CHAPTER 6 RAINWATER HARVESTING

6.1 INTRODUCTION

6.1.1 General

Rainwater harvesting is a technique of collecting rainfall as a supplementary source of water supply for households, commercial and industrial premises, landscape watering, livestock water, and irrigation of agriculture. The planning and development of rainwater harvesting systems shall be carried out adhering to the principles and guidelines described here. This is to ensure that the system complies with sustainability, water quality and design standard.

6.1.2 Principles

The value of rainwater as the primary source of clean water is always ignored. The aim of rainwater harvesting is to concentrate runoff and collect it in a basin for use. Rainwater harvesting using roof catchments is the easiest and most common method. Rainwater may also be collected from any impervious surface, such as stone, concrete, or asphaltic pavement. Landscape can also be contoured to maximize the catchment areas and runoff for rainwater collection.

6.1.3 Benefits

There are numerous benefits of rainwater harvesting:

- It provides an alternative water supply to supplement piped water;
- It is a green approach. It reduces the dependency of people on pipe water hence discourage dam construction and deforestation;
- It reduces water bills for consumer. Occasionally, there are economic advantages such as rebates from municipalities for a reduction in use and dependency on municipal water;
- On islands with limited fresh-water, rainwater harvesting is the major source of water for domestic use; and
- It reduces stormwater flooding and soil erosion.

6.2 COMPONENTS OF A SYSTEM

6.2.1 Components

Whether it is large or small, a rainwater harvesting system (RWHS) has five basic components:

- Catchment area – the surface area which catches the rainfall. It may be a roof or impervious pavement and may include landscaped areas;
- Conveyance – channels or pipes that transport the water from catchment area to a storage;
- First flush – the systems that filter and remove contaminants and debris using separation devices;
- Storage tanks – where collected rainwater is stored; and
- Distribution – the system that delivers the rainwater to the point of use, either by gravity or pump.

In certain case where collected rainwater is for potable usage, purification involving filtering, distillation and disinfection are the optional components in rainwater harvesting system. The harvesting process from rainfall up to end user is conceptually shown in Figure 6.1. A typical detailing of the system either above-ground storage or below-ground storage is diagrammatically illustrated by Figure 6.2.

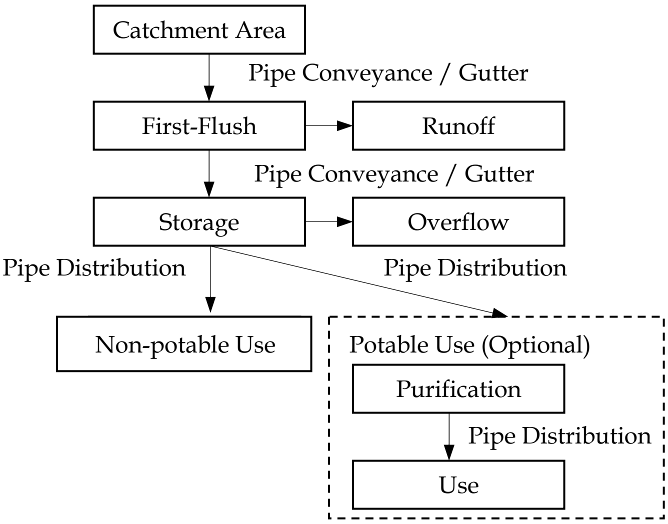
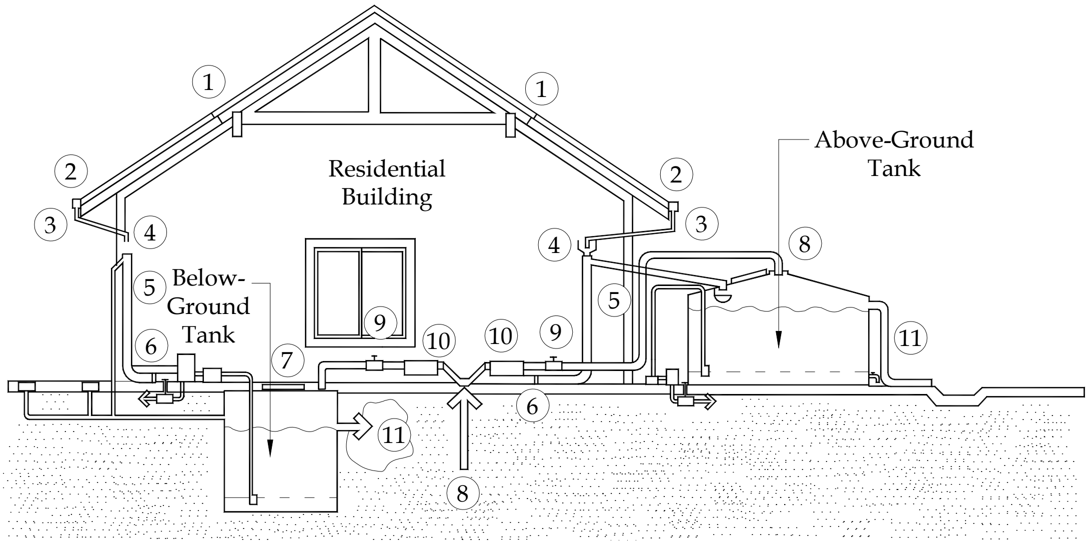


