ANALYSIS OF DESIGN CURVE AND RELIABILITY OF RAINWATER HARVESTING IN A COASTAL AREA OF BANGLADESH

Civil and Environmental Engineering

By

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An undergraduate thesis submitted to the Department of Civil & Environmental Engineering of Islamic University of Technology, Board Bazar, Gazipur in partial fulfillment of the requirements for the degree

OF

BACHELOR OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING

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Thesis approved as to style and content for the degree of B.Sc. Engineering (Civil and Environmental Engineering)

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DECLARATION

We hereby declare that the undergraduate project work reported in this thesis has been performed by us and this work has not been submitted elsewhere for any purpose (except for publication).

October 2013

Md. Rafat Arefin (095430)

Md. Istakimul Huq (095432)

Dedicated

To

Our Beloved Parents

ACKNOWLEDGEMENT

We would like to thank Allah Almighty and the most gracious that the thesis was completed in time. We would also like to thank the respected supervisor and prof. Dr. Md. Rezaul Karim, for his guidance and appreciation. At times of complications, he has helped with his knowledge and gave hope to us. Without his help, this thesis would never be completed.

We would like to thank our parents for their support and help without whom this work would not be possible.

ABSTRACT

The lack of safe drinking water is the primary cause of disease in the world today. Every day, tens of thousands of people die from causes directly related to contaminated water. Many study shows that contaminated water use causes 80% of the health problems throughout the world. Much of the reason is because in rural areas of developing countries, the only water source for people to cook with and drink from is often badly polluted shallow well or contaminated surface water used by both animals and humans.

In coastal area of Bangladesh, a number of people are suffering from water borne diseases due to the lack of safe water and due to the intrusion of saline water into the surface water bodies.

In some coastal areas the surface water and to a large extend the ground water is so saline that it is impossible to use for drinking and cooking purposes. Desalination may be a sound option but Bangladesh has neither the economic capability nor cheap technology to do it in a major volume. In such condition, many areas almost entirely depend on rainwater harvesting to supply their potable water. Therefore, it is very important to study the reliability of the RWH tank on a daily basis rainfall model.

As the water mainly used for drinking and cooking purposes so it is a chief concern that the tank storage volume will be such that it can supply the water for a period of 5-10 years with 100% reliability on the daily basis model. For such study, it is necessary to study the reliability of a storage tank not only for one year but also as function of its whole time period i.e. 5-10 years cycle.

The expected outcome of this study is to prepare a design curve of storage volume that will operate with 100% reliability across its operational period based on a real life data of daily rainfall in a coastal area of Bangladesh.

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Chapter One

Introduction

1.1 RAINWATER HARVESTING

Rainwater harvesting is the artificial process of collection, preservation and use of natural rainfall. Harvesting usually means productive use. Rainwater harvesting is actually the redirect use of rainwater by storing the rainfall through a catchment area. In many parts of the world now a day's Rainwater harvesting arrangements have been developed and used for collecting and preserving fresh water. Rainwater is an open source of water; everybody can use it for free once the initial cost of collection process is met. Building an artificial lake with a large catchment area or use small tank outside the house for direct collection of rainfall, rainwater harvesting can be both very complex and simple in nature and technical method. Rainwater can be harvested for both potable and non-potable use. For non-potable use the rainwater is directly available. But for potable use rainwater should be filtered or boiled. Rainwater harvesting ensures both economic and environmental sustainability of water resource.

This harvesting can be undertaken through a variety of ways-

- Capturing runoff from rooftops.
- Capturing runoff from local catchment.
- Conserving water through watershed management. (1)

Rainwater harvesting can be used for various work. The benefits that can be achieved through RWH are –

- Ensuring the productive use of rainwater.
- Reduce the use of ground water.
- If RWH is done in vast volume then it reduces the chance of flood during high rainfall period.
- In coastal area due to very high rainfall we can use rainwater as a direct alternative to the saline water for wide range of purposes.
- RWH can be very effective if it is integrated with normal water supply system.

- Economic benefits.
- Less energy consumption in the supply level of water.
- Helps in utilizing the primary source of water and prevent the runoff from going into sewer or storm drains, thereby reducing the load on treatment plants.

1.2 COMPONENTS OF ROOF TOPS RWH SYSTEM:

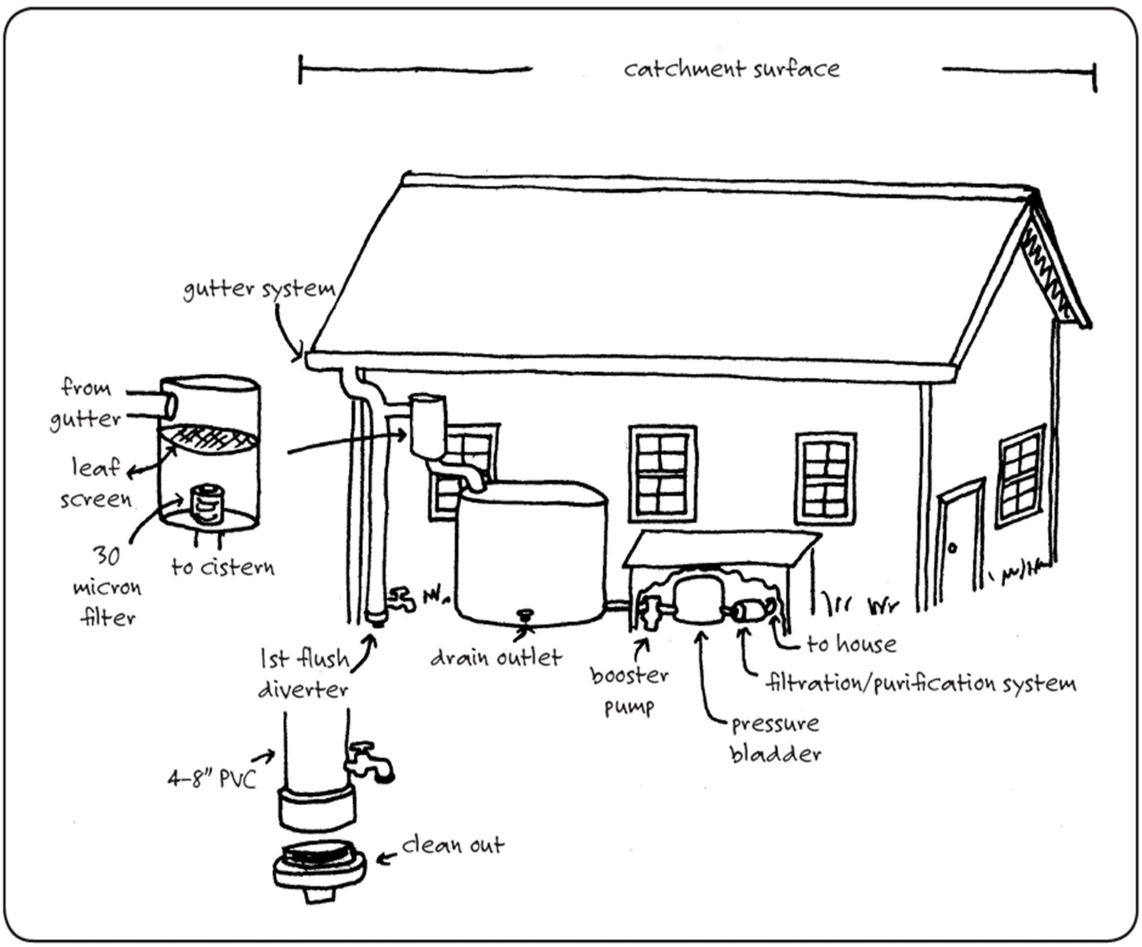
A rainwater harvesting system consists of components for - transporting rainwater through pipes or drains, filtration, and tanks for storage of harvested water. The common components of a rainwater harvesting system are:-

1. **Rainfall:** Rainfall can be described as water that reaches the earth surface from the atmosphere following the hydrologic cycle. Potential success of RWH directly depends on the available rainfall of that area.
2. **Catchments:** it can be described as the surface where rainfall is directly received and provide the water to the system. A roof made of reinforced cement concrete (RCC), galvanized iron or corrugated sheets are mainly used for water harvesting.
3. **Gutters:** Channels which surrounds edge of a sloping roof to collect and transport rainwater to the storage tank. Gutters can be semi-circular or rectangular and mostly made locally from plain galvanized iron sheet. Gutters need to be supported so they do not sag or fall off when it is loaded with rain water.
4. **Conduits:** Conduits are mainly the pipeline systems that connect gutter outlet to the storage tank. The available conduits are made up of materials like PVC, galvanized iron.
5. **First-flushing:** It is a valve system that prevents the early rainfall water from going into the storage tank. The first spell of rain contains atmospheric pollutants and also may be contaminated by the dust and debris present in the roof surface.

6. **Filters:** Filters are used to remove the suspended particles from the collected rainwater. There are different types of filters such as Charcoal water filter, Sand filters, Horizontal roughing filter and slow sand filter.
7. **Storage Tank:** It can be described as the constructed facility to store water. There are various options available for the construction of these tanks with respect to the shape, size, and material of construction and the position of tank. Also some maintenance measures like disinfection and cleaning are required to ensure the quality of water stored in the container.

Figure No: 1.1

Different components of Roof top rainwater harvesting



1.3 SCARCITY OF PURE WATER

"Water scarcity involves water stress, water deficits, and water shortage and water crisis. The concept of water stress is relatively new. Water stress is the difficulty of obtaining sources of fresh water for use, because of depleting resources. A water crisis is a situation where the available potable unpolluted water within a region is less than that region's demand." (2)

In the earth 97% of total water is saline water, 3% is fresh water among which only 13% is accessible. The world population is increasing day by day but the natural sources of water is depleting very fast. In the larger sense water affects very aspects of the animal life.

From physical to psychological all natural dynamics are hampered with the absence of pure water. The scarcity of water has gone such extent that in near future the water will be the most influencing resource in the economic and political field of the world.

According to the scientists, in the short-run, in the global market the high value will be assigned not to the water as a resource itself, but to the 'water-dependent' products. Increase in the prices for such products, along with the increased shortage of the water resources is inevitable. (Gazeta, 2010)

According to the (THE UNITED NATIONS WORLD WATER DEVELOPMENT REPORT 4, 2012), 480 million people in Asia lack access to improved water resources. In Bangladesh despite being a riverine country the price of bottled mineral water has been doubled in the last 20 years. The need of an alternative and sustainable source of water has never been clearer.

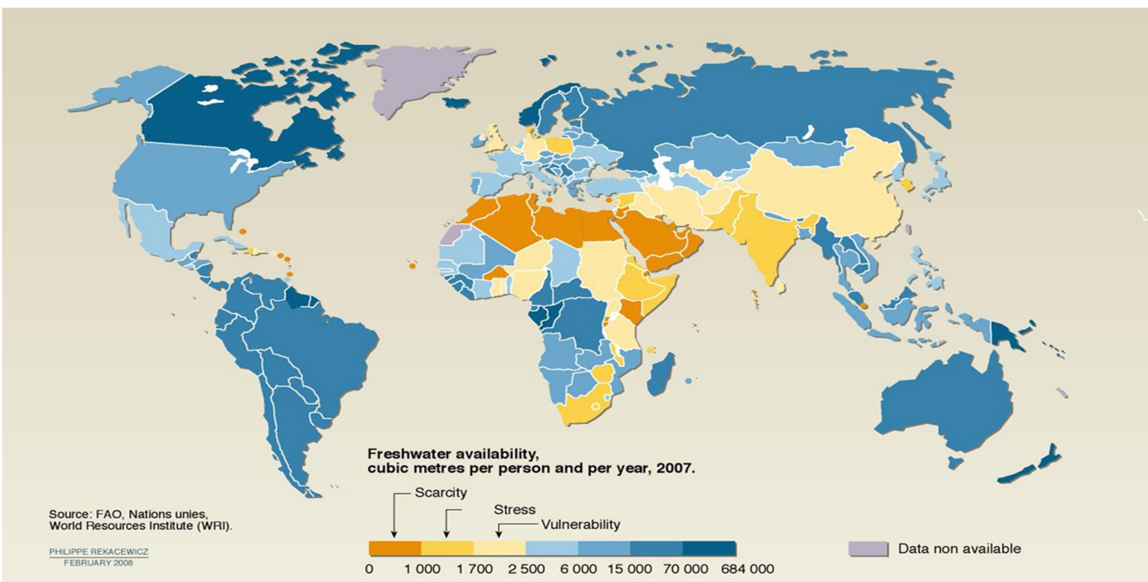
The lack of safe drinking water is the primary cause of disease in the world today. Every day, tens of thousands of people die from causes directly related to contaminated water. Many study shows that contaminated water use causes 80% of the health problems throughout the world. Much of the reason is because in rural areas of developing countries, the only water source for people to cook with and drink from is often badly polluted shallow well or contaminated surface water used by both animals and humans.

There are many water borne diseases like Dysentery, Cholera, Typhoid fever, Hepatitis, Botulism and many others. Contaminated water acts as poison to our health especially to the children and pregnant women. Impure water causes several injuries to heart and kidneys. It's also causes chronic digestive problems.

RWH can be a very effective solution against the recent scarcity of water. At least in the developing country like Bangladesh RWH can be used widely in the drinking and cooking purpose to prevent the health problems in the rural areas.

Figure no: 1.2

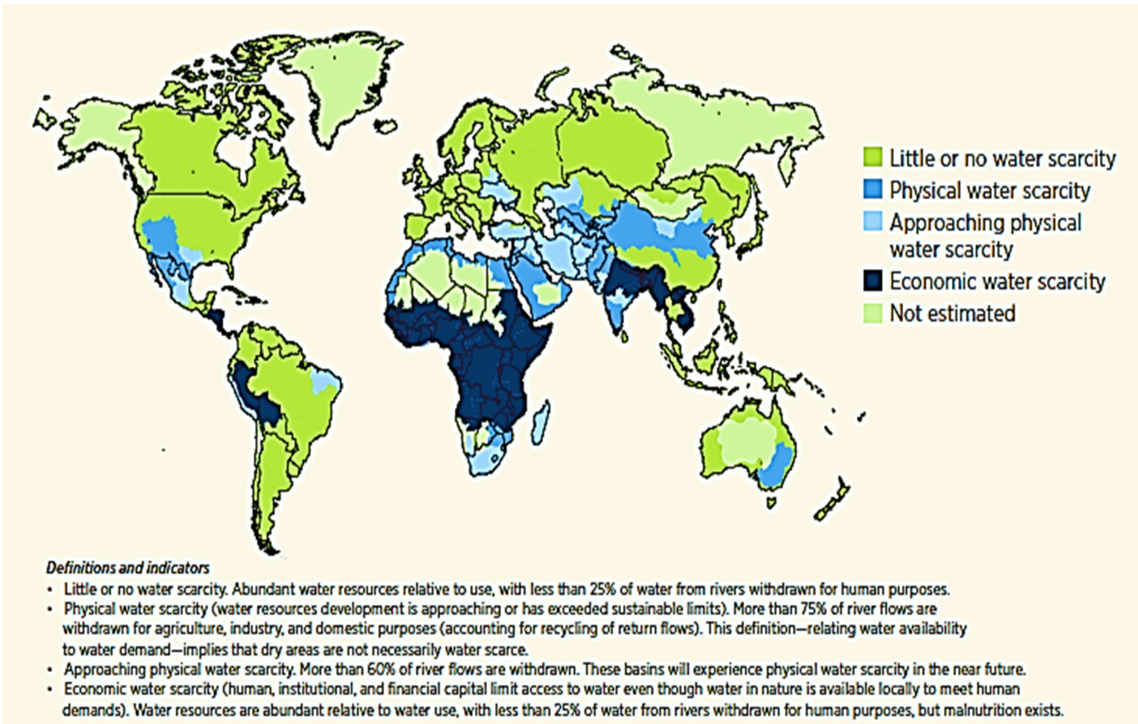
Freshwater availability (m^3 per person per year, 2007)



Source: UNEP/GRID-Arendal (2008) (http://maps.grida.no/go/graphic/global-waterstress-and-scarcity, P. Rekacewicz [cartographer]

Figure No: 1.3

Global physical and economic water scarcity



Source: (THE UNITED NATIONS WORLD WATER DEVELOPMENT REPORT 4, 2012)

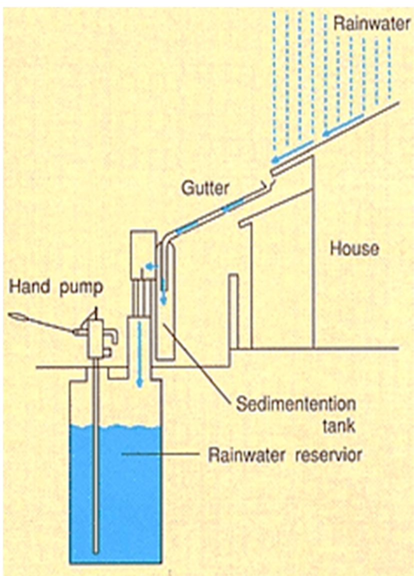
1.4 RWH WORKS CARRIED OUT GLOBALLY

With the rising of population of the world and also due to increase economic activity the demand of fresh water is increasing. Rainwater harvesting is seems to be a perfect replacement for surface and ground water as later is concerned with the rising cost as well as ecological problems. Since RWH is economical, many countries like Germany, Australia, India, Italy, Singapore, Brazil and USA have already conducted research and project works on RWH.

In Germany the biggest example of rainwater harvesting is at the Frankfurt Airport. They collect rainwater from roofs of new terminal which has a huge catchment area of about 26,800 m^2.

Currently in China and Brazil, rooftop rainwater harvesting is being practiced for providing drinking water, domestic water, water for livestock, water for small irrigation and a way to replenish ground water levels. Gansu province in China and semi-arid north east Brazil have the largest rooftop rainwater harvesting projects ongoing. In Australia rainwater harvesting is typically used as a supplement to the reticulated mains supply, and it is mandated in many building codes. In South East Queensland, households that harvested rainwater doubled each year from 2005 to 2008, reaching 40% penetration at that time. (3)

Figure No: 1.4



In Tokyo, rainwater harvesting and utilization is promoted to mitigate water shortages, control floods, and secure water for emergencies. At the community level, a simple and unique rainwater utilization facility "Rojison" has been set up by local residents in the Mukojima district of Tokyo to utilize rainwater collected from the roofs of private houses for garden watering, fire-fighting and drinking water. (4)

1.5 SCOPE OF RWH IN BANGLADESH

The Average precipitation in depth (mm per year) 2008-2012 is 2,666 mm. that is significantly higher than the most of the countries. (5)

So there is a huge scope of using rainwater harvesting to meet irrigation, industrial and household water demand. The coastal area of Bangladesh yields a very high amount of rainfall so in coastal area rainwater can be used widely to meet the household demand of the local people. The using of rainwater in place of slightly saline water in the coastal area for agricultural purpose might cause a significant amount of increase in crop production.

Many organizations are working in Bangladesh to help the rural people in rainwater harvesting. But due to lack of knowledge on people's side and sometimes installment of tanks not considering the demand and catchment area causing negative impact on the development.

1.6 OBJECTIVES

- Mass Curve Analysis of the rainfall in the study area
- Preparation of design curve according to the mass curve
- Operational Reliability Concept & It's use in preparation of design curve with 100% reliability
- Verification of results

Chapter Two

Literature review

This chapter reviews the articles and literatures that are relevant to the objective of the study i.e. "Rainwater harvesting in coastal area of Bangladesh: A relative analytic study of storage volume and Reliability of Mongla area for drinking and cooking water".

To determine the active storage capacity required to supply a given demand various methods may be used. Among them probability matrix method is noteworthy. This method is based on Moran's theory of storage and statistical method. The choice of analysis method is determined by the level of accuracy, the type of storage being assessed, and full-empty-refill-spill a year cycle or over year storage cycle.

Commonly behavior analysis is used to assess the storage-yield-reliability relationship of a rainwater tanks. Behavior analysis uses continuous simulation to track the inputs and outputs and change in storage volume according to a mass balance equation, including water inflow, evaporation, and seepage losses. The changes in storage volume of finite rainwater store during s time step t and calculated using a mass balance equation.

Spillage occurs when the storage capacity is exceeded, and yield is a function of rainwater tank inflow, demand, and storage volume. The behavior analysis approach takes into according serial correlation and flexible, enabling the use of any time interval and the simulation of variable demand patterns. In the special case of a covered rainwater tank, the incident precipitation and evaporation terms vanish.

(Fewkes, November 2000) Had done some work regarding rainwater tank model, on the basis of behavior analysis, to the use of daily and hourly rainfall input data. In a following paper, Feweks investigated how spatial and temporary fluctuation in rainfall alters the rainwater tank yield estimates given by a behavior model. A constant daily demand pattern was used to represent residential toilet flushing, along with different combinations of roof area and rain-water tank storage capacity.

Monzur Alam Imteaz, Aminul Ahsan, Jamal Naser and Ataur Rahman investigated on reliability of rain water tanks in Melbourne using daily water balance model. In this method of analysis the fewkes model of dimensionless design curves for rainwater tank size is used, Dixon's model of water saving, Coombes modeling of rain water tank and Jenkis model for continuous simulations of amount of rainwater stored in the tank, are also used.

(A. Campisano, 11-16 September 2011) In the article, DRWH system scheme was carried out by means of water balance simulations using a behavioral model based on the well-known yield-after-spillage (YAS) algorithm tank release rule. The YAS operating rule assumes the current yield as the minimum value between the volume of stored rainwater at the previous time interval and the demand in the current time interval. The current stored rainwater is then obtained adding the current rooftop rainwater runoff and subtracting the current yield to the volume of rainwater in storage at the previous time interval, with any excess (with respect to the tank storage capacity) discharged via the overflow to the sewer system.

Some researchers have devised RWH system sizing techniques using stochastic precipitation generators. The adaptability of these models to different locations is contingent upon the ability of the rainfall generation algorithms to produce statistical ensembles that match the observations of interest. For such approaches to be useful, these models must also be computationally robust, parsimonious, and relatively easy to understand. (Matt Basinger, 2010)

Table 2.1 Existing models for analyzing RWH systems

Model	**Developer**	**RWH only?**	**Functionality**
DRHM	(Dixon, 1999)	Yes	Mass balance with stochastic elements for demand profiling, simulates quantity, quality and costs
Rewaput	Vaes and Berlamont (2001)	Yes	Reservoir model, rainfall intensity-duration-frequency relationships and triangular distribution
RWIN (KOSIM)	Herrmann and Schmida (1999); ITWH (2007)	No	Hydrological-based high resolution (5 minute) rainfall runoff model
PURRS	Coombes and Kuczera (2001)	No	Probabilistic behavioral, continuous simulation, evaluates sources control strategies
RCSM	(Fewkes, 2004)	Yes	Behavioral, continuous simulation, detailed analysis of time interval variation and yield-before/after-spill
MUSIC	CRCCH (2005)	No	Continuous simulation, modeling water quality & quantity in catchments (0.01 to 100km²)
Aquacycle	Mitchell (2005)	No	Continuous water balance simulation using a yield – before-spill algorithm
RSR	Kim and Han (2006)	Yes	RWH tank sizing for storm water retention to reduce flooding, using Seoul as a case study
RainCycle	Roebuck and Ashley (2006)	Yes	Excel-based mass balance model using a yield-after-spill algorithm and whole life costing approach
HWCM	Liu et al (2006)	No	Object-based behavioral ,continuous simulation using Simulink

Source: (S. Ward*, 2008)

Chapter Three

Study Area and Data Collection

3.1 COASTAL AREA OF BANGLADESH

Coastal area is the spatial zone where the effect of sea is directly or passively present. The whole coastal area is situated in the south east of Bangladesh. The Bay of Bengal situated in the south of it.

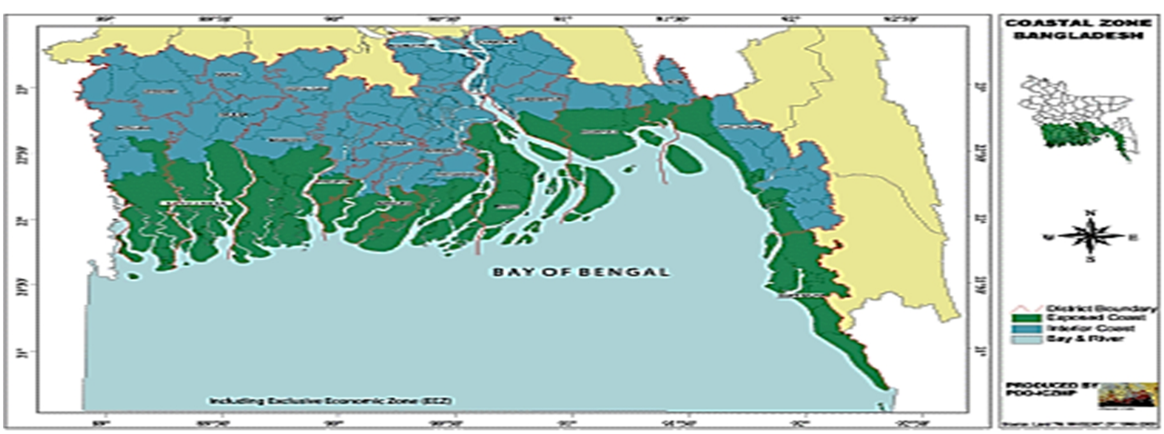
Bangladesh has a large marshy jungle coastline of 710 km on the northern littoral of the Bay of Bengal formed by a delta plain at the influence of Ganges(Padma), Brahmaputra(Jamuna) and Meghna river and their tributaries. On the south is a highly irregular deltaic coastline of about 580 km. (Geography of Bangladesh)

- Area of coastal zone: 47,201 km^2 (32% of land area of Bangladesh)
- Population in coastal zone: 35.1 million (27% of total population)
- Length of the coast: 710 km

It consists of 19 administrative districts of which 12 districts demonstrate all three vulnerabilities criteria and are defined as Exposed Coast. The remaining seven districts, where one or two of the criteria are observed, are defined as Interior Coast. The criteria are: tidal fluctuations, Salinity intrusion, and cyclone and storm surge risk. (Mohammed Fazlul Karim)

Figure: 3.1

<u>Coastal area of Bangladesh:</u>



3.2 DRINKING WATER CONDITION IN COASTAL AREA

The coastal population of Bangladesh relies heavily on rivers, tube wells (groundwater), and ponds for drinking and cooking water. Domestic ponds, which take up 10% of the total land area (excluding rice paddies), are primarily rain fed but can also, mix with saline water from rivers, soil runoff, and shallow groundwater. Approximately 20 million people living along the coast are affected by varying degrees of salinity in drinking water obtained from various natural sources. (Aneire Ehmar Khan)

The surface water in coastal area is not usable because salt water intrusion that occurs due to influence of tide. This water is not suitable for drinking, and cooking purposes. The ground water draws huge amount of saline water and due to the over exploration the water level is also decreasing at an alarming rate. Water supplied by the government is not enough for the people. The supplied water in some cases also found to be contaminated.

Typical coastal area river salinity is shown in a table below

Table 3.1

Level of salinity in the Saildaha River**:**

Date	Salinity(μS/cm)	Drinking suitability
26/4/09	1143	Not suitable
09/6/09 (morning)	3133	Very unsuitable
09/6/09 (noon)	3442	Very unsuitable

Source: (Sayma Khanom)

3.3 STUDY AREA: MONGLA

Mongla is the main seaport in the Bagerhat district. It is located at Chalna, about 18 km upstream of Pasur River. It is 48 km south of Khulna city.

