REPUBLIC OF LEBANON
MINISTRY OF ENVIRONMENT

الصندوق اللبناني للنهوض
المنبثق عن مؤتمر ستوكهولم

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NATIONAL GUIDELINES

FOR GREENHOUSE RAINWATER HARVESTING SYSTEMS IN THE AGRICULTURE SECTOR

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2016

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LIST OF ACRONYMS, ABBREVIATIONS AND UNIT CONVERSIONS

BHP	Brake Horsepower
ET_0	Reference Crop Evapotranspiration
ET_c	Crop Evapotranspiration
ET_{CG}	Crop Evapotranspiration inside the Greenhouse
FAO	Food and Agriculture Organization
HDPE	High Density Polyethylene
HL	Head Loss in the Pipe
I	Rainfall
IDF	Intensity-Duration-Frequency
K_c	Empirical Crop Coefficient
kW	Kilowatts
L	Liter
LARI	Lebanese Agricultural Research Institute
m^2	Square Meter
Mm	Millimeter
MoE	Ministry of Environment
PE	Polyethylene Film
PVC-SDR	Polyvinyl Chloride - Standard Dimension Ratio
RWHS	Rainwater Harvesting System
TDH	Total Dynamic Head
UNDP	United Nations Development Programme
UV	Ultraviolet

Unit Conversion
1 dunum = 1,000 square meters
1 mm of rain = 1 liter per square meter

I

INTRODUCTION

Human activities commonly affect the distribution, quantity, and chemical quality of water resources.

Agriculture has been the cause of significant modification of landscapes throughout the world. Tillage of land changes the infiltration and runoff characteristics of the land surface, which affects recharge to groundwater, delivery of water and sediment to surface-water bodies, and evapotranspiration.

All of these processes either directly or indirectly affect the interaction of groundwater and surface water. Lebanese farmers are aware of the substantial negative effects of agriculture on water resources but have no means to develop methods to alleviate some of these effects.

Many irrigation systems that initially relied solely on surface water now also use groundwater. The pumped groundwater commonly is used directly as irrigation water, but in some cases the water is distributed through a canalized system.

As would be expected, irrigation systems based on surface water are always located near streams. In general, these streams are perennial and (or) have significant flow for at least part of the year. In contrast, irrigation systems based on groundwater can be located nearly anywhere that has an adequate ground-water resource.

Areas where irrigated agriculture relies on ground-water, especially intensive protected agriculture which exploit the land almost all year around, has shown significant decline of the water table. This decline, caused by over-pumping of the groundwater, could not be offset by natural recharge (from precipitation and the presence of nearby flowing streams).

The most important consideration when designing and installing a RWH system is the estimation of the crop water requirements, since the crops are the end user of the collected water. Other considerations include how the design, installation and management of RWH systems can affect the quantity of collected water as well as the quality of rainwater harvested.

The design and installation guidelines are presented in three main chapters, including greenhouse cultivation in Lebanon (Chapter II) which provides a brief overview of the different type of greenhouses used in Lebanon, the irrigation scheduling within the greenhouses and method to determine the crop water requirements for a given crop, and the main crops grown in Lebanon. The information provided in this chapter is essential for the design of the RWHS since the type of greenhouse interferes with the choice of the system from one hand, and the Crop water demand determines the size of the storage tank in the system. Chapter III focuses on the major rainwater harvesting systems (direct/indirect pumping, gravity fed) and presents the main system components detailed according to the water flow: catchment area, collection and conveyance system, rainwater quality & pre-treatment, storage, pump and distribution systems. This chapter also provides a summarized rainwater harvesting system maintenance schedule.

All technical calculation sheets required to design a rainwater harvesting system are highlighted in six appendices (A to F) at the end of this guideline.

Throughout the guideline and for each given section, especially where equations are involved, a worked example, the case of a standard greenhouse located in Damour, is provided. Clear step by step instructions are given to guide the reader through the worked example process.

II

GREENHOUSE CULTIVATION

1
TYPES OF GREENHOUSES

2
IRRIGATION SCHEDULING IN GREENHOUSES

3
CROPS GROWN IN LEBANON IN GREENHOUSES

Greenhouse cultivation is a steadily growing agricultural sector all over the world. The utilization of greenhouses, mainly for cultivation of vegetables and ornamental is undergoing transformation for modernization that gives the opportunity to improve crop yield. Greenhouses may range from low cost such as plastic greenhouses to more sophisticated greenhouses for example the glass and controlled greenhouses. This type of modern agriculture has many advantages especially for reducing the climatic hazards (such as the ability to control and maintain a favorable microclimate within the greenhouse that suits the cultivated crop).

It is known that water is a major issue especially for countries which have insufficient water resources (including quality). With this great expansion of greenhouse cultivation, the need of proper irrigation management is important.

1 TYPES OF GREENHOUSES

Greenhouse types depend much on the structure, construction method and material, facilities and equipment made for the greenhouse. In central and northern Europe most greenhouses are glass covered where else in warmer climates the majority of the greenhouses are covered with plastic film. Globally, the plastic film greenhouses constitute the majority of adopted greenhouse systems, in particular, in the Mediterranean region.

The common greenhouse types are Venlo-type, wide-span, plastic, and arched greenhouses. The shape of the greenhouse structure influences the internal climate of the greenhouse environment especially the temperature, humidity and light transmission. The shapes that appear most frequently are gable roof or pitched roof, saw tooth or shed roof, round arched tunnel, round arch with vertical side wall, pointed arch with sloping side wall and pointed arch with vertical side wall.

Construction materials used for greenhouse are wood, steel, aluminum and some even have combinations of these materials. The commonly used cladding materials are glass, synthetic panes or rigid plastics and plastic film.

The facilities and equipments used inside a greenhouse can classify the greenhouse as a controlled environment greenhouse or not. These equipments include heating equipment, ventilation and cooling, screens, carbon dioxide (CO_2) enrichment and supplementary lighting.

The expansion of greenhouse cultivation worldwide had led to the need for reliable crop evapotranspiration (ET_C) estimation to encounter better yield and crop quality, water scarcity and environmental aspects.

Greenhouses are a technology based investment. The higher the level of technology used the greater potential for achieving controlled growing conditions. To find the best estimation of ET method or model in a greenhouse, three categories of greenhouse types are define here according to their technology.

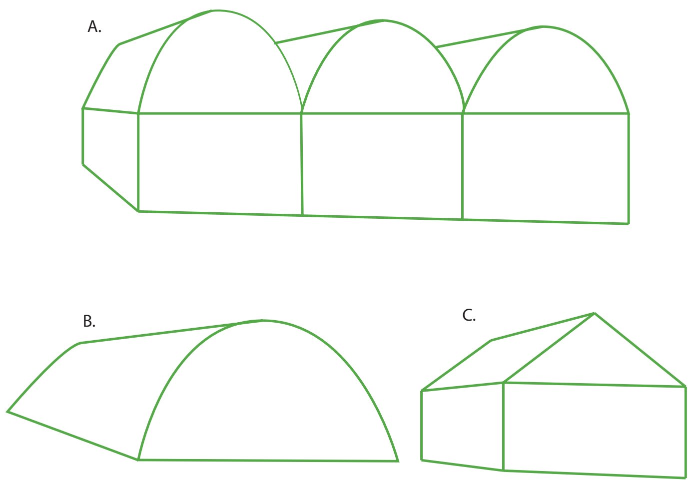


Figure 1: Commercial greenhouse structures: A) gutter connected, B) free standing Quonset (tunnel), C) single gable.

1.1 Low technology greenhouses

Greenhouses under this category use simple and low technology structure. These greenhouses may be less than 3 meters in total height especially for tunnel type. The tunnel greenhouses generally consist of bent trusses (hoops) which are screwed to the ground by means of screw anchors or cast in concrete. The frame structure is made either from wood, bamboo sticks or steel. They do not have vertical walls and have poor ventilation (mainly passive ventilation).

This type of structure is relatively inexpensive and easy to build with few or no automation equipments.

Generally, the internal climate of the low technology greenhouse is strongly dependent on external conditions. Plastic greenhouses with low technology of the structure are likely susceptible to damage which mainly cause by wind.

Moreover, the crop production is limited by the growing environment which restricts yields and does little to reduce the incidence of pests and diseases.

1.2 Medium technology greenhouses

Medium technology greenhouses are better in structure, compared to the low technology greenhouses, since the supporting structure is made of galvanized iron and aluminum. They are typically characterized by vertical walls more than 2m but less than 4 meters tall and a total height usually less than 5.5 meters. Medium level greenhouses are usually clad with either single or double skin plastic film or glass and use varying degrees of automation.

This type of greenhouse is closer to the low technology greenhouse in terms of the internal technology, but closer to the high technology greenhouse in terms of internal climate control.

1.3 High technology greenhouses

The most sophisticated structures belong to this category. They contain galvanized iron support structures, aluminum glass supports, and almost always use glass as a covering material. The wall construction height is at least 4 meters, with the roof peak being up to 8 meters above ground level. These high technology structures can provide optimum growth environment through climate control.

GENERALLY, THE INTERNAL CLIMATE OF THE LOW TECHNOLOGY GREENHOUSE IS STRONGLY DEPENDENT ON EXTERNAL CONDITIONS.

Air movement (ventilation), temperature and incident light in the greenhouse can be controlled by various facilities and equipments. These equipments are normally controlled and regulated by an information system.

Due to the sophisticated structures and facilities, the greenhouse cultivation is only profitable under high productivity. They are normally limited to industrial areas where production is high. However, with the use of high level technology greenhouses, the dependency on labor work can be reduced, thus reduce the cost for production.

2 IRRIGATION SCHEDULING IN GREENHOUSES

Water is a scarce resource in areas with low annual precipitation and a dry season for more than 4 months (summer). Irrigation must be carried out with high efficiency to minimize percolation losses and environmental pollution, and increase water productivity, especially in areas that fall under the Mediterranean climate.

Current irrigation practices are generally based on local farmers' experience and most of them irrigate without monitoring the soil-or plant-water status.

High variations in supplies of irrigation water to each of the main vegetable crops have been reported and over-irrigation has been detected for some crops and periods in Lebanon. In order to improve greenhouse irrigation efficiency, evapotranspiration (ET) for the main vegetable crops of the region has been determined using the worldwide K_C-ET_0 method as proposed by the FAO and complemented with recent or real-time meteorological data. Based on this method, daily irrigation water requirements for the major greenhouse crops can be estimated, which requires daily solar radiation and temperature data.

For outdoor conditions the Penman-Monteith equation is used to predict the potential ET for outdoor crops. Based on several studies that have computed actual outdoor ET using outdoor remote sensing, **the actual ET in the greenhouse was found to be 65% of actual ET outdoor.**

For all crops, the irrigation water requirements are determined as follows:
The most common way of estimating crop water requirements, as recommended by the United Nations Food and Agriculture Organization (FAO), consists of the so-called "two-step" approach: firstly, a reference crop evapotranspiration (ET_0), defined under optimal conditions, is calculated from weather data measured at a reference height; secondly, evapotranspiration from any other well-watered crop (ET_C) is obtained by multiplying the reference evapotranspiration by an empirical crop coefficient: K_C.

The basic relationship writes:

$$ET_C = K_C \times ET_0$$

(Equation 1)

Where, ET_0 is the Reference crop evapotranspiration, mm/day
K_C is the empirical crop coefficient
ET_C is the crop evapotranspiration, mm/day

The Reference crop evapotranspiration (ET_0) is the rate of evapotranspiration from a large area, covered by green grass, 8 to 15 cm tall, which grows actively, completely shades the ground and which is not short of water.

Several methods can be used to measure or predict the reference crop evapotranspiration rate:
1. Evaporation pan
2. Using equations that predict the evapotranspiration rate based on climatic parameters.

Also, many meteorological stations publish ET_0 values on monthly or even daily basis (Table 1).

Table 1. CLIMWAT long-term (for at least 15 years) monthly mean ET_0 values (in mm/month) observed agroclimatic data over the Lebanon.