Figure 6.1: Rainwater Harvesting Process



Notes:
1. Roof collection
2. Gutter with leaf screen
3. Rain gutters
4. Downpipe
5. Debris and sediment removal, first flush device
6. Screw-off end cap for cleaning
7. Access for cleaning
8. Alternate water supply
9. Typical valve
10. Backflow prevention device
11. Overflow pipe

Figure 6.2: Typical Components of Rainwater Harvesting System for a Residential Building

6.2.2 Integration with OSD

The rainwater harvesting system can be integrated with OSD facilities (Chapter 5) that control a minor storm event. It is appropriate for large scale landscapes such as parks, school, commercial sites, parking lots, and apartment complexes and also small scale residential landscapes. Rainwater can be stored on flat roofs provided that adequate protection against leakage is catered for in the structural design of the building.

This type of storage has limited application in residential areas and is more suited to commercial and industrial buildings where large flat roof are available. OSD storage-cum-rainwater harvesting system can be provided as below-ground storages, above-ground storages or a combination of both.

6.2.3 Pumps

There are several types of pumps with different operating principles suitable for various conditions of use such as reciprocating pumps, centrifugal pumps, centripetal pumps, and centrifugal jet pumps. Each pump impeller has its own operating characteristics, which define its capability and efficiency. These can either be calculated for each individual pump and its impeller or the pump characteristic read from graphs and nomographs normally furnished by pump manufacturers for their products.

6.2.4 First Flush Device

Rainwater quality varies and is affected by environmental factors and commercial industrial activities in the area. The inclusion of the first flush device will improve the quality of the water. The device can be part of the rainwater downpipe, be separated from a tank or be attached to a tank. It can also be installed below ground.

Collection and disposal of the first flush of water from a roof, is of particular concern for any rainwater harvesting system. This is due to the fact that first flush picks up most of the dirt, debris, and contaminants, such as bird droppings that have been collected on the roof and in the gutters during dry periods. Multiple first flush devices may be required instead of a single first flush depending on slope of the catchments surface and time required for rainwater to reach the first flush device(s). Figure 6.3 shows the typical first flush systems.

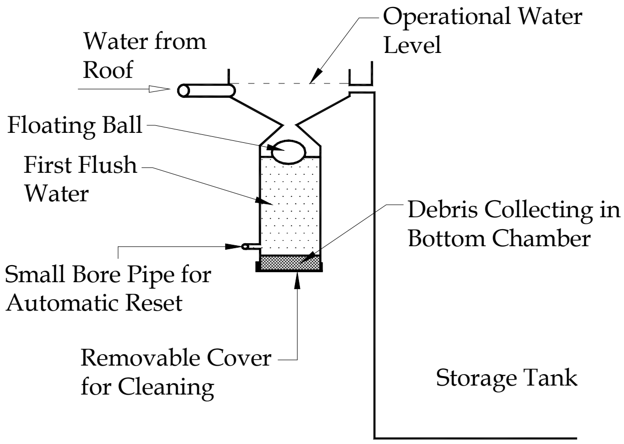


Figure 6.3: Typical First Flush Systems

6.3 CONFIGURATION OF TANK

6.3.1 Storage Type

There are various types for rainwater harvesting tank. In general, the rainwater tank can be divided into either above-ground tank or below-ground tank as shown in Figure 6.4.

6.3.2 Shape of Storage Tank

The tank shapes can be circular, rectangular and others, such as trapeziums and pipes as provided in Table 5.2 of Chapter 5.0. There are a number of factors that govern what tank or tanks would be suitable in varying situation. These include:

- height of roof;
- roof catchment area identification;

- gutter and downpipe arrangements;
- space around the building;
- alignment of building in relation to boundaries; and
- local regulatory authority regulations with regard to water tanks.

