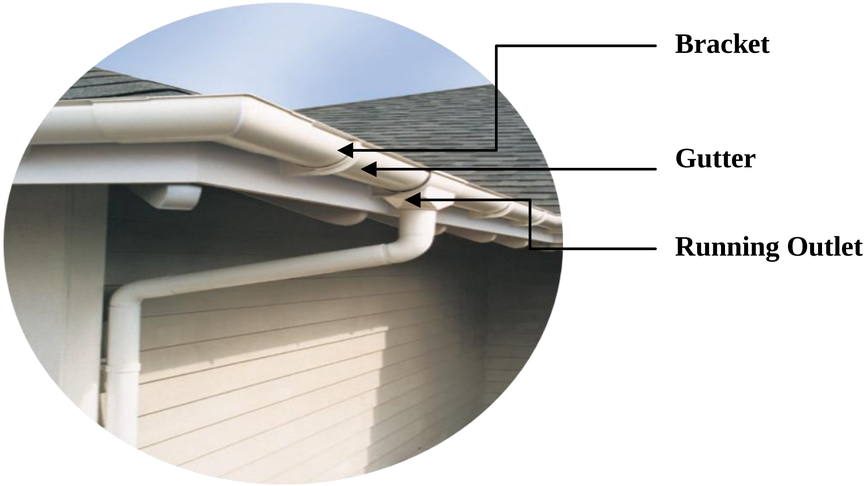
(**b**) **Conveyance systems** carry water from catchment to storage in gutters and pipes or earthen channels. Rainwater harvesting is for on-farm collection and storage: hence, a simple conveyance system serves the purpose.

(**c**) **Storage systems** are usually drums, tanks, ponds and/or mini-dams. Storage construction material may be earthen, cement or plastic, including plastic bags, depending on suitability and affordability to the farmer. The popular plastic drums[28] used in Caribbean households for water storage are suitable for backyard gardens and school gardens, as well as for the field. Seepage and infiltration should be avoided, and prevention may require technical input and light engineering works, depending on soil and geology.

Selected examples of catchment, storage and rainwater harvesting systems for small and micro farmers

Plastic provides high collection efficiency and may be applied in systems that intercept runoff from bare ground or from roof runoff.

Figure 13: System components for roof catchment system



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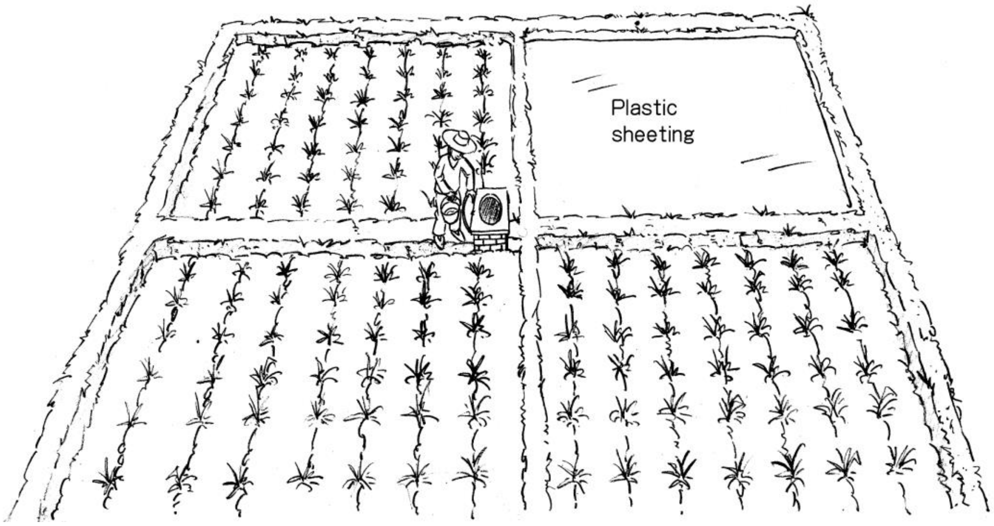
[28] Plastic drums are usually calibrated in gallons; use the conversion table in Appendix 4 if necessary.

Figure 14: Plastic sheeting

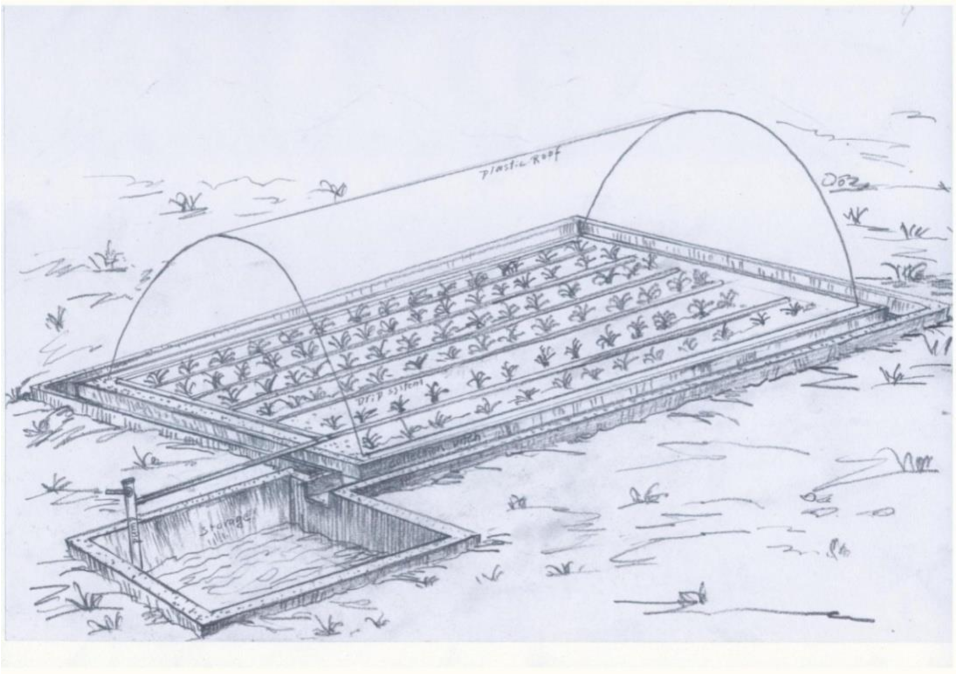
- Covering a portion of the ground is an effective catchment surface with about 85% - 90% efficiency



Source: FAO

Note: Storage tank is in the centre of the field.