Mongla upazilla area is 1461.22 km^2

Co-ordinates: $22^0$29’ N $89^0$36.5’ E

Source: (Mongla Upazilla)

Figure: 3.2

<u>BAGERHAT DISTRICT:</u>

3.4 DATA SELECTION (CATCHMENT AREA, DRINKING AND COOKING WATER DEMAND)

In the rural areas of Bangladesh, the water requirement has been estimated as follows:

Table: 3.2

Typical Water Demand for household use:

Bathing	14-20 lpcd
Washing utensils	6-8 lpcd
Drinking	2-3 lpcd
Cooking foods	3-5 lpcd
Washing clothes	8-10 lpcd
Others	9-14 lpcd

Source: (M.Feroze Ahmed, june,2000)

For our analysis, we have assumed a value of: (2+4) = 6 lpcd

Roofing size in Bangladesh

There is no data available on the roof size of Bangladesh. But a limited field survey was carried out by Ferdausi (1999) in Chuadanga. Only the metal sheet roofs were considered in the study. Since the study area is also in rural area where most of the roofs are metal sheet and since both are in coastal zone so the data is considered.

Table: 3.3

$<20\ m^2$	$20\text{-}40\ m^2$	$40\text{-}60\ m^2$	$60\text{-}80\ m^2$	$>100\ m^2$
6	5	10	4	3

Source: (Shakil A. Ferdausi, 2000)

Most number of houses has roofing area of 10-40 $m^{2.}$ So for the purpose of this study roofing area of 10-100 m^2 has been selected to develop the design curves and the reliability of the system.

Total water demand

In the rural area most of the family comprised of 4-5 people but we have calculated a total daily drinking and cooking water demand of 12-64 lpd in our design curves.

3.5 RAINFALL IN MONGLA AREA:

There are 33 rain gauge stations throughout Bangladesh. Very few of them are situated in the coastal areas. Mongla station started record the rainfall data from 1991. In this case only last available 10 years data from 1998-2007 has been taken.

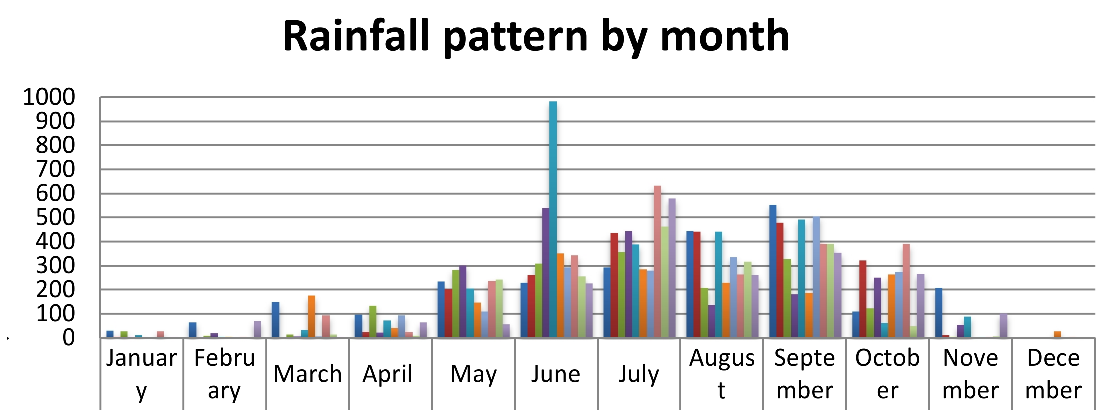
Table: 3.4

10 years rainfall in Mongla area (1998-2007)

Years	Total Rainfall	Frequency	Remarks
1998	2410	134	Highest frequency rainfall
1999	2179	126	
2000	1799	124	
2001	1954	128	
2002	2786	124	Wet year
2003	1708	131	Dry year with high frequency
2004	1903	119	
2005	2407	112	Year with low frequency but high Rainfall
2006	1745	112	Year with low frequency with low Rainfall
2007	1986	113	

Figure: 3.3

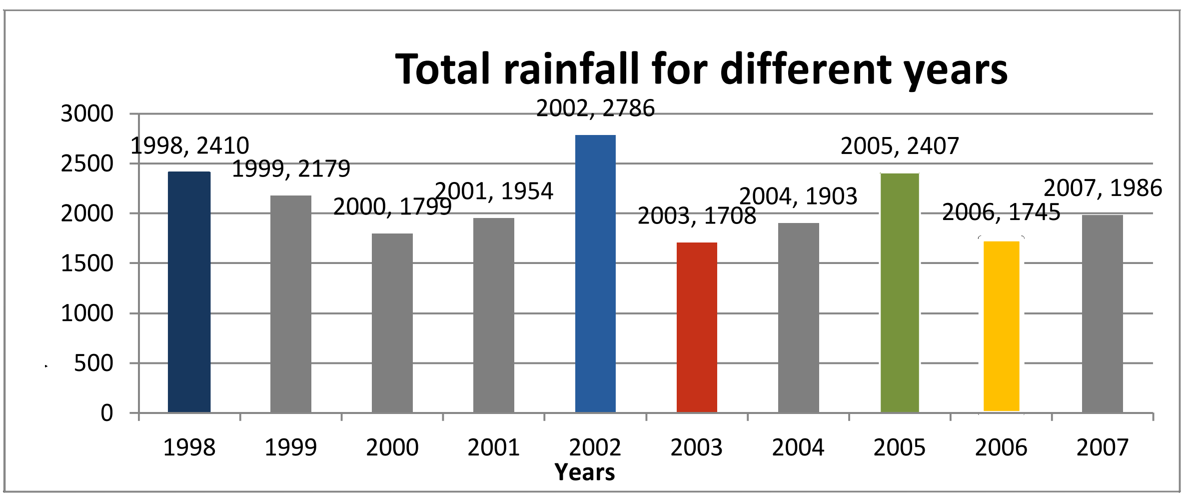
Rainfall pattern by month



	Januar y	Febru ary	March	April	May	June	July	Augus t	Septe mber	Octob er	Nove mber	Dece mber
1998	29	65	149	97	234	229	294	443	553	110	207	0
1999	1	0	0	25	202	262	435	442	479	321	12	0
2000	28	9	15	134	283	309	356	209	327	124	5	0
2001	1	19	6	22	301	539	445	136	181	251	53	0
2002	13	5	32	74	206	983	389	441	492	62	89	0
2003	0	2	175	41	147	351	284	229	188	263	0	28
2004	0	0	7	95	109	293	280	336	506	274	3	0
2005	28	1	93	25	238	342	633	264	391	390	1	1
2006	0	0	14	9	243	255	462	318	390	48	6	0
2007	2	71	1	64	57	226	580	262	355	267	101	0

Figure: 3.4

Total Rainfall pattern for different years



Chapter Four

Methodology

4.1 THEORIES

i. **Available Inflow Storage volume:** is only total inflow volume in a specific day for the rainfall depth of that day over a definite catchment area. The formula for the inflow volume calculation is-

$$Q_{in} = C * I * A$$

Here, C = Runoff Co-efficient.

I = Rainfall intensity in (mm).

A = Catchment Area, in m^3

Q_{in} = Available inflow storage Volume.

ii. **Daily Water storage volume:** It is the actual volume of water that is stored in the storage tank after fulfilling the daily demand.

If, $Q_{in} - Q_{use} > 0$

Then, $Q_{storage} = Q_{in} - Q_{use}$

iii. **Volume of spilled water:** It is the excess amount of water that is spilled out from the tank due to the lack of volume.

If, $Q_{storage} > V_{tank}$

Then, $Q_{spilled} = Q_{storage} - V_{tank}$

iv. **Reliability:** Reliability is the ability of the tank to supply intended demand. It is measured in percentage of no of days in a year the tank was able to meet the demand.

$$\textbf{Reliability, } R_e = (P/N) * 100\%$$

Here,

P = N-U

N = no. of days in a year.

U = no. of days the tank was unable to meet the demand.

v. **Average year rainfall:** It is the designed year that is comprised of arithmetic average of daily rainfall for 'n' number of year.

$$I_{avg} = I_1 + I_2 + I_3 \ldots\ldots + I_N / N$$

4.2 WATER BALANCE MODEL DEVELOPMENT

For the purpose of reliability analysis of the system a daily water balance model was developed. The variables were catchment area, demand and tank volume. The main equation used here is,

$V = Q_{in} - Q_{use} + V_{t-1} - Q_{spill}$

Here,

V = Storage Volume of Tank.

Q_{in} = Input rainwater volume.

= Catchment area x Rainfall depth

= $m^2 x m = m^3$ (Input volume is in m^3)

Q_{use} =Volume of Water usage demand.

=Daily water use (m^3)

V_{t-1} = Storage volume from previous day (m^3)

Q_{spill}= Volume of spilled water (m^3)

Chapter Five

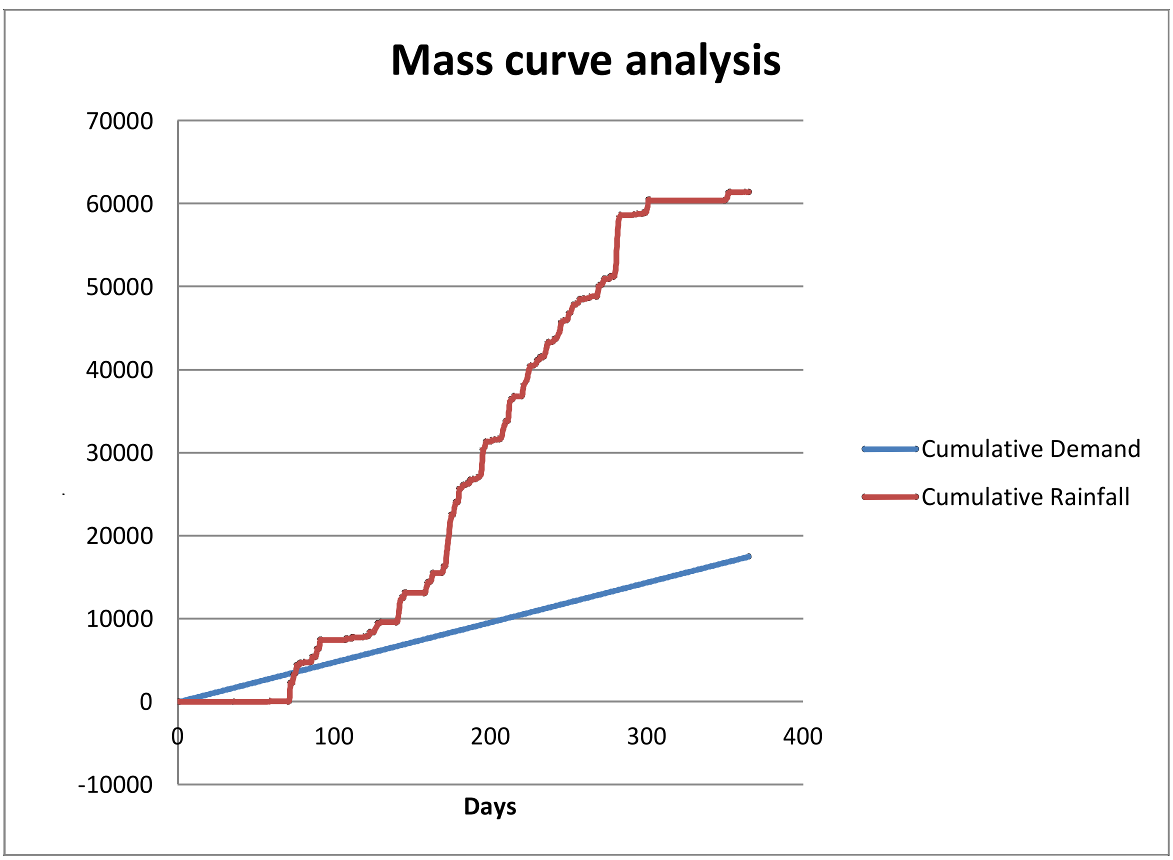
Analysis of mass curve

5.1 GENERAL

A "mass curve" is a plot of the cumulative flow volumes as function of time. It is used to determine the critical period of a reservoir showing the relationship between withdraw and addition to the reservoir. The mass curve analysis gives us two important volumes, (a) the negative volume that is the shortage between demand and supply, (b) the positive excess supply volume, which is the maximum amount of rainwater we can harvest for a definite catchment area and demand. In many cases, the volume (a) is taken as the storage volume for RWH. In our work, we used a daily basis model with a period of one year.

Figure: 5.1

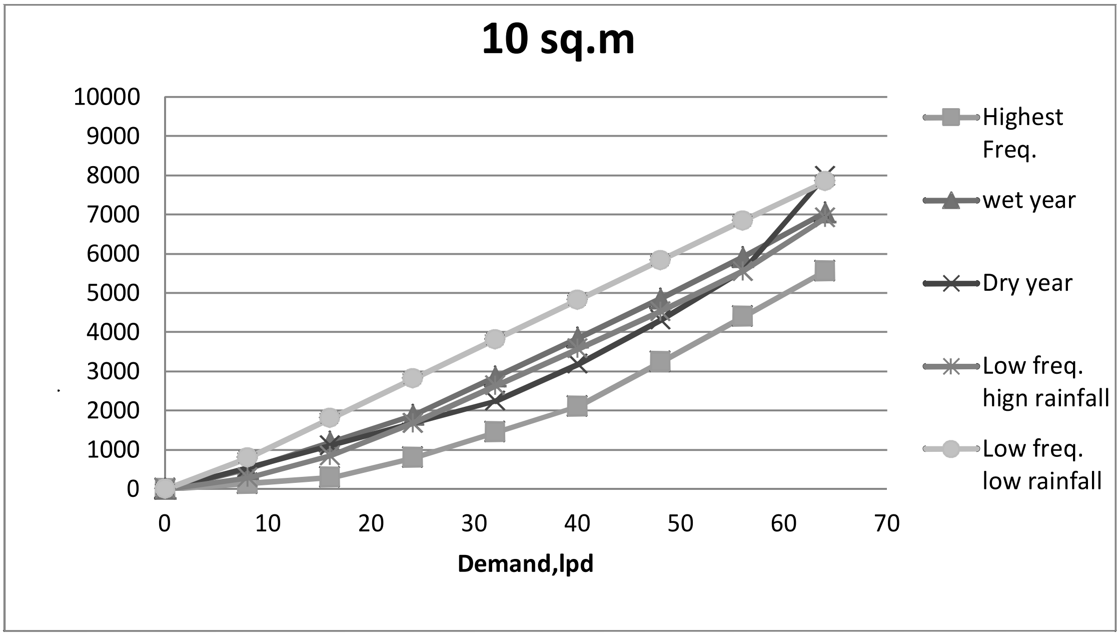
Typical Mass Curve:

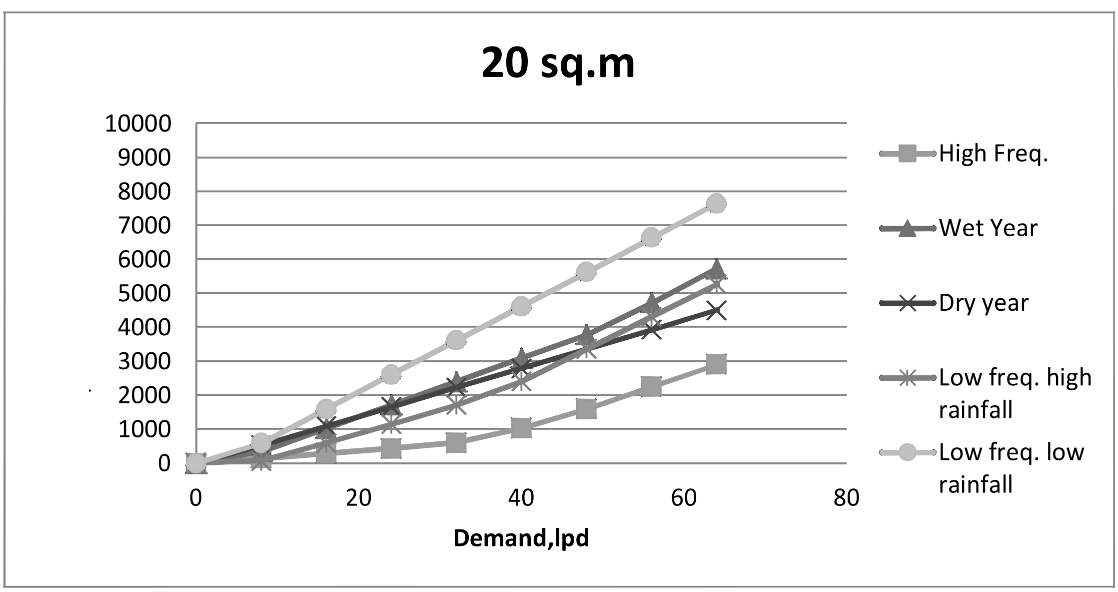


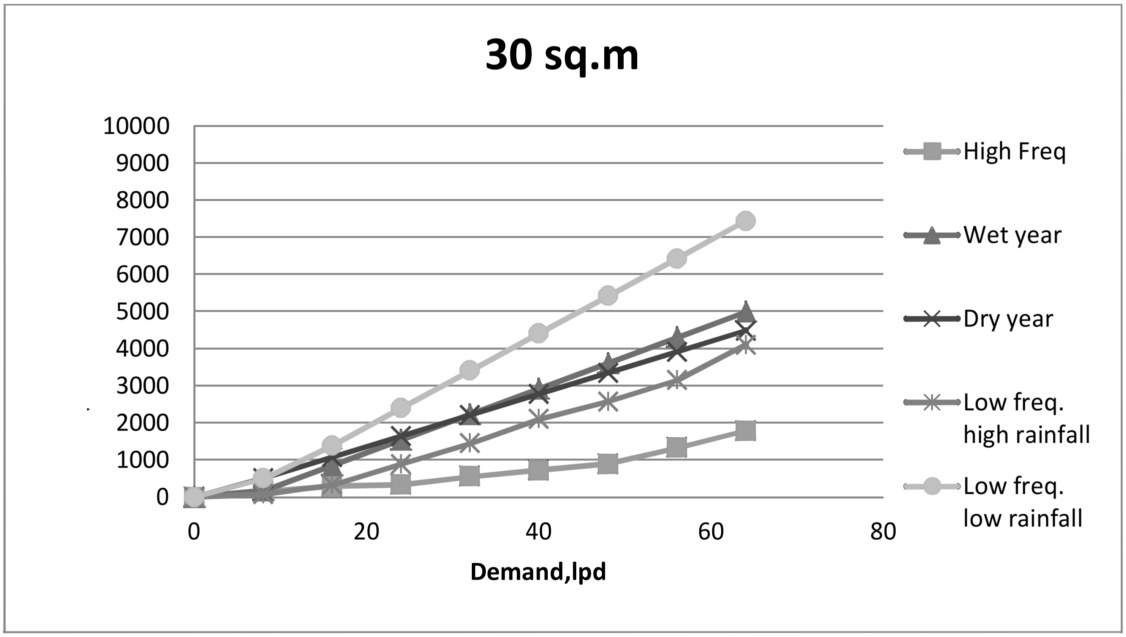
5.2 DESIGN CURVE BASED ON MASS CURVE ANALYSIS:

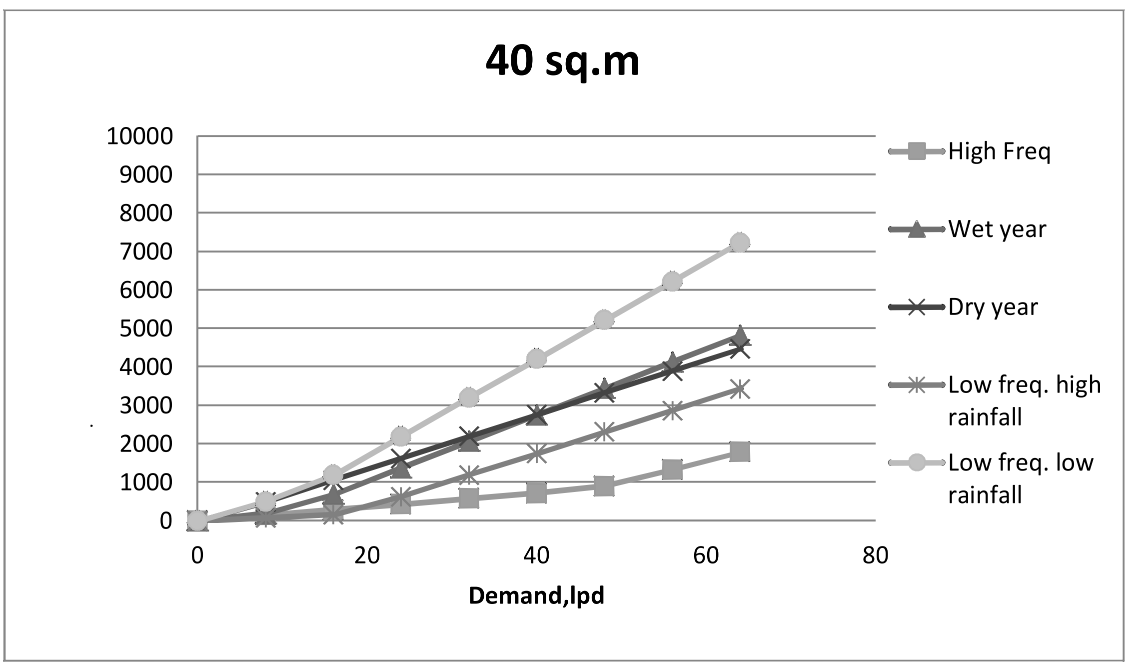
Design curve is a curve representing the Storage volume Vs. Demand for a definite catchment area. From a design curve, people can choose their tank volume according to their respected demand.

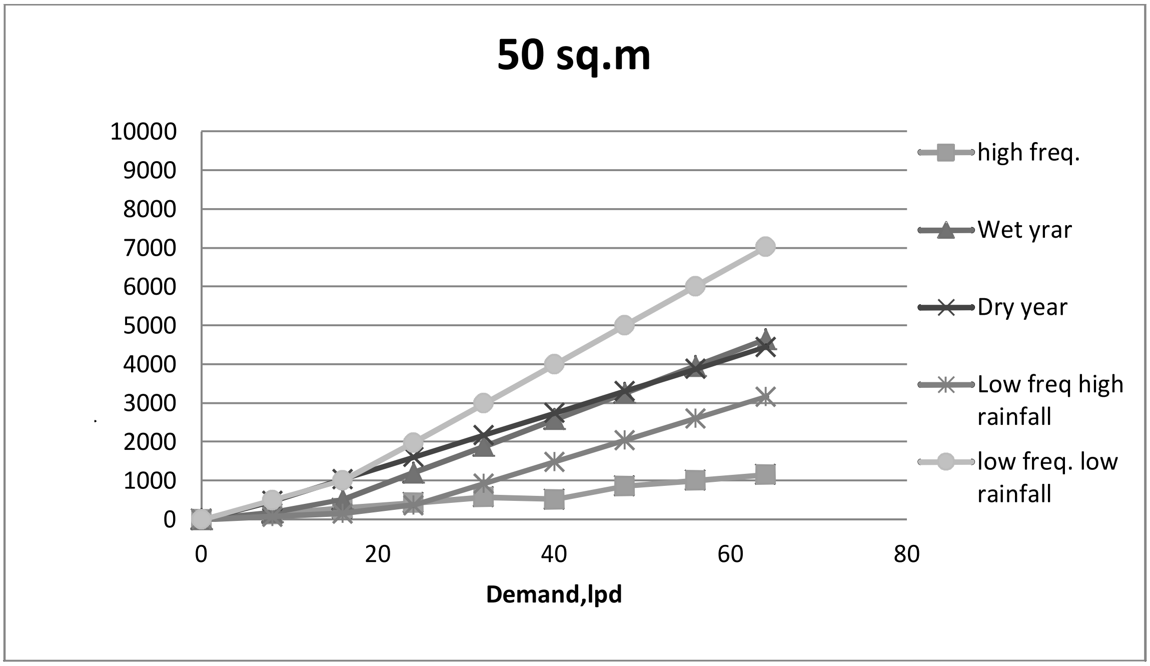
Figure: 5.2-5.11






30 sq.m
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
20
40
60
80
Demand,lpd
High Freq
Wet year
Dry year
Low freq. high rainfall
Low freq. low rainfall