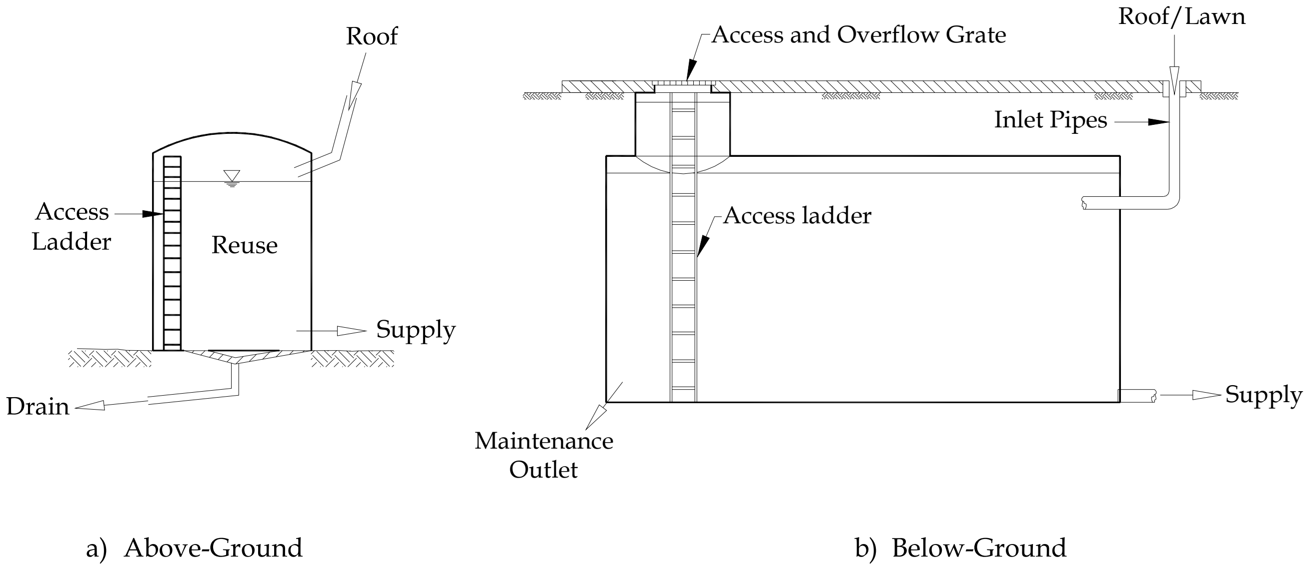


Figure 6.4: Types of Storage Tank

Larger tanks often have to be cast in-situ. Fibreglass tanks, although more expensive, are more durable because they resist corrosion and are not generally affected by chemical or moisture. These tanks are manufactured with a good-grade coating on their interior surface. The tanks should also be manufactured to prevent the entry of light, which could encourage algae growth.

6.4 SIZING STORAGE TANK

6.4.1 Rainwater Demand

The rainwater demand depends on several factors. Table 6.1 shows the amount of water uses for different appliances and outdoor application which was adopted from Rainwater Harvesting Guidebook: Planning and Design (DID, 2009). Rainwater demand depends on:

- The number of people using the water;
- Average consumption per person; and
- The range of uses (drinking, bathroom, laundry, toilet, garden watering, etc.)

The rainwater demand can be reduced in certain water stress area and during dry period using water conservation devices.

6.4.2 Factors Affecting Rainwater Availability

Rainwater availability depends directly on several parameters such as rainfall characteristics, catchment area (roof area), and tank size. The other minor factors which affect the yield are first flush amount and losses on the roof, such as evaporation and splashing.

Table 6.1: Rainwater Demand for Domestic Application (DID, 2009)

Use (Appliance)	Type	Average Consumption	Average Total Rainwater Demand
A. Indoor			
Toilet	Single Flush	9 litres per flush	120 litres per day
	Dual Flush	6 or 3 litres per flush	40 litres per day
Washing Machine	Twin Tub (Semi- auto)		40 litres per wash
	Front Loading		80 litres per wash
	Top Loading		170 litres per wash
Dishwasher	-		20-50 litres per load
General Cleaning	-	10-20 litres per minute	150 litres per day
B. Outdoor			
Sprinkler or Handheld Hose		10-20 litres per minute	1000 litres per hour
Drip System			4 litres per hour
Hosing Paths/Driveways		20 litres per minute	200 litres per wash
Washing Car with a Running Hose		10-20 litres per minute	100-300 litres per wash

(a) Rainfall Characteristics

For a typical RWHS with a defined roof area, tank size and rainwater use pattern, the rainwater harvestable yield will depend mainly on the rainfall characteristics such as the sequence of rain-days and the daily rainfall amount. Generally, more rain-days yield higher rainwater amounts. Since the rainfall characteristics vary from place to place in Malaysia, the RWHS yield will therefore vary. A total of 17 major towns within Malaysia have been selected for the rainwater yield assessment. Table 6.2 shows the average annual rainfall and the number of rain-days for the selected towns.

Table 6.2: Mean Annual Rainfall and Number of Rain-days for Selected Towns

No.	Name of Town	Rainfall Station	Period of Record	Mean Annual Rainfall (mm)	Number of Annual Rain-day	Years of Record
1	Alor Star	6103047	1948-2007	2,365	147	42
2	Ipoh	4511111	1972-2008	2,288	181	38
3	Klang	3014084	1953-2008	2,197	132	55
4	Kuala Lumpur	3117070	1953-2008	2,527	177	56
5	Seremban	2719043	1959-2008	1,901	141	50
6	Melaka	2222010	1954-1998	1,989	179	45
7	Kluang	1833092	1948-2006	2,295	163	58
8	Johor Bahru	1537113	1948-2007	2,787	158	59
9	Kota Bharu	6121001	1981-2008	2,622	138	21
10	Kuala Terengganu	5331048	1954-2008	2,659	161	53
11	Kuantan	3833004	1948-2008	2,881	136	59
12	Kuching	1403001	1950-2008	4,043	242	59
13	Sibu	2219001	1999-2007	3,282	229	9
14	Bintulu	MMS 96441	1999-2008	4,136	225	10
15	Kota Kinabalu	5961002	1985-2009	2,629	177	25
16	Sandakan	5875001	1987-2008	3,070	190	18
17	Tawau	4278004	1989-2006	1,626	155	14

Note: When large gaps occur in a particular year, the entire data series of that year were discarded in analysis *(b) Rooftop Area*

The rooftop area corresponds to the rainwater catchment area. The rainwater harvestable yield is higher when rooftop area is larger.