Figure 15: Layout of rainwater harvesting system with greenhouse plastic roof as catchment



Source: FAO

Note: Collection tank is at the lower end of the greenhouse structure, and equipped with gutter inlet and irrigation outlet.

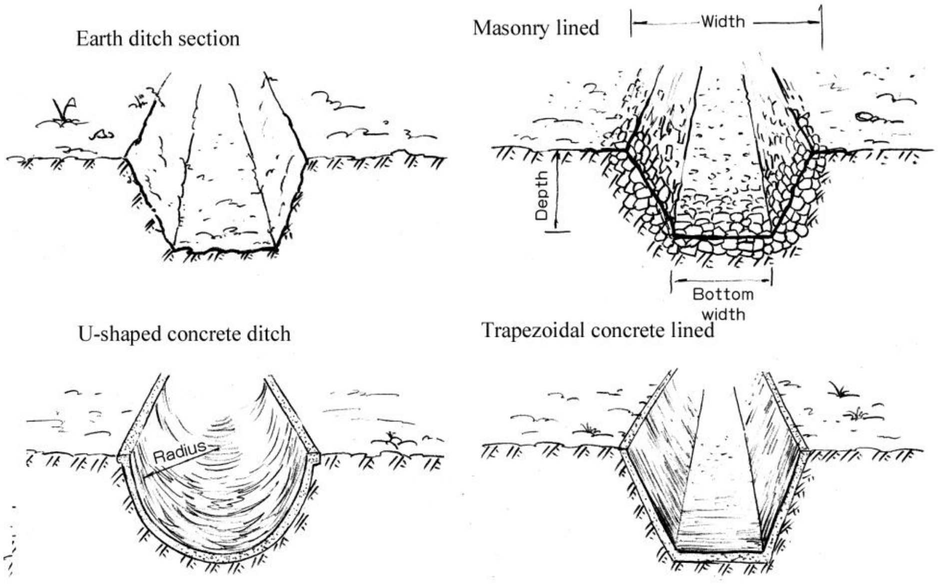
Natural slopes are very common and provide satisfactory rainwater runoff when rainfall is concentrated in short periods. The slope should be moderate, with normal soil infiltration and fair-to-good plant cover.

Figure 16: Layout of system for collection of rainwater from natural slope

Source: FAO

Collection efficiencies of the natural slopes can be increased by building interception ditches and collection channels

Figure 17: Section of interception and collection channel



Source: FAO

Ponds make good storage for runoff from natural slopes. Here, plastic sheeting provides protection from seepage in excavated pond. However, ponds do dry out under extreme conditions. The catchment area of the natural slope should be large enough to maintain water in the pond during dry periods. Ponds are best excavated at the lower end of a natural depression.

Figure 18: Excavation pond compliments of a FAO project in Rwanda

Figure 19: Lined reservoir in Manchester, Jamaica

This system is established in a natural depression Lined with polyethelyene membrane

Figure 20: Pictorial depiction of the rainwater harvesting design using pond storage