Station	Bhamdoun	Beirut (AUB)	Beirut (Airport)	Ksara	Alma-Chaab	Merjayoun	Ain-Ebel	Tell-Amara	Tyr	Rayack	Tripoli	Abde	Tripoli	Chlifa	Al-Arz (Les Cèdres)	Qlaiaat (Airpot)
JAN	49.91	53.63	64.17	40.61	63.55	48.36	50.84	39.06	76.88	39.06	62.93	43.71	62.93	47.12	31	56.73
FEB	50.68	56.84	63.56	46.76	62.16	51.8	59.08	45.64	74.76	45.64	64.96	50.12	64.96	53.2	35.56	61.04
MAR	73.47	79.98	91.76	79.98	97.03	80.29	86.49	74.4	103.54	74.4	90.21	69.75	90.21	86.18	55.8	83.08
APR	105	102.9	107.4	120	114	101.7	122.4	103.2	124.2	103.2	105	94.2	105	122.1	81	99.6
MAY	142.91	138.57	135.16	164.61	158.41	142.29	157.17	143.53	144.77	143.53	133.61	115.94	133.61	163.37	112.84	116.87
JUN	168.9	166.8	161.1	206.1	171	164.4	185.4	182.4	169.8	182.4	152.7	134.7	152.7	207	132.9	138.9
JUL	181.04	181.97	173.6	232.81	165.85	158.72	186.93	204.29	182.59	204.29	171.43	142.6	171.43	243.35	154.69	156.86
AUG	177.32	171.74	168.33	215.45	169.57	154.69	176.08	190.34	172.98	190.34	161.82	138.88	161.82	224.75	148.8	153.45
SEP	134.7	131.7	129.9	160.5	142.5	136.2	134.1	147	141	147	131.4	114.3	131.4	162.9	108.3	131.4
OCT	98.58	102.61	101.99	109.74	101.68	123.07	110.36	106.33	108.81	106.33	98.27	88.04	98.27	110.98	81.22	110.05
NOV	67.2	68.1	74.7	63.6	88.5	84.6	73.8	66.6	81	66.6	72.9	65.7	72.9	64.2	50.7	75
DEC	54.25	53.94	67.27	42.47	77.19	58.28	58.28	39.68	73.47	39.68	63.55	52.7	63.55	48.36	36.27	60.76
Mean	**108.66**	**109.07**	**111.58**	**123.55**	**117.62**	**108.70**	**116.74**	**111.87**	**121.15**	**111.87**	**109.07**	**92.55**	**109.07**	**127.79**	**85.76**	**103.65**

SUMMARY

In summary, the determination of the irrigation water need for a given crop requires the following steps:

Step 1: Determine the reference crop evapotranspiration: ET_0

Step 2: Determine the crop factors: K_C

Step 3: Calculate the crop water need: ET crop $= ET_C = ET_0 \times K_C$

Step 4: Calculate the actual crop water need inside the greenhouse: $ET_{CG} = 0.65 \times ET_C$

EXAMPLE

For the month of January, estimate the monthly crop water demand of tomatoes grown in a 332 m^2 greenhouse in Damour. The following steps are taken:

1. Determine the reference crop evapotranspiration: ET_0. Using Table 1, the closest station to Damour is Beirut and the average January ET_0 is 64.17 mm/month

2. Determine the crop factors: K_C. Using Table 2, Crop coefficient for tomatoes during January: $K_C = 1.15$

3. Calculate the crop water need: ET crop $= ET_C = ET_0 \times K_C$
$ET_C = ET_0 \times K_C = 64.17 \times 1.15 = 73.8$ mm/month $= 73{,}800$ liters/Dunum/month

4. Calculate the actual crop water need inside the greenhouse: $ET_{CG} = 0.65 \times ET_C$
$ET_{CG} = 0.65 \times 73.8 = 48$ mm/month $= 48$ L/m^2/month

5. Determine the total monthly irrigation demand (liters) for the greenhouse:
Total monthly demand (liters) $= ET_{CG} \times$ Greenhouse surface area = Total monthly demand (liters) $= 48 \times 332 = 15{,}936$ L

3 CROPS GROWN IN LEBANON IN GREENHOUSES

The adjacent Mediterranean coastal areas of Lebanon are one of the largest concentrations of greenhouses on the Mediterranean Sea with approximately 14,000 Dunums mainly dedicated to intensive vegetable production. Most of these are low-cost structures covered with plastic film, without climatic control systems and with soil-grown crops.

Greenhouses create favorable micro-climates, which make the crop production possible throughout the whole year or part of the year as required allowing the production of off-season ornamentals and foods of high value when outdoor production is not possible. As such, most crops listed below are grown on an extended crop cycle, starting in September and ending by June.

A desk survey among greenhouses productions revealed the major crops produced under those structures in Lebanon. Table 2 summarizes our findings.

Table 2: Crops grown in Lebanon in greenhouses

Crop	$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	Maximum Crop Height (h) (m)	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Field Crop cycle
a. Small Vegetables	**0.7**	**1.05**	**0.95**						
Broccoli		1.05	0.95	0.3	35	45	40	15	135
Lettuce		1.00	0.95	0.3	20	30	15	10	75
Spinach		1.00	0.95	0.3	20	20	15/25	5	60/70
b. Vegetables - Solanum Family *(Solanaceae)*	**0.6**	**1.15**	**0.80**						
Egg Plant		1.05	0.90	0.8	30	45	40	25	40
Sweet Peppers (bell)		1.05	0.90	0.7	25/30	35	40	20	125
Tomato		1.15	0.70-0.90	0.6	30	40	45	30	145
c. Vegetables - Cucumber Family (Cucurbitaceae)	**0.5**	**1.00**	**0.80**						
Cucumber	0.6	1.00	0.75	0.3	20	30	40	15	105
Squash, Zucchini		0.95	0.75	0.3	20	30	25	15	90
Sweet Melons		1.05	0.75	0.4	25	35	40	20	120
d. Legumes (Leguminosae)	**0.4**	**1.15**	**0.55**						
Beans, green	0.5	1.05	0.90	0.4	15	25	25	10	75
Peas	0.5	1.15	1.10	0.5	20	30	35	15	100
e. Perennial Vegetables (with winter dormancy and initially bare or mulched soil)	**0.5**	**1.00**	**0.80**						
Strawberries	0.40	0.85	0.75	0.2					

III

RAINWATER HARVESTING TECHNOLOGY

1

MAJOR RAINWATER HARVESTING SYSTEMS

2

SYSTEM COMPONENTS

3

RAINWATER HARVESTING SYSTEM MAINTENANCE SCHEDULE

1 MAJOR RAINWATER HARVESTING SYSTEMS

The following section gives details of three different systems:

- Indirectly pumped;
- Directly pumped;
- Gravity fed.

1.1 Indirectly Pumped Systems

Rainwater is initially held in a storage tank and then pumped to a header tank. Water is delivered to appliances via gravity.

RAINWATER IS COLLECTED FROM THE GREENHOUSE ROOF, FILTERED AND PIPED BY GRAVITY TO A STORAGE (HEADER) TANK.

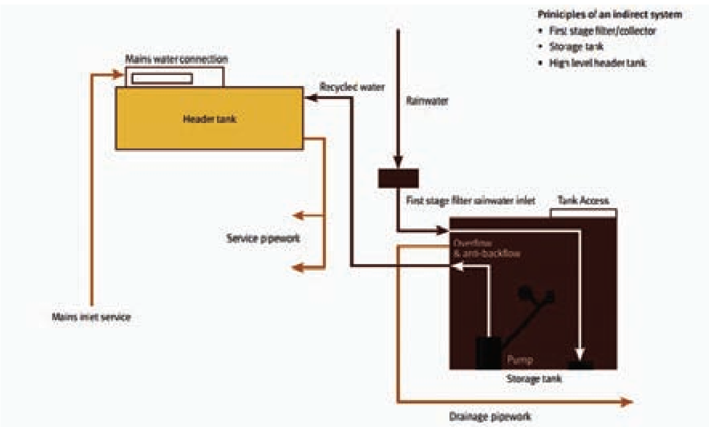


Figure 2: Principles of an indirect system

Advantages	Disadvantages
If the pump fails then water is still supplied via the mains top-up function.	Water is delivered at low pressure (may be solved by using a hybrid system).
Low cost pumps.	Requires a header tank which can add to the overall cost.
Simple controls.	Need for sufficient roof space, or high tank mounting.
Energy efficient as the pump runs at full flow.	Issues with high, structural loads.

1.2 Directly Pumped Systems

A directly pumped system is a pressurized system. Rainwater, collected and held in a storage tank or reservoir, is then pumped directly to the point of use when required. This is typical of most horticultural irrigation applications. There is usually a mains or abstraction supply option that maintains a minimum level that is able to meet short term demand.

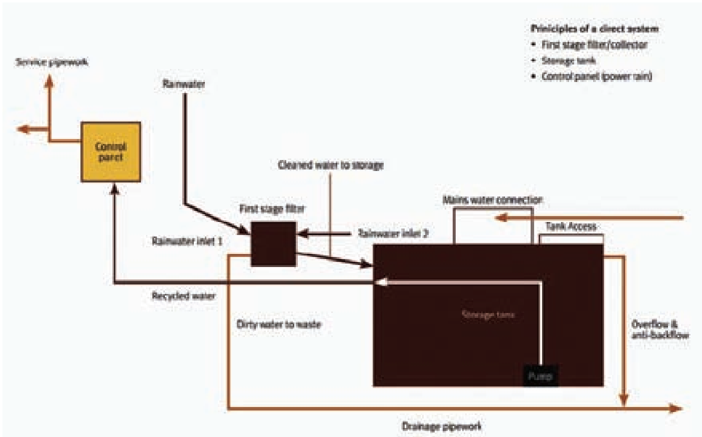


Figure 3: Principles of a direct system

Advantage	Disadvantages
Water is provided at pressure.	If the pump fails then no water can be supplied.
No header tank is required.	The use of mains top-up controls are more complicated.

1.3 Gravity Fed Systems

Rainwater is collected from the greenhouse roof, filtered and piped by gravity to a storage (header) tank. Water is delivered to appliances via gravity. Mains top-up water can also be fitted if needed.

Advantages	Disadvantages
Does not require a pump.	Low water pressure – pumps may be required to boost the pressure.
No electrical supply required.	Issues with high, structural loads.
No risk of pump-associated failure.	Water quality issues, due to fluctuating temperatures in the stored water.

2 SYSTEM COMPONENTS

The relative height of the components (roof, filter, tank) is critical.There are six primary components of a rainwater harvesting system:

- Catchment area
- Collection and conveyance system (e.g. gutter and downspouts)
- Rainwater Quality & Pre-Treatment
- Storage tank
- Pumping and Distribution system

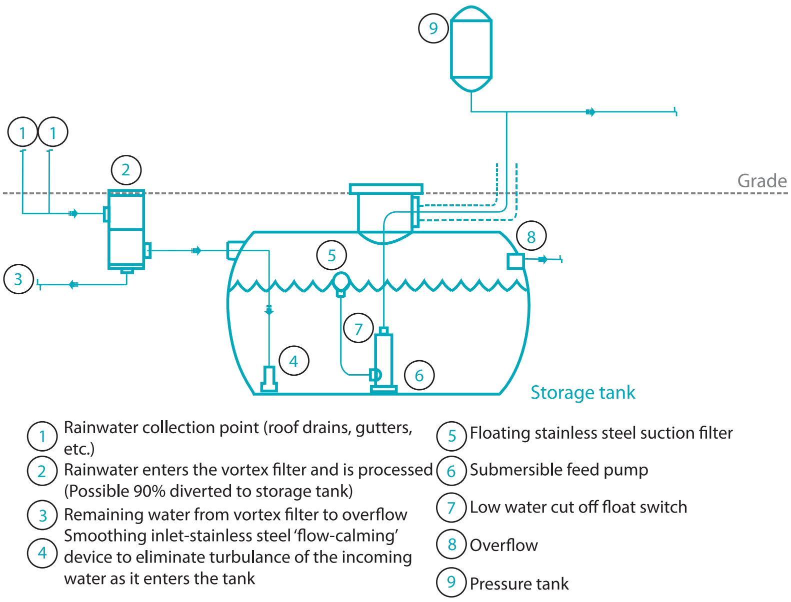


Figure 4: Sample Rainwater harvesting system detail

2.1 Catchment Area

2.1.1 Introduction and definitions

The rooftop is made of polyethylene film which is a smooth, non-porous material with efficient drainage either from a sloped roof or an efficient roof drain system. Greenhouses have enough roof slopes which allows a fast drainage of the roof leading to good rinsing and a fast first flush, which can increase water quality.

MONTHLY RAINFALL DISTRIBUTION OVER LEBANON VARIES (NEARLY 60%) WITH MOST OF THE RAIN FALLING IN THE MONTHS OF DECEMBER, JANUARY AND FEBRUARY.

2.1.2 Issues for consideration

2.1.2.1 Rainfall in the targeted area

The volume of harvested rainwater is directly dependent on the surface area on which rain is falling. So as a first step the amount of rainfall – annually or monthly depending on data availability – should be determined. This information may be obtained from such institutions as the National Weather Service within the Ministry of Public Works, the Lebanese Agricultural Research Institute, or any other reference or source.

Monthly rainfall distribution over Lebanon varies (nearly 60%) with most of the rain falling in the months of December, January and February. Table 3 summarizes the rainfall percentages on a monthly basis.

Table 3. Monthly rainfall distribution -as a percentage of total rainfall

SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
0.7%	6.8%	11.8%	19.9%	22.4%	17.1%	12.9%	6.4%	1.6%	0.3%	0.1%	0.1%

Rainfall varies geographically as well with most of the rain falling along the coast and on the Mount Lebanon's western facing slopes. The eastern slopes of Mount Lebanon are drier but still wetter than the inland areas. Table 4 shows average annual rainfall in select cities and towns throughout Lebanon along the various regions derived from CLIMWAT, a joint publication of the Water Development and Management Unit and the Climate Change and Bioenergy Unit of FAO.

Table 4. CLIMWAT long-term (for at least 15 years) monthly mean rainfall values (in mm/month) observed agroclimatic data over the Lebanon

Station	Bhamdoun	Beirut (AUB)	Beirut (Airport)	Ksara	Alma-Chaab	Merjayoun	Ain-Ebel	Tell-Amara	Tyr	Rayack	Tripoli	Abde	Chlifa	Al-Arz (Les Cèdres)	Qlaiaat (Airpot)
JAN	302	195	185	141	186	193	195	150	212	140	169	185	96	239	208
FEB	262	116	132	112	158	181	175	107	109	108	122	130	80	207	124
MAR	194	107	105	94	70	129	102	84	80	93	108	114	53	145	110
APR	95	48	47	42	32	73	53	41	42	49	48	55	31	68	48
MAY	40	18	19	10	10	26	6	17	5	16	15	15	14	32	18
JUN	1	1	1	1	1	1	1	0	0	2	3	1	1	5	1
JUL	0	1	0	0	0	1	0	0	0	0	1	0	0	1	1
AUG	0	0	1	0	0	1	0	0	0	0	1	1	0	1	1
SEP	3	9	6	1	4	3	4	1	6	1	7	9	1	5	13
OCT	54	35	48	34	31	24	32	23	40	31	66	84	7	32	25
NOV	132	149	86	68	73	91	65	57	100	61	112	100	47	93	110
DEC	239	148	147	134	184	162	181	134	200	115	167	219	74	158	157
Total	302	195	185	141	186	193	195	150	212	140	169	185	96	239	208

2.1.2.2. Determination of catchment area

The catchment area on which the rain is falling and from which rainwater is harvested must be determined. For all structures this area is the vertical projection of the roof or the footprint of the greenhouse rooftop. This is illustrated in Figure 5.