(c) Rainwater Storage Tank Size

Rainwater tank is an important component in the RWHS from perspective of cost and space allocation. The rainwater harvestable yield is higher when the tank size is bigger. When tank size is increasing, the incremental increase in yield is decreasing because it is limited by roof area. Hence it is essential to determine the optimum tank size.

(d) First Flush Volume

The first flush is required to prevent contaminants collected at the roof surface from entering the storage tank. The first flush volume adopted is equivalent to 0.5mm of rainfall as shown in Table 6.3 (DID, 2009).

Table 6.3: First Flush Requirement According To Roof Area (DID, 2009)

Roof Area (m^2)	First Flush Volume (m^3)
Less than 100	0.025 - 0.05
100 - 4356	0.05 - 2.5
Greater than 4356	2.5

Note: Adopt first flush of 5 m^3 if surface contains excessive soil, dust or debris.

(e) Losses from Roofs

For houses in tropical region such as Malaysia, roof structures usually heat up due to prolonged exposure to sunshine. Other than in the Northeast Monsoon season, rainfall usually occurs in the late afternoon. Hence, 0.5 mm of rain falling on the roof is considered as evaporation and splashing losses.

6.4.3 Rainwater Availability Estimation

Two models are available in the rainwater availability estimation procedures suggested by Jenkins et al. (1987) which are:

- Yield Before Spillage (YBS) model; and
- Yield After Spillage (YAS) model.

The YBS model adopts an optimistic approach where the rainwater harvested will be supplied for daily consumption and the balance will be stored in the storage tank for next day use. On the other hand, the YAS model assumes a conservative approach where rainwater harvested will be channelled to the tank first, and the excess of rainwater will be overflowed. The daily consumption will be drawn from the tank.

With the RWHS described above and the adopted parameters, a daily water balance model has been configured to compute the daily rainwater yield based on YBS as shown in Figure 6.5. A spreadsheet has been developed to facilitate the daily water balance computation.

6.4.4 Average Annual Rainwater Yield Estimation

Estimation of the Average Annual Rainwater Yield (AARY) was carried out using daily water balance model for the selected towns in Malaysia adopting YBS method. The estimation was carried out to assess a typical case of household/residential house with 5 persons. Roof area of the building is 100m². The adopted first flush and losses from roof were estimated to be 1 mm as recommended in Section 6.4.2.

The analyses results shown that, e.g. in Alor Star, the AARY is 103m³ if tank size of 1m³ is used. When the tank size is 3 times bigger (3m³), the AARY is merely increased by 32% to 136m³ only. Therefore, tank size of 1m³ is the near optimum in term of highest AARY per unit tank size for Alor Star. Similarly for other towns, a tank size of 1m³ is the near optimum tank size. Table 6.4 below presents the AARY from the YBS model for all the selected towns.

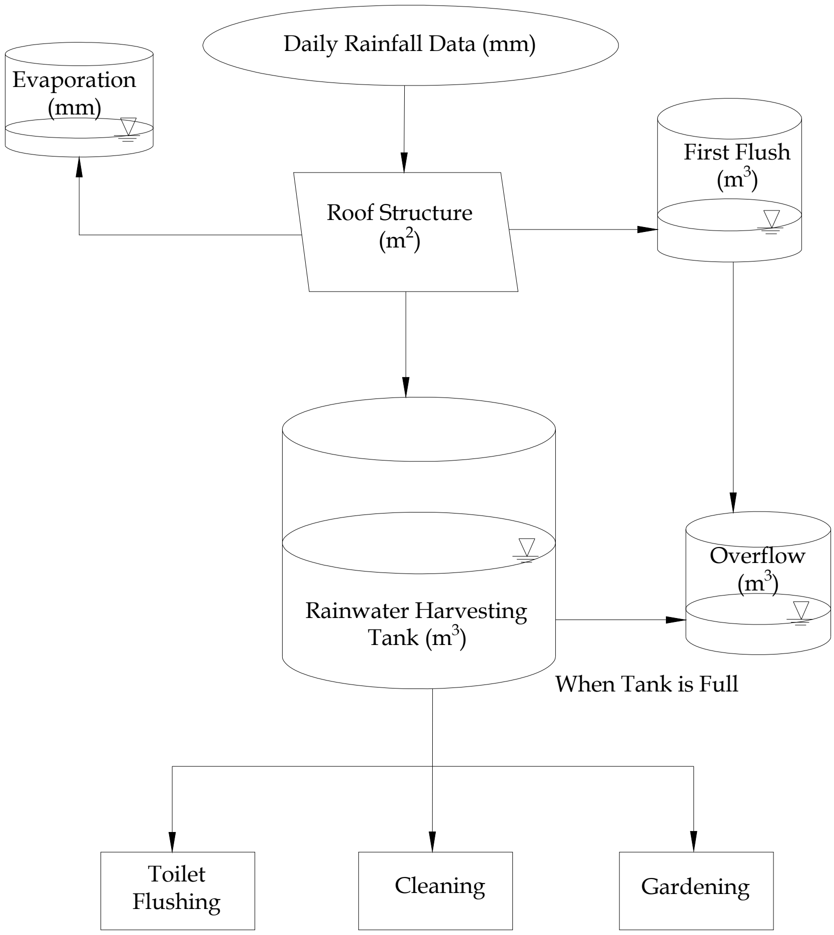


Figure 6.5: Schematic Diagram for the Daily Water Balance based on YBS Model

6.4.5 Tank Size Estimation

From Section 6.4.4, the tank size for Malaysia regardless of location is 1 m³ for roof area of 100m². It is equivalent to store 10mm of rainfall with 100m² of roof area. As such, tank size can be estimated with the following equation:

$$S_t = 0.01A_r \quad (6.1)$$

where,

S_t = Tank Size (m³); and

A_r = Rooftop Catchment Area (m²).