Source: FAO Somalia

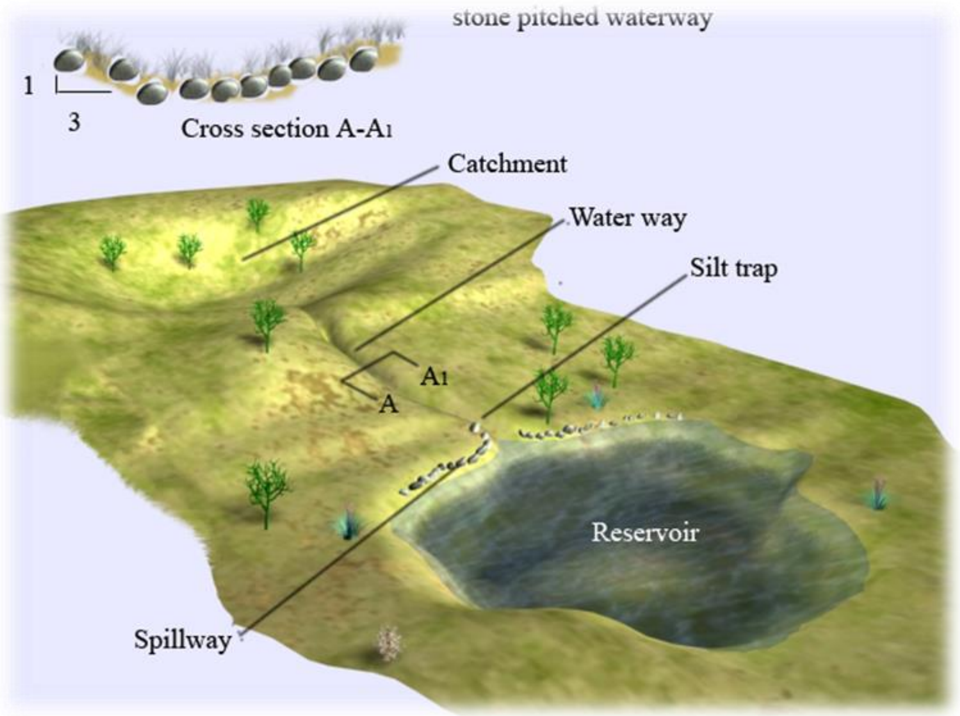


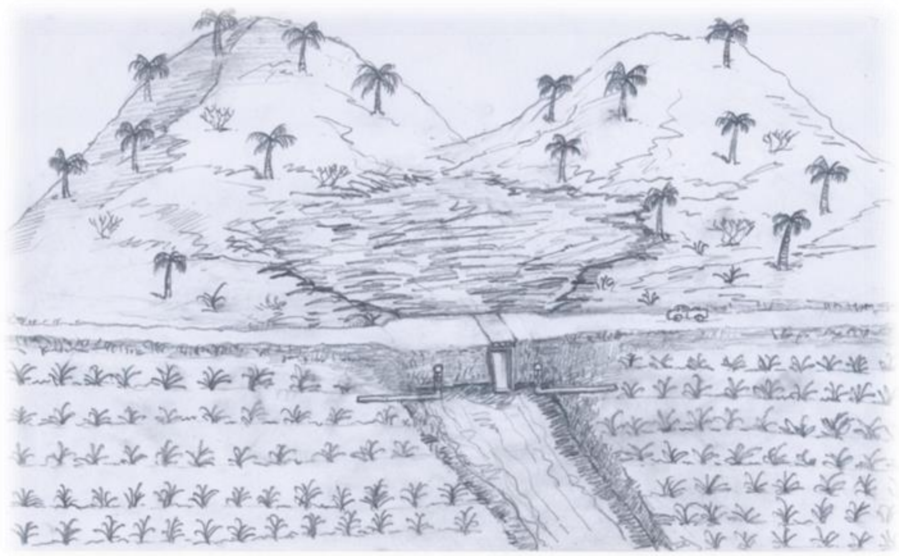
Figure 21: Excavation pond with no sealing

Note: Depending on the geology and soil type, it might not be necessary to use sealing or plastic

Source: Earth reservoir in Douglas Castle, Clarendon Jamaica
This system is established in a natural depression compacted clay soil Dimensions 50m x 40m x 3.5m

Building mini-dams to create reservoirs is also a common form of storage, especially in seasonal water courses and ephemeral streams. Mini-dams built on seasonal waterways can store large amounts of water. They are suitable for farms located on hillsides and can store from 5000m^3~200 000 m^3 of water, and do not usually dry out.

Figure 22. Sample layout of mini-dam for rainwater harvesting

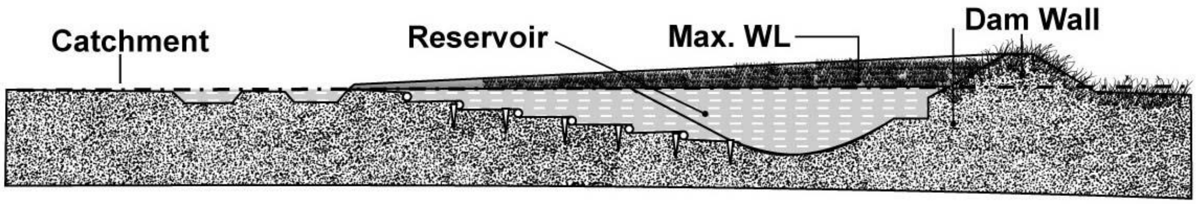


Source: FAO

The mini-dam is simply a smaller version of the dams seen around the Caribbean. In such cases, the barriers are placed in flowing rivers to harness the water for household use. The mini-dam for rainwater harvesting for agriculture is usually built on seasonal waterways and ephemeral streams, including those occurring at crossroads.

Figure 21 shows the principle of the dam.

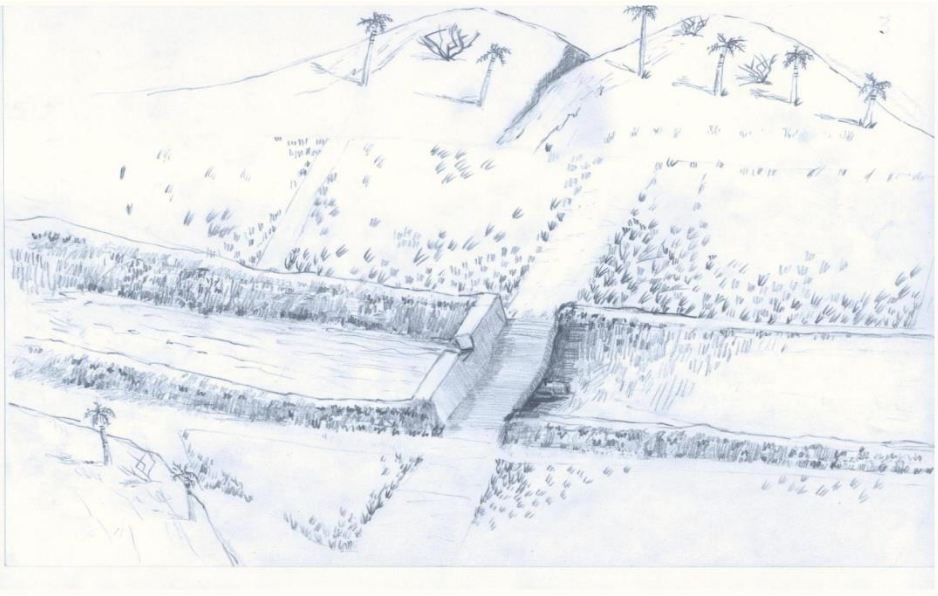
Figure 23: Cross-section of the principle of mini-dam construction in rainwater harvesting for agriculture



Source: *Rainwater Harvesting: a life line for human well-being*, United Nations Environment Programme