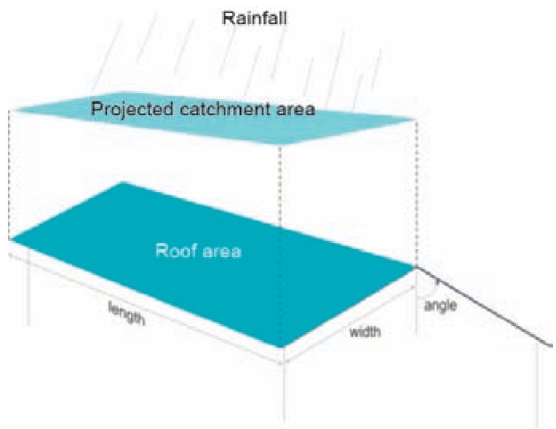


Figure 5: *Footprint of greenhouse roofs - used to determine catchment areas*

The catchment area of a single greenhouse can be determined using Equation 2:

Catchment Area (m²) = Length (m) × Width (m)
(Equation 2)

Where: Length = length of the catchment surface (m)
Width = width of the catchment surface (m)

Once these two key parameters – rainfall and catchment area – have been determined the amount of runoff generated from the rooftop catchment area would be estimated.

To calculate the amount of rain that can be captured off a roof surface per year, a procedure known as the 'Rational Method' can be applied.

The Rational Method is given as follows:

Supply (liters/year) = rainfall (mm/year) × greenhouse roof area (m²) × runoff coefficient of PE film
(Equation 3)

The runoff coefficient is the amount of water that actually drains free of the surface relative to the amount of rain that falls on the surface. It is used to reflect how much of the rainfall is lost to infiltration and other abstractions. In the case of greenhouses the materials typically used are various forms of plastic (polyethylene film (PE)) which have little to no infiltration capacity and thus nearly all the water runs off. However, there are losses to evaporation and splashing as well as detention such that the general runoff coefficient for the polyethylene greenhouse film is estimated to be 0.8. This means that of the total volume of rain that falls on the catchment surface, 80% drains off the surface; the other 20% stays on the surface.

EXAMPLE

For the month of November, determine the volume generated from the roof of a greenhouse in Damour that is 40 m long and 8 m wide. The following steps are taken:

1. Determine rainfall: Using Table 4, the closest station to Damour is Beirut and the average November rainfall is I = 86 mm/month

2. Calculate the area of the rooftop: A = 40 m 8 m = 320 m²

3. Select runoff coefficient: C = 0.8

4. Calculate captured from the rooftop:
   Supply (liters/month) = rainfall (mm/month) × greenhouse roof area (m²) × runoff coefficient of PE film
   = 86 × 320 × 0.8
   = 22,016 liters/month

2.1.3 Design & Installation Guidelines

2.1.3.1 When selecting the catchment(s) for collecting rainwater:

a. Only roof surfaces are recommended;
b. Avoid sections of the roof with overhanging foliage, or trim where possible.

2.1.3.2 To maximize the volume of rainwater collected by the RWH system:

a. The catchment surface should be as large as possible;
b. The roof catchment material used for greenhouses is commonly polyethylene film (PE);
c. Convey rainwater using appropriately sized and sloped components, including gutters, downspouts, and/or conveyance drainage piping; and
d. Where possible, in the case of multiple gutter connected greenhouses, the roof catchments can be connected to a central rainwater storage tank;
e. In cases where a single greenhouse roof catchment is utilized, catchment area can be determined using equation (2);
f. In cases where multiple connected greenhouses roofs are utilized as catchment surfaces, the catchment area can be determined by summing the multiple smaller areas.

2.1.4 Management Guidelines

The catchment surface should be inspected once every six months, to:

a. Identify any sources of contamination, including accumulated dirt and debris, presence of overhanging tree branches or other foliage, and/or signs of animal activity (i.e., bird droppings); and
b. If contaminants are present, these should be removed by cleaning the catchment surface by garden hose or sweeping, and if applicable trimming overhanging tree branches/foliage.

2.2 Collection and conveyance system

2.2.1 Introduction and definitions

The collection and conveyance system consists of the gutters, downspouts and pipes that channel storm water runoff into storage tanks. Gutters and downspouts should be designed as they would for a building without a rainwater harvesting system. Aluminum, round-bottom gutters and round downspouts are generally recommended for rainwater harvesting. Minimum slopes of gutters should be specified. Pipes (connecting downspouts to the cistern tank) should be at a minimum slope of 1.5% and sized/designed to convey the intended design storm. In some cases, a steeper slope and larger sizes may be recommended and/or necessary to convey the required runoff, depending on the design objective and design storm intensity. Gutters and downspouts should be kept clean and free of debris and rust.

Each of these system components is discussed below.

2.2.2 Issues for consideration

2.2.2.1 Selection of a typical storm or design storm

The collection gutters and conveyance pipes must be able to convey the flow of water from a typical storm event. The selection of a typical storm or design storm is typically set by national standards and norms. There is no such published standard and most engineers rely on experience in other countries or on non-Lebanese norms to select the design storm when designing stormwater drainage networks whose sizing is extremely dependent on such a selection. The practice in Lebanon is to select the 5-yr 1-hr storm for the design of stormwater drainage networks in urban areas. That is, it is a storm that lasts one hour and has a chance of occurrence of 1/5 or 20%. Intensity-Duration-Frequency (IDF) curves are typically used to determine the rainfall intensity from such design storms. Figure 6 shows the IDF curves determined for Lebanon.

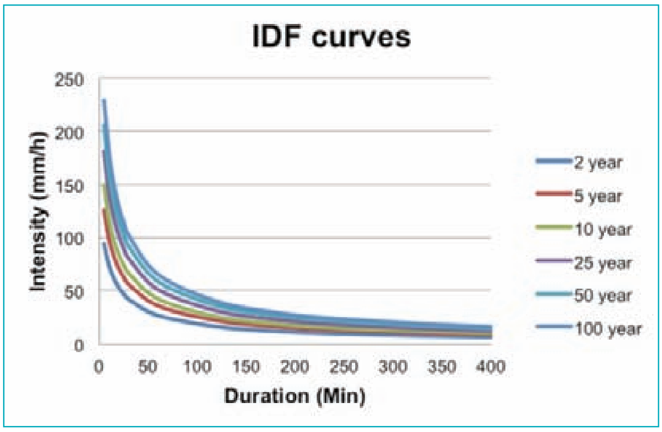


Figure 6: *IDF Curves for Lebanon* (Provided by Dr. Nadim Farajalla)

GALVANIZED STEEL ARE COMMONLY USED FOR GUTTERS GIVEN THEIR LOW MAINTENANCE REQUIREMENTS.

Once the rainfall intensity is determined then the Rational Method is used to determine the runoff from the rooftop.

The Rational Method equation which relates runoff to rainfall intensity and area along with a runoff coefficient as follows:

$$Q = C \times I \times A$$

(Equation 4)

where,
- Q = runoff; m^3/hr
- C = runoff coefficient (unitless)
- I = Rainfall intensity; m/hr
- A = Area drained by one gutter; m^2

2.2.2.2 Sizing of Gutters

Galvanized steel are commonly used for gutters given their low maintenance requirements. Gutters must slope toward the direction of the storage tank and the gradient should be equal to or more than 1 centimeter per meter. Gutters need to be regularly cleaned to reduce debris collection to catch the most rain, and ensure that leakage is kept to a minimum.

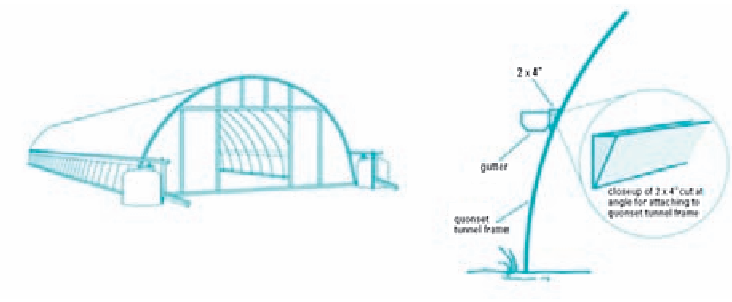


Figure 7: *Gutter support board mounted on Quonset (tunnel) greenhouse*

Upon determining the flow generated in the previous equation, the gutter can then be sized. This is done by using the Manning Equation:

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}}$$

(Equation 5)

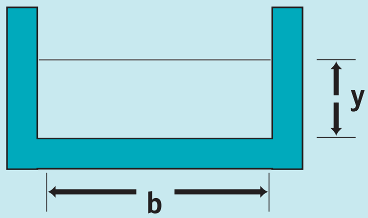
where,
- Q is discharge, m^3/s
- n is the Manning roughness coefficient of the gutter
- A is the cross-sectional flow area, m^2
- R is the hydraulic radius, m
- S is the slope of the conduit m/m

The K-style gutters usually used in greenhouse industry are similar to a rectangular or triangular open channel.

The Manning roughness coefficient, n, for use in the Manning equation, for the galvanised steel gutters is 0.016.

The approach of how to estimate the cross sectional area and the hydraulic flow in both cases to be applied to the above formula is shown below:

Rectangular Cross Section



Rectangular channel

The hydraulic radius

$R_H = A/P$,

Where; A is the cross sectional area of flow and P is its wetted perimeter.

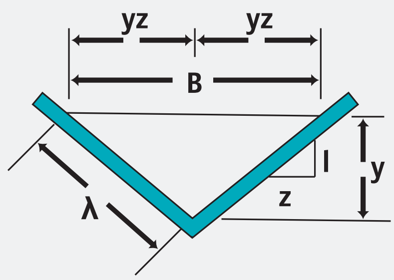
$A = by$

and $P = 2y + b$,

so the hydraulic radius is:

$R_H = by/(2y + b)$

Triangular Cross Section



Triangular channel

The hydraulic radius

$R_H = A/P$,

Where; A is the cross sectional area of flow and P is its wetted perimeter.

$A = A = y^2z$

and $P = 2\lambda$ with $\lambda^2 = y^2 + (yz)^2$, $P = 2[y^2(1 + z^2)]^{1/2}$

so the hydraulic radius is:

$R_H = A/P = y^2z/\{2[y^2(1 + z^2)]^{1/2}\}$

An iterative process then ensues to determine the diameter of the pipe or the width of the gutter.

EXAMPLE

For a typical greenhouse in Damour to determine the gutter size to convey the flow from the design storm the following steps are taken:

1. From the IDF curves select the rainfall intensity corresponding to a 5yr-1hr storm: Storm duration from the x-axis is 120 min. Then moving vertically from the 120min mark until the 5-yr frequency curve is intersected. Then moving horizontally across until the y-axis is intersected the intensity is then identified. In this case it is approximately 25 mm/hr.

2. Determine runoff using the Rational Method (Equation 4) for the rooftop of a tunnel greenhouse served by one U shape gutter from each side: $Q = CIA = 0.85 \times 0.025 m/hr \times 166 m =$ 3.53 m^3/hr or 0.001m^3/s.

3. Use Manning's Equation (Equation 5) to size the gutter. The n is selected to be 0.016 for galvanized steel material; the slope for the gutter running along the greenhouse roof is set at 0.005m/m and the pipe is estimated to be flowing at 75% full. After an iterative process, **the gutter dimensions to be adopted are "10 cm × 12 cm × 10 cm"**. for this size Q generated is 0.0037 m^3/s which is below the runoff generated by the rooftop ($Q = 0.001\ m^3/s$).

2.2.2.3 Sizing of downpipes and conveyance pipes

In order to size the downpipes and the conveyance pipes, the aforementioned formulas are reapplied for a circular closed HDPE pipes.

The Manning roughness coefficient, n, for use in the Manning equation, for the HDPE pipes is 0.012.

Table 5. Generated flow calculated by Manning Equation for the different readily available HDPE pipes for a typical greenhouse rooftop size

Runoff generated by a typical greenhouse rooftop (332 m^2) = 0.002 m^3/s									
HDPE pipes diameter available in the Lebanese market (mm)	20	25	32	40	50	63	75	90	110
Generated flow, Manning Equation (m^3/s)	0.0001	0.0001	0.0002	0.0004	0.0007	0.0014	**0.0022**	**0.0036**	**0.0061**

The suitability of the pipe is determined by selecting the pipe diameter that generates a flow higher than the runoff generated by the rooftop of the greenhouse.