Equation 6.1 is established by assuming the demand is proportional to the roof area and tank size. The tank size with varying daily demand and roof area may have variation of ± 25% using the above simplified approach. A more methodical approach, i.e., a daily water balance model using the specific roof area and daily rainwater demand for a particular project can be carried out if a more accurate result is required.

Table 6.4: Average Annual Rainwater Yield for Selected Towns

No.	Name of Town	Average Annual Rainwater Yield (m^3)
1	Alor Star	103
2	Ipoh	99
3	Klang	107
4	Kuala Lumpur	116
5	Seremban	98
6	Melaka	100
7	Kluang	115
8	Johor Bahru	128
9	Kota Bharu	95
10	Kuala Terengganu	94
11	Kuantan	111
12	Kuching	156
13	Sibu	144
14	Bintulu	148
15	Kota Kinabalu	109
16	Sandakan	120
17	Tawau	89

Note: AARY was computed from tank size of $1m^3$ and roof area of $100m^2$.

6.5 SIZING CONVEYANCE AND DISTRIBUTION SYSTEMS

6.5.1 Rainwater Collection and Conveyance

This system component is designed based on the procedure presented in Chapter 4, Section 4.3. It comprises gutters, rainheads, sumps and downpipes.

6.5.2 Distribution Pipe

In designing for water supply installation, an assessment must first be made of the probable maximum water flow. In most buildings it seldom happens that the total numbers of appliances installed are ever in use at the same time, and therefore, for economic reasons, it is usual for a system to be designed for a peak usage which is less than the possible maximum usage. The probable maximum demand can be assessed based on the theory of probability. This method uses a loading unit rating which is devised for each type of appliance, based on its rate of water delivery, the time the taps are open during usage, and the simultaneous demand for the particular type of appliance. Table 6.5 gives the loading unit rating for various appliances.

In building where high peak demands occur, a loading unit rating for such appliances is not applicable and 100% of the flow rate for these appliances is required as shown in Table 6.6. The same applies to automatic flushing cisterns for urinals.

The pipe sizing can be determined using the Thomas-Box equation (DID, 2009):

$$q = \sqrt{\frac{d^5 \times H}{25 \times L \times 10^5}} \qquad (6.2)$$

where,

q = Discharge through the pipe (L/s);

d = Diameter of pipe (mm);
H = Head of water (m); and
L = Total length of pipe (m).

The diameter of the pipe necessary to give a required flow rate will depend upon the head of water available, the smoothness of the internal bore of the pipe and the effective length of the pipe. An allowance for the frictional resistance set up by fittings such as elbows, tees, taps and valves must be added to the actual length of the pipe. Table 6.7 gives the allowance for fittings expressed in equivalent pipe lengths.

Table 6.5: Loading Unit Rating for Various Applications

Type of Appliance	Loading Unit Rating
Dwelling and Flats	
W.C. Flushing Cistern	2
Wash Basin	1.5
Bath	10
Sink	3 - 5
Offices	
W.C. Flushing Cistern	2
Wash Basin (Distributed Use)	1.5
Wash Basin (Concentrated Use)	3
School and Industrial Buildings	
W.C. Flushing Cistern	2
Wash Basin	3
Shower (with Nozzle)	3
Public Bath	22

Table 6.6: Recommended Minimum Flow Rate at Various Appliances

Type of Appliance	Rate of Flow (*l*/s)
W.C. Flushing Cistern	0.12
Wash Basin	0.15
Wash Basin with Spray Taps	0.04
Bath (Private)	0.30
Bath (Public)	0.60
Shower (with Nozzle)	0.12
Sink with 13 mm Taps	0.20
Sink with 19 mm Taps	0.30
Sink with 25 mm Taps	0.60

Table 6.7: Frictional Resistance of Fittings Expressed in Equivalent Pipe Length

Nominal Outside Diameter (mm)	Equivalent Pipe Length (m)		
	Elbow	Bend	Tee
15	0.5	0.4	1.2
20	0.6	0.5	1.4
25	0.7	0.6	1.8
32	1.0	0.7	2.3
40	1.2	1.0	2.7
50	1.4	1.2	3.4
65	1.7	1.3	4.2
80	2.0	1.6	5.3
100	2.7	2.0	6.8

In calculating the diameter of a pipe to supply individual fittings, the head loss through the draw-off tap should also be taken into account. Table 6.8 gives the allowances for draw-off taps expressed in equivalent pipe lengths.