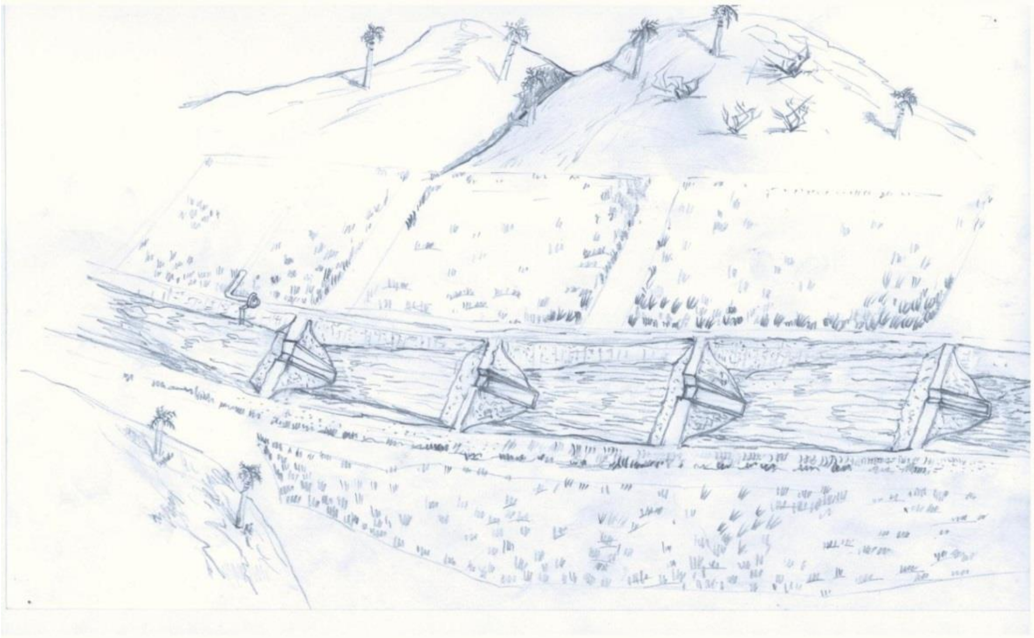
Two types of mini-dam are proposed for the Caribbean: road cross dams, usually for hilly, rural communities where seasonal waterways exist at culverts during rainy periods, and series mini-dams on those same seasonal river courses, in areas such as Antigua and Barbuda where the farms are on lower-lying areas.

Figure 24: Layout of a road-cross dike for rainwater harvesting



Source: FAO

Figure 25: Layout of series dams on same river-course suitable for flatter areas



Source: FAO

Siltation may become a problem for mini-dams and ponds. When this happens, the storage capacity of the system will be reduced, and planning for the use of cumulative water storage may be compromised. The system could also become subject to spillage, which means loss of the already-limited quantities of water. Silting can be reduced by building silt traps in the conveyance channel, as shown in figure 24.

Figure 26: Silt trap to intercept sediment and avoid silting of dam

Source: Rainwater Harvesting: a lifeline for human well-being (UNEP)

The system of using ponds has led farmers in India to adopt a community-based approach to rainwater harvesting from natural slopes.

Figure 27: Community based rainwater harvesting where impounded water flows from one pond to another

Source: Water harvesting Community-led Natural Resource Management. FAO

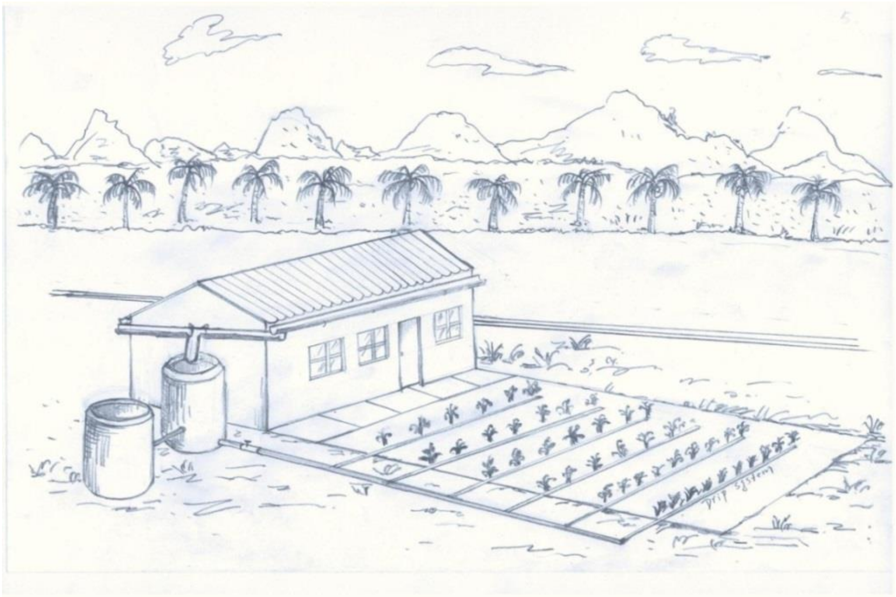
Rooftop catchment systems are perhaps the most popular in the Caribbean, as many householders harvest rainwater for household purposes. The catchment material is normally some type of galvanized zinc which has a high RCE. The proposal is that this practice should be more widely extended to include rainwater harvesting for backyard farms and farms closer to homes.

In the Caribbean, rooftop runoff is usually stored in readily-available plastic drums or in concrete tanks. The ferro-cement tank introduced to the subregion under an FAO-supported project in Dominica is being used in some countries.

Figure 28: Rooftop rainwater runoff on a local farm

Source: FAO

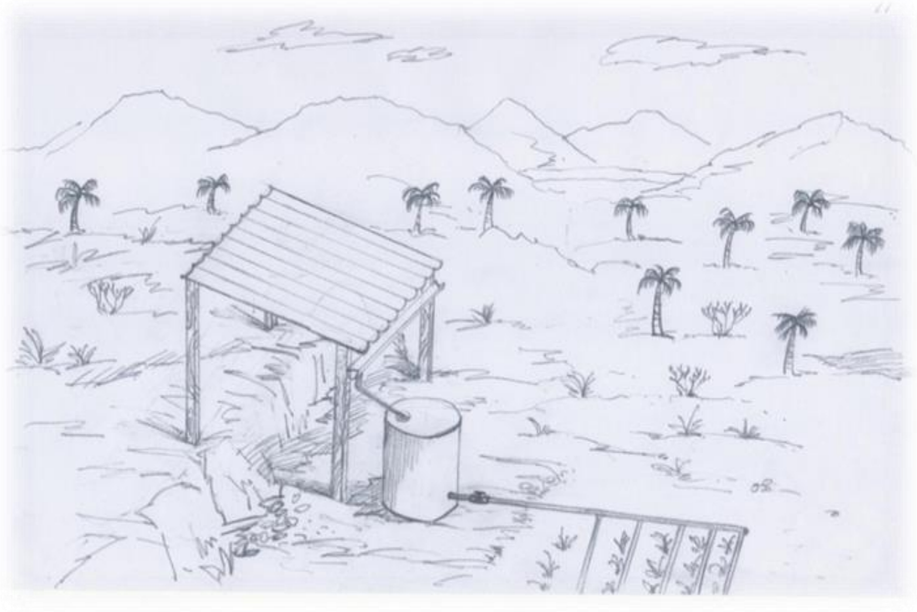
Figure 29: Layout of household rooftop rainwater harvesting for backyard farm irrigation