EXAMPLE

For a typical greenhouse in Damour to determine the pipe size to convey the flow from the design storm the following steps are taken:

1. From the IDF curves select the rainfall intensity corresponding to a 5yr-1hr storm: Storm duration from the x-axis is 120 min. Then moving vertically from the 120min mark until the 5-yr frequency curve is intersected. Then moving horizontally across until the y-axis is intersected the intensity is then identified. In this case it is approximately 25 mm/hr.
2. Determine runoff using the Rational Method for the rooftop of the greenhouse served by one downspout from each side: $Q = CIA = 0.85 \times 0.025 m/hr \times 332 m = 7.05\ m^3/hr$ or $0.002 m^3/s$.
3. Use Manning's Equation to size the pipe. The n is selected to be 0.012 for HDPE material; the slope for the pipe running along the greenhouse roof is set at 0.005 m/m and the pipe is estimated to be flowing at 75% full. After an iterative process, the pipe diameter is determined to be 75 mm. To remain on the safe side, we select one higher size pipe diameter available in the market which is 90 mm.

2.2.3 Design and Installation Guidelines

2.2.3.1 Gutters and downspouts:

a. Gutter and downspout material:

i. Aluminum or galvanized steel are recommended,

ii. Copper, wood, vinyl, and plastic gutter and downspout materials are not recommended,

iii. If rainwater conveyed through gutters and downspouts must be of very high quality.

b. Gutter slope:

i. Where possible, slope gutters in the direction of the location of the rainwater storage tank,

ii. Ensure a minimum slope of 0.5-2% (the greater the slope the better) is maintained throughout the gutter length.

c. Gutter size:

i. In general, 10 × 12 × 10 cm K-style galvanized sheet gutter is commonly used and should be suitable for most typical greenhouses roof drainage areas and gutter lengths;

ii. To determine the size of gutter required for a given roof drainage area:

1. Choose the 5-year frequency 1 hr rainfall. Record the corresponding intensity.

2. Calculate the area of roof draining into the gutter:

$$\text{Roof Drainage Area } (m2) = \text{ Length } (m) \times \text{Width } (m)$$
(Equation 6)

Where: Length = length of the gutter served by a downspout (m)

Width = distance from the eave to the ridge of the roof drainage area served (m)

3. Determine runoff using the Rational Method

4. Choose a roof gutter type, size and slope and apply the Manning's Equation to check its suitability.

d. Location and spacing of downspouts:

i. Where possible, locate downspout(s) near the location of the rainwater storage tank,

ii. Usually, one downspout serves the entire gutter for a standard greenhouse.

e. Downspout size:

i. In general, 90 mm circular-type downspouts are commonly used and should be suitable for most typical Greenhouses roof drainage areas and gutter lengths,

ii. To determine the size of downspout required:
Refer to Table 5 to determine the minimum size of downspout based upon the Generated flow calculated by Manning Equation.

f. Gutter and downspout installation:

i. Gutters should be custom-fabricated and installed such that there are no seams along the length of guttering,

ii. Gutters shall be supported by hangers (hidden hanger or spike and ferrule) that are spaced at a maximum of 450 mm,

g. Refer to Appendix B for an example of sizing gutters and downspouts.

2.2.3.2 Plan the layout of the conveyance network:

a. For rainwater tanks located above ground:

i. Determine the location of the tank (refer to Section 2.4 Rainwater Storage and Tank Sizing for guidance),

ii. Route downspout(s) and/or conveyance drainage piping to the tank.

b. For rainwater tanks located below ground:

i. Determine the location of the tank (refer to Section 2.4 Rainwater Storage and Tank Sizing for guidance),

ii. Plan route of conveyance drainage piping from the downspout(s) to the tank,

iii. For additional guidance on planning the layout of conveyance drainage piping for below ground tanks, refer to Appendix B, Step 4.

2.2.3.3 Conveyance drainage pipes:

a. Pipe material:

HDPE pipe PN10 (recommended), or PVC SDR 21 pipe.

b. Pipe size and slope:

i. Ensure a minimum slope of 0.5-2% (the greater the slope the better) is maintained throughout the pipe length,

ii. For estimation purposes, consult Appendix B.

c. Cleanouts:

Cleanouts are required on conveyance drainage pipes to facilitate cleaning of the conveyance drainage pipes,

d. Tank connection:

Rainwater conveyance drainage piping should enter the tank at a height no lower than that of the overflow drainage piping, or ideally, at a height 50 mm above the bottom of the overflow drainage pipe(s) entering the tank.

2.2.3.4 Installation of conveyance drainage pipe:

a. Above ground pipes shall be supported;

b. Below ground pipes shall be located in a properly excavated space, be supported and properly backfilled.

2.2.3.5 Ensure that there are no means of entry for small animals or insects into the rainwater storage tank from the conveyance network by:

a. Properly installing all sections of the conveyance network, such that they do not have any holes or other points of entry other than those required for water flow; and

b. Installing downspout-to-pipe transition fittings.

2.2.3.6 Install pre-storage treatment devices as required (refer to Section 2.3 Rainwater Quality & Pre-Treatment for details).

2.2.4 Management Guidelines

The gutters and downspouts should be inspected once every six months, to:

a. Remove any dirt and debris that have accumulated; and

b. Repair and/or replace damaged components to ensure proper rainwater flow and prevent entry of birds, rodents or insects into the RWH system.

2.3 Rainwater Quality & Pre-Treatment

2.3.1 Introduction and definitions

There are currently no water quality guidelines that pertain specifically to the use of rainwater for agricultural use.

The quality of harvested rainwater varies greatly based on environmental and site conditions and can be improved through simple measures in the design, installation and maintenance process.

Pre-storage treatment involves either:

1. **First-flush diversion** – where the first portion of runoff (collected from the catchment surface) is diverted away from the storage tank; or
2. **Settling** – where rainwater first enters a settling tank or a settling chamber of a two-compartment tank, where suspended debris can settle out before rainwater is subsequently conveyed to the rainwater storage tank (or storage chamber); or
3. **Filtration** – where leaves and other debris are captured on screens and prevented from entering the tank. Filtration can take place in gutters, on downspouts, or be integrated into the conveyance drainage pipes.

Pre-filtration is required to keep sediment, leaves, contaminants and other debris from the system. Leaf screens and gutter guards meet the minimal requirement for pre-filtration of small systems, although direct water filtration is preferred. All pre-filtration devices should be low-maintenance or maintenance-free. The purpose of pre-filtration is to significantly cut down on maintenance by preventing organic buildup in the tank, thereby decreasing microbial food sources.

For larger tank systems, the initial first flush must be diverted from the system before rainwater enters the storage tank. The diverted flows (first flush diversion and overflow from the filter) must be directed to an acceptable pervious flow path. Preferably the diversion will be conveyed to the same secondary runoff reduction practice that is used to receive tank overflows.

2.3.1.1 Leaf screens

Leaf screens are mesh screens (1 mm mesh) installed over either the gutter or downspout to separate leaves and other large debris from rooftop runoff. Leaf screens must be regularly cleaned to be effective; if not maintained, they can become clogged and prevent rainwater from flowing into the storage tanks. Built-up debris can also harbor bacterial growth within gutters or downspouts.

Figure 8: *Leaf screen model.*

2.3.1.2 First Flush Diverters

First flush diverters direct the initial pulse of storm water runoff away from the storage tank. While leaf screens effectively remove larger debris such as leaves, twigs and blooms from harvested rainwater, first flush diverters can be used to remove smaller contaminants such as dust, pollen and bird and rodent feces (Figure 9). Simple first flush diverters require active management, by draining the first flush water volume to a pervious area following each rainstorm.

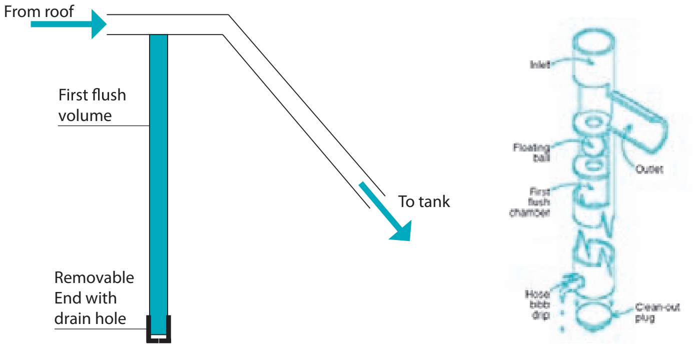


Figure 9: *First flush diverter details*

A first-flush diverter is a simple installation that is part of the downpipe, configured to remove the initial wash off the roof so it does not enter the tank. The first flush diverter works by channeling the first flow down the downpipe to its base where it encounters a cap with a small drain hole (the drain hole will allow for gradually drainage else, the system will need to be drained manually). This permits the first flow of water containing the roof debris to settle at the bottom of the downpipe, with the cleaner 'later' water settling on top, permitting relatively clean water to enter the tank.

There are a few simple maintenance procedures that are needed for first-flush diverters. The cap at the end of the first flush pipe needs to be easily removable to facilitate cleaning.

Regular inspection of the pipe is required to ensure no leaves or other materials have become lodged in the pipe and that the system is draining properly. An inappropriately maintained filter is worse than no filter at all.

The amount of water that needs to be diverted off the roof as first-flush and the capacity or required length of the downpipe can be calculated.

It is generally assumed that a depth of rainfall on the roof equivalent to 0.5 mm is required to wash off the accumulated contaminants.

Volume of diverted water (liters) =
greenhouse length (m) greenhouse width (m) 0.5 (mm)
(Equation 7)

2.3.2 Baffle tanks

A baffle tank can also be installed ahead of the main storage to filter out debris (Figure 10). These tanks have two screens; the first screen, called the flow baffle, filters out the more coarse material while the second with a finer mesh grade, filters the smaller particles.

The filtered residue will settle to the base of the tank while the cleaner water (upper layer) is allowed to flow into the main storage. The sediment build-up in the baffle tank needs to be removed from time to time. This configuration will assist in reducing sediment/sludge build-up in the main storage.

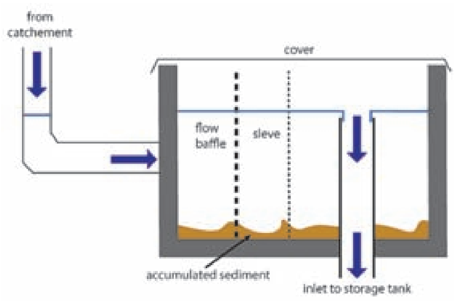


Figure 10: *Baffle tank design.*

2.3.3 Design and Installation Guidelines

1. Identify factors that impact the quality of rainwater in the rainwater harvesting system, and can be mitigated through proper design and installation;
2. Select and install pre-storage treatment devices:

a. Pre-storage treatment devices must be sized to handle the peak runoff from the catchment surface

b. First-flush diverters:
Size the first-flush chamber based on the desired amount of runoff (typical diversion height is 0.5 mm) to divert from the storage tank, using the following formulas:

Diversion Volume (L) = Diversion height (mm) × Catchment Area (m^2)
(Equation 8)

PRE-STORAGE TREATMENT DEVICES SHALL BE INSTALLED SUCH THAT THEY ARE READILY ACCESSIBLE. ACCESS OPENINGS TO FACILITATE ENTRY INTO THE DEVICE AND/OR TANK.

c. Settling tank or a settling chamber:
Size the settling tank or settling chamber based on the temporary storage of a prescribed volume of runoff,

i. Where the prescribed volume can be based on rainwater height (i.e., 1.5 mm of rain), as given by:

Settling Tank Volume (L) = Rainwater Height (mm) × Catchment Area (m^2)
(Equation 9)

ii. Where the prescribed volume can be based on a percentage of the capacity of the rainwater storage tank (i.e., settling chambers within two-compartment tanks typically have 1/3 the capacity of the storage chamber).

d. Pre-storage treatment filtration devices:

i. The following components may be included as part of the filtering system:
- High quality gutter guards, available from gutter contractors,
- Leaf screens placed on the downspout, available from gutter contractors, and/or
- Commercially supplied rainwater filter installed in-line with conveyance drainage pipe or inside tank.

e. Pre-storage treatment devices shall be installed such that they are readily accessible. Access openings to facilitate entry into the device and/or tank.

2.3.4 Management Guidelines

1. Identify the factors that can impact the quality of rainwater in the RWH system, and take steps to mitigate the risks posed by these factors by implementing the following maintenance activities:

a. Consult the maintenance best practices provided in Table 6.

Table 6. Factors affecting rainwater quality and recommendations for mitigating rainwater contamination through maintenance best practices

Component of RWH System	Risk Factors	Maintenance Best Practices
Catchment surface	1. Proximity to sources of air pollution (industry, major roadways, etc.) 2. Overhanging tree branches 3. Animal activity 4. Leaching of chemicals and/or metals from catchment material	At least once every 6 months: • Inspect catchment surface for sources of contamination (accumulated debris, leaves, pine needles, etc.) and clean area • Trim overhanging tree branches
Conveyance network	1. Entry of potentially poor quality groundwater/surface water from poorly sealed joins 2. Entry of animals, rodents and/or insects from poorly sealed joins	At least once every 6 months: • Inspect gutters for sources of contamination (accumulated debris, leaves, pine needles, etc.) and clean gutters as required • Inspect area(s) where downspouts connect to conveyance network to ensure fittings are secure • Inspect pre-storage treatment device(s) connected with conveyance network and clean devices as required
Rainwater storage tank	1. Leaching of chemicals and/or metals from rainwater tank storage material 2. Leaching of chemicals and/or metals from components located within rainwater tank 3. Pump intake located at bottom of tank where it can draw in sediment	At least once annually: • Inspect components inside tank for signs of corrosion and/or degradation and replace components as necessary • Monitor rainwater quality at point-of-use for indication of sediment accumulation in tank.

b. Consider other site specific risk factor(s) and adapt the maintenance of the RWH system as appropriate to mitigate the risks posed to rainwater quality.