40 sq.m
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
20
40
60
80
Demand,lpd
High Freq
Wet year
Dry year
Low freq. high rainfall
Low freq. low rainfall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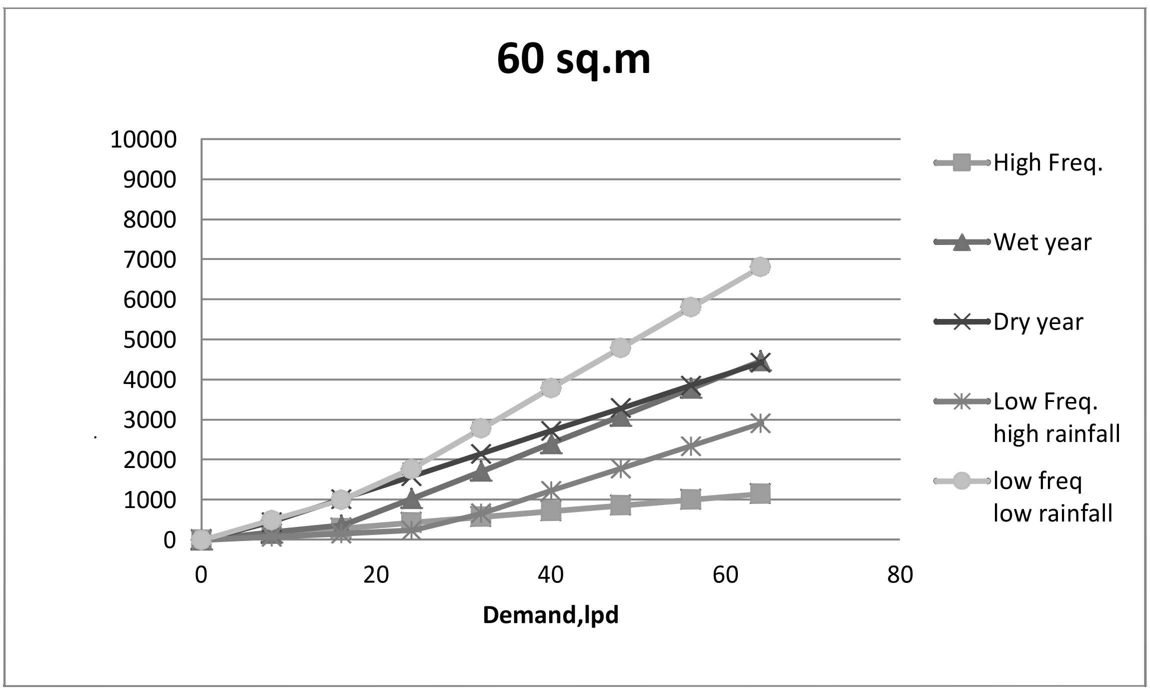
Demand,lpd
high freq.
Wet yrar
Dry year
Low freq high rainfall
low freq. low rainfall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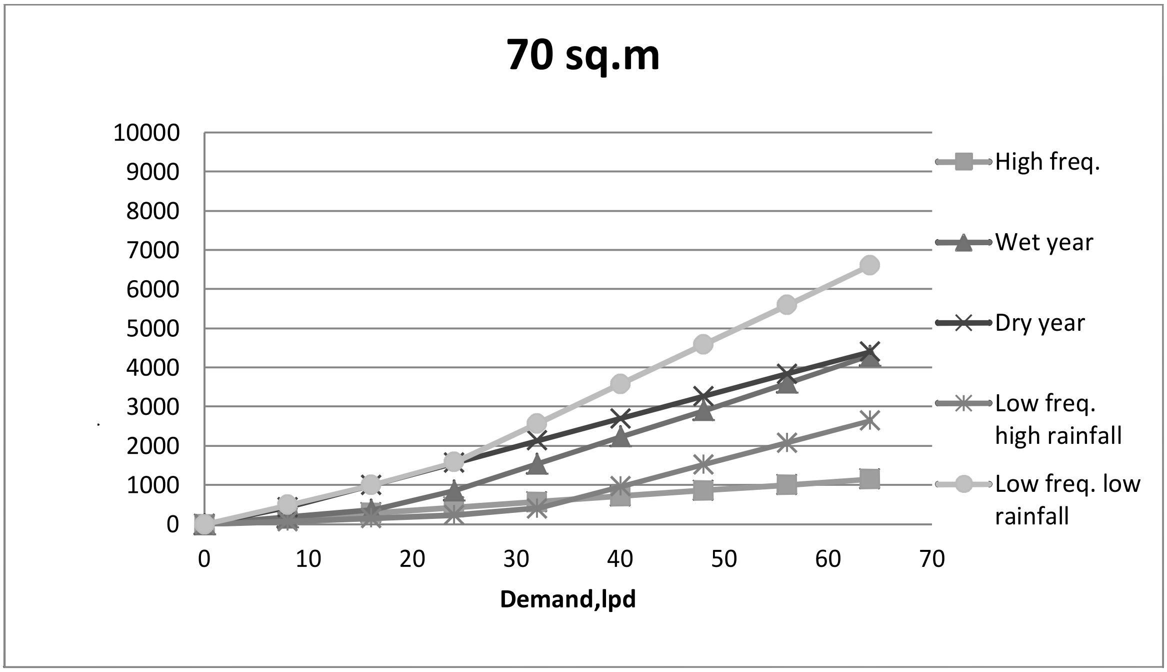
Demand,lpd
High Freq.
Wet year
Dry year
Low Freq. high rainfall
low freq low rainfall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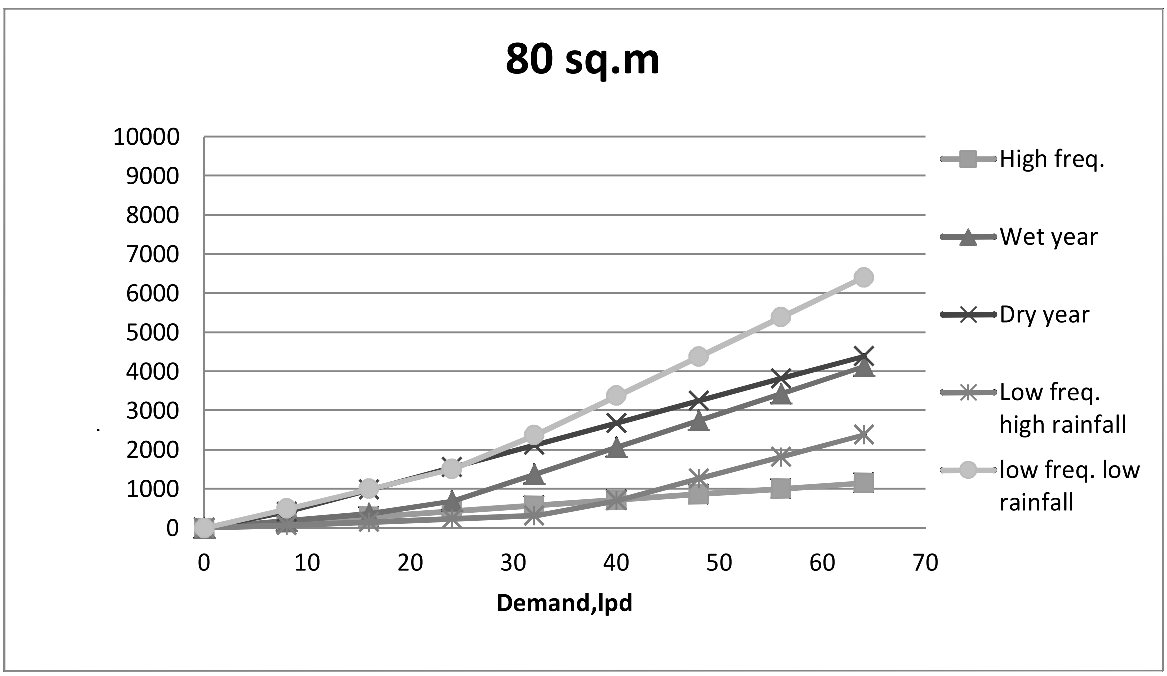
Demand,lpd
High freq.
Wet year
Dry year
Low freq. high rainfall
Low freq. low rainfall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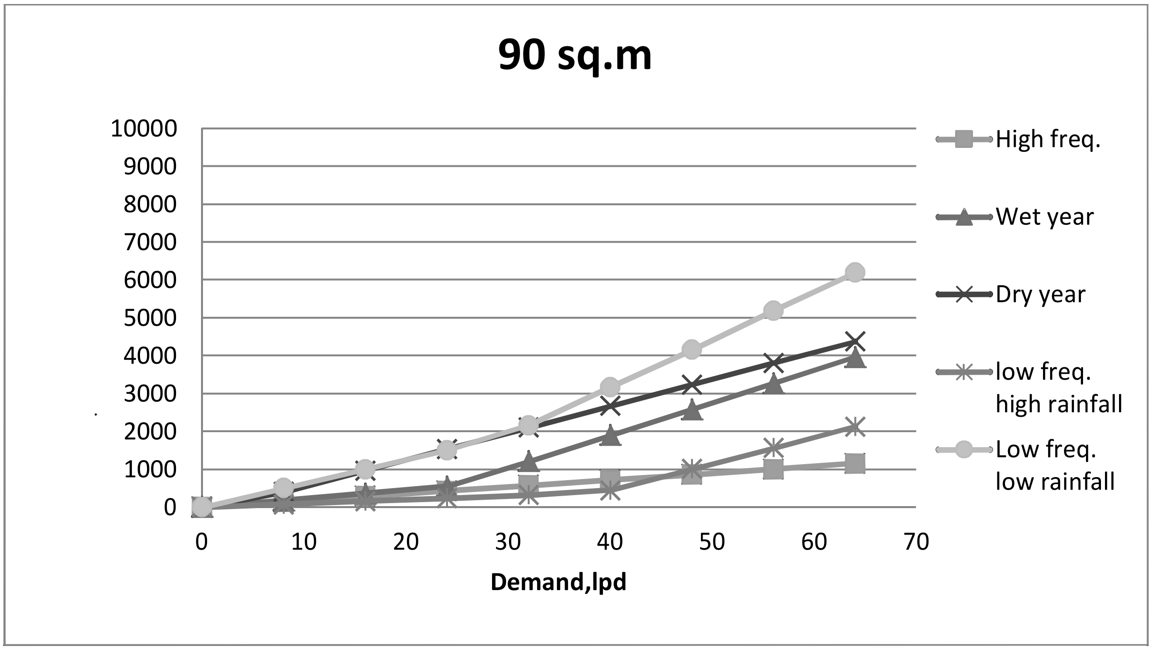
Demand,lpd
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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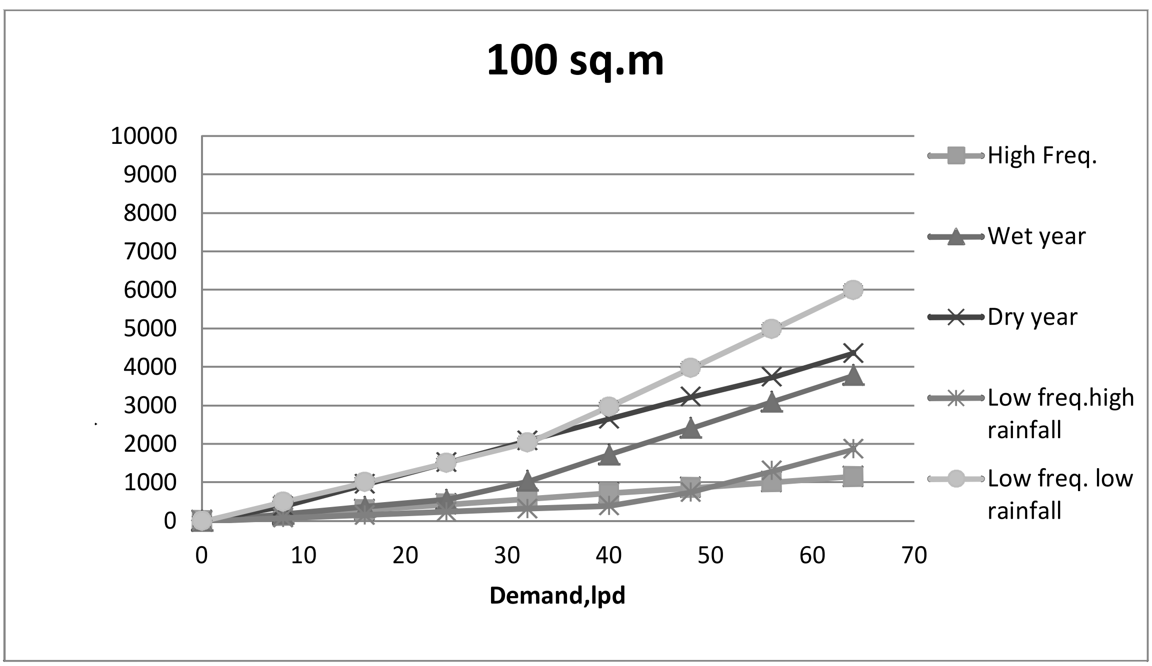
Demand,lpd
High freq.
Wet year
Dry year
low freq. high rainfall
Low freq. low rainfall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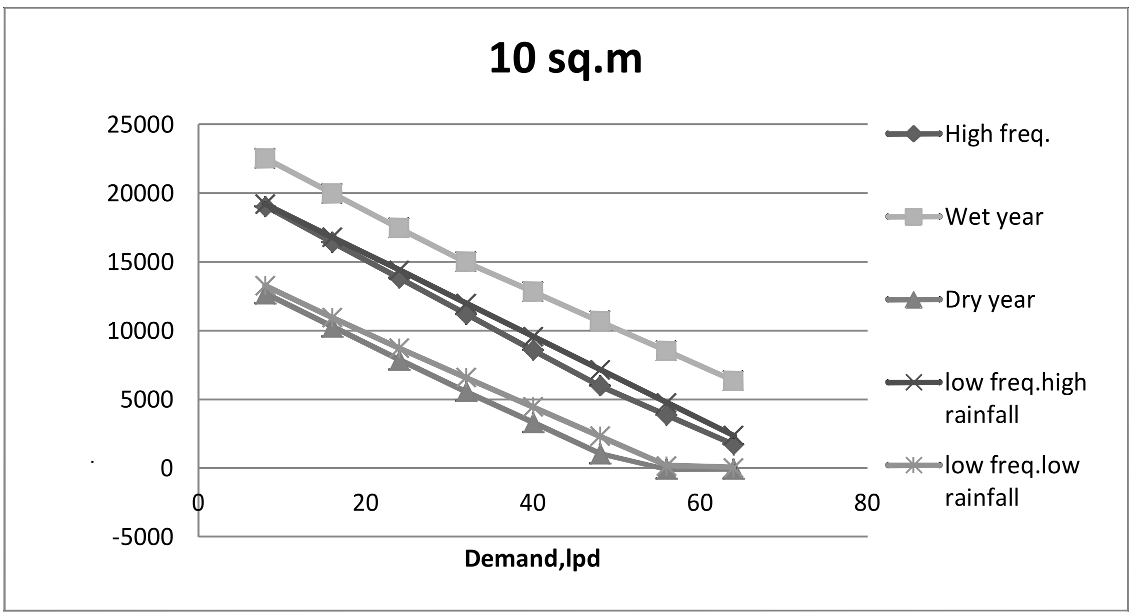
60
70
Demand,lpd
High Freq.
Wet year
Dry year
Low freq.high rainfall
Low freq. low rainfall

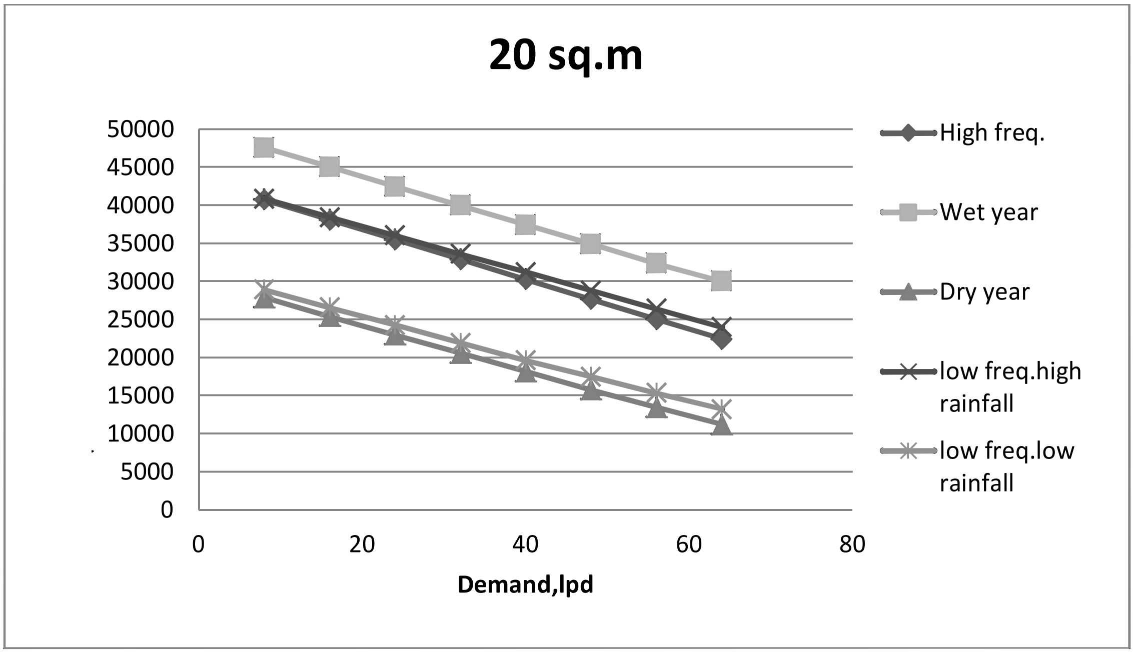
5.3 RELATION BETWEEN MAXIMUM STORAGE POTENTIAL AND DEMANDS:

These graphs represent the highest storage potential that can be achieved for different demand in a definite catchment area. It shows that highest storage potential can be attained in the wet year whereas lowest storage potential found in the dry year. For a particular rainfall in a definite catchment area if the volume achieved from design curve for a particular demand is higher than the Max storage potential found in the similar condition then the RWH system will never achieve 100% reliability regardless of tank size.

Figure: 5.12-5.21

Graphs Max storage potential against Demands:

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15000
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40
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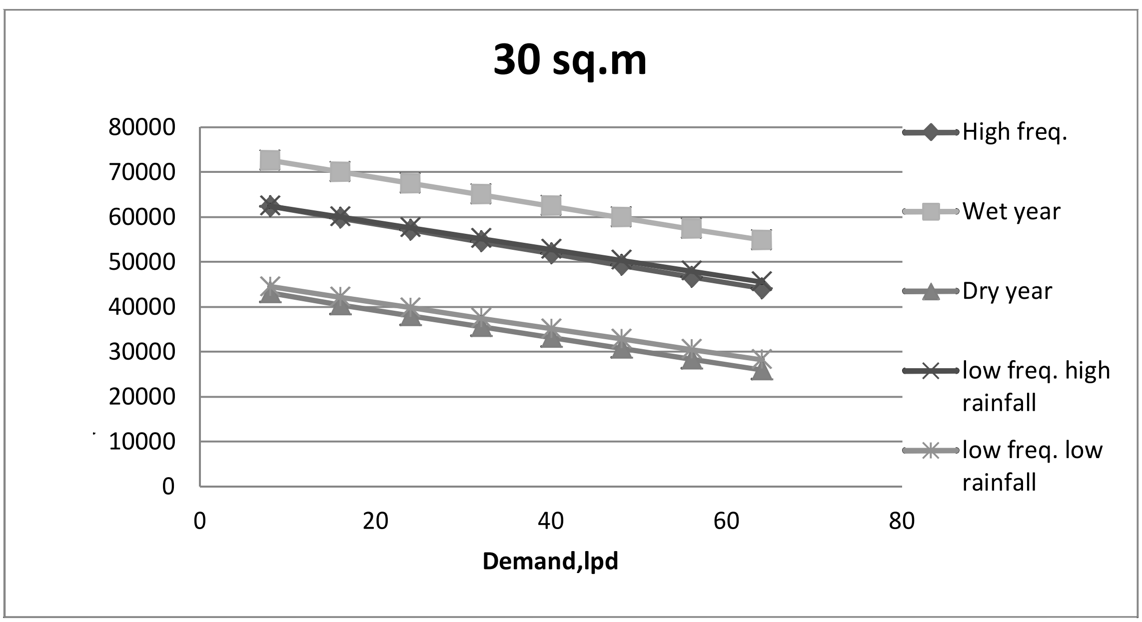
Demand,lpd
High freq.
Wet year
Dry year
low freq.high rainfall
low freq.low rainfall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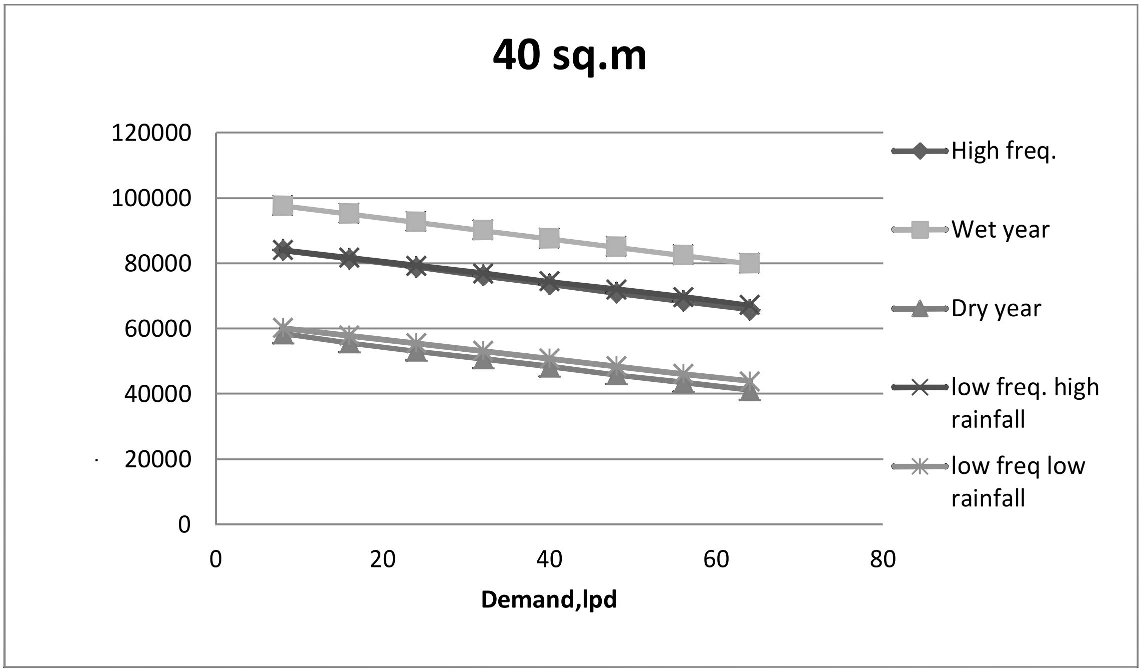
Demand,lpd
High freq.
Wet year
Dry year
low freq. high rainfall
low freq. low rainfall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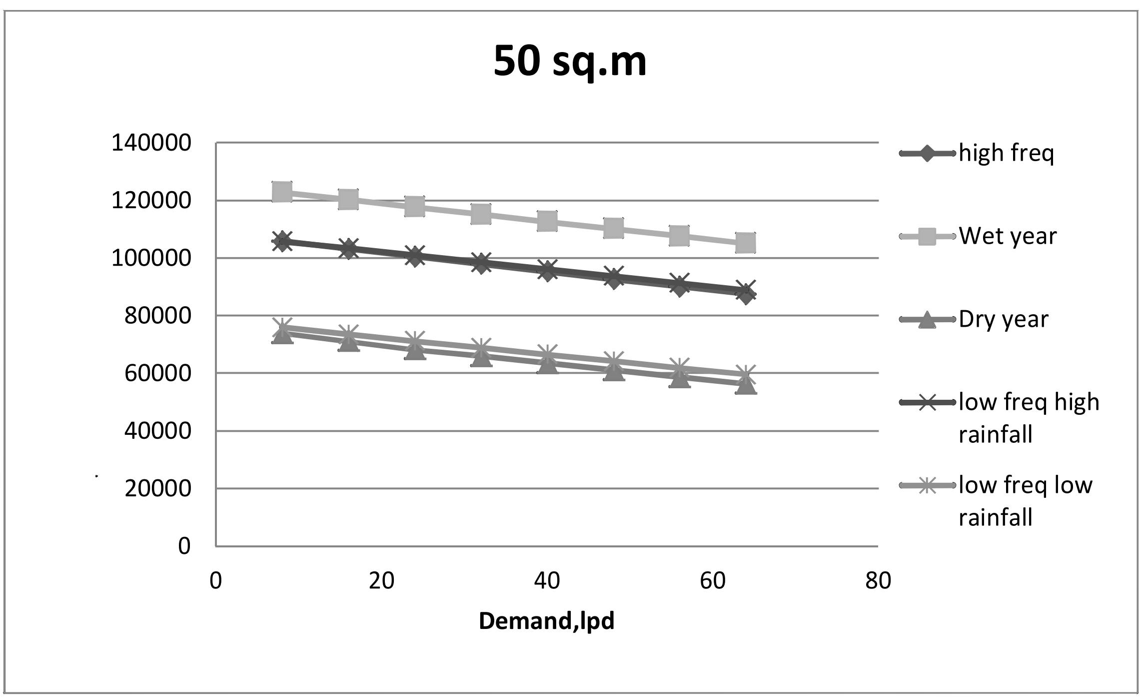
Demand,lpd
High freq.
Wet year
Dry year
low freq. high rainfall
low freq low rainfall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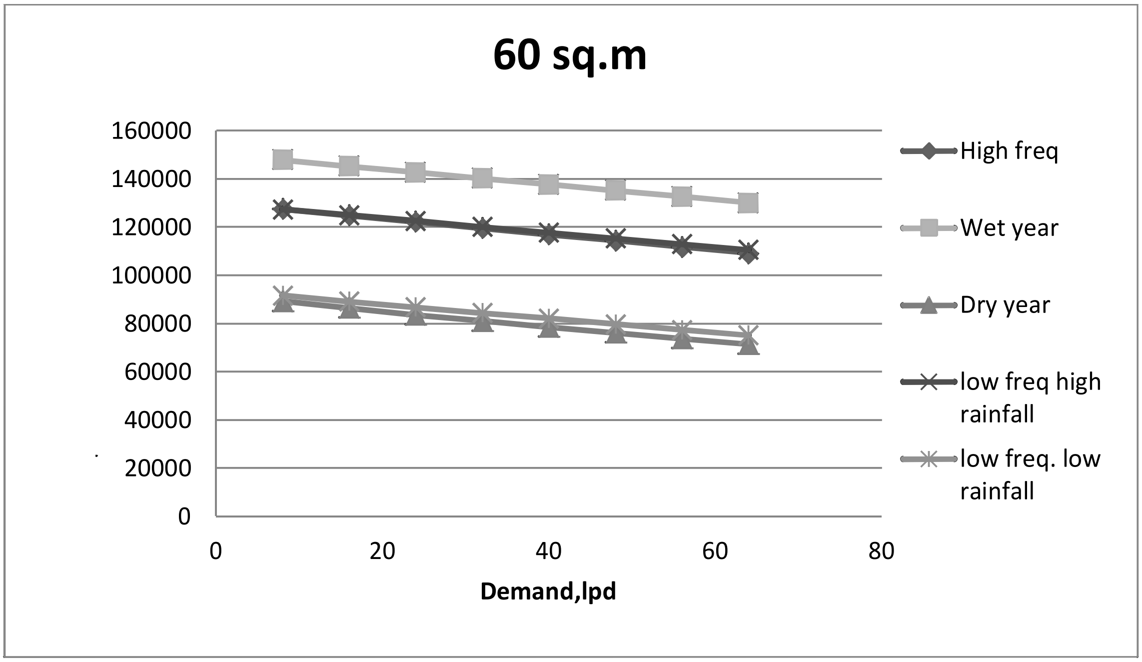
Demand,lpd
high freq
Wet year
Dry year
low freq high rainfall
low freq low rainfall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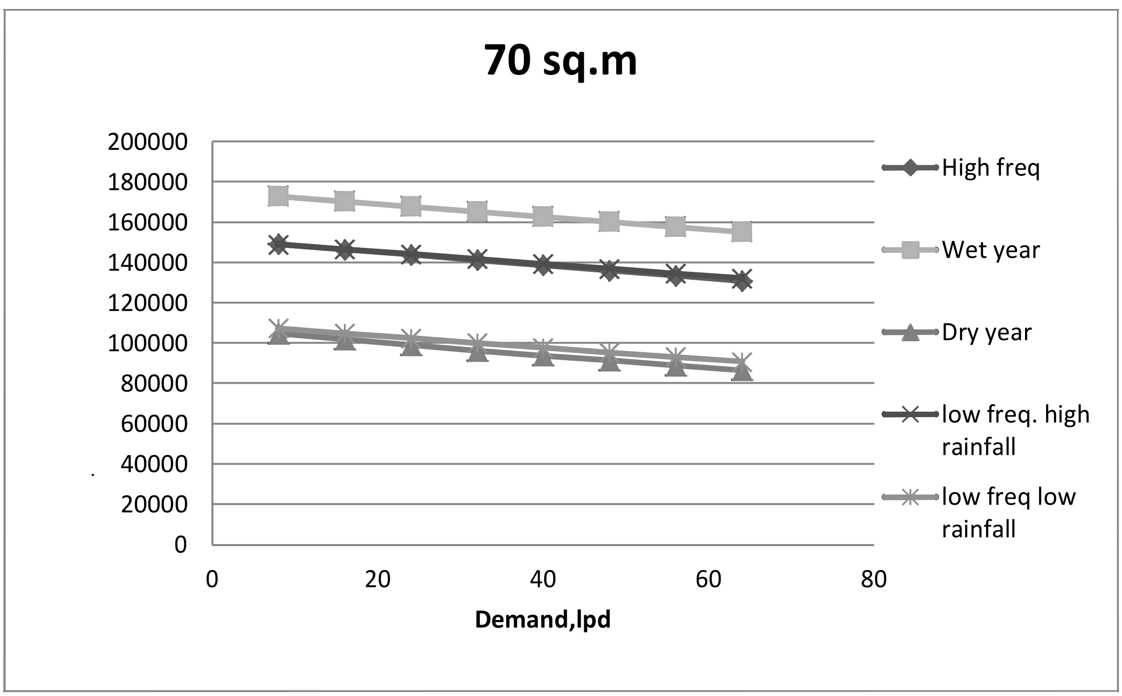
Demand,lpd
High freq
Wet year
Dry year
low freq high rainfall
low freq. low rainfall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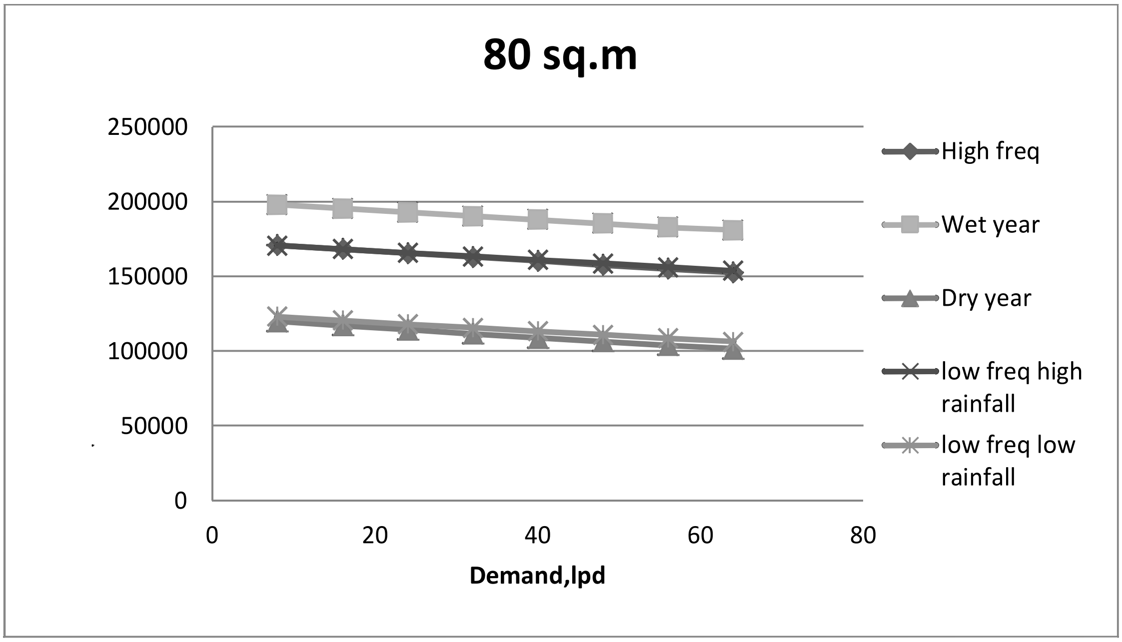
Demand,lpd
High freq
Wet year
Dry year
low freq. high rainfall
low freq low rainfall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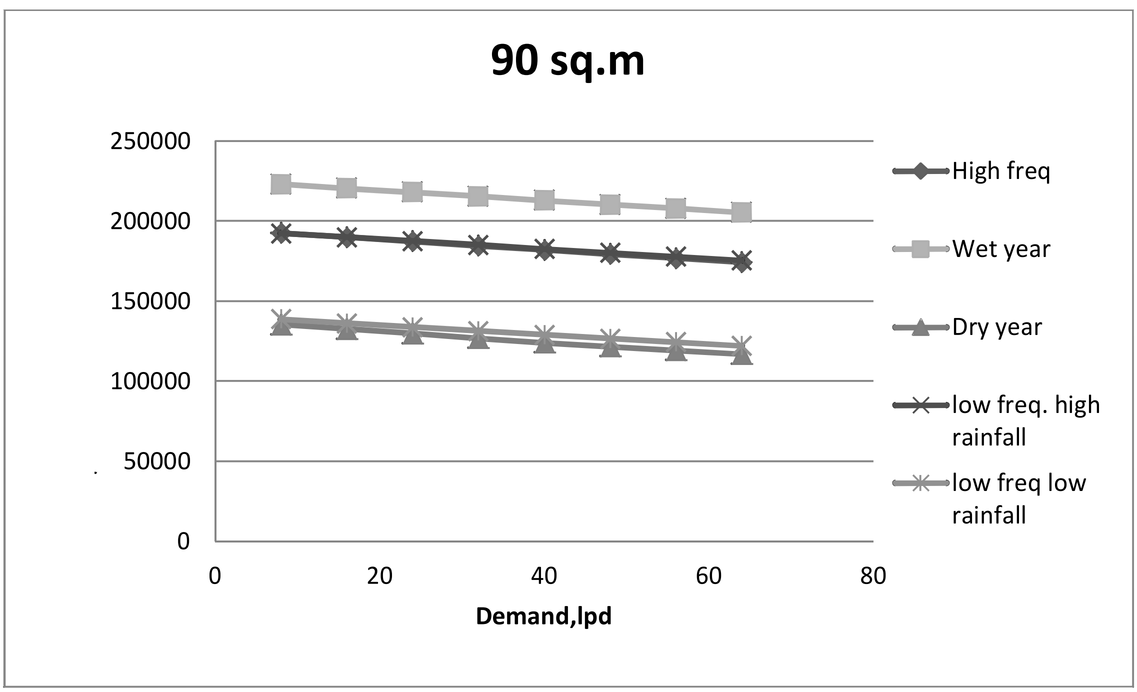
Demand,lpd
High freq
Wet year
Dry year
low freq high rainfall
low freq low rainfall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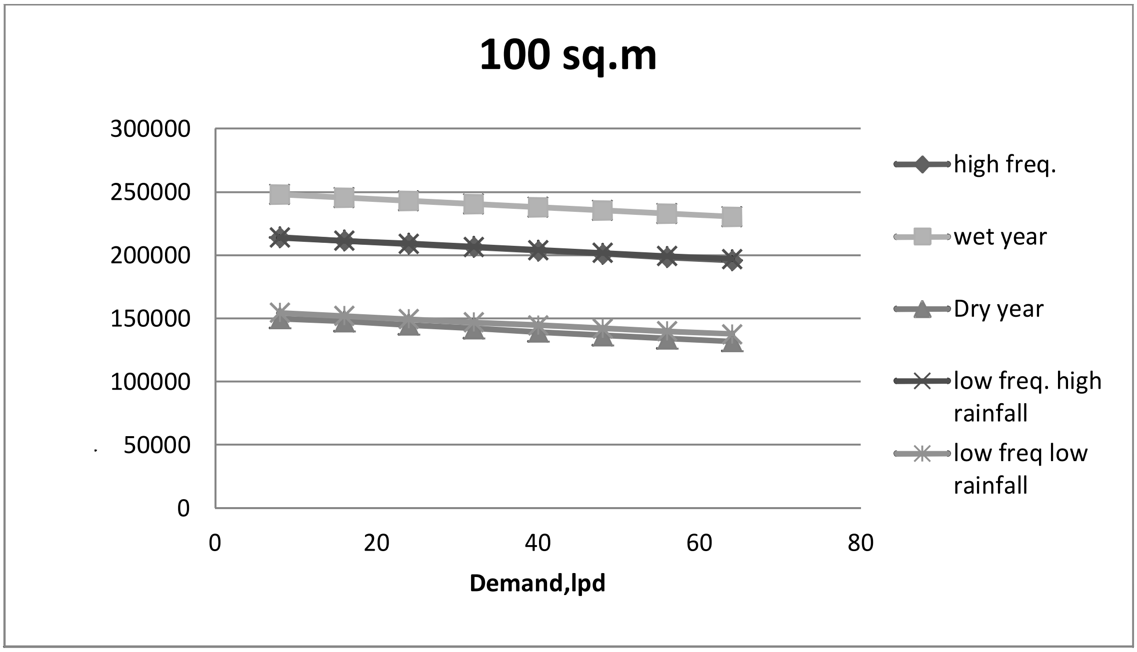
Demand,lpd
High freq
Wet year
Dry year
low freq. high rainfall
low freq low rainfall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Demand,lpd
high freq.
wet year
Dry year
low freq. high rainfall
low freq low rainfall