Source: FAO

Figure 30: Rainwater harvest system for backyard gardening in Antigua

Figure 31: Layout of mini-rooftop rainwater harvesting system for vegetable irrigation



Source: FAO

Figure 32: The ferro-cement tank[29] and the plastic drum

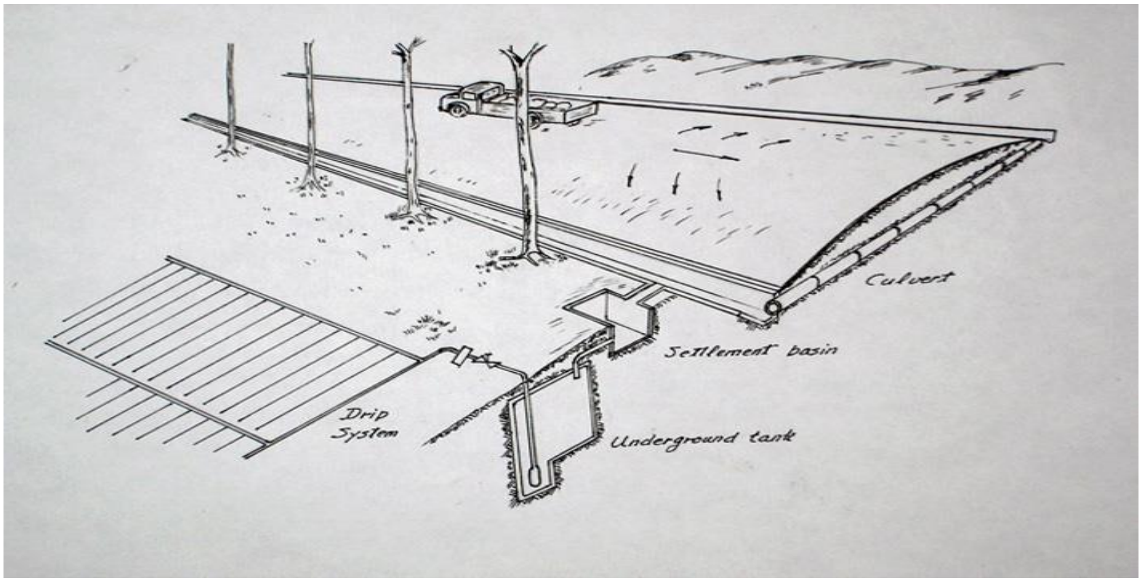
- **popular for storage of water and should be more widely-used in the rainwater harvesting system**

Source: Photograph compliments of IICA –Saint Lucia

Hard surfaces of highways, airports and pavements of public buildings all have high rainwater collection efficiencies. Airports, such as the Grantley Adams International Airport, and wide highways, such as those found in Montserrat, have been proposed as highly-suitable catchment surfaces for rainwater runoff. The layout of this system is shown in figure 30 below.

Figure 33: Layout of the rainwater harvesting irrigation system

- **by intercepting rainwater runoff from the surfaces of highways**



Source: FAO

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[29] The ferro-cement tank is a German technology which was introduced in Dominica under a FAO Project.

Figure 34: Small barrel with zinc, water used to irrigate small nursery and pesticide mix
Location: Isolated farm in Guys Hill, Jamaica

Simple system with barrel and zinc

Downpipe and storage barrel with a simple screen

Greenhouse rainwater harvesting system

Rainwater harvest system for school operations

Concrete catchment and reservoirs with solar driven submersible pump
Location: St. Elizabeth

Hand Pump system to lift water from underground storage reservoir

Rain water harvest system for livestock - Manchester, Jamaica

CHAPTER 7

Enhancing the Use of Rainwater Runoff in Storage

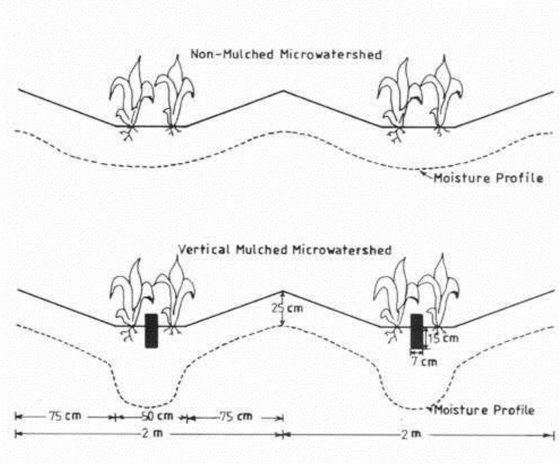
Storing water in soil

The practice of storing water on the soil surface is common in areas where farmers experience long dry periods. Dry mulching is practiced by many farmers, especially on the dry plains of Jamaica. Vertical mulching is practiced in India, and pitted basins in parts of Africa.

The practice can be implemented before the start of the rainy season, so that water can be stored effectively in the soil from the first rainfall event.

Figure 31: Optimizing the use of runoff in storage

- **storing water in soil**



Vertical mulching- FAO Soil and water Project

Pitting- use of small basins to catch and store water - FAO Malawi

Dry mulching in Jamaica
Source: IICA Saint Lucia

Summary

Rainwater Harvesting

Rainwater harvesting systems are being used around the world to capture, store and efficiently utilize rainwater to improve the social, economic and environmental state of families, communities or regions. It is an economical, safe and potentially successful water source.

A number of unique methods have been employed in agricultural practices to harvest rainwater. Geographic locations and available resources often determine the method utilized some of which include reservoirs, tanks, drums, use of dams and underground wells.