2. Pre-storage treatment device(s) should be inspected at least twice per year, or more frequently as required by manufacturer's instructions and site conditions:

a. Observe rainwater passing through the device(s) during a rainfall event, or simulate a rainfall event by discharging water from a hose onto the catchment surface. Look for potential problems such as:
   i. Accumulated dirt and debris blocking flow through filter,
   ii. Loose fittings or other problems with the treatment device(s) such that rainwater is passing through without treatment taking place, or
   iii. Other problems with the treatment device(s).

b. Clean the filtration device(s) according to the manufacturer's maintenance instructions, repair as required.

2.4 Storage

It is important that you have sufficient storage to meet your needs and can accommodate the amount of water to be harvested. It is also recommended that the tank should be sized, so that it overflows at least twice a year to remove floating debris.

2.4.1 Introduction and definitions

2.4.1.1 Storage systems

2.4.1.2 Above Ground Storage

There is usually adequate space on-farm for the use of above ground storage tanks and, the height of modern agricultural buildings is sufficient to enable rainwater harvesting by gravity. Where tanks are above ground, fitting insulation and frost protection to pipes and pumps close to the tank, is recommended. Covers for the tank are also needed to prevent debris, leaves and access of animals and birds.

COVERS FOR THE TANK ARE ALSO NEEDED TO PREVENT DEBRIS, LEAVES AND ACCESS OF ANIMALS AND BIRDS.

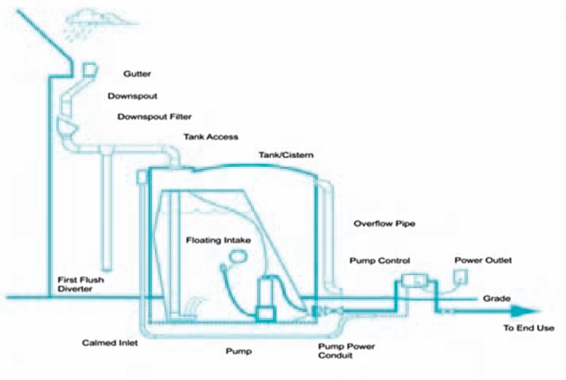


Figure 11: Above ground storage design

The advantages and disadvantages of above ground tanks include:

Advantages	Disadvantages
Ease of inspection.	Risk of frost damage to the pipe and equipment.
Ease of repair and maintenance of the tank and equipment.	Occupies ground space.
Lighter and less expensive construction.	Susceptibility to damage/vandalism.
Easier to add or increase capacity.	Appearance.
Lower cost of installation.	Requires a cover.
Avoids groundwater problems (high water table).	More susceptible to algal growth and poor water quality.
	Requires a tank specifically designed for use above ground.

2.4.1.3 Underground storage tanks

Many RWH systems use underground storage tanks. Installing a tank underground will result in additional installation costs in excavating the ground and, where water tables are high, securing the tank – however, there are also a number of advantages.

THE STORAGE TANK IS THE MOST IMPORTANT AND TYPICALLY THE MOST EXPENSIVE COMPONENT OF A RAINWATER HARVESTING SYSTEM.

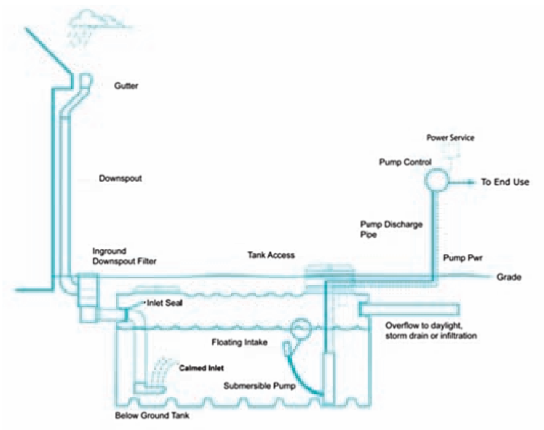


Figure 12: Underground ground storage design

An underground storage tank is often used to keep the stored water out of view.

Advantages	Disadvantages
It helps to prevent algal growth by shielding the tank from daylight. Protects the tank from extreme weather conditions such as frost damage. Protected against mechanical damage. Helps to regulate the water temperature in the tank, keeping it cool and limiting bacterial growth. Saves space on site. Hidden from view at ground level.	Additional cost of excavation. Additional cost of installation, particularly in high water tables. Less accessible for inspection and maintenance.

2.4.2 Issues for Consideration

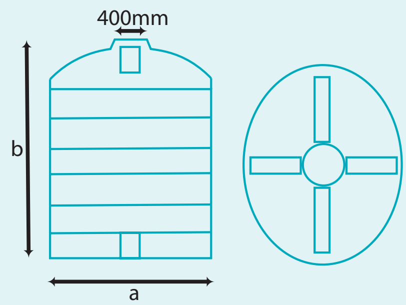
2.4.2.1 Storage Tanks

The storage tank is the most important and typically the most expensive component of a rainwater harvesting system. Multiple tanks can be placed adjacent to each other and connected with pipes to balance water levels and increase overall storage on-site as needed.

Here below the large-capacity tanks specifications available in the Lebanese market:

Table 7. Large-capacity one layer tanks specifications available in the Lebanese market

Capacity (Liters)	Measurements (cm)	
	a	b
6,000	194	215
8,000	216	240
10,000	240	260
22000	338	282



While many of the graphics and photos in this specification depict cisterns with a cylindrical shape, the tanks can be made of many materials and configured in various shapes, depending on the type used and the site conditions where the tanks will be installed.

The following factors should be considered when designing rainwater harvesting system and selecting a storage tank:

- Aboveground storage tanks should be UV and impact resistant.
- Underground storage tanks must be designed to support the overlying sediment and any other anticipated loads (e.g., vehicles, pedestrian traffic, etc.).
- Underground rainwater harvesting systems should have a standard size manhole or equivalent opening to allow access for cleaning, inspection, and maintenance purposes. This access point should be secured/locked to prevent unwanted access.
- Storage tanks should be opaque or otherwise protected from direct sunlight to inhibit algal growth and should be screened to discourage mosquito breeding and reproduction.
- Dead storage below the outlet to the distribution system and an air gap at the top of the tank should be added to the total volume. For systems using a pump, the dead storage depth will be based on the pump specifications.
- Any hookup to a municipal backup water supply should have a backflow prevention device to keep municipal water separate from stored rainwater; this may include incorporating an air gap to separate the two supplies.

Table 8: Advantages and Disadvantages of Various Cistern Materials

Tank Material	Advantages	Disadvantages
Fiberglass	Commercially available, alterable and moveable; durable with little maintenance; light weight; integral fittings (no leaks); broad application	Must be installed on smooth, solid, level footing; pressure proof for below-ground installation; expensive in smaller sizes
Polyethylene	Commercially available, alterable, moveable, affordable; available in wide range of sizes; can install above or below ground; little maintenance; broad application	Can be UV-degradable; must be painted or tinted for above-ground installations; pressure-proof for below-ground installation
Modular Storage	Can modify to topography; can alter footprint and create various shapes to fit site; relatively inexpensive	Longevity may be less than other materials; higher risk of puncturing of water tight membrane during construction
Plastic Barrels	Commercially available; inexpensive	Low storage capacity (75 to 190 L); limited application
Galvanized Steel	Commercially available, alterable and moveable; available in a range of sizes; film develops inside to prevent corrosion	Possible external corrosion and rust; must be lined for potable use; can only install above ground; soil pH may limit underground applications
Steel Drums	Commercially available, alterable and moveable	Small storage capacity; prone to corrosion, and rust can lead to leaching of metals; verify prior to reuse for toxics; water pH and soil pH may also limit applications
FerroConcrete	Durable and immoveable; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; expensive
Cast in Place Concrete	Durable, immoveable, versatile; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; permanent; will need to provide adequate platform and design for placement in clay soils
Stone or concrete Block	Durable and immoveable; keeps water cool in summer months	Difficult to maintain; expensive to build

2.4.2.2 Storage Tanks sizing

The size of the storage facility depends on the rainfall regime, the roof material and area, the expected water demand, the cost of construction/installation and the degree of reliability the farmer desires. An undersized storage system will not satisfy demands while an oversized one might never be fully utilized.

As a rule-of-thumb, it is advised that the system be 'over-designed' to provide at least 20% more than the estimated demand.

There are several methods that can be used to estimate the size of the storage tank. In this guideline, we will only provide example of the simple tabular method.

This method is used in the estimation of tank size based on rainfall variability and demand over the course of a year. The process comprises of four key steps.

1. Obtain monthly rainfall data for a year that was particularly dry or the rainfall erratic. These data will be gathered from CLIMWAT, a joint publication of the Water Development and Management Unit and the Climate Change and Bioenergy Unit of FAO. CLIMWAT is a reliable source which provides long-term (for at least 15 years) monthly mean values observed agroclimatic data of over 5000 stations worldwide.
   Agrometeorological data could also be collected from the Lebanese Agricultural Research Institute (LARI) stations.
2. Estimate the volume captured off the roof based on the area of the roof and the runoff coefficient.
3. Estimate the monthly irrigation demand on the basis of the Evapotranspiration of reference for the area, the crop grown under this greenhouse (K_C and ET_C).
4. Use the monthly volume capture and demand estimates to calculate the minimum storage required. This information is assembled in a tabular format that tracks the changes in the cumulative volume captured and stored, the cumulative demand and the total amount that is stored in any given month. The difference between the highest volume stored and the amount left in the tank at the end of the year represents the minimum storage volume.

A worked example is provided in *Appendix E*.

2.4.3 Design and Installation Guidelines

1. Determine the rainwater storage tank capacity:

a. For storage tanks used for rainwater harvesting purposes: Use the method provided in the *Rainwater Storage Tank Sizing* section of *Appendix E*.

b. If sizing the tank without reference to the Tank Sizing method, consider:

   i. The unused volume (typically referred to as the dead space') when selecting tank size. If unknown, assume 20% of tank capacity will be dead space,

   ii. The collection losses from pre-storage treatment devices (refer to Section 2.3 Rainwater Quality & Pre-Treatment for details).

2. Determine the type of material utilized for the rainwater tank, based on:

a. Placement (above- or below-ground);

b. Storage volume requirements;

3. Determine the location of the rainwater storage tank:

a. For all rainwater storage tank locations:

   i. Ensure the location allows for:

   - Proper drainage of rainwater through the conveyance network (refer to *Section 2.2 Rainwater Collection and Conveyance* for details),
   - Proper drainage of rainwater from the storage tank to an appropriate discharge location.

b. For below ground storage tanks:
i. Identify the area(s) where the tank can be located:
- Ensure the location is free from buried service lines (piping).
- Ensure the location is accessible for excavation equipment and the tank delivery vehicle. Consult the excavation contractor and tank supplier for exact requirements.

c. For above ground storage tanks:
i. Identify the area(s) where the tank can be located:
- Ensure the location has sufficient space for access above and around the tanks for inspection and maintenance.

4. Tank access and openings:
a. Tanks shall be provided with an access opening;

b. Access openings shall be a minimum of 450 mm to facilitate installation, inspection and maintenance of components within the rainwater storage tank;

c. Access openings shall have drip-proof, non-corrosive covers;

d. Openings that are larger than 100 mm shall have lockable covers.

5. Tank venting:
a. For below ground rainwater storage tanks:

i. In general, venting of the tank through the rainwater conveyance drainage piping and overflow drainage piping connected to the tank(s) is considered to be sufficient for typical small scale greenhouses,

ii. For larger scale greenhouses, or in cases where venting by means of conveyance drainage piping and overflow drainage piping connections is considered insufficient, a vent shall be installed on each tank, where:

- The vent pipe shall extend from the top of tank to a minimum height of 150 mm above grade,
- The vent pipe shall be of a sufficient size to permit the flow of air while the tank is filling, and shall be no less than 75 mm in size,
- Vent shall terminate in a gooseneck fitting with a screen to prevent the entry of birds, rodents and insects.

6. Installation of storage tanks:

a. Below ground tanks shall be placed in a properly excavated space, be supported on a tank bedding and be properly backfilled;

b. Consult the tank manufacturer's installation instructions regarding recommended tank bedding, support and backfilling procedures;

c. Connect the rainwater conveyance drainage pipe(s), overflow drainage pipe(s), rainwater pressure pipe(s) and electrical conduit(s) to the tank, ensuring that the connections are properly sealed and watertight.

7. Installation of components within the rainwater storage tank:

a. Components installed within the tank typically include:

i. A pump or pump intake (refer to Section 2.5 Pump and Pressurized Distribution System for details),

ii. Water level sensors and/or other types of control equipment,

b. Entry into the rainwater storage tank, for the purposes of installing components within the tank is not recommended;

c. Install components such that they are accessible for inspection and maintenance, without entry into tank;

d. Components installed in the tank should be suited for a wet environment.

2.4.4 Management Guidelines

1. Rainwater tanks should be inspected at least once every year for the following:

a. Leaks:
i. For below-ground storage tanks, leaks may be identified through poor performance of the RWH system, from moist soil conditions surrounding the tank and/or excessive settling of the tank in the excavated space;
ii. For above-ground storage tanks and integrated storage, leaks can be identified visually by examining the area surrounding the tanks, or through poor system performance or soil moisture (if applicable).

b. Accumulation of debris:

i. Sediment may accumulate on the bottom of the tank and, depending on the treatment provided, appear at the point of use. In such cases, the location (height) of the pump intake may need adjustment. Adjust the location of the pump intake such that it is located 100-150 mm above the bottom of the tank;

ii. If sediment is still detected at the point of use, pre-storage and/or post-storage treatment devices may need to be installed (or cleaned/maintained) to improve rainwater quality (refer to Section 2.3 Rainwater Quality & Pre-Treatment for details);

iii. In some cases, it may be necessary to remove the accumulated sediment on the bottom of the tank. (Note: removal of sediment and/or tank cleaning is not generally recommended on an annual basis).