Chapter Six

Analysis of Reliability

6.1 GENERAL

Reliability is the ability of the tank to supply intended demand. Reliability of rwh system can be defined as time-based reliability or a volume based reliability. The volume-based reliability is also termed as efficiency. Normally in the sensitive operation of Rainwater harvesting system like supply of drinking water, time based reliability is used. Since a daily basis model is used in this study so it is measured in percentage of no of days in a year, the tank was able to meet the demand.

Reliability, Re= (P/N) * 100%

Here,

P = N-U

N = no. of days in a year.

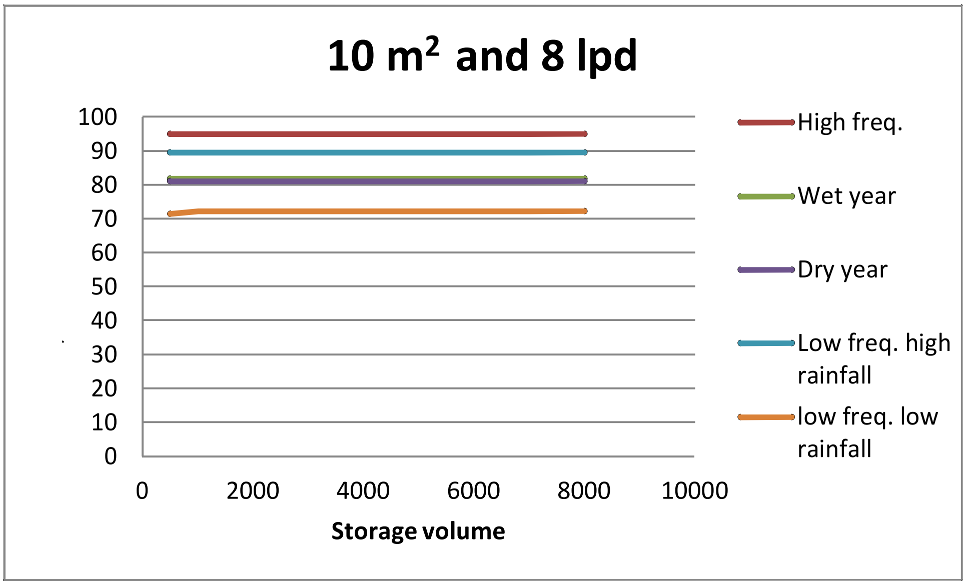
U = no. of days the tank was unable to meet the demand.

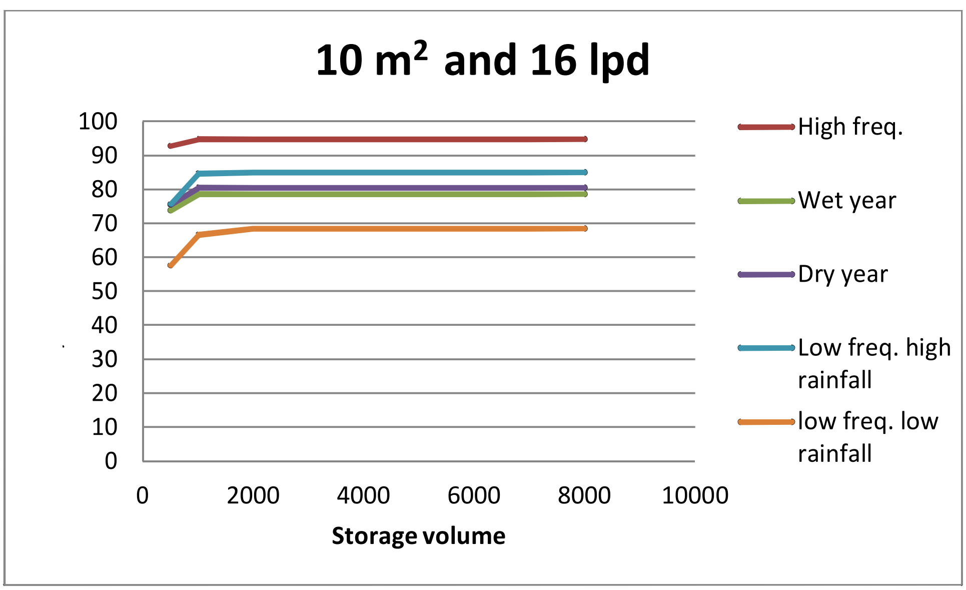
In this study, we have selected the five significant years with a varied range of demand and catchment area. The available tank size in Bangladesh is varying from 500-8000 liter. The storage volume analysis of these tanks in respect to its reliability can be seen from the following graphs.

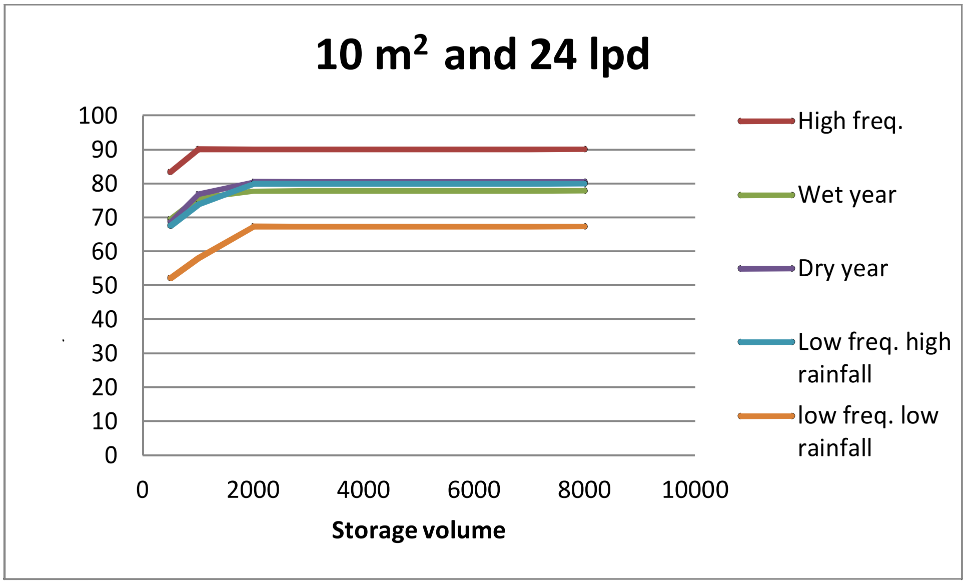
6.2 RESULTS AND DISCUSSION:

Figures: 6.1-6.80

Graph representing the relation between catchment area, daily demand, storage volume and reliability for different rainfall pattern:



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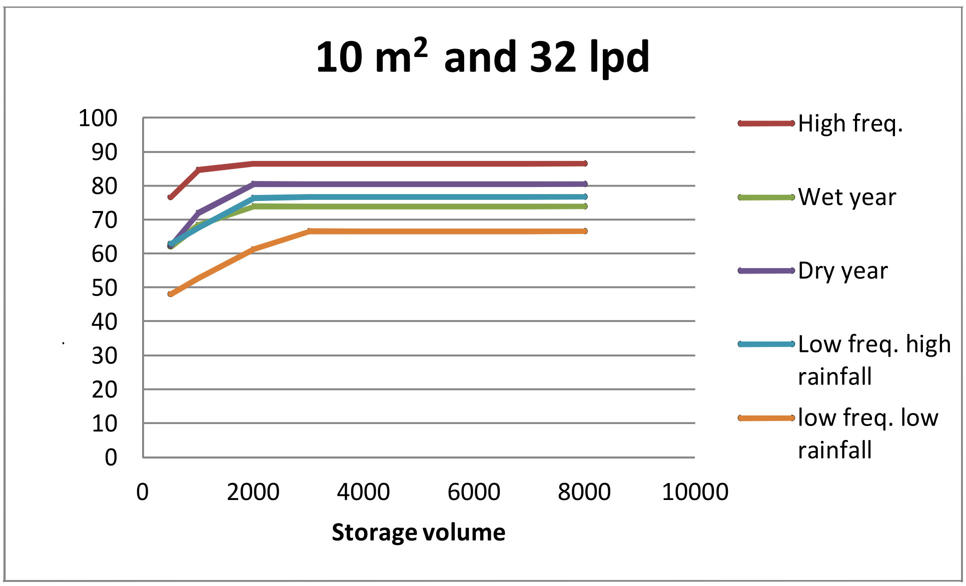
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall


10 m² and 32 lpd
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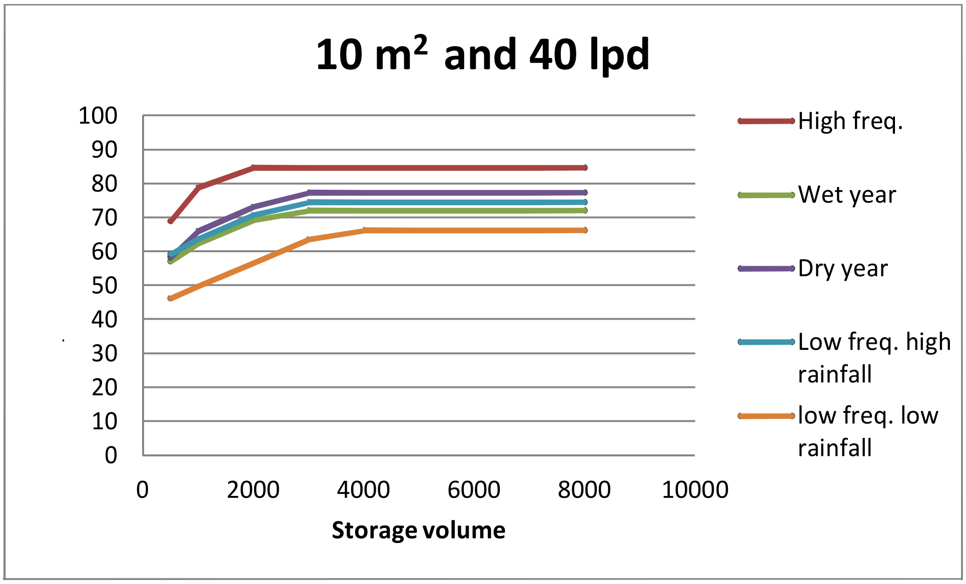
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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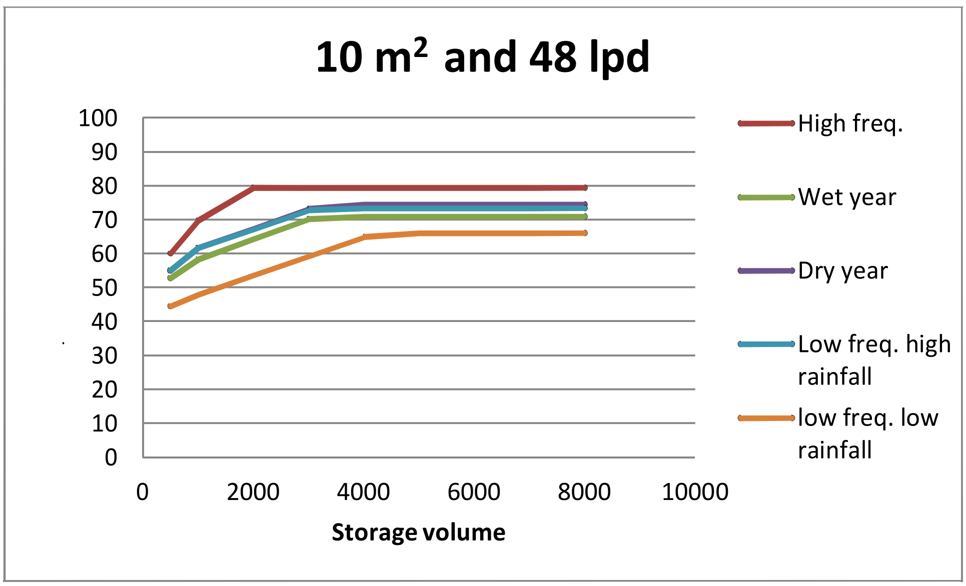
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall


10 m² and 48 lpd
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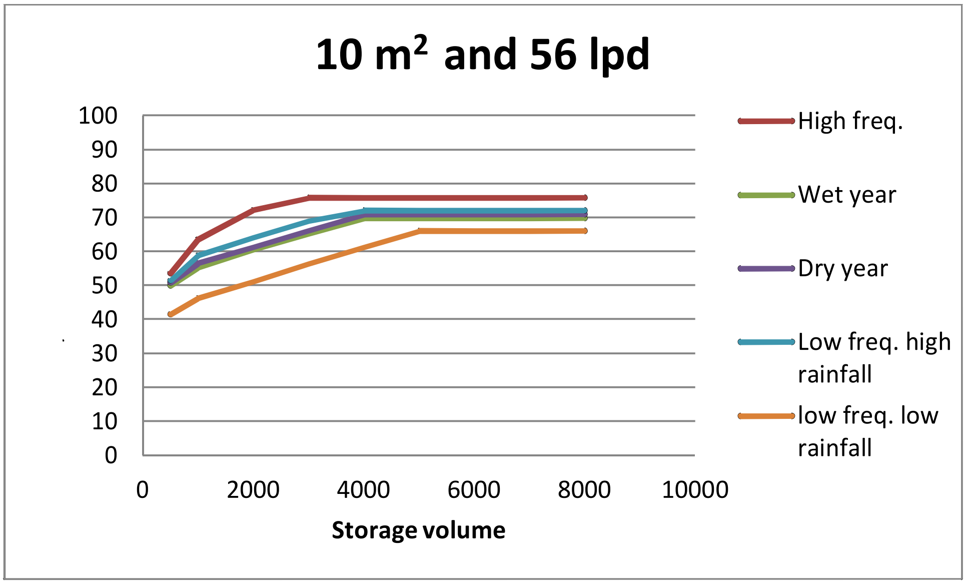
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall


10 m² and 56 lpd
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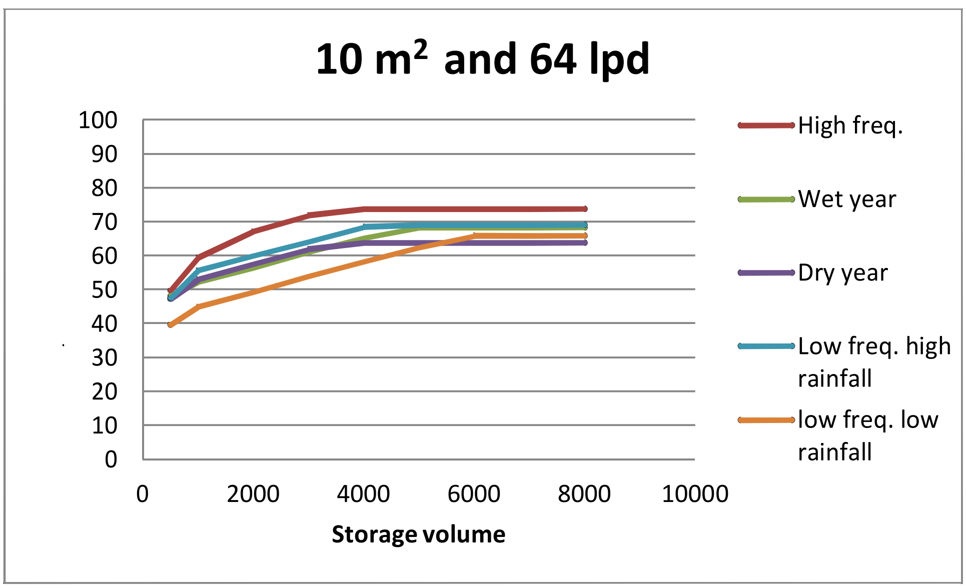
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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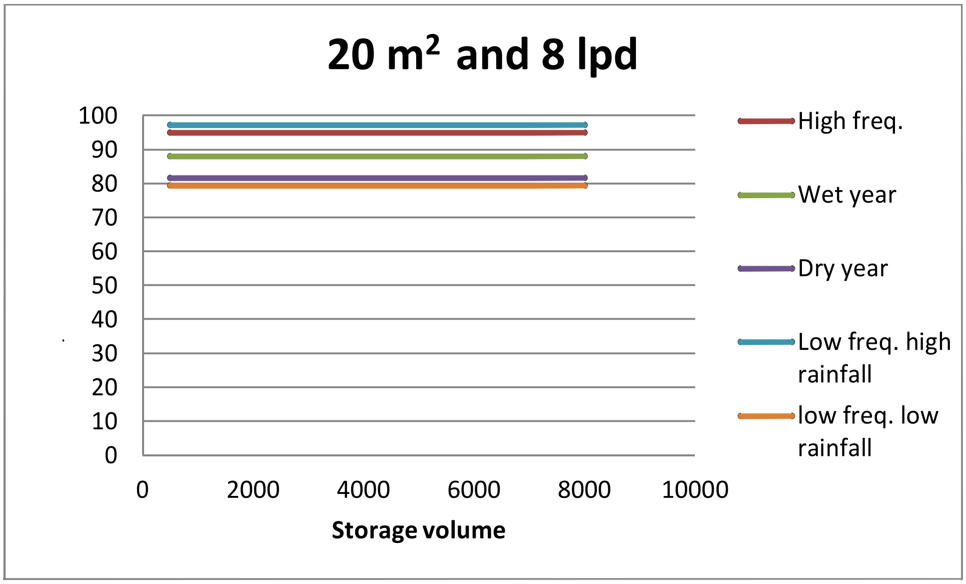
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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Storage volume
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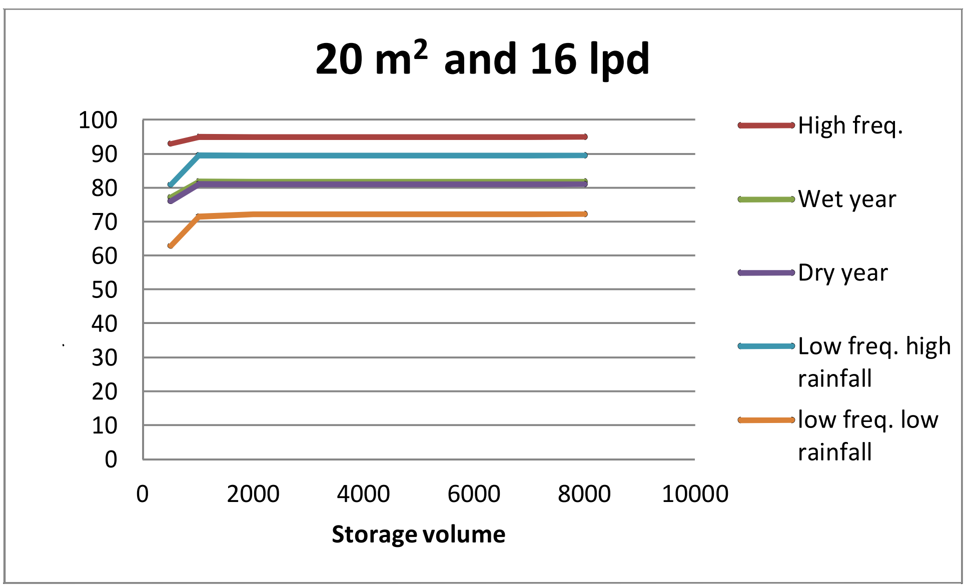
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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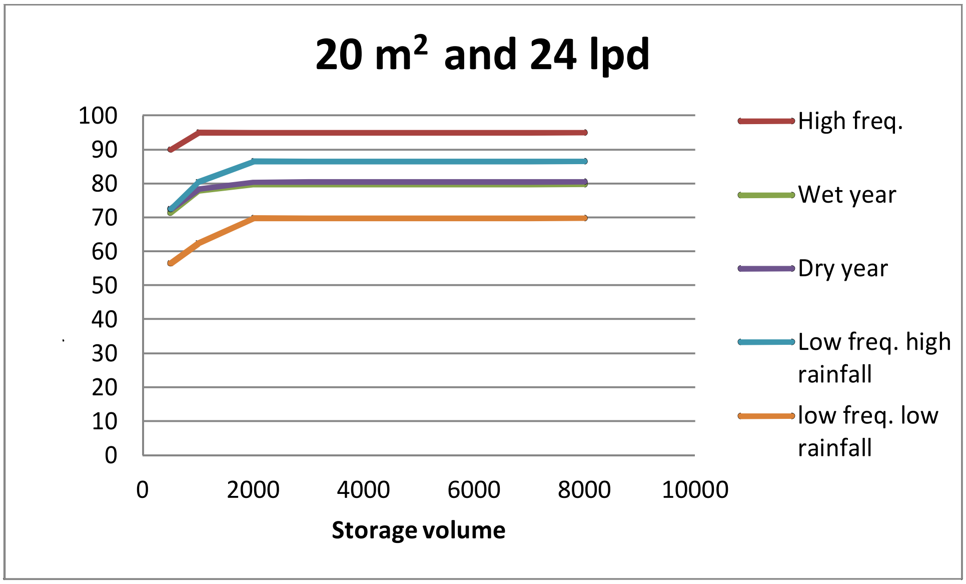
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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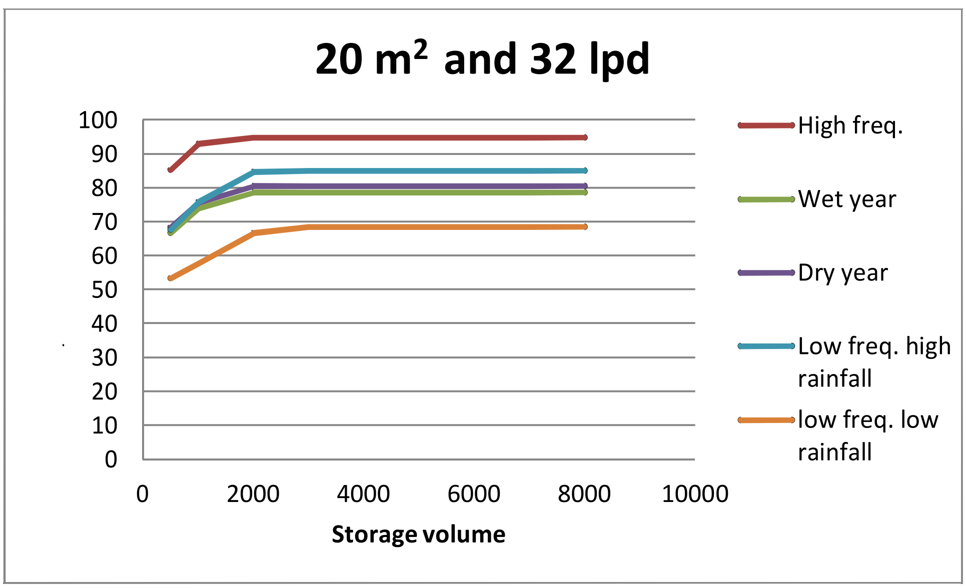
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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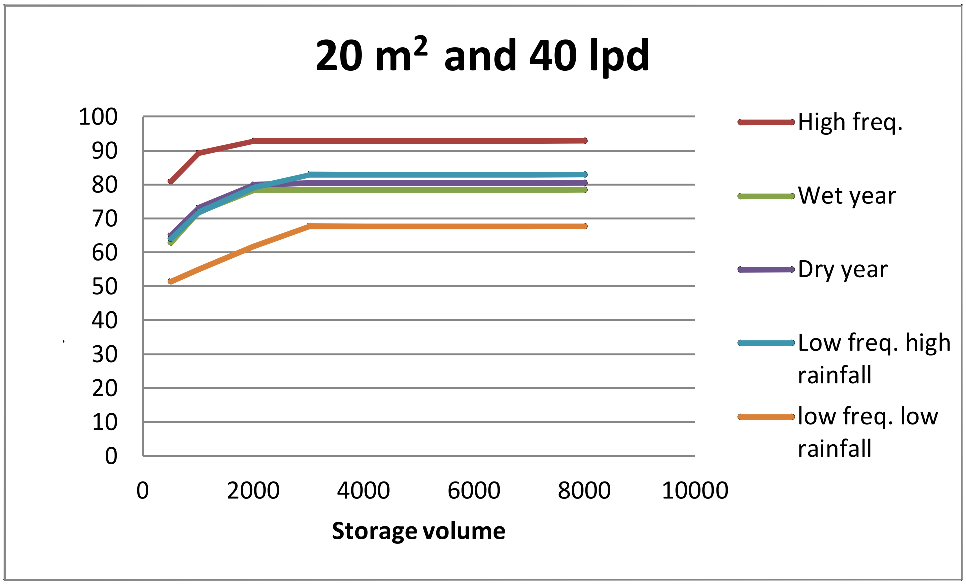
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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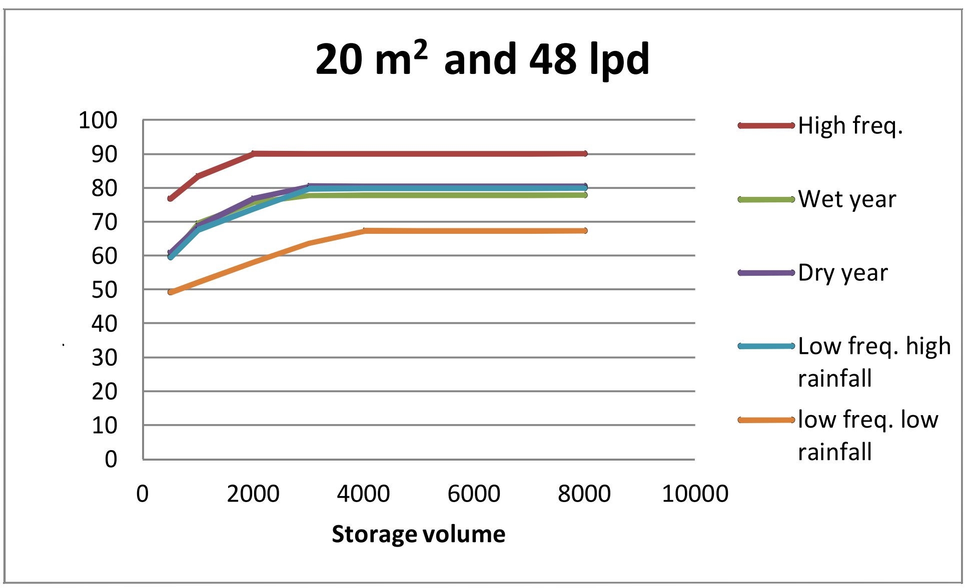
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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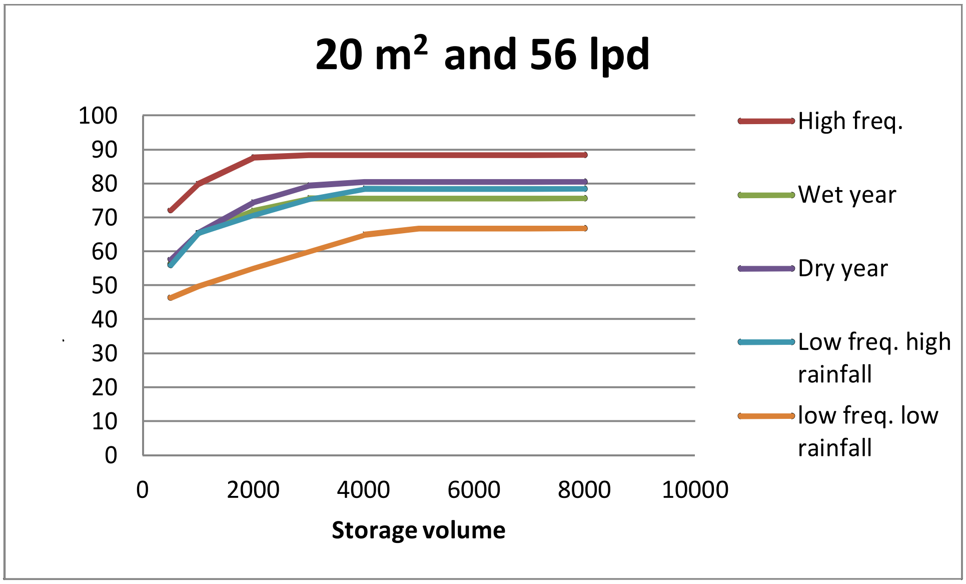
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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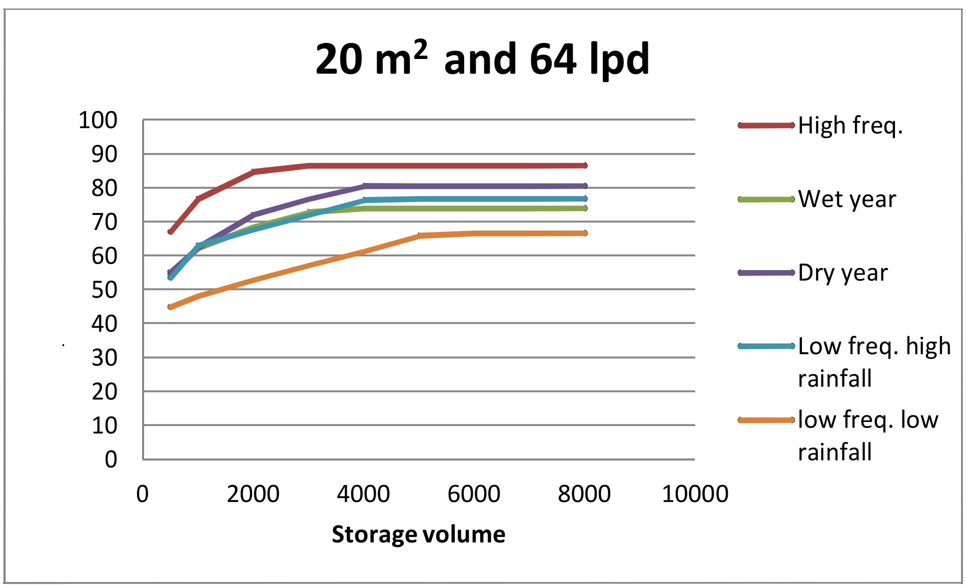
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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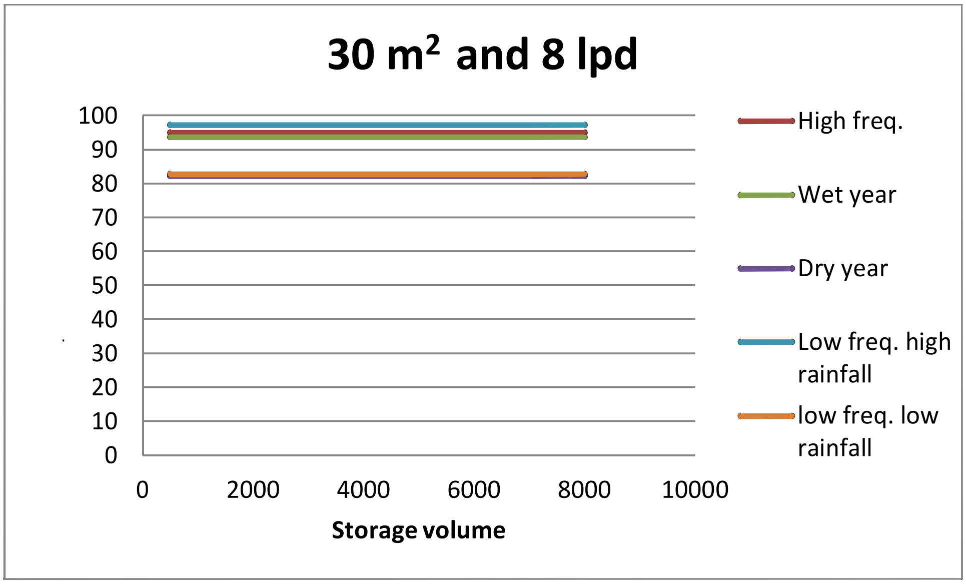
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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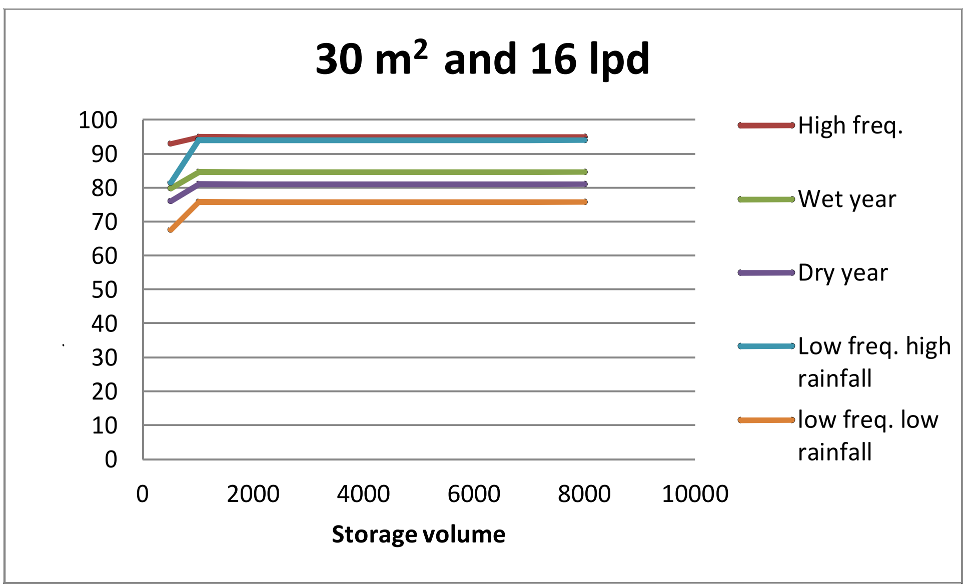
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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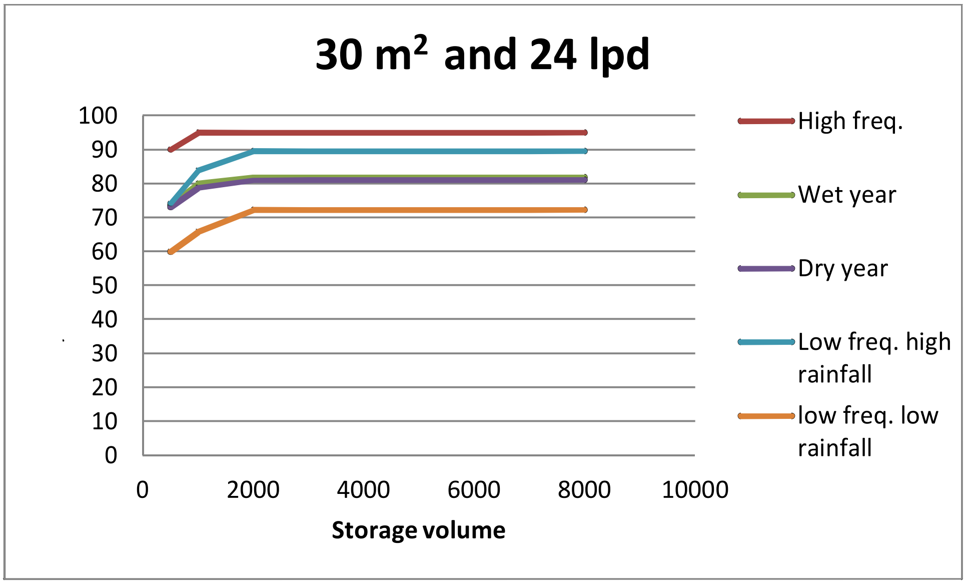
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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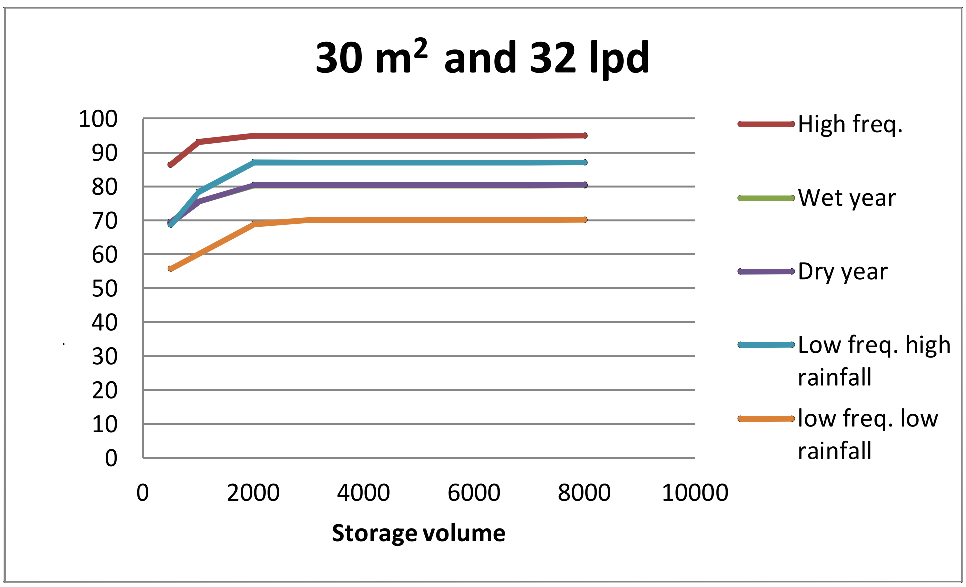
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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Storage volume
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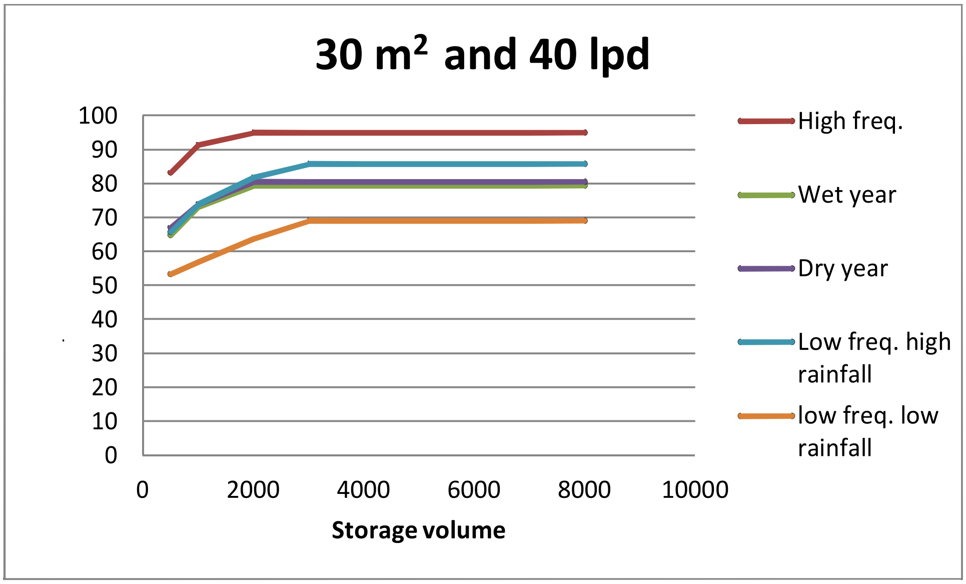