The rationale for such practices is due to the following:

- Commercial supply of domestic and irrigation water not available in all agricultural areas.
- High cost of commercial water.
- Ease the burden and reliance on ground and surface water sources.
- Potentially promote food security.
- Reduce the demand of potable water for agricultural use.
- Enhance the potential of crop diversification.

Rainwater harvesting systems are usually a combination of the following components:

- Catchment area;
- Conveyance system;
- Storage facility;
- Distribution systems/network; and
- Treatment – depending on use

There are a number of benefits associated with proper rainwater harvesting practices such as the following:

- Cost effective and safe method for water supply.
- RWH provide clean water for domestic and agricultural use (When compared with some local surface and ground sources).
- Important source of water for isolated rural communities not served by the municipal system
- Provide water for home gardens.
- RWH systems can complement the water supply to schools.
- Provide water for agricultural crops and livestock in areas with little or no water source.
- Mitigate the effect of drought.
    - Improve crop yield and crop quality.

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Appendix I

Glossary

Bubbler: Water emission devices that bubble water directly onto the ground or throw water a short distance.

Catchment: The catchment in rainwater harvesting is the collection area for rainwater runoff. The type of surface material and the evenness of the surface determine efficiency of the surface runoff. The harder the surface, the higher rainwater collection efficiency.

Coefficient of variation: A normalized measure of dispersion of a probability distribution. Its application is used commonly in probability fields such as reliability theory.

Curve fitting: Curve fitting is used to find the "best fit" line for a series of data points. Curve fitting is useful in finding design rainfall because of the many data points in rainfall series data.

Crop factor K_c: The crop factor is a coefficient used to relate crop water requirement to crop type and stage of crop development.

Crop water requirement: Crop water requirement is the quantity of water required to compensate for the total loss of soil water through evapotranspiration in order to maintain optimum crop growth and yield.

Crop reference evapotranspiration (ET_0): The rate of evapotranspiration from a large area covered by grass 8-15 cm tall which is growing actively, completely shading the ground and not short of water supply, integrated with climatic conditions (relative humidity, sunshine hours, precipitation, and wind speed) at the site.

Dam: A manmade concrete barrier placed in a permanent or seasonal waterway to control the flow of water for a specific purpose. The water is stored behind the barrier in reservoirs. Rainwater harvesting involves the control of rainwater runoff in seasonal waterways for the purpose of storing the water for later use on the farm. The entire structure is described as a dam.

Design rainfall: The total amount of annual or seasonal rainfall received by the farm at which, or above which, the catchment area will provide sufficient rainwater runoff for harvesting and storage to satisfy planned crop water requirements. The design rainfall is set by calculations based on empirical formula and 90% probability. If the annual rainfall received is below the design rainfall for rainwater harvesting, there is a risk of crop failure due to water scarcity. If annual rainfall is far in excess of design rainfall, valuable runoff water could be lost, or cause damage to some of the collection and storage systems.

Drip irrigation: Method of irrigation using the slow application of water under low pressure through tube openings or attached devices just above, at, or below the soil surface.

Dike: A flood-diversion structure built to mitigate and capture excess runoff rainwater for later use. The construction of a dike is usually expensive.

Dimensioning: The calculations for determining the volume specifications for storage capacity. This process may require the input of light engineering. In rainwater harvesting, the objective is to relate the pattern of annual cumulative storage to the pattern of annual cumulative demand on the farm, and their influence on optimal storage capacity.

Drought: An extended period of inadequate—or total lack of—rainfall, sufficient to cause moisture stress, permanent wilting, and eventual death of crops. The potential effects of drought can be mitigated through irrigation, either from rainwater harvesting or from surface and groundwater irrigation schemes where these have been developed.

Effective rainfall: The fraction of the total amount of rainwater useful for meeting the water demand of the crop. It is equal to total rainfall minus the sum of runoff plus evaporation plus deep percolation, and effectively represents the water retained in the root zone.

Emitter: Dispensing device in a micro- irrigation system that regulates water flow

Empirical: Information acquired by means of observation and experimentation.

Evapotranspiration: Sum of evaporation and plant transpiration from land surface. Evapotranspiration rates vary according to climatic conditions, primarily relative humidity, number of sunshine hours, temperature and wind speed*.*

Field capacity: The maximum amount of water that a soil can hold after gravitational water has drained away – usually one to two days after soil is fully saturated. The moisture at field capacity is held with a tension of 0.1-0.3 atmosphere (bars), depending on soil type.

Fittings: The array of coupling and closure devices used to construct a drip system, including connectors, tees, elbows, goof plugs and end caps. Fittings may be of several types, including compression, barbed and locking.

Flow: The rate or amount of water that moves through pipes in a given time. Flow in drip devices is expressed in gallons per hour, as opposed to the gallons per minute rate used for high-pressure sprinkler systems.

Ground catchment systems: Systems that channel water from a prepared catchment area into storage. Generally, they are used only in areas where rainwater is very scarce and other sources of water are not available. They are suited more to small communities than to individual families. Properly designed ground catchment systems can collect large quantities of rainwater.

Gutters: Conveyances from catchment to storage placed either parallel or perpendicular to the catchment, depending on the structure of the rainwater harvesting system.

Hygrometer: Instrument used to measure the level of humidity. An example is a sling psychrometer which measures the difference between the readings of a wet bulb and a dry bulb of two thermometers to provide a value for relative humidity. It involves reading the value of the difference on the x-axis of a relative humidity table against the value of the dry bulb on the y-axis. The point where they meet on the horizontal on a relative humidity chart is the percentage relative humidity (see Appendix 5).

Irrigation water: The difference between crop water need and that part of the rainfall which can be used by the plants.

Infiltration: Water percolation loss through the soil profile.

Lysimeter: A device used to measure the amount of actual evapotranspiration which is released by a field. It involves measuring the daily soil water loss by evapotranspiration from a column of soil growing plants under optimum conditions. The method is expensive.

Moisture stress: Symptoms of water scarcity in plants

Mini-dam: Usually a small dam on a seasonal water course holding about 5,000 m^3 of water.