2.5 Pump and Distribution Systems

2.5.1 Introduction

Most distribution systems require a pump to convey harvested rainwater from the storage tank to its final destination, whether inside the greenhouse, an automated irrigation system, or gradually discharged to a secondary runoff reduction practice. The rainwater harvesting system should be equipped with an appropriately-sized pump that produces sufficient pressure for all end-uses.

The typical pump and pressure tank arrangement consists of a multi-stage centrifugal pump, which draws water out of the storage tank and sends it into the pressure tank, where it is stored for distribution. When water is drawn out of the pressure tank, the pump activates to supply additional water to the distribution system.

A drain plug or cleanout sump, also draining to a pervious area, should be installed to allow the system to be completely emptied, if needed.

2.5.2 Issues for Consideration

The fact that the storage facility has to be placed below the level of the catchment surface pumping will be required to lift the water from storage and maintain pressure in the water distribution network if the water is to be used for drip irrigation or sprinklers.

In general for average greenhouses, an electric centrifugal pump of 2 horse power (hp), 1.5 KW, monophase with a 50 L pressure tank and 32 mm HPPE pipes throughout the structure will suffice. A pressure switch that will maintain the pressure between about 2 bars and 8 bars should be installed.

2.5.2.1 Pumping unit

The pumping unit is sized according to both total head requirement and power requirement.

2.5.2.2 Total head requirement

The head loss is calculated in all the piping using William-Hazen equations as below:

For less than 20 outlets:

$HL = 1135000 \times Q^{1.852} \times D^{-4.871} \times L$
(Equation 10)

Where, HL is the head loss in the pipe (m)
Q is the flow rate (L/s)
D is the internal pipe diameter (mm)
L is the length of the pipe (m)

For more than 20 outlets:

$HL = 398000 \times Q^{1.852} \times D^{-4.871} \times L$
(Equation 11)

Where, HL is the head loss in the pipe (m)
Q is the flow rate (L/s)
D is the internal pipe diameter (mm)
L is the length of the pipe (m)

The total head requirement is composed of the head losses in all pipes that has to be calculated earlier plus the total sum of the following: the suction lift, the difference in elevation between the level of the water tank and the position of the greenhouse, the head losses in fitting, the head requirement of the control head and the irrigation system (dripper) operating pressure.

The control head, which is composed of the filtering system and the water meter, is considered to be 7 m while the head losses in fitting are estimated to be 10% of all piping head losses.

This is translated as follows:

$HL = h_s + h_p + h_c + h_o + h_f + h_e$
(Equation 12)

Where, h_s is the suction lift, m
h_p is the head loss due to friction for all piping, m
h_c is the control head, m
h_o is the operating head, m
h_f is the head loss due to friction for all fitting, m
h_e is the elevation head, m (difference between pump location and location to which water will be delivered)

Once the head of the pump, TDH, is determined, the required power can be calculated

Suction lift HL piping (lateral, manifold, mainline) HL control head Emitter operating pressure
Subtotal 10% for fitting Difference in elevation
Total Dynamic Head (TDH)

2.5.2.3 Power requirements

The following equations can be applied to calculate the power requirements of the pump in Kilowatts (kW) and Brake Horse Power (BHP) respectively.

Power requirements in

$$KW = \frac{Q \times TDH \times Sg}{360 \times e}$$
(Equation 13)

Where, Q is the flow rate (m^3/hr)
TDH is the Total Dynamic Head (m)
Sg = specific gravity (unitless)
e is the efficiency of the pump (fraction)

Power requirements in

$$BHP = \frac{Q \times TDH \times Sg}{273 \times e}$$
(Equation 14)

Where, Q is the flow rate (m^3/hr)
TDH is the Total Dynamic Head (m)
Sg = specific gravity (unitless)
e is the efficiency of the pump (%)

For water the specific gravity is 1.0 while the efficiency of the pump may be determined from a pump performance curve which relates the total head, discharge (or flow to be pumped), and efficiency. These performance curves are typically provided by pump manufacturers.

Assuming a derating of 20%, the power requirement would be:

Final Power requirements in kW = Power requirements in kW × 1.2

Final Power requirements in BHP = Power requirements in BHP × 1.2

EXAMPLE

The storage tanks for the greenhouse in Damour will be above ground level. The water will be pumped to irrigate a greenhouse around 10 m away and 2 m higher than the pump level. The required operating head for the dripper irrigation system is 10 m (1 bar).

The greenhouse size is L = 41.5 m & l = 8 m. The irrigation system within this greenhouse consists of 9 later lines with 166 emitters per line and 41.5 m each, one manifold installed at the entrance of the greenhouse of 8 m length and connects the lateral lines to the pumping unit situated at 10 meters away from greenhouse. The emitters' flow rate is 4 l/hr.

And according to the pump manufacturer, the efficiency is 77%.

To properly size the pump, the following steps need to be completed:

1. The first step is to determining the Total Dynamic Head TDH,

$$TDH = h_s + h_p + h_c + h_o + h_f + h_e$$

Head loss	Explanation
Suction lift	Pump placed above ground
HL piping (lateral, manifold, mainline)	Using William-Hazen formulae
HL control head	Estimation
Emitter operating pressure	1 bar
Subtotal	
10% for fitting	Subtotal × 0.1
Difference in elevation	
Total Dynamic Head (TDH)	

2. The flow rate,
Q = number of lateral lines × number of emitters per line × Q emitters = 9 × 166 × 4 = 5976 l/hr = 59.76 m^3/hr

3. Efficiency, e = 77% = 0.77

4. The pump's power is then determined as:

$$P\,(kW) = \frac{Q \times TDH \times Sg}{360 \times e} = \frac{59.76 \times 24.9 \times 1}{360 \times 0.77} = 5.3\ kW$$

$$P\,(BHP) = \frac{Q \times TDH \times Sg}{273 \times e} = \frac{59.76 \times 24.9 \times 1}{360 \times 0.77} = 7.1\ BHP$$

Assuming a derating of 20%, the power requirement would be:
Final Power requirements in kW = 5.3 × 1.2 = 6.4 kW
Final Power requirements in BHP = 7.1 × 1.2 = 8.5 BHP

5. Thus the needed pump has to have a lift capacity of 25 m and a power of 7 kW.

2.5.2.4 Tank inlet and outlet configurations

The quality of water resident in the tank generally improves with time since suspended particles fall to the bottom and sediment. Incoming rainwater is often turbid. To ensure the separation of these different water qualities, the outflow of the down-pipe should be placed at the near-bottom of the tank so that the older clear water is forced to the top layer. A low-rise pipe surrounding the down pipe called the 'break ring' helps break the force of the outflow preventing it from disturbing any sediment that may have accumulated on the tank bottom (Figure 13a). To extract the cleaner top layer of water, a flexible intake hose attached to a float is recommended (as shown in Figure 13b).

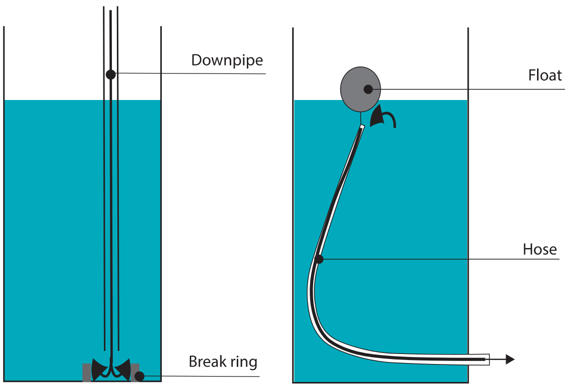


Figure 13: Design configurations for (a) tank inflow and (b) outflow

2.5.2.5 Overflow

An overflow mechanism should be included in the rainwater harvesting system design in order to handle an individual storm event or multiple storms in succession that exceed the capacity of the tank. Overflow pipes should have a capacity equal to or greater than the inflow pipe(s) and have a diameter and slope sufficient to drain the cistern while maintaining an adequate freeboard height. The overflow pipe should be screened to prevent access to the tank by rodents and birds.

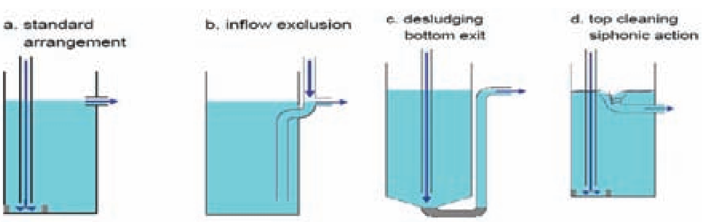


Figure 14: Design configurations for tank overflows

2.5.2.6 Drip Irrigation System

The covered high tunnel creates a desert-like environment that requires regular irrigation. Drip irrigation is an efficient and accurate way to water crops in a high tunnel. It uses a low flow rate and supplies water only to the root zone of the plants. Drip irrigation is often used with plastic mulch for transplanted crops to conserve moisture and create a more consistent moisture level in the soil.

The drip tape requires a low pressure, 1 bar, at the main line. The water pressure can be maintained with a low flow pressure regulator after the pump and before the header line. A pressure regulator reduces incoming water pressure to a set pressure usable by a drip system. It is used when the incoming pressure is too high for the emitters or fittings. The flow rate of the regulator should be matched with the system.

The header line, a layflat hose or a 32 mm polyethylene tube, is connected to the pump with appropriate-sized fittings. The lateral lines or drip lines run the length of the rows and are typically attached to the header line with ¼-inch tubing and valve fittings. It is necessary to have a "back up" line from your primary water source for use during dry periods. This line can be attached to the drip system by bypassing the pump.

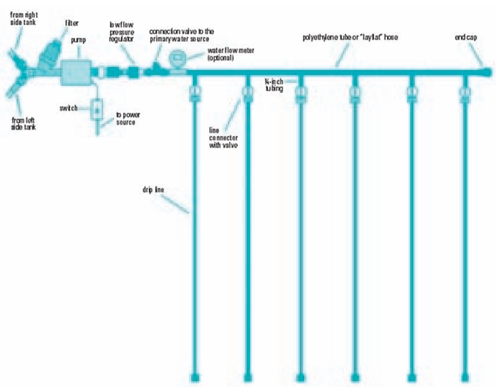


Figure 15: Drip irrigation system main components

THE FLOW RATE OF THE REGULATOR SHOULD BE MATCHED WITH THE SYSTEM.

2.5.3 Design & Installation Guidelines

1. Select the pump:

a. Determine the style and operating characteristics:

i. Style: centrifugal pump or submersible pump,

ii. Electrical or fuel powered pump.

b. Determine the required flow rate as per irrigation system needs:

For guidance purposes only, a method for estimating minimum pump flow rate is provided in *Appendix F*.

c. Determine the pump head:

A method for determining the pump head is provided in *Appendix F*.

d. Consult the pump manufacturer or supplier, or use pump manufacturer's pump curve charts, to select the appropriate pump model, given the pump style and operating characteristics, required flow rate, and pump head.

2. Plan the layout of the pump and distribution system:

3. Rainwater piping:

a. Pipe material:

i. HDPE, PN 10 Pipes (recommended) or,

ii. PVC SDR 21 Pipes.

b. Pipe size:

i. Pipe shall be sized to handle the maximum flow rate of the pump in accordance with the pump manufacturer's instructions;

ii. For estimation purposes, service pipe size can be calculated using the method provided in *Appendix F*.

c. Tank connection:

Rainwater service piping should enter the tank at a height no lower than that of the overflow drainage piping, or ideally, at a height 50 mm above the top of the overflow drainage pipe(s) entering the tank, or

4. Operation and maintenance considerations:

a. Rainwater service piping connected to a jet pump must be installed on a horizontal, or on a consistent upward slope from the storage tank to the pump;

b. To minimize the possibility of leaks, underground rainwater service piping should be installed with no, or few, pipe fittings;

c. To facilitate repair and/or replacement of underground rainwater piping, piping should be installed in an easy access zone.

5. Installation of pump:

a. Pumps shall be installed in accordance with the manufacturer's installation instructions;

b. Pumps shall be installed such that they are readily accessible (submersible pumps must be retrievable without entry into the tank);

c. Pump shall be provided with dry run protection. Consult pump specifications to determine if pump has built-in dry run protection, if not, provide a water level sensor;

d. For jet pumps:

i. Rainwater service pipe should terminate no less than 100-150 mm above the bottom of the tank;

ii. Pump prime shall be maintained by a foot valve located at the rainwater service pipe intake, or a check valve located in the rainwater service pipe upstream of the jet pump.

e. For submersible pumps:

i. The pump intake should be located no less than 100-150 mm above the bottom of the tank;

ii. Pump prime shall be maintained a check valve located in the rainwater service pipe downstream of the jet pump (consult pump manufacturer's instructions to determine if required).

3 RAINWATER HARVESTING SYSTEM MAINTENANCE SCHEDULE

Maintenance requirements for rainwater harvesting systems vary according to use. Systems that are used to provide supplemental irrigation water have relatively low maintenance requirements, while systems designed for indoor uses have much higher maintenance requirements. Table 9 describes routine maintenance tasks to keep rainwater harvesting systems in working condition.