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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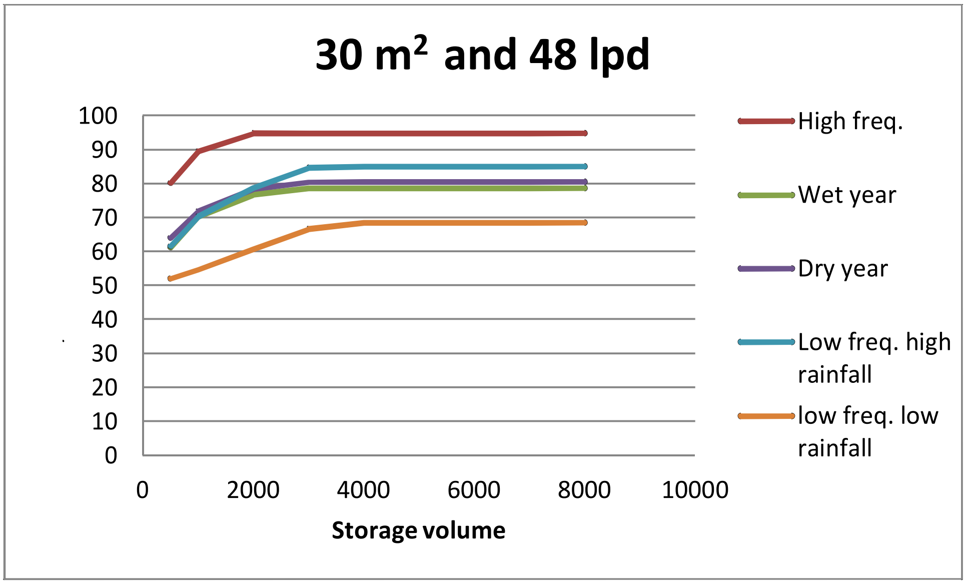
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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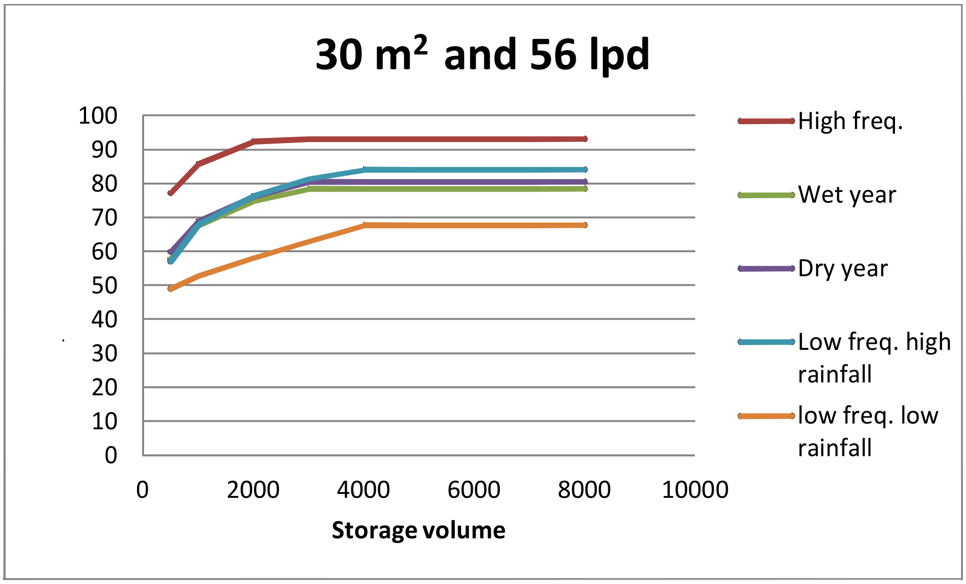
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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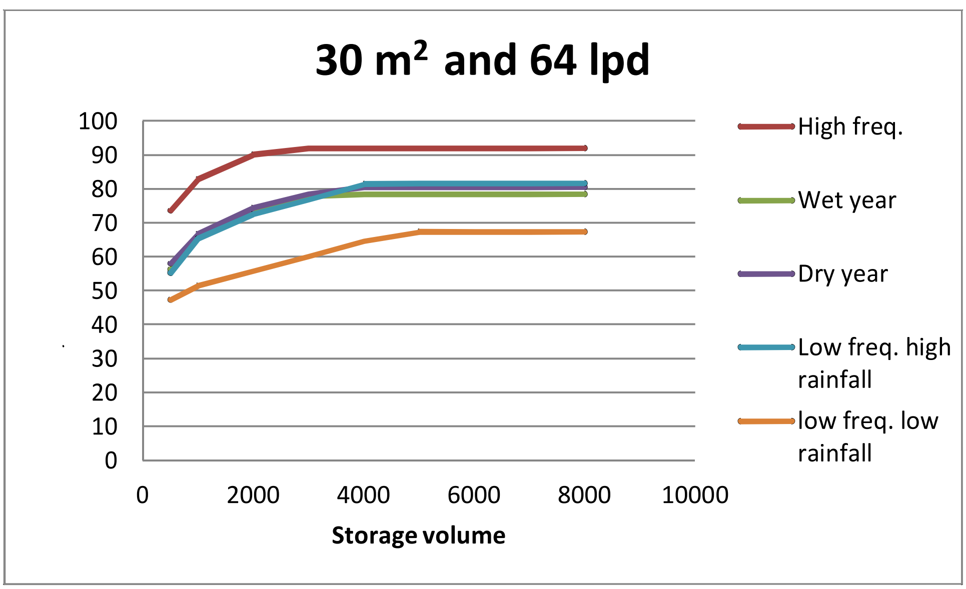
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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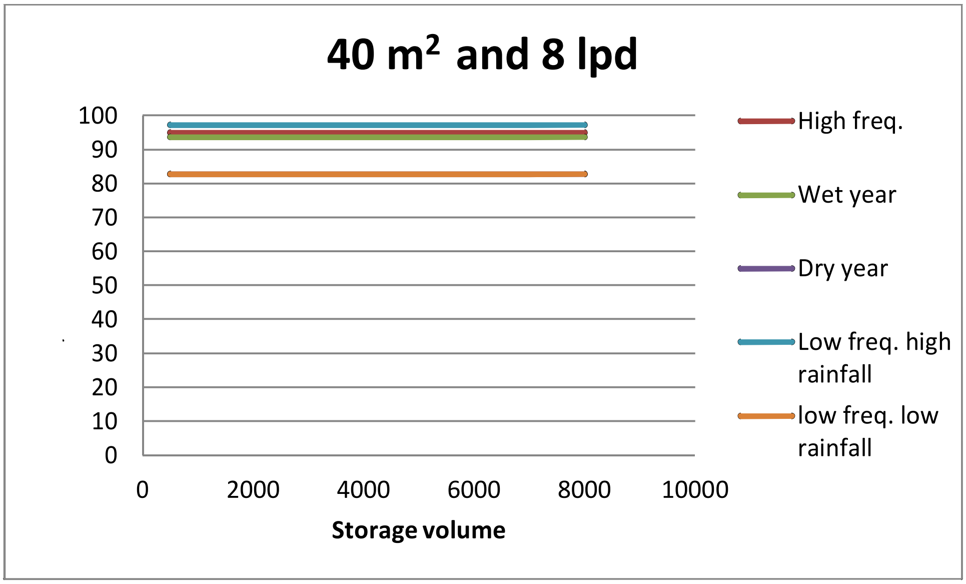
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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Storage volume
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Wet year
Dry year
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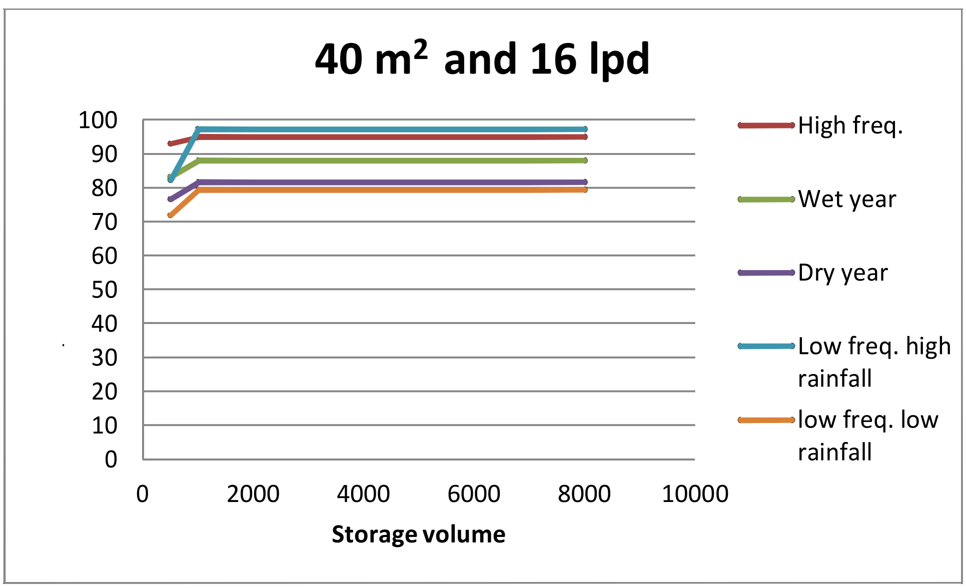
low freq. low rainfall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Storage volume
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Wet year
Dry year
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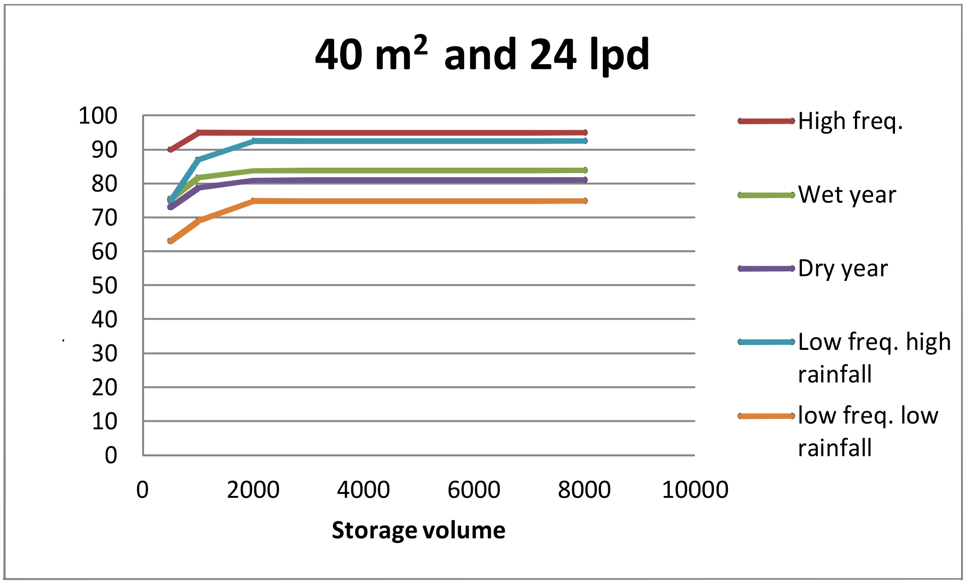
low freq. low rainfall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Wet year
Dry year
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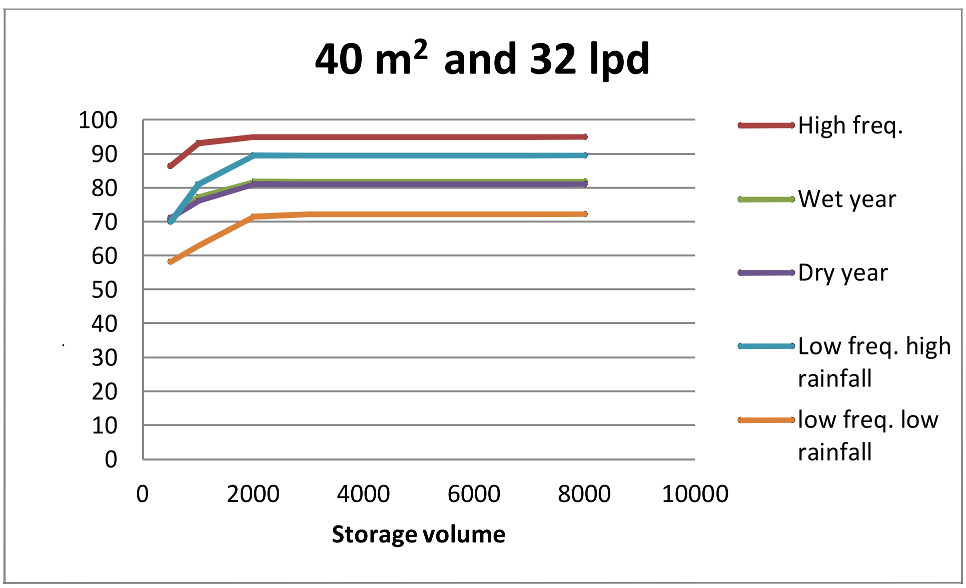
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Wet year
Dry year
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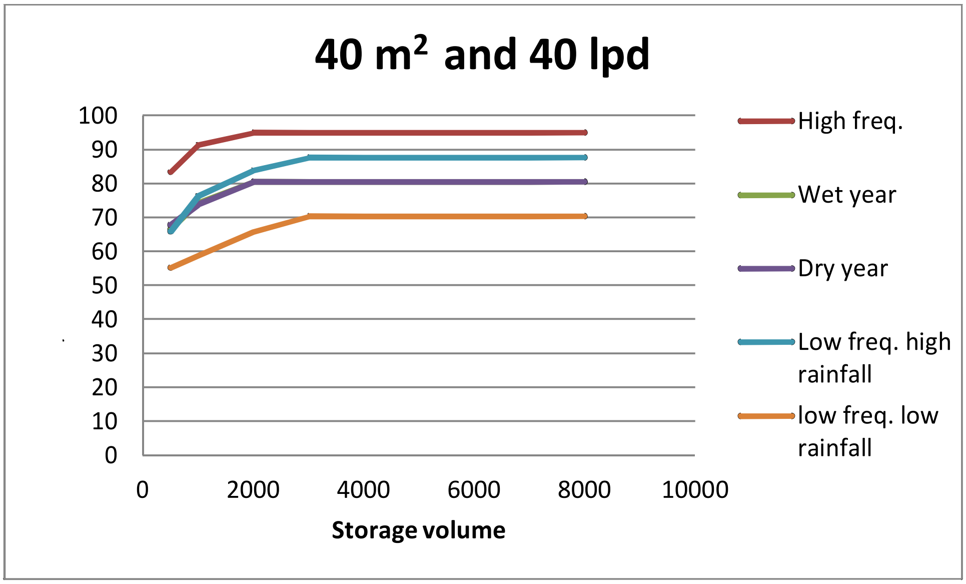
low freq. low rainfall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Wet year
Dry year
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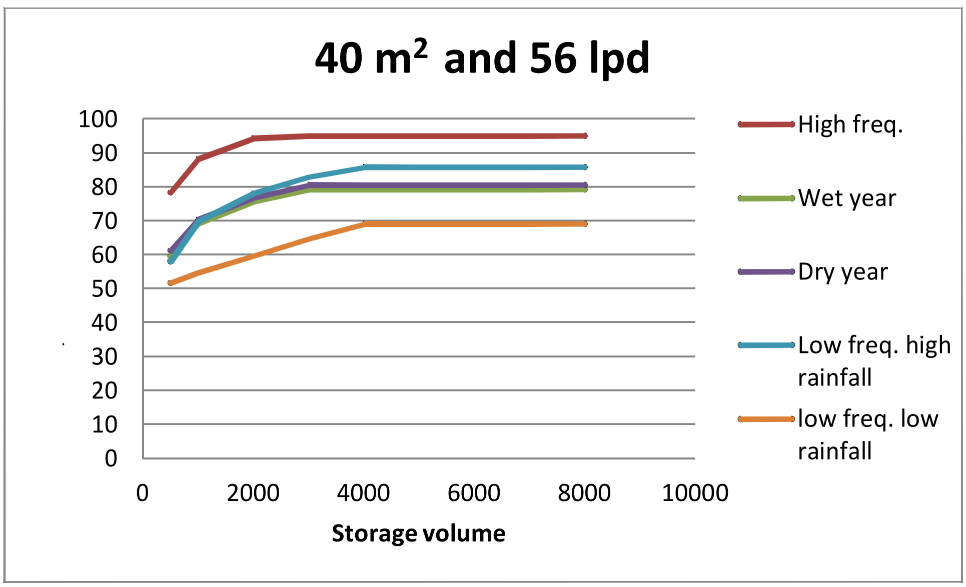
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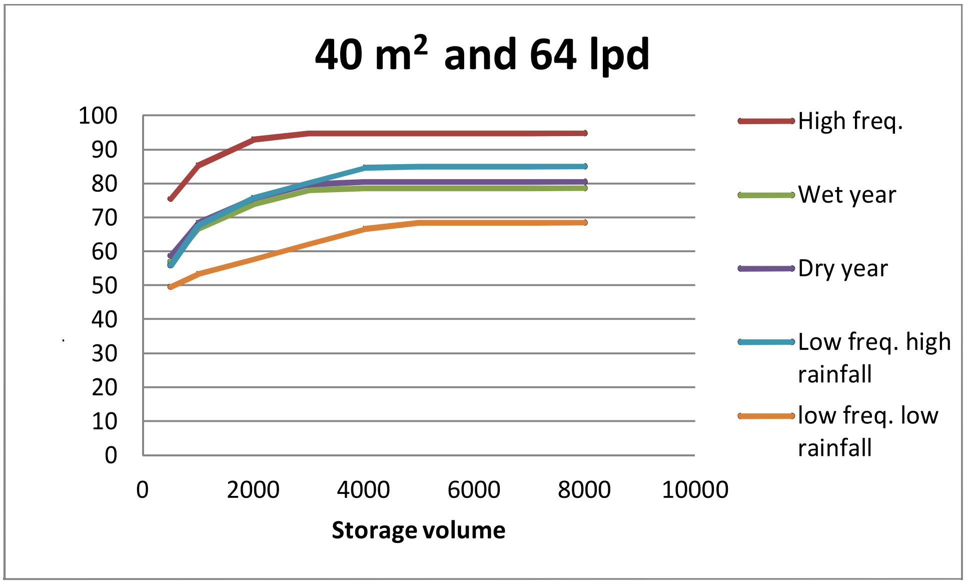
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Dry year
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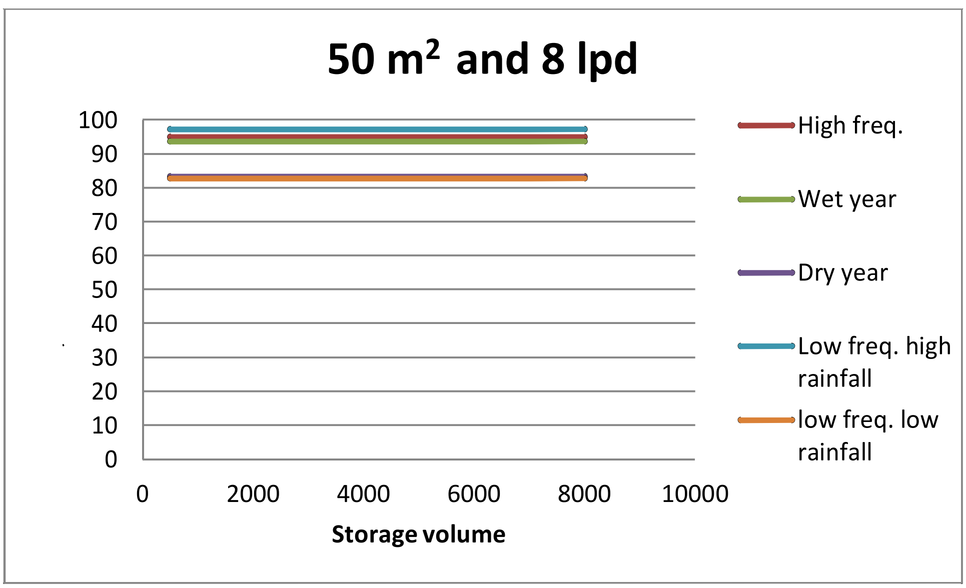
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Wet year
Dry year
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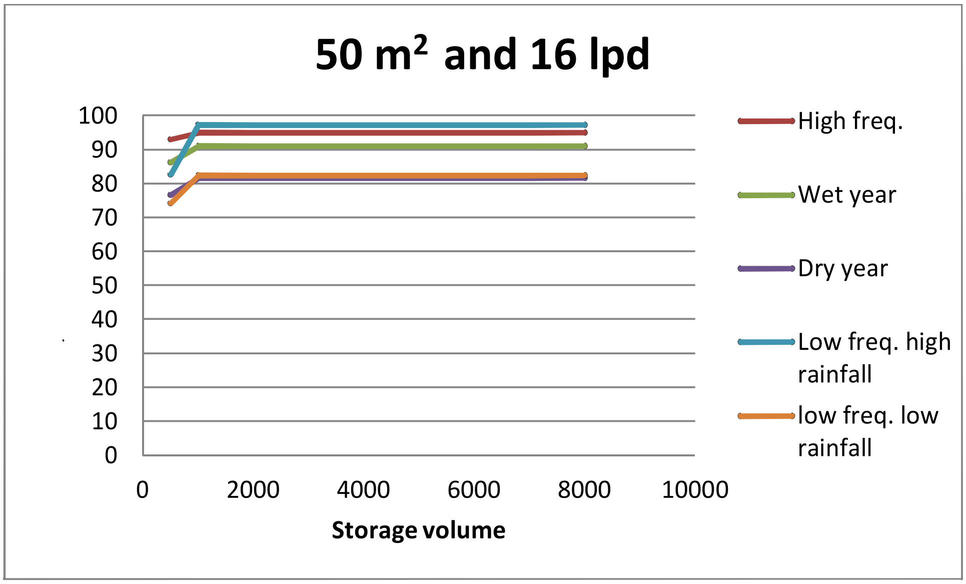