Pond: A body of standing water, either of natural origin or created by the excavation of a pit or the widening of a natural depression. The low point of the natural depression is the best location for the pit.

Natural slope: The ground used in rainwater harvesting as the catchment area for rainwater runoff. The efficiency of the natural slope is influenced by soil type, vegetation cover, soil moisture, and rainfall intensity and duration. The acceptable runoff coefficient usually ranges between 0.25 to 0.5. This range takes into account the inefficiency of uneven distribution of the water on the slope, as well as losses due to evaporation and deep percolation. Where the area is levelled and smooth, the efficiency is higher.

Permanent wilting point: The condition where the suction force of plant roots cannot overcome the tension of 15 atmospheres (bars) and the remaining water is held around the soil particles. Probability analysis: The probability that an event will occur based on an analysis in which each measure is based on a recorded observation, rather than a subjective estimate.

Rainwater collection efficiency (RCE): The percentage of rainwater runoff which a surface will collect from a known rainfall intensity and duration. The higher the impermeability of the surface, the higher the RCE.

Rainwater harvesting: The collecting and concentrating of rainfall as runoff from a larger catchment area to a smaller area. The collected water is either applied directly to the cropping area and stored in the soil profile for immediate uptake by the crop, or stored in water reservoirs (ponds, mini-dams) or storage tanks.

Rainwater runoff: The proportion of rainfall which flows along a catchment as surface runoff. The volume of runoff depends—among other factors—on the type of surface, the degree and length of slope, and rainfall intensity and duration.

Relative humidity: The extent to which air is saturated with moisture at a given temperature. Relative humidity influences evapotranspiration rates. In general, a high percentage of relative humidity reduces evapotranspiration rates and a low percentage of relative humidity increases evapotranspiration rates.

Reservoir: The impounding of water in a permanent, or seasonal, flowing waterway

Road-cross dam: a dam constructed on a seasonal waterway across a road for rainwater harvesting.

Series dams: Method of storage in the same river course through a series of small dams rather than one large dam, in order to protect submerged areas of arable lands. This is particularly necessary where the area is flat with gentle slopes**.**

Series rainfall data: Annual rainfall data, in monthly or daily distribution measured in millimetres, over a continuous period of at least 10 years. The higher the number of years, the more reliable the data will be for calculating design rainfall for rainwater harvesting for agriculture.

Seepage: Conveyance loss through the channel.

Spillway: Device designed to carry runoff from heavy rainfall safely around the dam. Spillway is usually located at one end of the dam in undisturbed soil, and should be well vegetated to avoid runoff.

Water-holding capacity (available moisture): The difference between field capacity and permanent wilting point.

Water scarcity: Excess of water demand over available supply.

Wilting point: The physical and physiological state of a plant under moisture stress. Plants will recover from the first stage, called temporary wilting, when water is added to the soil, but will eventually die if soil moisture stress is extended, causing the plant to reach permanent wilting point.

Appendix II

Pan coefficients (K_p) for Class A pans for different pan sites and environments and different levels of mean relative humidity and wind speed

Class A pan	**Case A: Pan placed in short, green cropped area**				**Case B: Pan placed in dry, fallow area**			
RH mean (%) □H		**low < 40**	**medium 40 - 70**	**high > 70**		**low < 40**	**medium 40 - 70**	**high > 70**
Wind speed (metres/ Sec)	**Windward side distance of green crop (m)**				**Windward side distance of dry fallow (m)**			
Light	1	.55	.65	.75	1	.7	.8	.85
< 2	10	.65	.75	.85	10	.6	.7	.8
	100	.7	.8	.85	100	.55	.65	.75
	1000	.75	.85	.85	1000	.5	.6	.7
Moderate	1	.5	.6	.65	1	.65	.75.	.8
2-5	10	.6	.7	.75	10	.55	.65	.7
	100	.65	.75	.8	100	.5	.6	.65
	1000	.7	.8	.8	1000	.45	.55	.6.
Strong	1	.45	.5	.6	1	.6	.65	.7
5-8	10	.55	.6	.65	10	.5	.55	.65
	100	.6	.65	.7	100	.45	.5	.6
	1000	.65	.7	.75	1000	.4	.45	.55
Very strong	1	.4	.45	.5	1	.5	.6	.65
> 8	10	.45	.55	.6	10	.45	.5	.55
	100	.5	.6	.65	100	.4	.45	.5
	1000	.55	.6	.65	1000	.35	.4	.45

Source: Adapted from FAO Irrigation and Drainage Paper No. 24

Appendix III

Important conversions

1 acre of land **=** 43 560 square feet

1 acre/ ft of water **=** 43 560 cubic ft = 325 851 gallons

1 cubic metre **=** 220 gallons = 1 000 litres

1 cubic ft **=** 7.48 gallons

3.785 litres **=** 1 gallon

1 litre **=** 1.057 quarts

10 000 m^2 of land **=** I hectare

1 inch = 27 152 gal/acre

1 acre	=	0.4047 ha	1 hectare (ha)	=	2.47 acres
1 foot	=	0.3048 m	1 metre (m)	=	3.2803 feet
1 inch	=	25.4 mm	0.1 m = 1 centimetre (cm)	=	10 millimetres (mm)
1 inch	=	27,152 gallons	0.001 m = 0.1 cm	=	1 millimetre (mm)
1 mm	=	0.04 inches	1 m = 100 cm	=	1 000 mm
1 gallon	=	4.546 litres	1 litre	=	0.22 gallons
1 cubic metre (m^3)	=	220 gallons	1 cubic metre (m^3)	=	264.6 US gallons

Surface area x mm rainfall (depth) x runoff factor **=** cubic metres harvested

1 mm/day evapotranspiration loss **=** 10 m^3 water per hectare (volume per unit area)