Table 9. Suggested Maintenance Tasks for Rainwater harvesting systems

Activity	Frequency
Keep gutters and downspouts free of leaves and other debris	Twice a year
Inspect and clean pre-screening devices and first flush diverters	Four times a year
Inspect and clean storage tank lids, paying special attention to vents and screens on inflow and outflow spigots. Check mosquito screens and patch holes or gaps immediately	Once a year
Inspect condition of overflow pipes, overflow filter path and/or secondary runoff reduction practices	Once a year
Inspect tank for sediment buildup	Every third year
Check integrity of backflow preventer	Every third year
Inspect structural integrity of tank, pump, pipe and electrical system	Every third year
Replace damaged or defective system components	Every third year

IV

REFERENCES

Abdulal H, Arsenault L, Bachiu T, Garrey S, MacGillivray M, & Uloth D, 2006. Rainwater Collection System: A Feasibility Study for Dalhousie University. Prepared for Gregor MacAskill, Dalhousie University, Halifax, Nova Scotia.

Bonachela S., Maria Gonzalez A, & Dolores Fernandez M, 2006. Irrigation scheduling of plastic greenhouse vegetable crops based on historical weather data. Irrigation Science. Vol 25: 53–62

Chimonidou D., Polycarpou P., Vassiliou L. Rational use of water resources in Cyprus. In : El Moujabber M., Mandi L., Trisorio-Liuzzi G., Martín I., Rabi A., and R. Rodríguez (eds.). Technological perspectives for rational use of water resources in the Mediterranean region. Bari: CIHEAM, 2009. p. 109-118 (Options Méditerranéennes : Série A. Séminaires Méditerranéens; n.88)

Council for Development and Reconstruction, 2005. National Physical Master Plan for the Lebanese Territory. Council for Development and Reconstruction

Despins, C. 2010. The Alberta Guidelines for Residential Rainwater Harvesting Systems. Georgia, USA.

Despins, C. 2010. The Alberta Handbook for Residential Rainwater Harvesting Systems. Georgia, USA.

El Moujabber M., Atallah T., Darwish T and B. Bou Samra. 2004. Monitoring of groundwater salination by seawater intrusion on the Lebanese coast. Lebanese Science Journal Vol. 5, No. 2.

El. Moujabber, M. and B. Bou Samra. 2002. Assessment of Groundwater Salination by Seawater Intrusion in a Typical Lebanese Horticultural Area. In Proc. IS on Salination for Hort. Prod. (Eds. U. Aksoy et al.) Acta Hort. 573, ISHS 2002.

El-Fadel, M., Massoud, M., Kalinian, H. Screening Groundwater Quality in Lebanon: A Preliminary Assessment. Analysis conducted at Water Resources Center (AUB). Report submitted to USAID. 2000.

Environment Agency, 2019. Rainwater Harvesting: an on-farm guide.

Food and Agriculture Organization (FAO) of the United Nations, 1993. CLIMWAT for CROPWAT: a climatic database for irrigation planning and management / developed by Martin Smith in collaboration with the Agrometeorological Group Research and Technology Development Division.

Food and Agriculture Organization (FAO) of the United Nations, 2002. Irrigation Manual. Planning, Development, Monitoring and Evaluation of Irrigated Agriculture with Farmers Participation. Volume IV.

Food and Agriculture Organization (FAO) of the United Nations. 2009. Irrigation in the Middle East region in figures – AQUASTAT Survey 2008. Rome, Italy.

John Sutton, 2011. Rainwater harvesting guidelines: design, construction and specification. Government of Kiribati. GWP Consultants.

Korfali, S.I. and M. Jurdi, 2010. Deterioration of Coastal Water Aquifers: Causes and Impacts. European Water 29: 3 - 10

Kowalsky G. and Thomason K.,2010. Rainwater Harvesting and Re-Use: A Tool for Stormwater Runoff Reduction. Professional Development Series.

Lababidi H, Shatila A, A. Acra. 1987. The Progressive Salination of Groundwater in Beirut, Lebanon. International Journal of Environmental Studies, 30:203-208.

Lawson, S., LaBranche-Tucker, A. and H. Otto-Wack. 2009. Virginia Rainwater Harvesting Manual. Second Edition. Salem, VA, USA.

Mekdaschi Studer, R. and H. Liniger. 2013. Water Harvesting: Guidelines to Good Practice. Centre for Development and Environment (CDE), Bern; Rainwater Harvesting Implementation Network (RAIN), Amsterdam; MetaMeta, Wageningen; The International Fund for Agricultural Development (IFAD), Rome.

Ministry of Energy and Water (MoEW), 2010. National Water Sector Strategy: Ministry of Energy and Water, Beirut, Lebanon.

Ministry of Environment (MoE), 2012. Lebanon Technology Needs Assessment Report for Climate Change. Ministry of Environment. Lebanon.

Ministry of Environment/Ecodit, 2010. State of the Environment Report, Ministry of Environment, Beirut Lebanon.

Oweis, Theib Yousef, and Dieter Prinz. Water Harvesting for Agriculture in the Dry Areas. Leiden, the Netherlands: CRC Press/Balkema, 2012. Print.

Sample, D. and L. Doumar. 2013. Best Management Practice Fact Sheet 6: Rainwater Harvesting. Virginia Tech, Virginia State University, USA.

Shouse, S. and L. Naeve. 2012. Rainwater Catchment from a High Tunnel for Irrigation Use. Iowa State University of Science and Technology, US Department of Agriculture, Iowa, USA.

Singapore Public Utilities Board (PUB), 2014. Water Saving Habits. Accessed on August 30, 2014 URL:
http://www.pub.gov.sg/CONSERVE/HOUSEHOLDS/Pages/Watersavinghabits.aspx

Texas Rainwater Harvesting Evaluation Committee. 2005. Rainwater Harvesting Potential and Guidelines for Texas Report to the 80th Legislature. Austin, TX: Texas Water Development Board. Print.

Texas Rainwater Harvesting Evaluation Committee. 2006. Rainwater Harvesting Potential and Guidelines for Texas Report to the 80th Legislature. Austin, TX: Texas Water Development Board. Print.

Texas Water Development Board, 2005. The Texas Manual on Rainwater Harvesting 3rd Edition, Autin, Texas, USA. Available: http://www.eng.warwick.ac.uk/ircsa/factsheets/RainwaterHarvestingManual_3rdedition.pdf.

The Water Channel TV: Azores: a hundred years of greenhouse water harvesting, August 2014. Accessed on August 5, 2014. URL: http://www.thewaterchannel.tv/thewaterblog

The Water Channel TV: Greenhouse Innovations in Spain, May 2013. Accessed on August 5, 2014. URL: http://thewaterchannel.tv/thewaterblog/270-greenhouse-innovations-in-spain

Tipis Ole Mpusia P, 2006. Comp[arison of water consumption between greenhouse and outdoor cultivation. Master Degree Thesis submitted to the international institute for Geo-information Science and Earth Observation. Enschede, The Netherlands.

United Nations Environment Programme & Caribbean Environmental Health Institute (CEHI), 2009. Handbook for Rainwater Harvesting for the Caribbean.

Van Giesen, E. and F. Carpenter. 2009. Georgia Rainwater Harvesting Guidelines. Georgia, USA.

Vita Nuova LLC, 2009. Rainwater Harvesting System Design. Report prepared for U.S. Environmental Protection Agency.

Waterwise Organization, 2014. Which activities are most water intensive? Accessed on August 31, 2014. URL: http://www.waterwise.org.uk/pages/at-home.html

World Bank, 2009. Lebanon Social Impact Analysis- Electricity and Water Sectors.

World Bank, 2010. Republic of Lebanon Water Sector: Public Expenditure Review.

V

APPENDIX

APPENDIX A

APPENDIX B

APPENDIX C

APPENDIX D

APPENDIX E

APPENDIX F

APPENDIX A

CALCULATING THE AMOUNT OF WATER YOU CAN CAPTURE OFF YOUR GREENHOUSE ROOF

Using the Rational Method to calculate the volume of rainwater which could be captured

For the amount of water you can capture in one year you will need to estimate the area of your greenhouse roof, the average annual rainfall at your location and the runoff coefficient for the surface.

The mathematical relationship is given as:

Supply (liters per year) = rainfall (mm/year) × area (m²) × runoff coefficient

Note that since the greenhouse roof is an arc, you will need to 'project' the surface to the horizontal to correctly estimate the amount of rain that falls on the roof.

The roof area is calculated by the following relationship:

Roof surface area (m²) = greenhouse roof length (m) × greenhouse roof width (m)

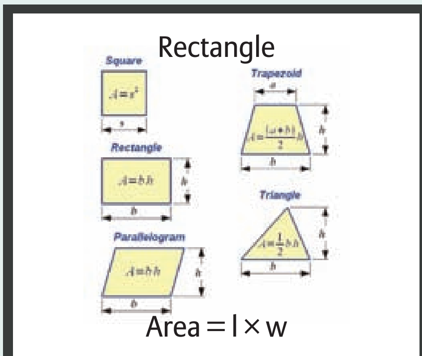
The runoff coefficients for the polyethylene plastic film covering the greenhouse, is estimated at 0.8.

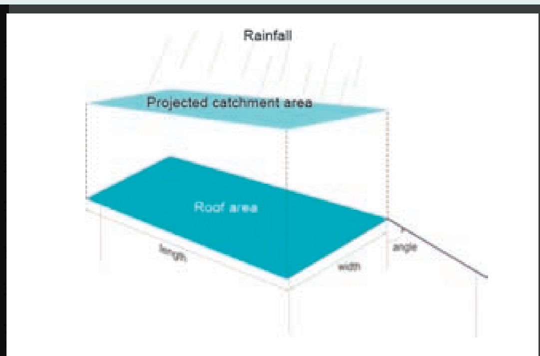
A worked example:

- Mean annual rainfall = 800 mm per year
- Greenhouse Roof area = 40 m (length) × 8 m (width) = 320 m²
- Roof surface is smooth polyethylene plastic film. This surface is assumed to have a runoff coefficient of 0.8

Supply = 800 × 320 × 0.8 = 204,800 liters per year

The following is the formula to estimate the areas of each roof section for a greenhouse



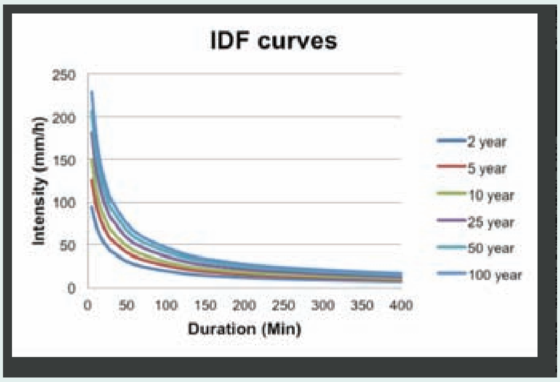


APPENDIX B
GUTTERS AND DOWNSPOUT SIZING

STEP 1: Rainfall intensity determination using IDF curves

The collection gutters and conveyance pipes must be able to convey the flow of water from a typical storm event.

Lacking standards, the practice in Lebanon is to select the 5-yr 1-hr storm for the design of stormwater drainage networks in urban areas. That is, it is a storm that lasts one hour and has a chance of occurrence of 1/5 or 20%. Intensity-Duration-Frequency (IDF) curves are typically used to determine the rainfall intensity from such design storms.



From the IDF curves select the rainfall intensity corresponding to a 5yr-1hr storm: Storm duration from the x-axis is 120 min. Then moving vertically from the 120 min mark until the 5-yr frequency curve is intersected. Then moving horizontally across until the y-axis is intersected the intensity is then identified. In this case it is approximately 25 mm/hr.

STEP 2: Runoff determination using the Rational Method equation

Once the rainfall intensity is determined then the Rational Method is used to determine the runoff from the rooftop.

The Rational Method equation which relates runoff to rainfall intensity and area along with a runoff coefficient as follows:

$$Q = C \times I \times A$$

where,

Q = runoff; m^3/hr
C = runoff coefficient (unitless)
I = Rainfall intensity; m/hr
A = Area drained by one gutter; m^2

STEP 3: Gutters sizing

Usually greenhouse gutters are readily available in the market with a standard size suitable for most structures.

But if we still need to determine the gutter size to convey the flow from the design storm the following steps are taken:

1. Rainfall determination using IDF curves in step 1.
2. Runoff Determination using the Rational Method for the rooftop in step 2
3. Upon determining the flow generated in the previous equation, the gutter can then be sized.

This is done by using the Manning Equation:

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}}$$

where, Q is discharge, m^3/s
n is the Manning roughness coefficient of the gutter
A is the cross-sectional flow area, m^2
R is the hydraulic radius, m
S is the slope of the conduit m/m

The K-style gutters usually used in greenhouse industry are similar to a rectangular or triangular open channel.
The Manning roughness coefficient, n, for use in the Manning equation, for the galvanised steel gutters is 0.016.

A worked example:

For a typical greenhouse in Damour to determine the downspout size:

1. Rainfall intensity from the IDF curves is approximately 25 mm/hr.
2. Determine runoff using the Rational Method for the rooftop of a tunnel greenhouse served by one U shape gutter from each side:

   $Q = CIA = 0.850.025\ m/hr \times 166m = 3.53\ m^3/hr$ or $0.001 m^3/s$.