Table 6.8: Frictional Resistance of Draw-off Taps Expressed as Equivalent Pipe Lengths

Fitting (BS 1010)	Discharge Rate with Tap Fully Open (litre/s)	Equivalent Pipe Length (m)	
		Copper	Galvanized Steel
15 mm Diameter Bib-tap or Pillar Tap	0.20	2.70	4.00
20 mm Diameter Bib-tap or Pillar Tap	0.30	8.50	5.75
25 mm Diameter Bib-tap or Pillar Tap	0.60	20.00	13.00

REFERENCES

1. Chong S.F., Lim C.K., Lee C.S. (2010). *Rainwater Harvesting Systems in Malaysia: How Much Can We Harvest?* IEM Colloquium.

2. Department of Irrigation and Drainage, Malaysia, (2009). *Rainwater Harvesting: Guidebook on Planning and Design*.

3. Jenkins, D., Pearson, F. Moore, E. Sun, K. Valentine, R. (1987). *Feasibility of Rainwater Collection Systems in California, Contribution no. 173*. University of California (UCLA).

4. Ministry of Housing and Local Government, Malaysia, (1999). *Guidelines for Installing a Rainwater Collection and Utilization System.*

APPENDIX 6.A SIZING CHARTS

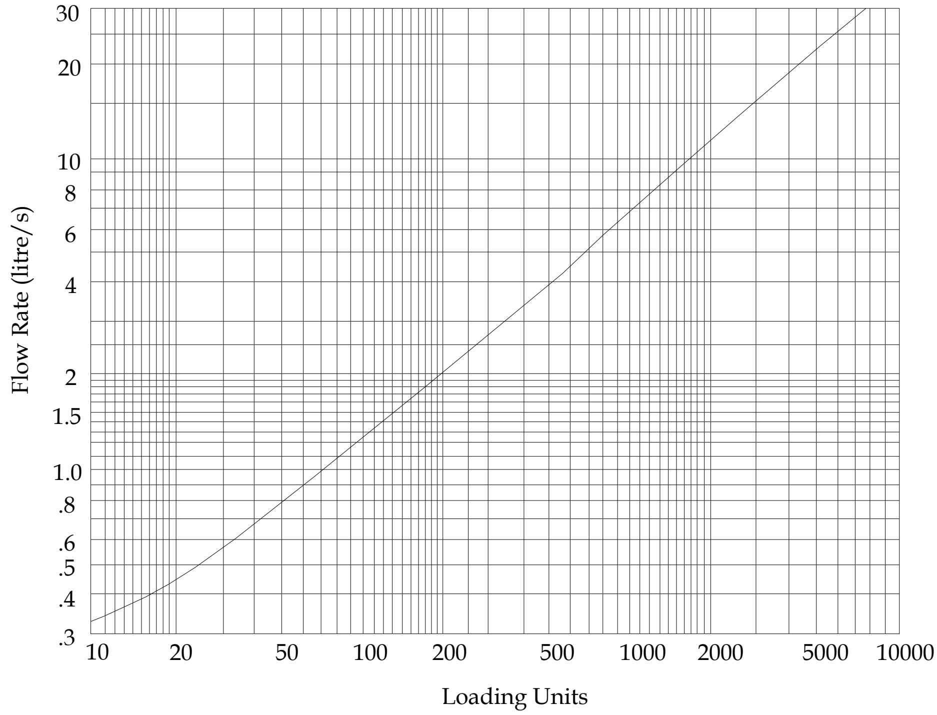


Figure 6.A1: Design Flow Rate for Various Loading Units

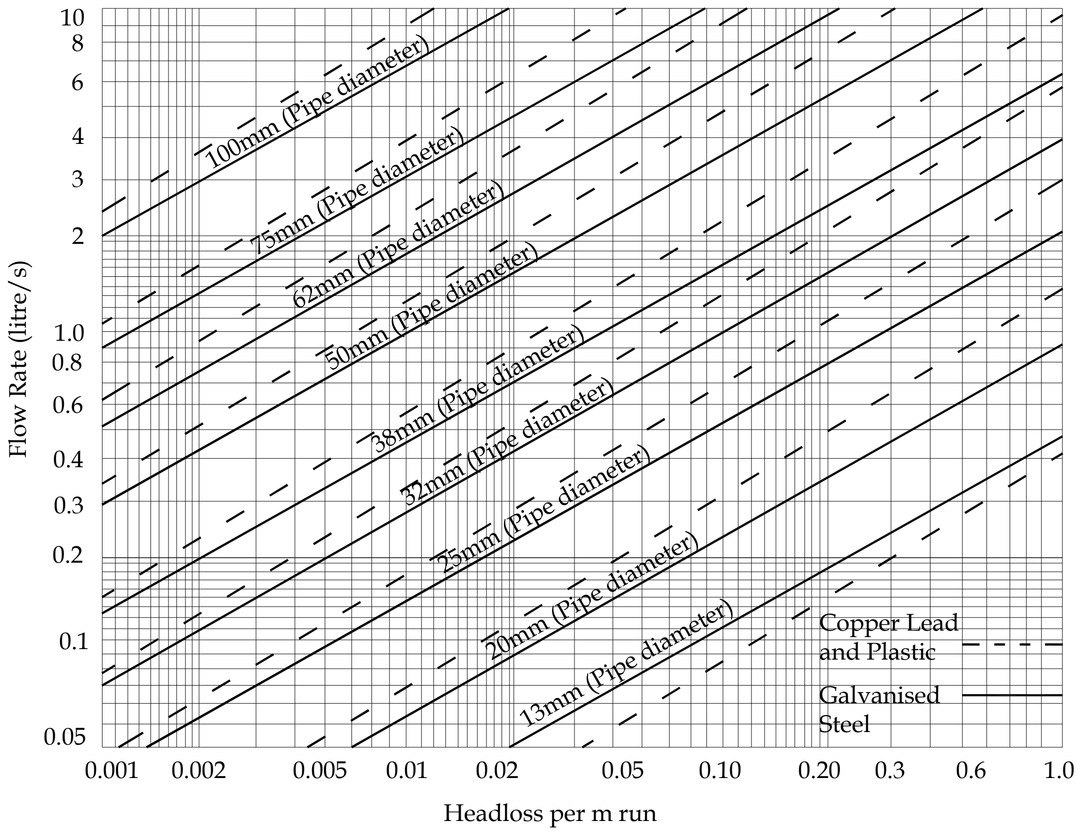


Figure 6.A2: Headloss for Various Pipe Size and Flow Rate

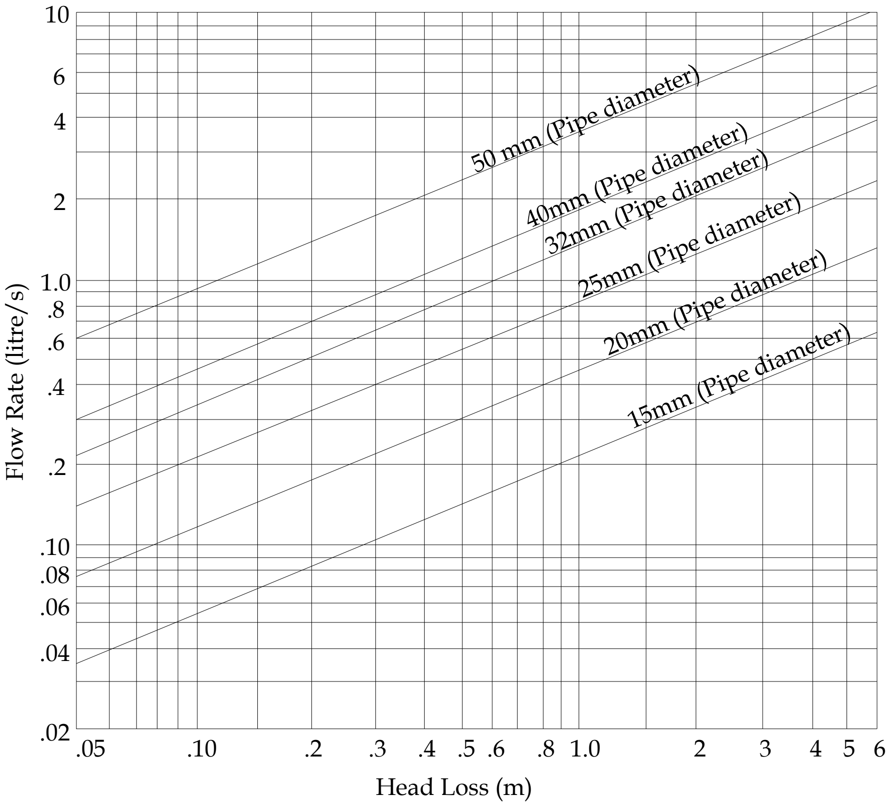