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Dry year
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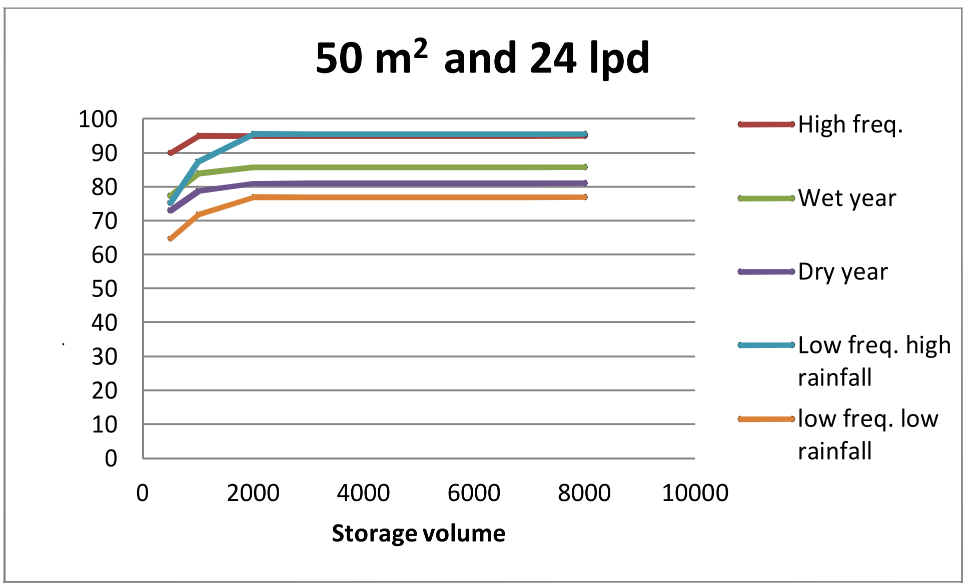
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Dry year
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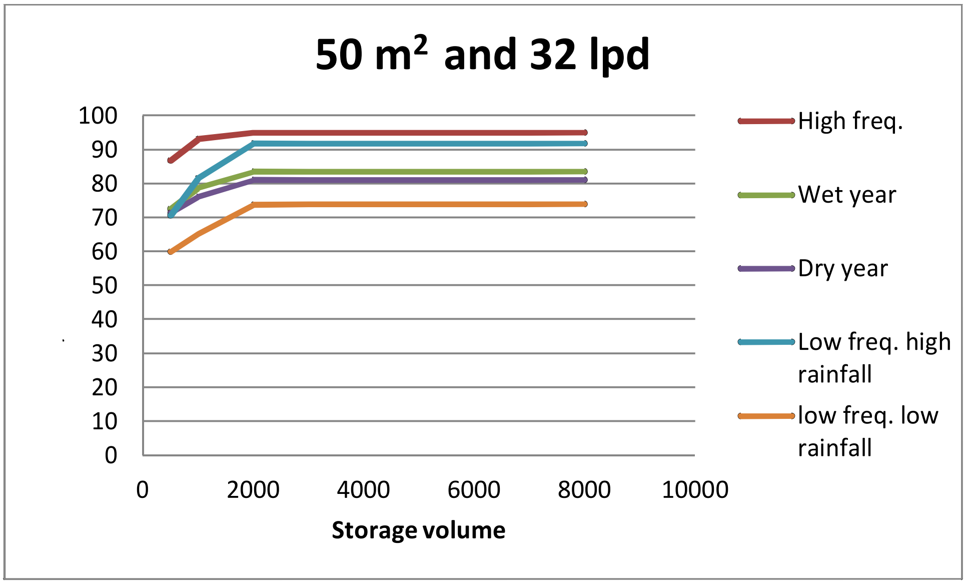
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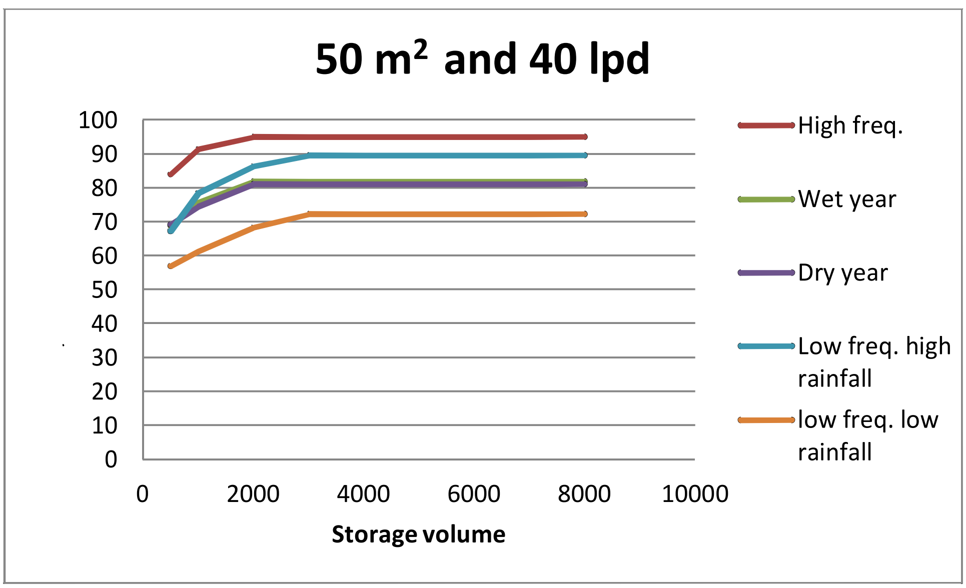
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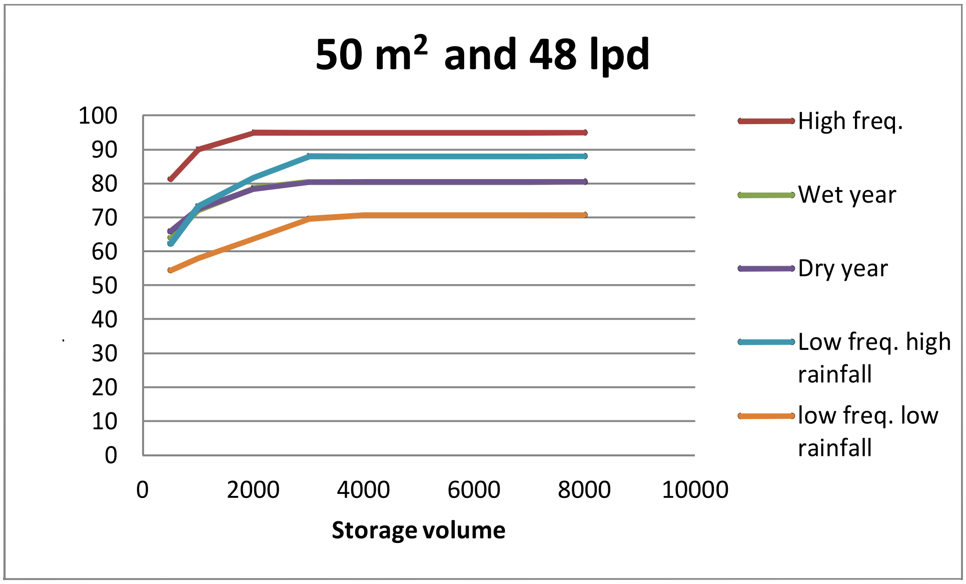
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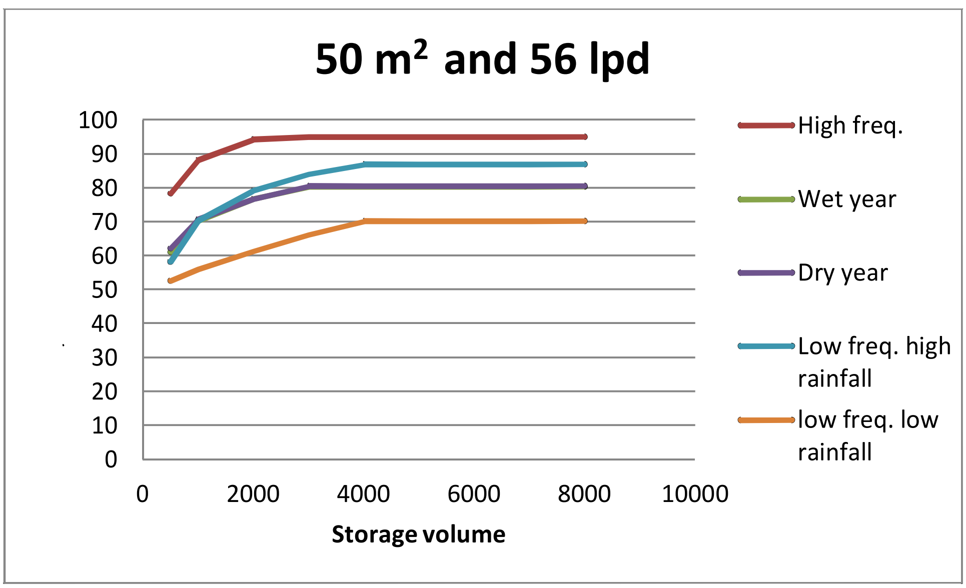
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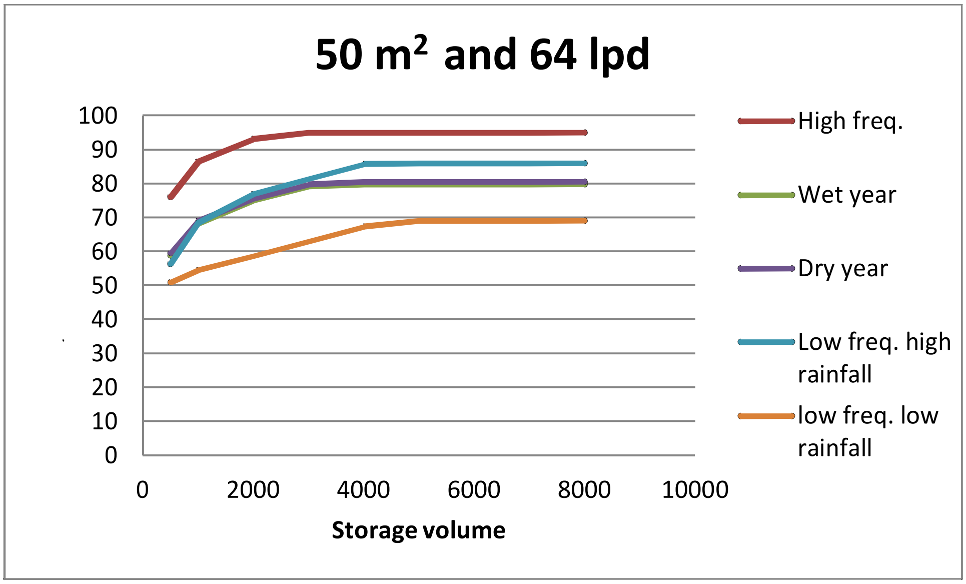
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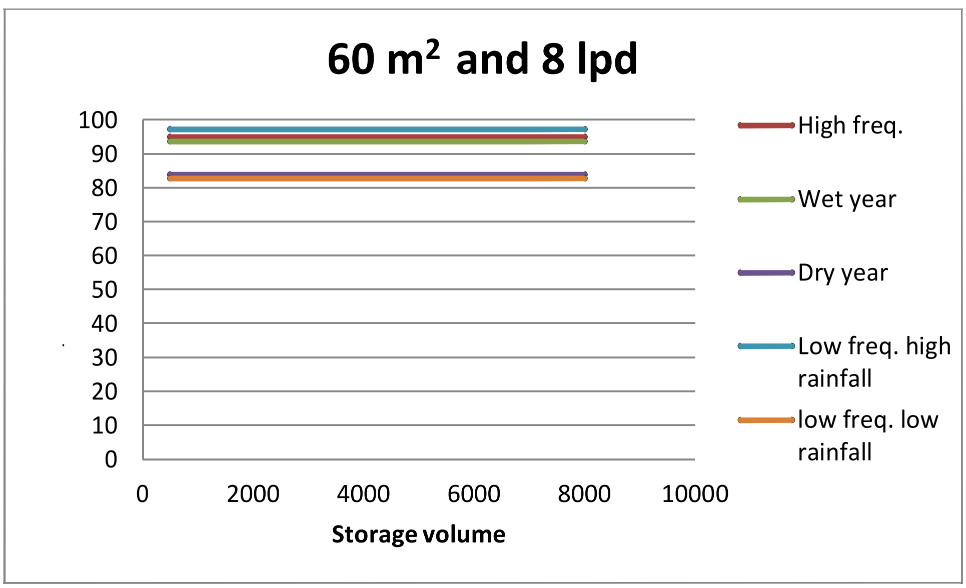
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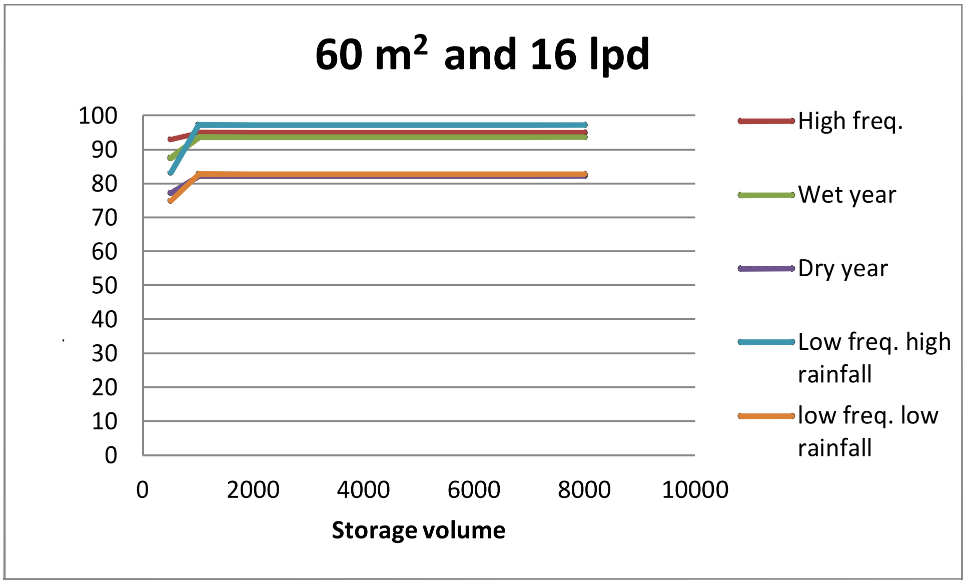
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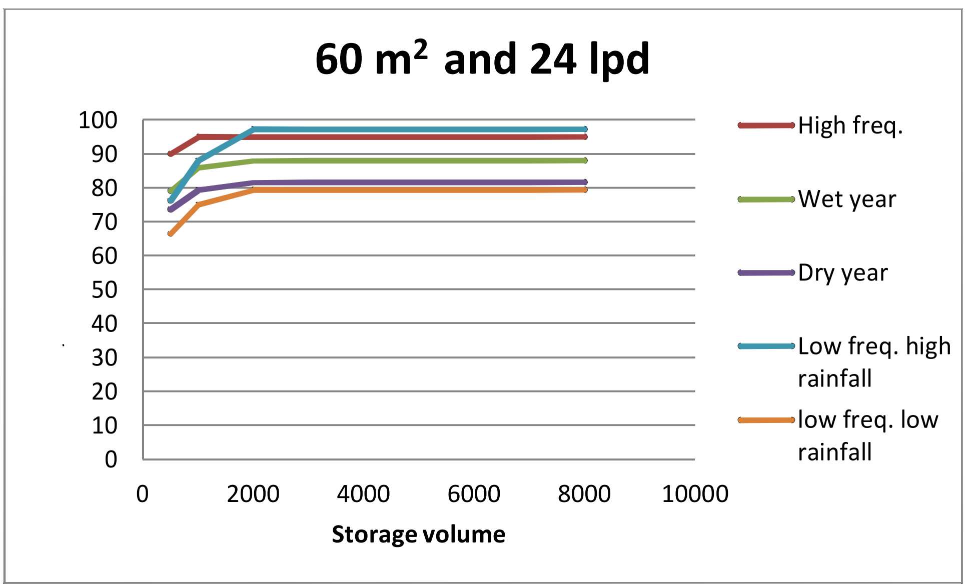
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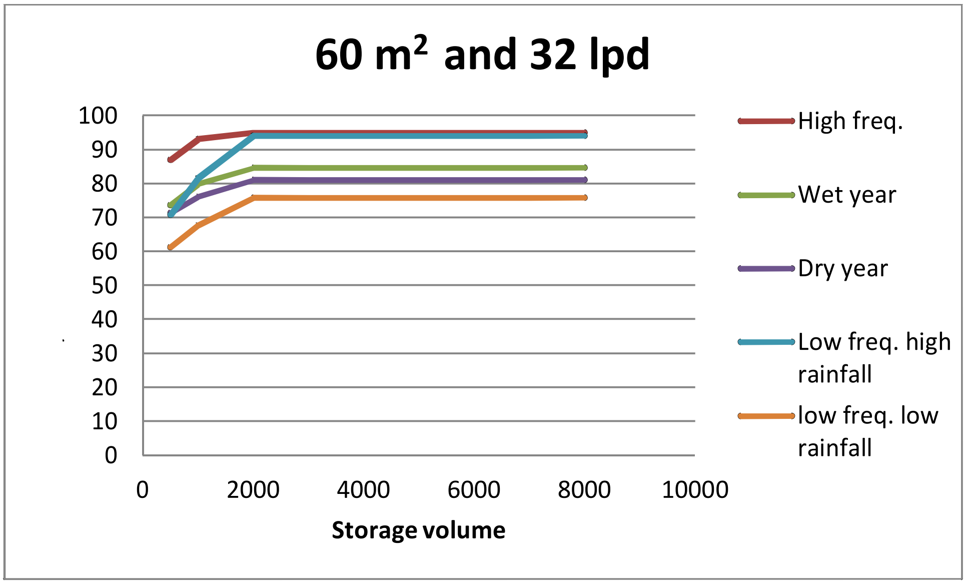
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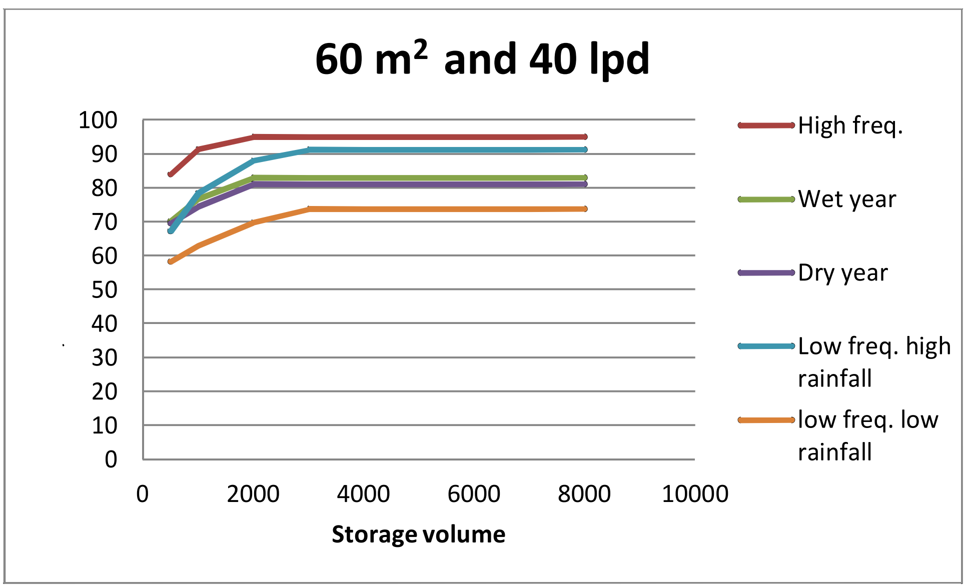
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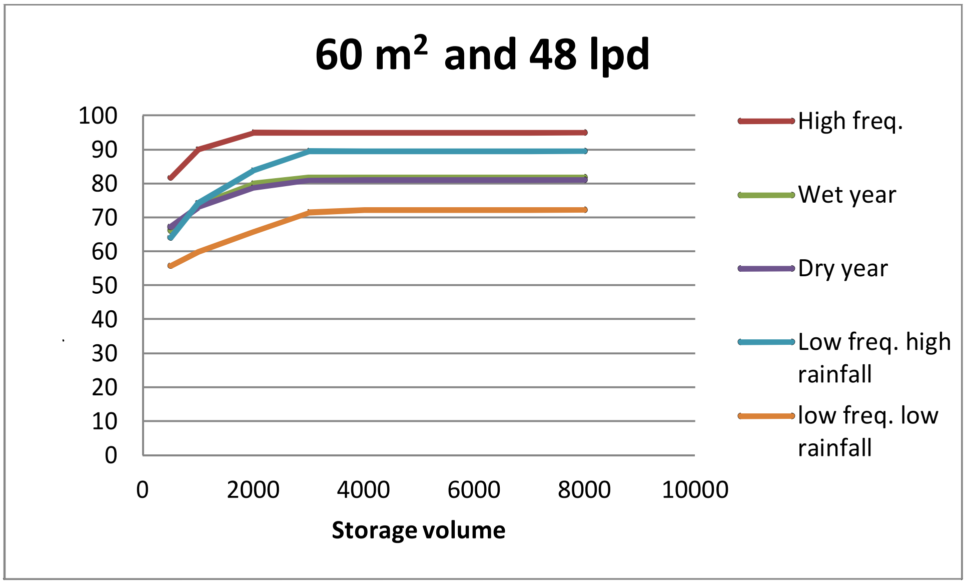
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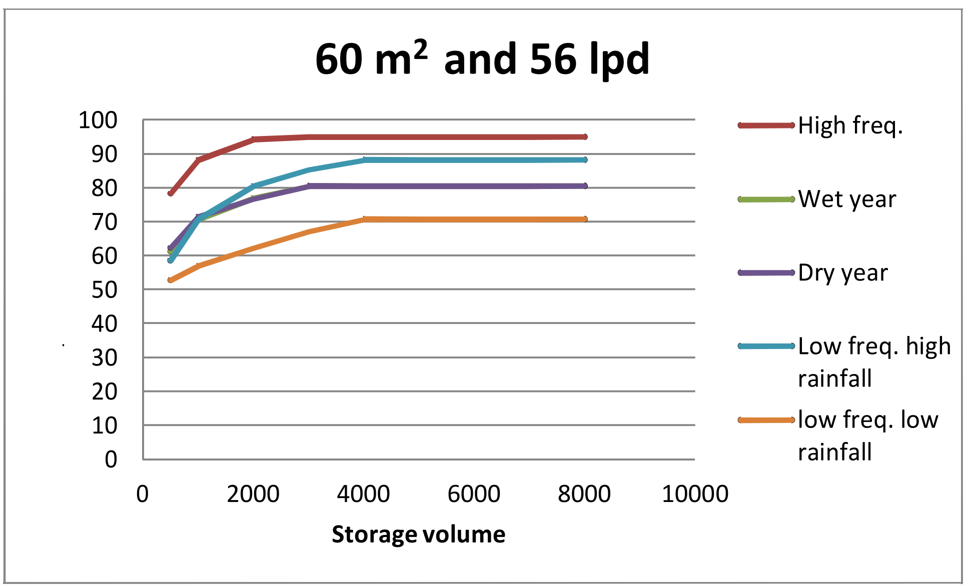
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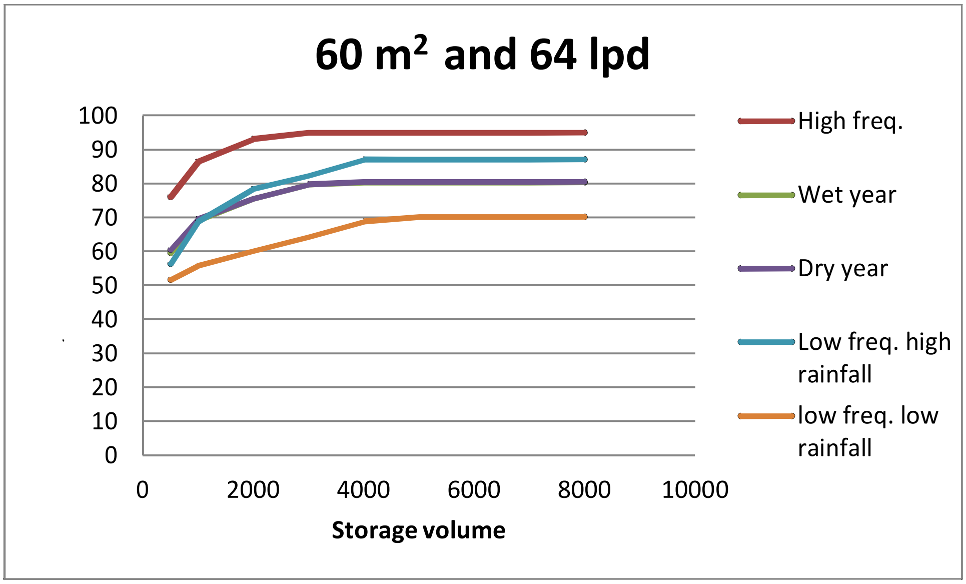
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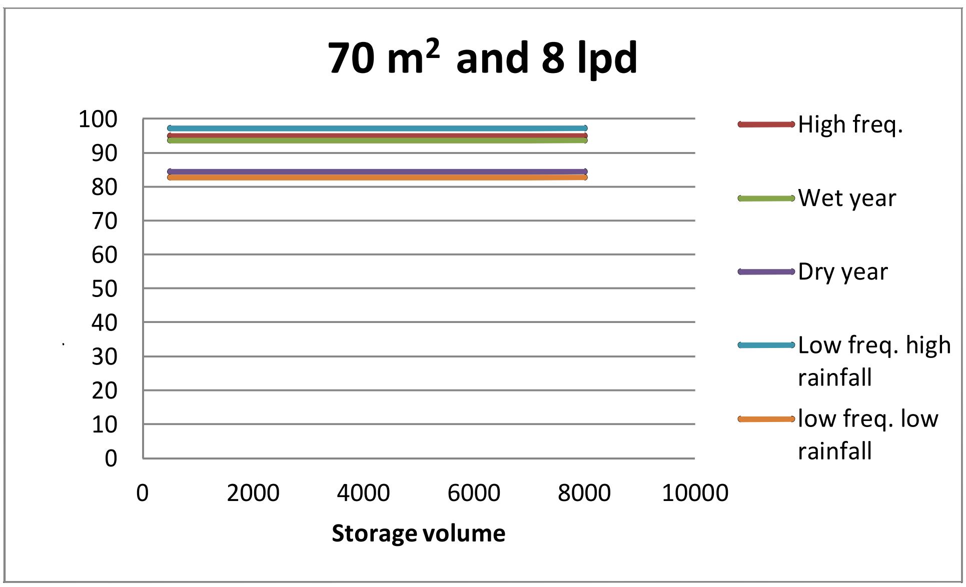
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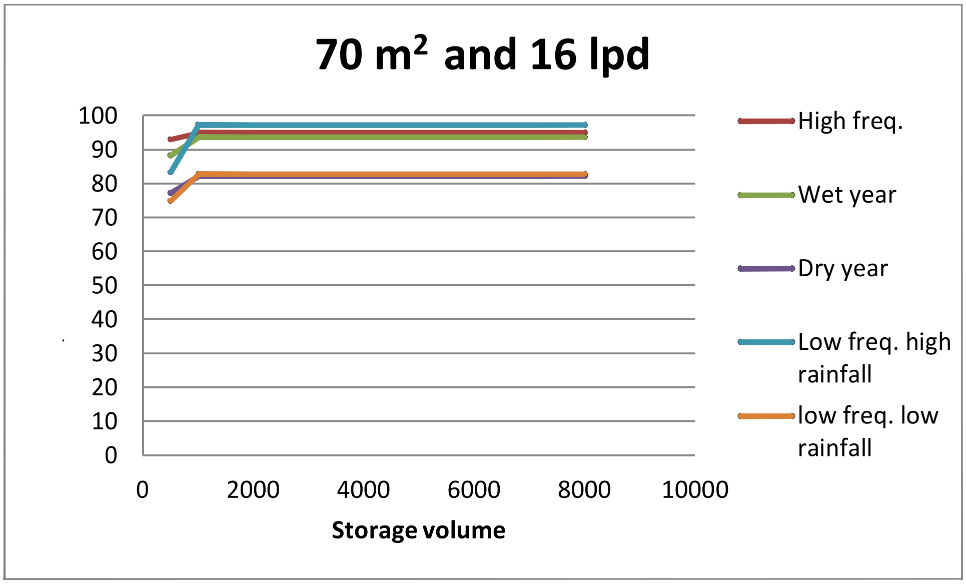
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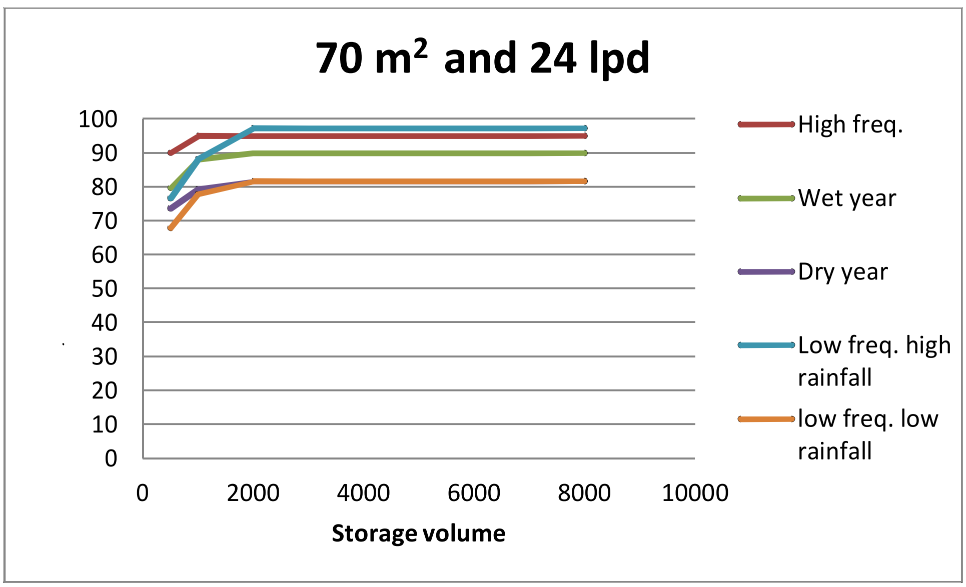
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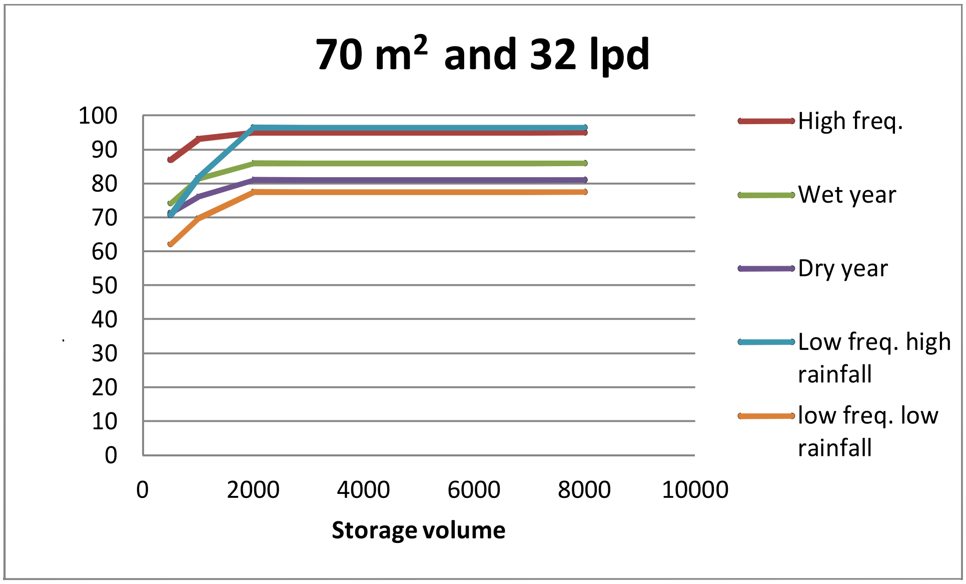
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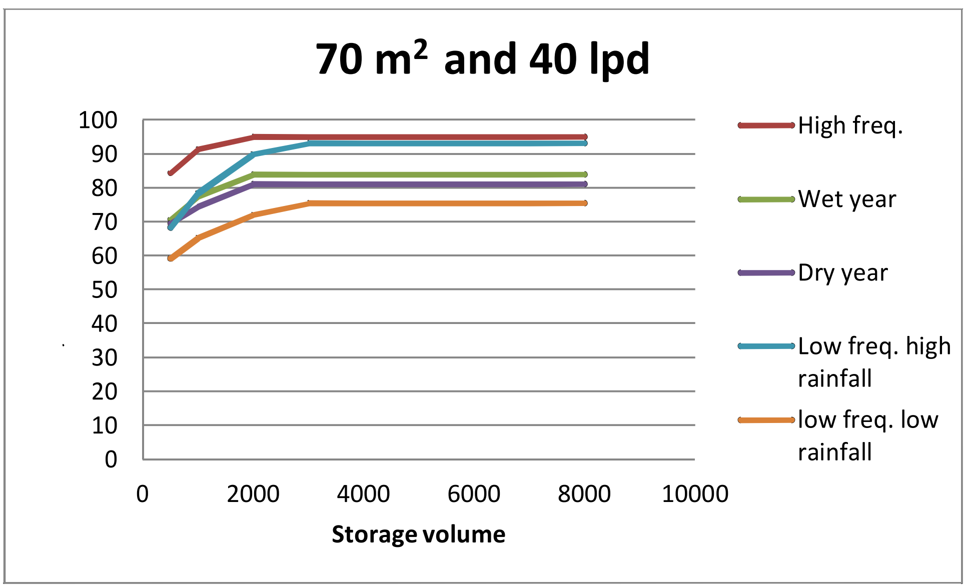
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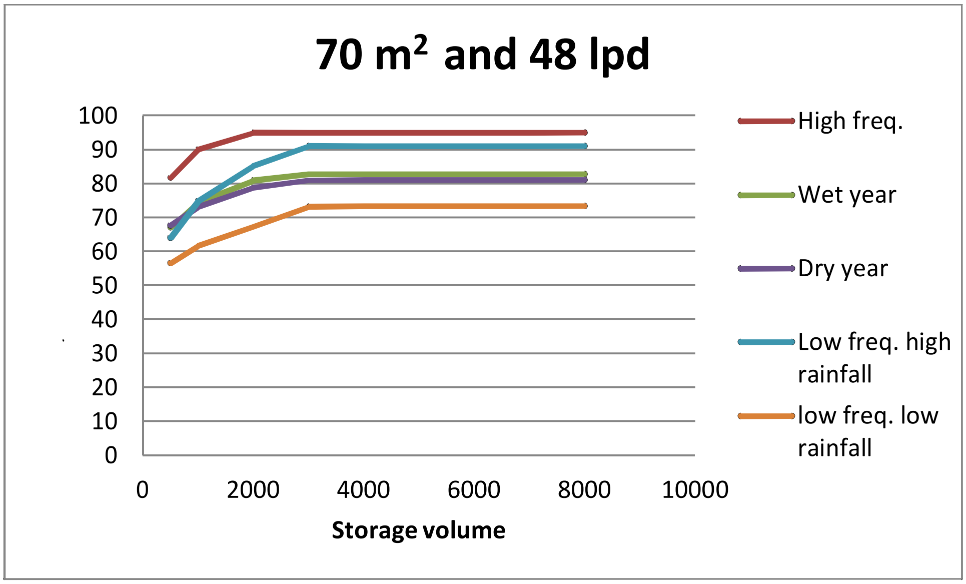
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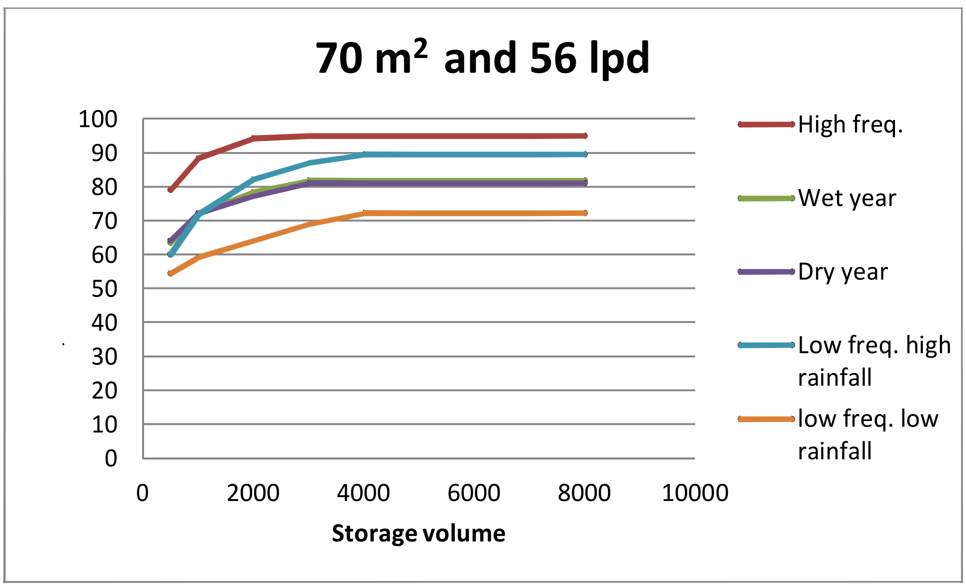
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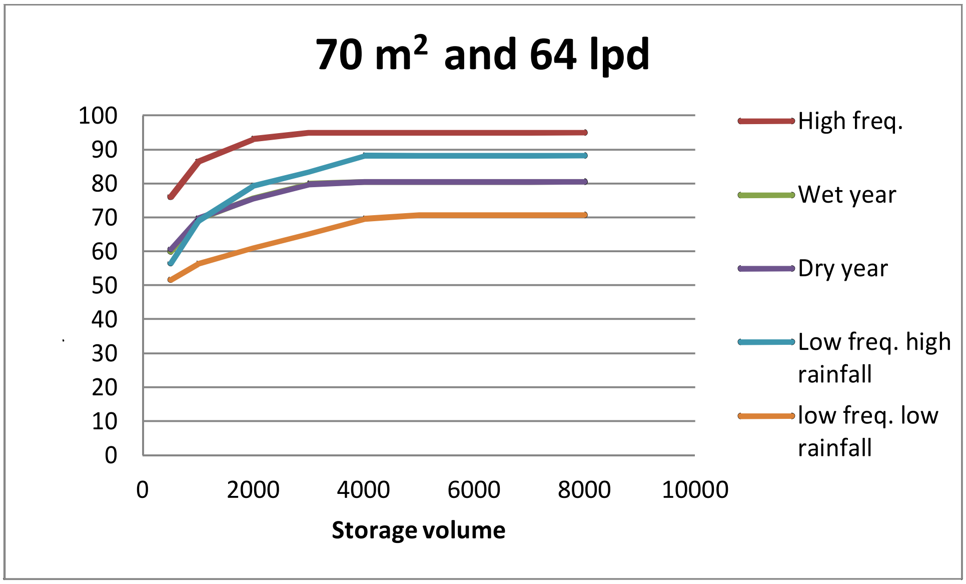