3. Use Manning's Equation to size the gutter. The n is selected to be 0.016 for galvanized steel material; the slope for the gutter running along the greenhouse roof is set at 0.005m/m and the pipe is estimated to be flowing at 75% full. After an iterative process, the gutter dimensions to be adopted are 10 cm × 12 cm × 10 cm. for this size Q generated is 0.0037 m^3/s which is below the runoff generated by the rooftop ($Q = 0.001\ m^3/s$).

APPENDIX B

GUTTERS AND DOWNSPOUT SIZING

STEP 4: Downspout sizing

In order to determine the downspout size to convey the flow from the gutters to the RWHS, the same steps as for the gutter sizing should be followed as well:

1. Rainfall determination using IDF curves in step 1.
2. Runoff Determination using the Rational Method for the rooftop in step 2.
3. Upon determining the flow generated in the previous equation, the downspout can then be sized using the Manning Equation as for the gutter.

The Manning roughness coefficient, n, for use in the Manning equation, for the HDPE pipes is 0.012.

A worked example:

For a typical greenhouse in Damour to determine the downspout size:

1. Rainfall intensity from the IDF curves is approximately 25 mm/hr.

2. Determine runoff using the Rational Method for the rooftop of the greenhouse served by one downspout from each side:

   $Q = CIA = 0.85 \times 0.025 m/hr \times 332 m = 7.05\ m^3/hr$ or $0.002 m^3/s$.

3. Use Manning's Equation to size the pipe. The n is selected to be 0.012 for HDPE material; the slope for the pipe running along the greenhouse roof is set at 0.005m/m and the pipe is estimated to be flowing at 75% full. After an iterative process, the pipe diameter is determined to be 75 mm. To remain on the safe side, we select one higher size pipe diameter available in the market which is 90 mm.

APPENDIX C
FIRST FLUSH DIVERTER

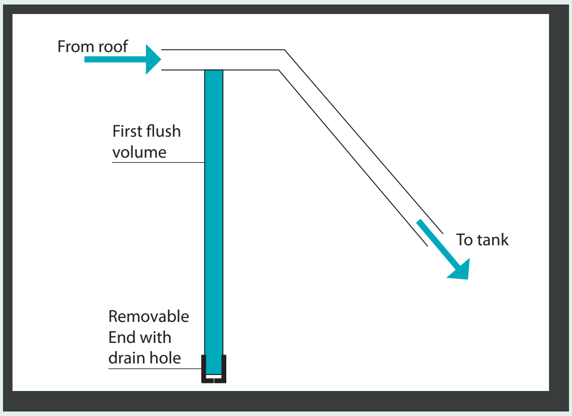
Minimizing contamination from the catchment

A **first-flush diverter** is a simple installation that is part of the downpipe, designed to remove the initial wash or "first-flush" that is sometimes laden with dirt, soot, animal droppings (when it first starts raining after a dry period) off the roof so that this contaminated water does not enter the tank.

The first flush diverter works by channeling the first flow down the downpipe to its base where it encounters a cap with a small drain hole (the drain hole will allow for gradually drainage else, the system will need to be drained manually).

This permits the first flow of water containing the roof debris to settle at the bottom of the downpipe, with the cleaner 'later' water settling on top permitting relatively clean water to enter the tank.

Simple first-flush diverter



How to calculate the volume of water you need to divert using a first flush system

It is generally assumed that a depth of rainfall on the roof equivalent to 0.5 mm is required to wash off the accumulated contaminants. You just need to determine the area of the roof and multiply by 0.5 mm.

Volume of diverted water (litres) = roof length (m) × roof width (m) × 0.5 (mm)

A worked example:
Greenhouse Roof length = 40 meters
Greenhouse Roof width = 8 meters
Volume of diverted water (liters): 40 × 8 × 0.5 = 160 liters

APPENDIX **D**

BAFFLE TANKS

Minimizing contamination from the catchment

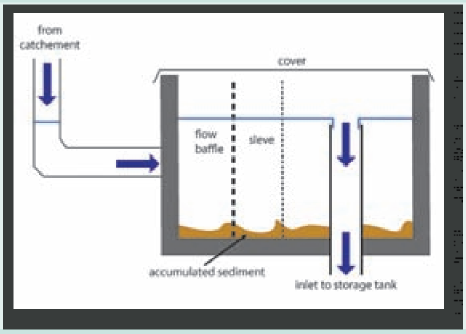
A **settlement tank** is a container where particulates carried out by rainwater tend to fall to the bottom of the vessel, forming slurry at the vessel base by gravity.

The settlement tank works by slowing down the flow of the water collected promoting the settlement of particulates (mainly sand) before moving to the storage tanks.

Sizing the settling tank or settling chamber is based on the temporary storage of a prescribed volume of runoff,
• Where the prescribed volume can be based on rainwater height (i.e., 1.5 mm of rain), as given by:

Settling Tank Volume (L) = Rainwater Height (mm) × Catchment Area (m^2)
• Where the prescribed volume can be based on a percentage of the capacity of the rainwater storage tank (i.e., settling chambers within two-compartment tanks typically have 1/3 the capacity of the storage chamber).

Simple first-flush diverter



How to calculate the volume of the baffle tank

It is generally assumed that a depth of rainfall on the roof equivalent to 1.5 mm is required to settle before entering the storage tanks. You just need to determine the area of the roof and multiply by 1.5 mm.

Volume of diverted water (litres) = roof length (m) × roof width (m) × 1.5 (mm)

A worked example:
Greenhouse Roof length = 40 meters
Greenhouse Roof width = 8 meters
Volume of diverted water (liters): 40 × 8 × 1.5 = 480 liters

APPENDIX E

ESTIMATING STORAGE REQUIREMENTS; SIMPLE TABULAR METHOD

STEP 1: Obtain rainfall data for your area

These data will be gathered from CLIMWAT, a joint publication of the Water Development and Management Unit and the Climate Change and Bioenergy Unit of FAO. CLIMWAT is a reliable source which provides long-term (for at least 15 years) monthly mean values observed agroclimatic data of over 5,000 stations worldwide.

Any additional agrometeorological data needed will be collected from the Lebanese Agricultural Research Institute (LARI) stations.

It is recommended that you use data from a notably dry year so as to better ensure considerations are made for prolonged dry spells.

APPENDIX E

ESTIMATING STORAGE REQUIREMENTS; SIMPLE TABULAR METHOD

STEP 2: Estimate the potential volume of water that can be harvested from your greenhouse rooftop

In order to estimate the potential volume of water that can be harvested from a given greenhouse, we determine for each month the average rainfall of the closest station the location of the greenhouse (using Table 4 or any close meteorological station).

A worked example:

Assume the following:

A standard greenhouse in Damour

Roof area: 332 m^2

Runoff coefficient: 0.8 (for a polyethylene plastic film roof)

Using LARI stations, the closest station to Damour is Tyr and the average January Rainfall I is 191.3 mm/month

Volume captured (litres) = rainfall (mm) × roof area (m^2) × runoff coefficient

Volume captured in January (litres) = 191.3 mm × 332 m^2 × 0.8 = 50,809 L

The same procedure is repeated for the 12 months.

STEP 3: Estimate monthly crop water demand

For each month starting from the planting month we perform the following steps:

1. Determine the crop factors: K_C using Table 2

2. Calculate the crop water need:
ET crop = ET_C (mm/month) = ET_0 (mm/month) × Kc (unitless)

3. Calculate the actual crop water need inside the greenhouse:
ET_{CG} (mm/month) = 0.65 × ET_C (mm/month)

4. Determine the total monthly irrigation demand (liters) for the greenhouse:
Total monthly demand (liters) = ET_{CG} (mm/month) × Greenhouse surface area (m^2)

A worked example:
Assume the following:

Greenhouse location: Damour

Surface area of the greenhouse : 332 m^2

Crop grown under this greenhouse: Tomato

For each month, the following steps are executed, here for January:

1. Determine the reference crop evapotranspiration: ET_0. Using Table 1, the closest station to Damour is Beirut and the average January ET_0 is 64.17 mm/month

2. Determine the crop factors: K_C. Using Table 2, Crop coefficient for tomatoes during January: Kc = 1.15

3. Calculate the crop water need: ET crop = $ET_C = ET_0 \times K_C$
$ET_C = ET_0 \times K_C = 64.17 \times 1.15 = 73.8$ mm/month = 73,800 liters/Dunum/month

4. Calculate the actual crop water need inside the greenhouse: $ET_{CG} = 0.65 \times ET_C$
$ET_{CG} = 0.65 \times 73.8 = 48$ mm/month = 48 L/m^2/month

5. Determine the total monthly irrigation demand (liters) for the greenhouse:

Total monthly demand (liters) = ET_{CG} × Greenhouse surface area
Total monthly demand (liters) = 48 × 332 = 15,936 L

APPENDIX E

ESTIMATING STORAGE REQUIREMENTS; SIMPLE TABULAR METHOD

Rainfall data & capture

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall (mm)	191.3	157.7	96.1	51.1	17.3	3.3	0.5	0.4	6.7	47.2	133.4	188	893
Volume Capture (L)	50,809	41,885	25,524	13,572	4,595	876	133	106	1,780	12,536	35,431	49,933	237,181

STEP 4: Use the volume capture and demand estimates to calculate the minimum storage needed (*steps above*)

This calculation is best assembled using a spreadsheet.

The data is contained in the table below.

The minimum storage required is the maximum value in column G minus the surplus water left at the end of the year. The surplus water in the tank is the final value in column G.

Minimum storage tank volume = 94,438 – *55,681* = *38,757 liters*

APPENDIX E

ESTIMATING STORAGE REQUIREMENTS; SIMPLE TABULAR METHOD

Greenhouse Catchment Area (m^2) =	332			Runoff Coefficient =		0.8	
A	B	C	D	E	F	G	H
Month	Mean Rainfall (mm/month)	Volume Captured (L/month)	Cumulative volume captured	Volume demanded in month	Cumulative Demand	Total Amount Stored (column D minus column F)	Deficit/Surplus per month (column C minus column E)
January	191.3	50,809	50,809	10,500	10,500	40,309	40,309
February	157.7	41,885	92,694	10,500	21,000	71,694	31,385
March	96.1	25,524	118,219	13,500	34,500	83,719*	12,024
April	51.1	13,572	131,791	15,000	49,500	82,291	-1,428
May	17.3	4,595	136,386	45,000	94,500	41,886	-40,405
June	3.3	876	137,262	45,000	139,500	-2,238	-44,124
July	0.5	133	137,395	0	139,500	-2,105	133
August	0.4	106	137,501	0	139,500	-1,999	106
September	6.7	1,780	139,281	10,500	150,000	-10,719*	-8,720
October	47.2	12,536	151,817	10,500	160,500	-8,683	2,036
November	133.4	35,431	187,248	10,500	171,000	16,248	24,931
December	188	49,933	237,181	10,500	181,500	55,681	39,433
Annual Mean	**893**	**237,181**					**55,681**
Maximum Stored	Volume						94,438
Minimum Storage Tank Volume (L)							**38,757**
Minimum Storage Tank Volume (m^3)							**39**

NOTE: if when constructing the table (as was the case in this example), column G contains some negative values, then it means the correct month was not chosen to begin the calculations. The minimum storage volume can still be found by finding the largest negative number, changing it to a positive figure and adding it to the largest positive number in column G. in this case, the figures in column G denoted by asterisks were changed from -10,719 to 10,719 and from 83,719 to 94,438 respectively.

APPENDIX F

PUMPING UNIT SIZING

Determination of head loss in piping

The head loss is calculated in all the piping using William-Hazen equations as below:

For less than 20 outlets:

$$HL = 1135000 \times Q^{1.852} \times D^{-4.871} \times L$$

Where, HL is the head loss in the pipe (m)
Q is the flow rate (L/s)
D is the internal pipe diameter (mm)
L is the length of the pipe (m)

For more than 20 outlets:

$$HL = 398000 \times Q^{1.852} \times D^{-4.871} \times L$$

Where, HL is the head loss in the pipe (m)
Q is the flow rate (L/s)
D is the internal pipe diameter (mm)
L is the length of the pipe (m)

Total head requirement

The pumping unit is sized according to both **total head** requirement and **power** requirement.

The total head requirement is composed of the head losses in all pipes that has to be calculated earlier plus the sum total of the following: the suction lift, the difference in elevation between the level of the water tank and the position of the greenhouse, the head losses in fitting, the head requirement of the control head and the irrigation system (dripper) operating pressure.

The control head, which is composed of the filtering system and the water meter, is considered to be 7 m.

The head losses in fitting are estimated to be 10% of all piping head losses.

This is translated as follows:

$HL = h_s + h_p + h_c + h_o + h_f + h_e$

Suction lift HL piping (lateral, manifold, mainline) HL control head Emitter operating pressure
Subtotal 10% for fitting Difference in elevation
Total Dynamic Head (TDH)

Power requirement

Once the head of the pump, TDH, is determined, the required power can be calculated

The **following equations** can be applied to calculate the power requirements of the pump in KW and BHP respectively.

$$\text{Power requirements in kW} = \frac{Q \times TDH \times Sg}{360 \times e}$$

$$\text{Power requirements in BHP} = \frac{Q \times TDH \times Sg}{273 \times e}$$

For water the specific gravity is 1.0

The efficiency of the pump may be determined from a pump performance curve which relates the total head, discharge (or flow to be pumped), and efficiency. These performance curves are typically provided by pump manufacturers.

Assuming a derating of 20%, the power requirement would be:

Final Power requirements in kW = Power requirements in kW × 1.2

Final Power requirements in BHP = Power requirements in BHP × 1.2