Appendix IV

Climate and Rainwater Harvesting

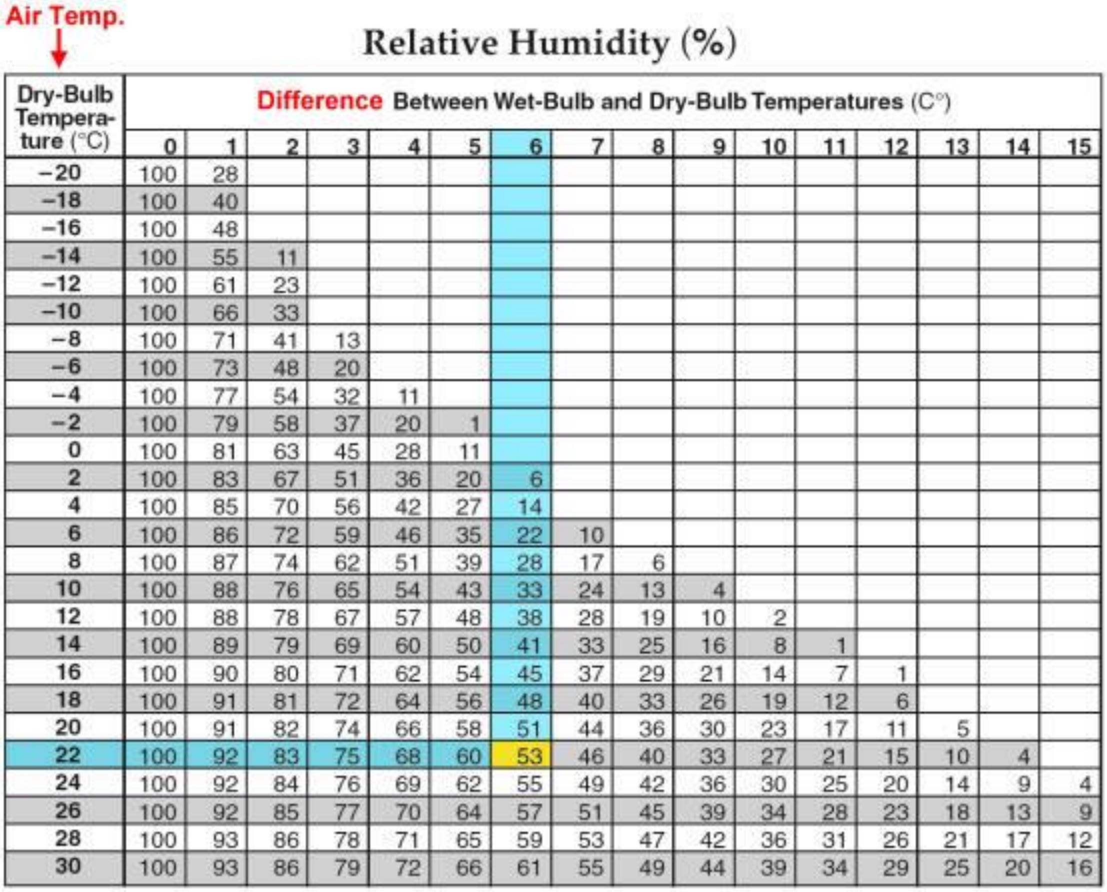
Measuring daily rainfall

The rain gauge shown below is used for measuring daily amounts of rainfall. There are many types of rain gauge, but the one shown below can be mounted in an area on your farm where it is not shaded by your crops. The rain gauge should be read as soon as possible after a shower, and calculated on a 24-hour basis. Remember to date and record all your readings. They should be available both for your use and for seeking advice from your agricultural extension officer.

Ideally, in determining how much water to put on your crops, you should refer to Section 4 of the document on how to treat rainfall. However, for efficient use of your stored water, you should observe your crop behaviour carefully (whether leaves are turgid, or soil surface is still damp) and use your discretion, as subsequent weather conditions may favour adding less water to your field. Dew point is also a factor in decisions on watering, in cases where water is limited.

Rain gauge mounted in the field

Table of relative humidity



Air Temp.

Relative Humidity (%)

Dry-Bulb Temperature (°C)	Difference Between Wet-Bulb and Dry-Bulb Temperatures (C°)															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
−20	100	28														
−18	100	40														
−16	100	48														
−14	100	55	11													
−12	100	61	23													
−10	100	66	33													
−8	100	71	41	13												
−6	100	73	48	20												
−4	100	77	54	32	11											
−2	100	79	58	37	20	1										
0	100	81	63	45	28	11										
2	100	83	67	51	36	20	6									
4	100	85	70	56	42	27	14									
6	100	86	72	59	46	35	22	10								
8	100	87	74	62	51	39	28	17	6							
10	100	88	76	65	54	43	33	24	13	4						
12	100	88	78	67	57	48	38	28	19	10	2					
14	100	89	79	69	60	50	41	33	25	16	8	1				
16	100	90	80	71	62	54	45	37	29	21	14	7	1			
18	100	91	81	72	64	56	48	40	33	26	19	12	6			
20	100	91	82	74	66	58	51	44	36	30	23	17	11	5		
22	100	92	83	75	68	60	53	46	40	33	27	21	15	10	4	
24	100	92	84	76	69	62	55	49	42	36	30	25	20	14	9	4
26	100	92	85	77	70	64	57	51	45	39	34	28	23	18	13	9
28	100	93	86	78	71	65	59	53	47	42	36	31	26	21	17	12
30	100	93	86	79	72	66	61	55	49	44	39	34	29	25	20	16

Appendix V

Ranges of average moisture content for different soil types

Textural class	Field capacity (v %)	Permanent wilting point (v %)	Water holding capacity/available water (v% dm)	Water holding capacity or available moisture (v% mm/m)
Sandy	10-20 (15)	4-10 (7)	6-10 (8)	0-100 (80)
Sandy loam	15-27 (21)	6-12 (9)	9-15 (12)	90-150 (120)
Loam	25-36 (31)	11-17 (14)	14-19 (17)	140-190 (70)
Clay loam	31-41 (36)	15-20 (17)	16-21 (19)	160-210 (190)
Silty clay	35-46 (40)	17-23 (19)	18-23 (21)	180-230 (210)
Clay	39-49 (44)	19-24 (27)	20-25 (23)	200-250(230)

Source: Euroconsult (1989).