Figure 6.A3: Headloss through Stop Valve

APPENDIX 6.B EXAMPLE – SIZING TANK AND PIPE

6.B1 Tank Sizing for Residential Development

<u>Problem:</u>

A bungalow development is proposed in Kuala Lumpur with the inclusion of a rainwater harvesting system in the design. The roof area of each bungalow is 200m² with a car porch and garden. The bungalow is designed with five rooms with a twin sharing concept. Each room is equipped with one dual flush toilet. Given that domestic water demand is 250 litre/capita/day, compute:

- Annual rain water demand;
- Rainwater tank size;
- Percentage of rainwater yield over rainwater demand; and
- Percentage of rainwater yield over domestic water demand.

<u>Solution:</u>

Reference	Calculation	Output
	<u>Compute annual rain water demand (m^3)</u>	

Reference	Use (Appliance)	Unit	Average Water Use	Total Water Use (litre/day)
Table 6.1	Dual Flush Toilet	5 nos	40 litres/day	200
	Washing Machine (Front Loading)	1 wash	80 litres/wash	80
	Dishwasher/ General Cleaning	3 loads	50 litres per load	150 150
	Gardening	20minutes	20 litres/minute	400
	Washing 5 Cars with Running Hose for 20 Minutes/Car Once a Week	20minutes/ car	20 litres/minute	285.7 (5 x 20 x 20 /7)
	Total			1266

Reference	Calculation		Output
	The annual rainwater demand = 365 days x 1266 l/day	=	462m³
	<u>Tank size estimation (m^3)</u>		
Equation 6.1	With rooftop catchment, A_r = 200m², Tank Size , S_t = 0.01m x 200m²	=	2m³
	<u>Compute Average Annual Rainwater Yield (m^3)</u>		
Table 6.4	For Kuala Lumpur, the AARY for 2m³ tank size = 2 x 116	=	232m³
	<u>Compute percentage of water yield over rainwater demand</u>		
	Percentage of rainwater yield over rainwater demand = 232/462 x 100	=	50.2%
	<u>Compute annual domestic water demand (m^3)</u>		
	Annual domestic water demand = 365 days x 10 capita x 250 litres/capita/day	=	912m³
	<u>Compute percentage of water yield over domestic water demand</u>		
	Percentage of water yield over domestic water demand = 232/912 x 100	=	25.4%

6.B2 Tank Sizing for Industry/Factory

Problem:

A development project is proposed involving building a factory with roof area of 5000m² in Pasir Mas, Kelantan. The factory is designed to house 500 workers. The factory toilets are equipped with single flush system. This factory has a small landscaping area at the entrance of the factory. Compute:

- annual rain water demand;
- rainwater tank size; and
- percentage of rainwater yield over rainwater demand.

Solution:

Reference	Calculation					Output
	Compute annual rain water demand (m^3)					
Table 6.1	Use (Appliance)	Unit	Average Water Use	Total Water Use (l/day)		
	Single flush toilet with 9 l/flush	500 workers	5 flushes/day	22500		
	Gardening	40 minutes	20 l/minute	800		
	Total			23300		
	The annual rainwater demand = 365 days x 23300 litres/day				=	8504m³
	Tank size estimation (m^3)					
Equation 6.1	With rooftop catchment, A_r = 5000m², Tank Size , S_t = 0.01m x 5000m²				=	50m³
	Compute Average Annual Rainwater Yield for town (m3)					
Table 6.4	Take the nearest Kota Bharu, the AARY for 50m³ tank size = 50 X 95				=	4750m³
	Compute percentage of water yield over rainwater demand					
	Percentage of rainwater yield over rainwater demand = 4750/8504 X 100				=	55.9%

6.B3 Pipe Sizing

Problem:

This worked example shows how the main pipe can be sized up for rainwater tank serving a typical bathroom at the same factory in Worked Example 6.B2. The appliances in the bathroom consists of 5 W.C. flushing cisterns, 5 wash basins and 5 showers with nozzles. The actual length of the main pipe is 15 metres. The layout of the system is shown in Figure 6.B1. Assuming the system used 25mm (O.D) copper pipe with an available head of 5m:

- compute the design flow rate (l/s) of the loading units; and
- determine whether the pipe size used acceptable?

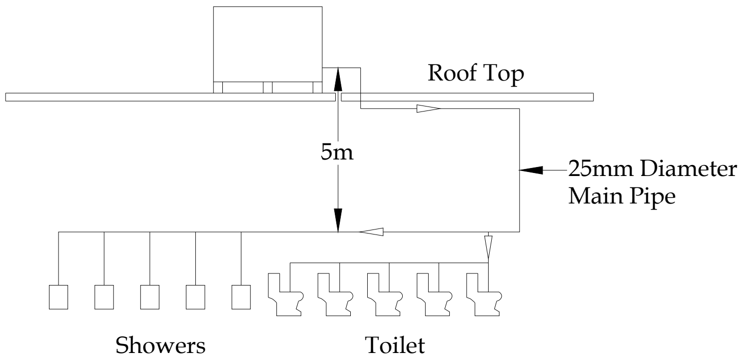


Figure 6.B1: Example layout of the Plumbing System

Solution:

Reference	Calculation	Output
	Compute the loading rating per unit appliance	
Table 6.5		

Piping Component	Loading Rating per Unit Appliance (unit)	Number of Appliance (nos)	Total Loading (unit)
W.C. flushing system (WC)	2	5	10
Wash basin (WB)	3	5	15
Shower (SR)	3	5	15
Total loading			40

Reference	Calculation	Output
	Compute the flow rate	
Figure 6A1	The flow rate for 40 units loading =	0.70 *l*/s
	Compute the flow rate	
	With 25 mm of OD copper pipe,	
Table 6.7		

Piping Component	Equivalent Length (m)	Number of Component (Nos.)	Total Headloss (m)
Elbow	0.7	4	2.8
Tee	1.8	1	1.8
Total Headloss due to friction resistance in fittings			4.6

Reference	Calculation		Output
	Compute Effective Length of Pipe		
	Effective length =15 + 4.6	=	19.6m
	Compute headloss in pipe due to frictional resis6-7tance		
Figure 6A2	The head loss in 25mm copper pipe due to frictional resistance	=	0.10m
	Compute headloss due to fitting of stop valve		
Figure 6A3	The head loss due to fitting of stop valve	=	0.6m
	Compute total headloss		
	The total headloss due to pipe and fittings = (19.6 × 0.1) + 0.6	=	2.56m
	Compute residual head (>0)		
	Residual head = available head – total headloss= 5 – 2.56	=	2.44m Since >0, OK
	Compute required pipe size using Thomas-Box equation		
Equation 6.2	$d = \sqrt[5]{\dfrac{0.70^2 \times 25 \times 19.6 \times 10^5}{2.44}}$	=	25.04mm 25mm is OK