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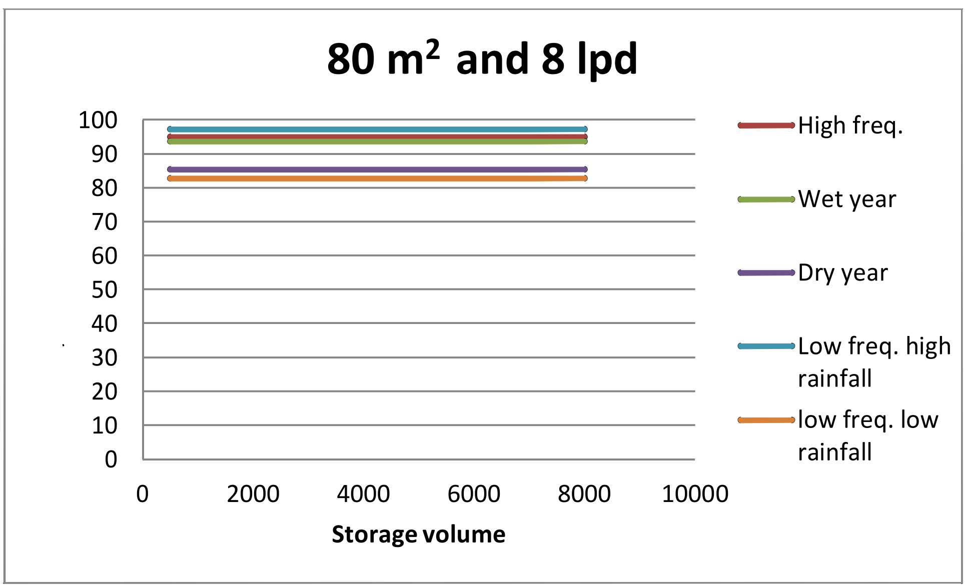
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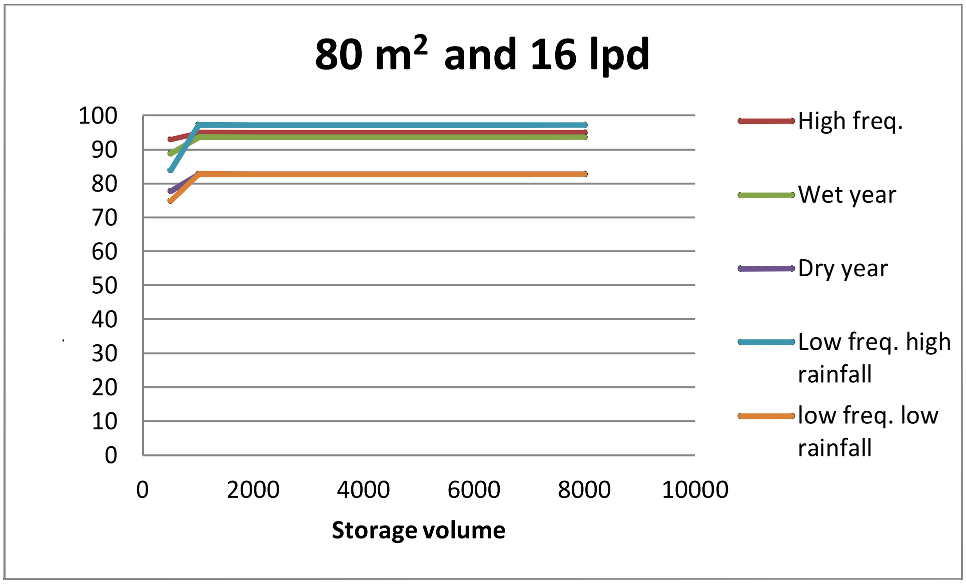
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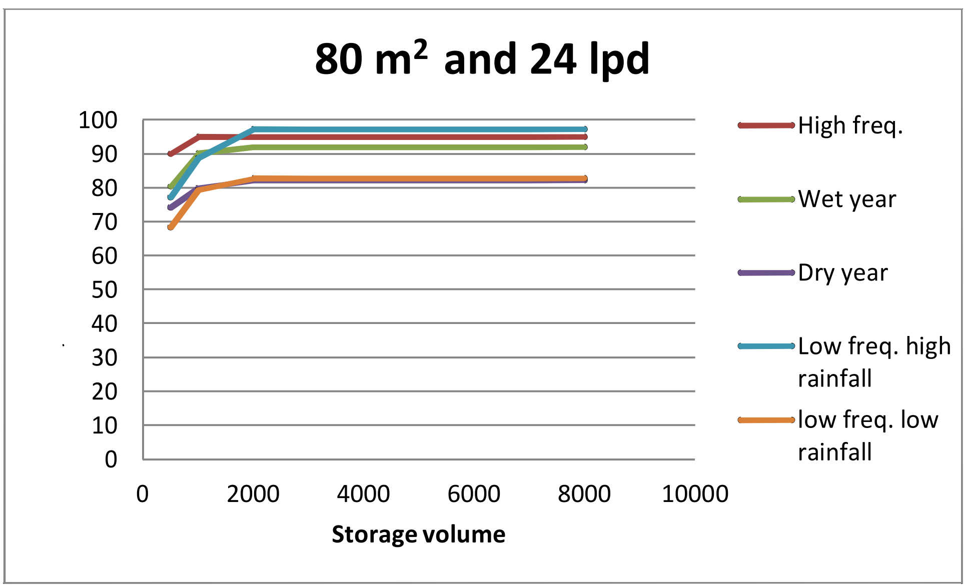
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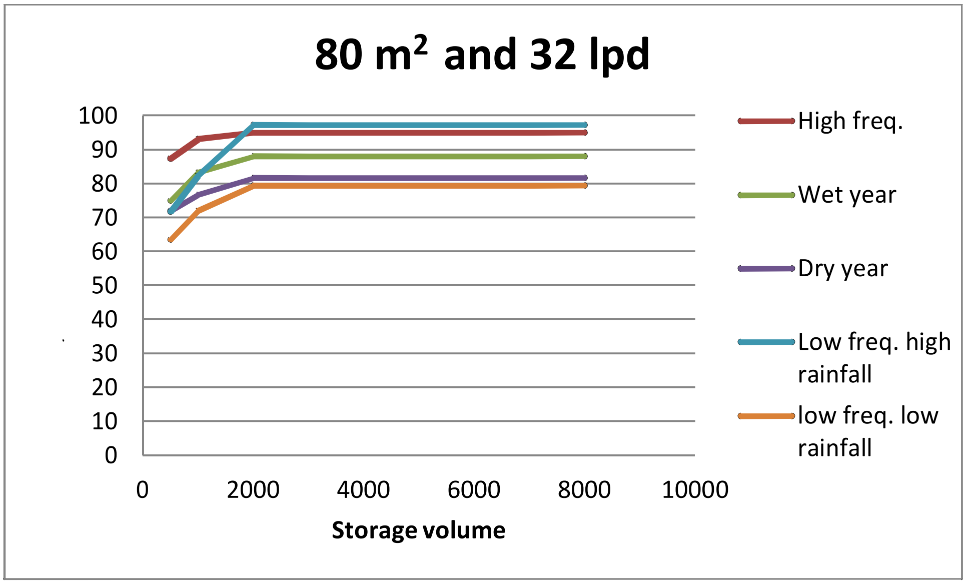
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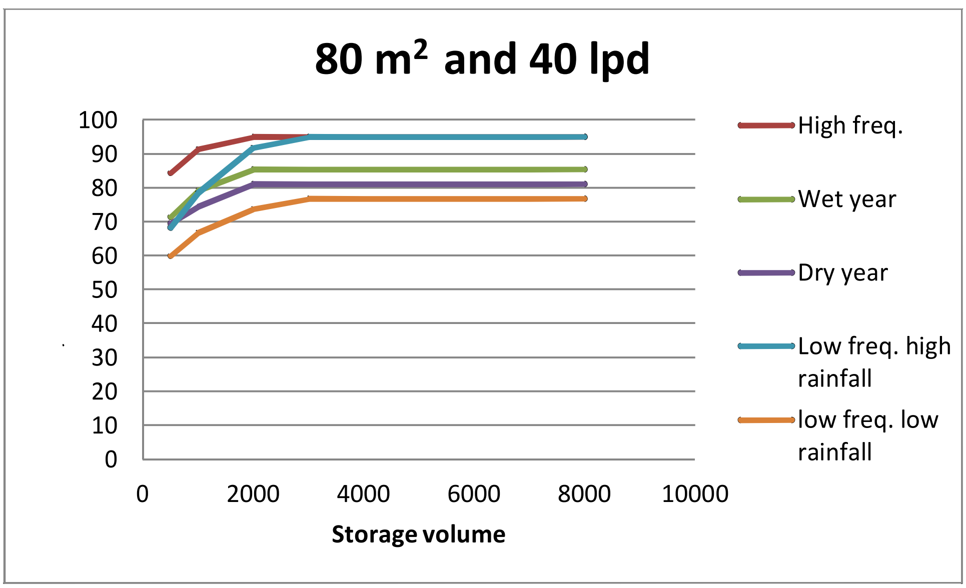
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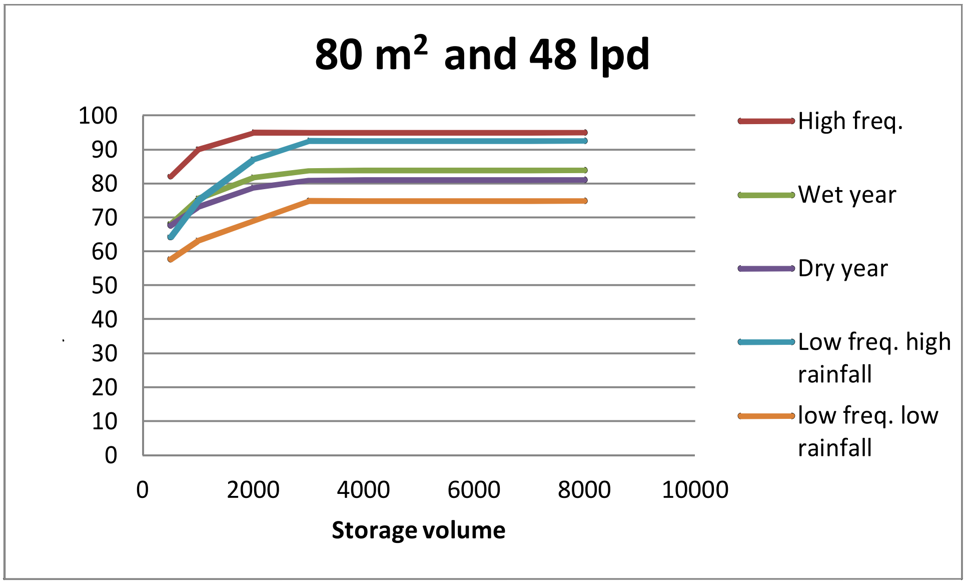
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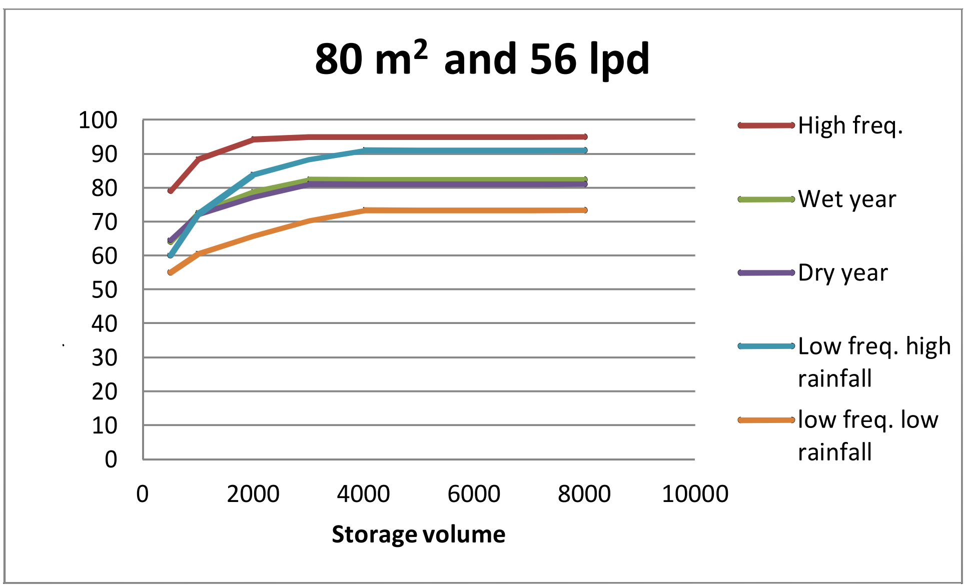
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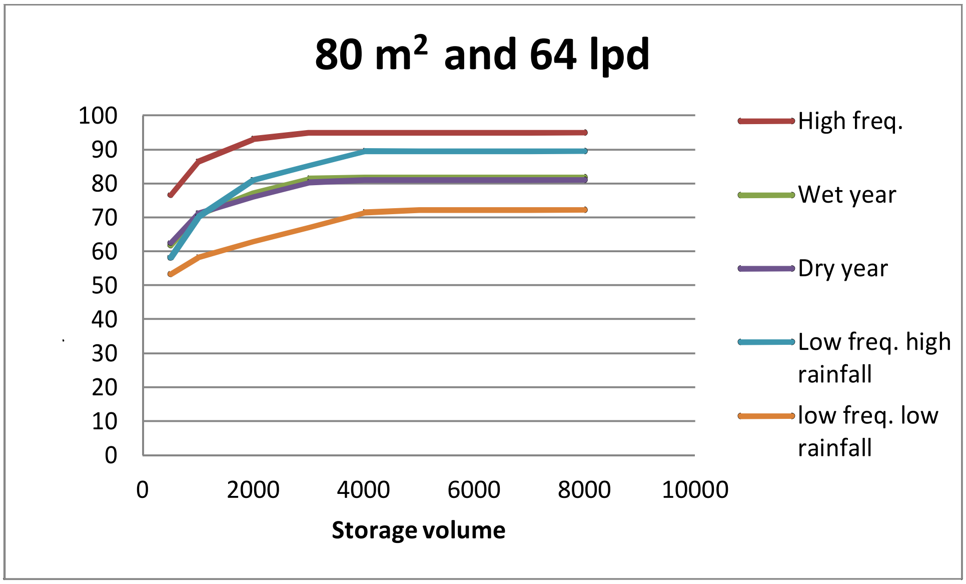
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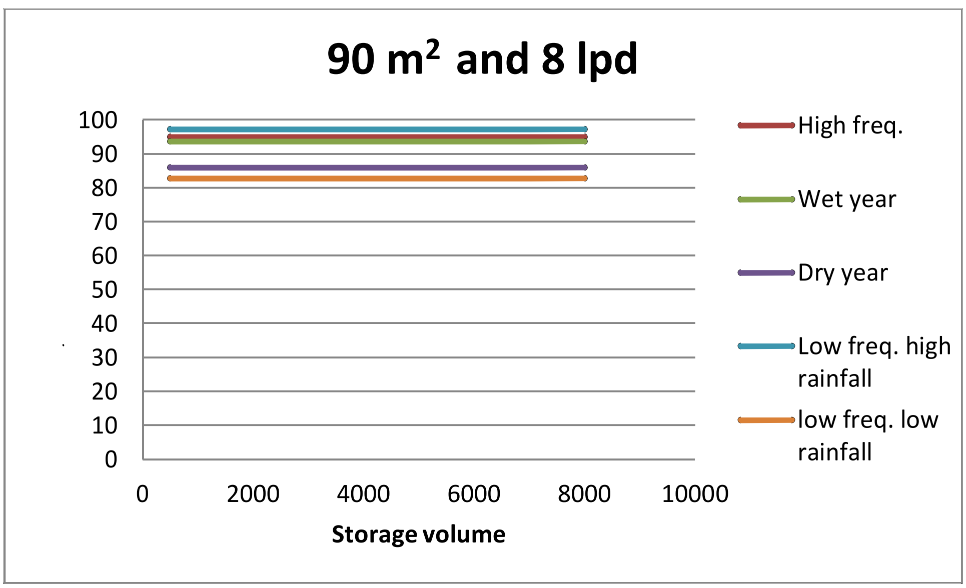
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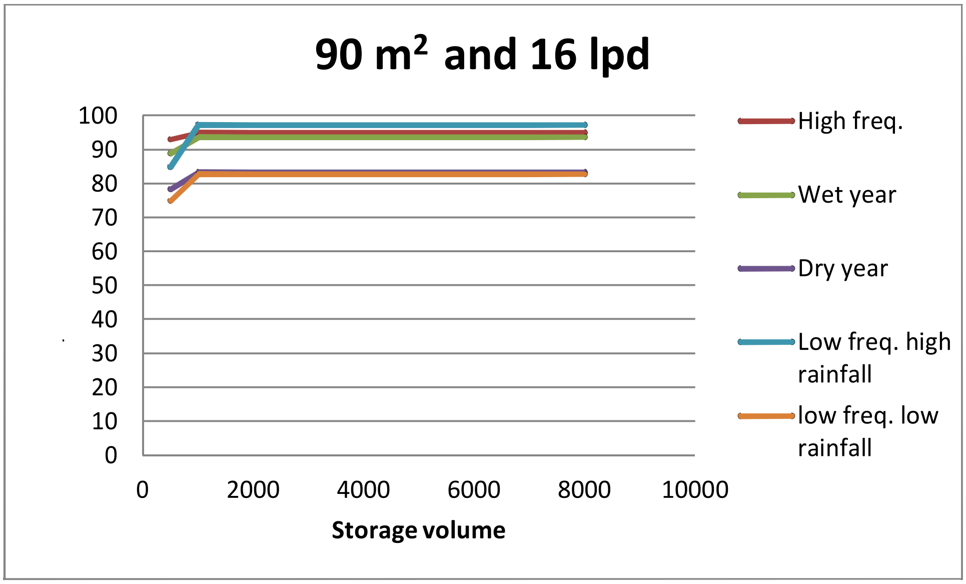
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Low freq. high rainfall
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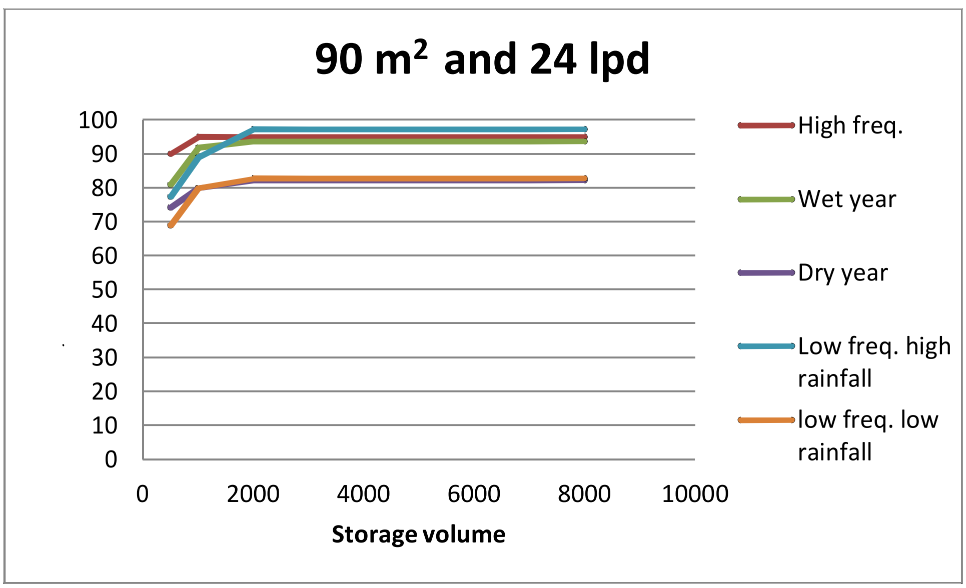
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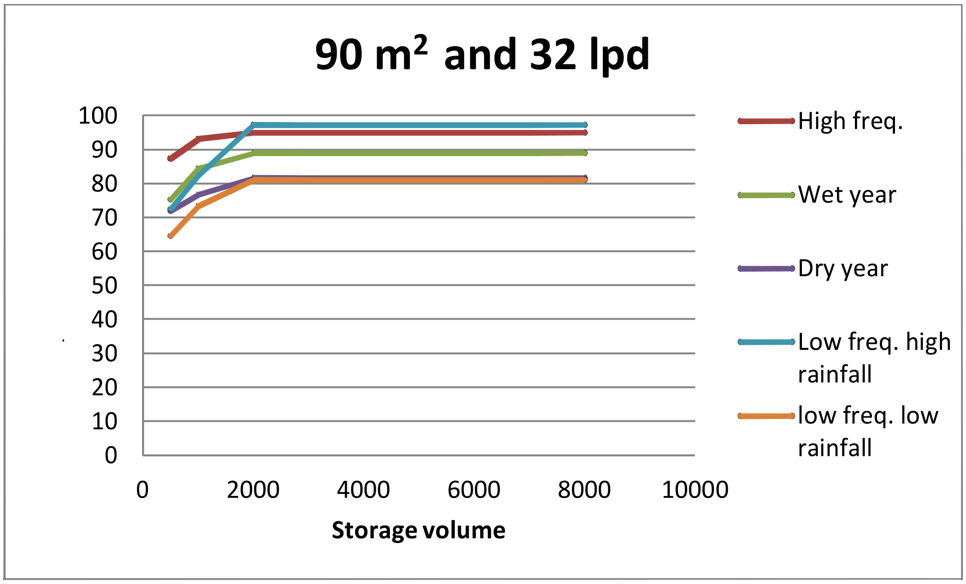
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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Wet year
Dry year
Low freq. high rainfall
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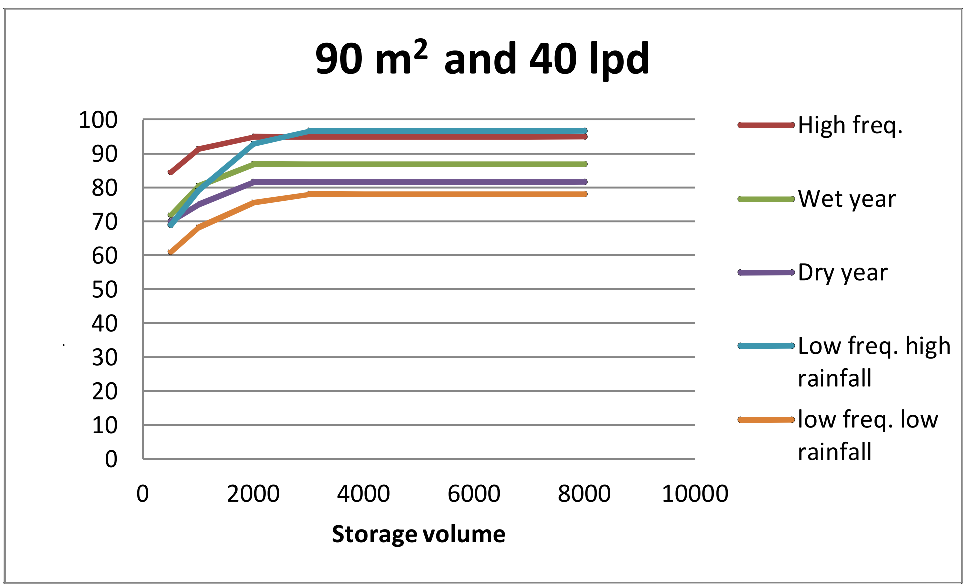
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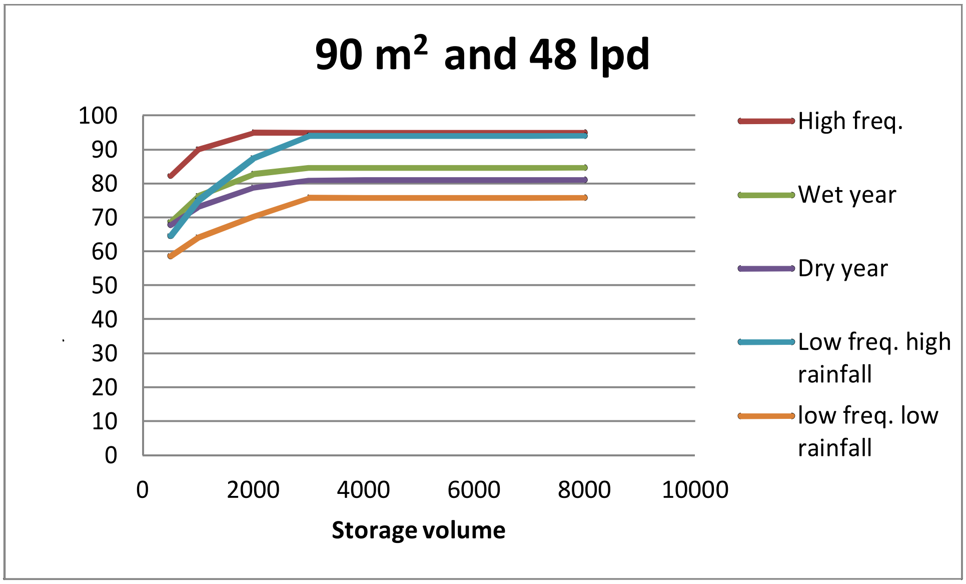
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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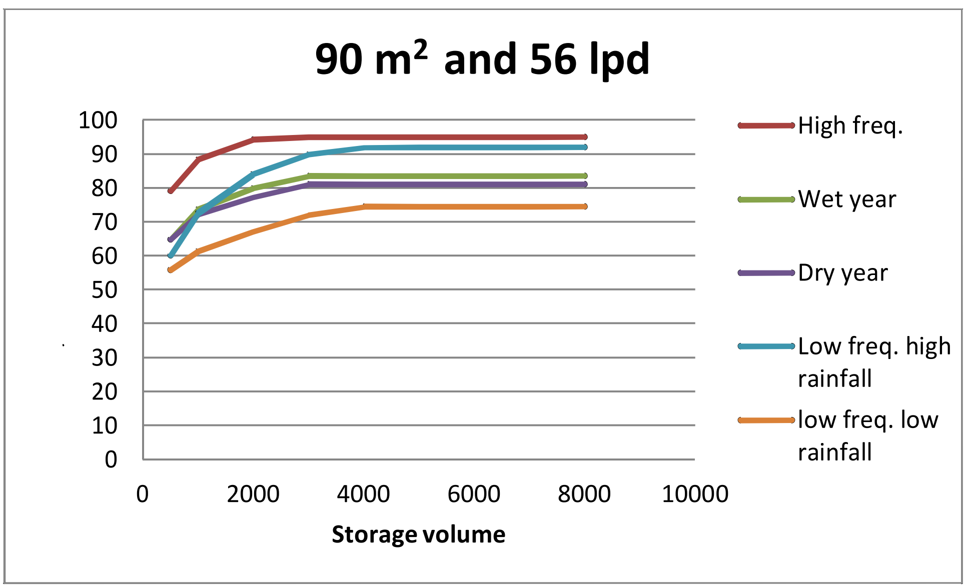
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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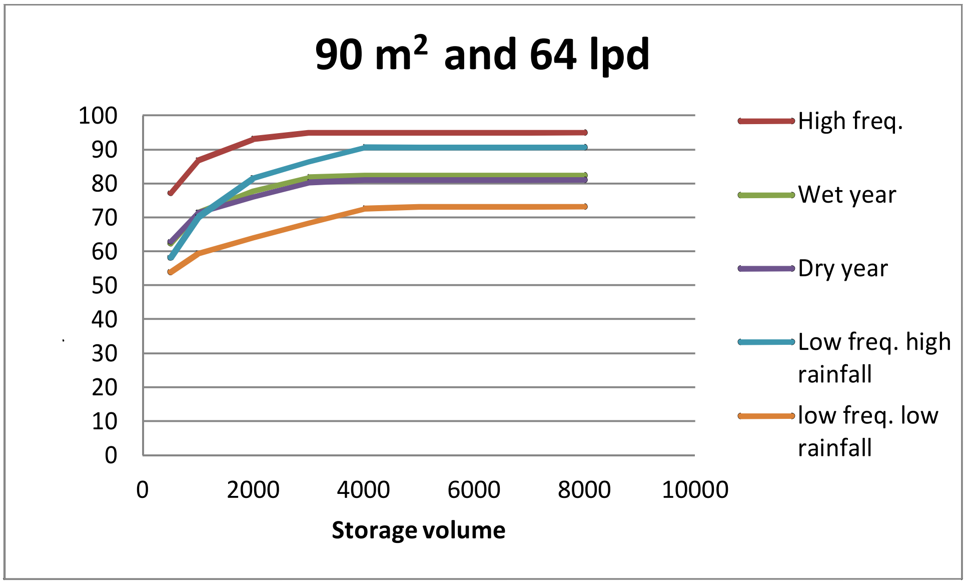
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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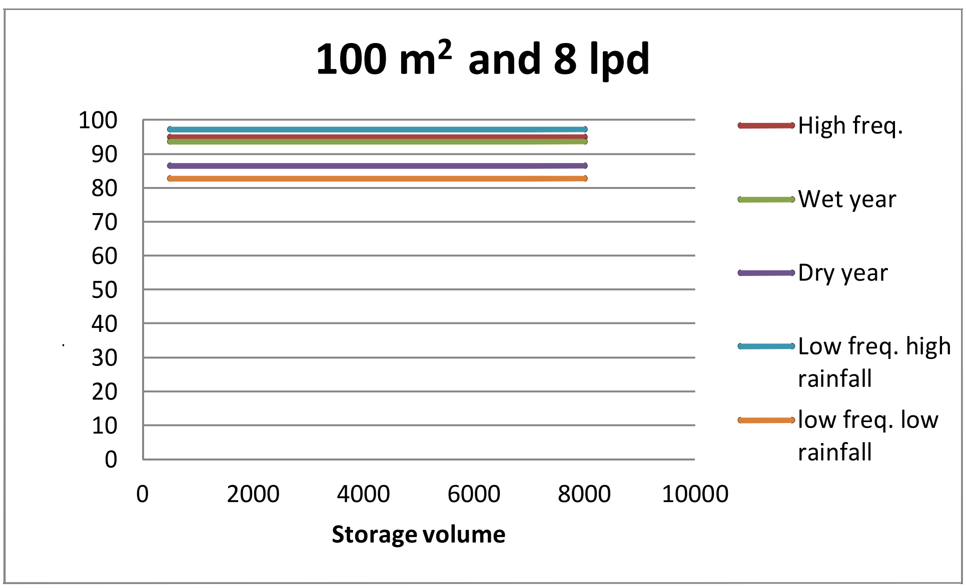
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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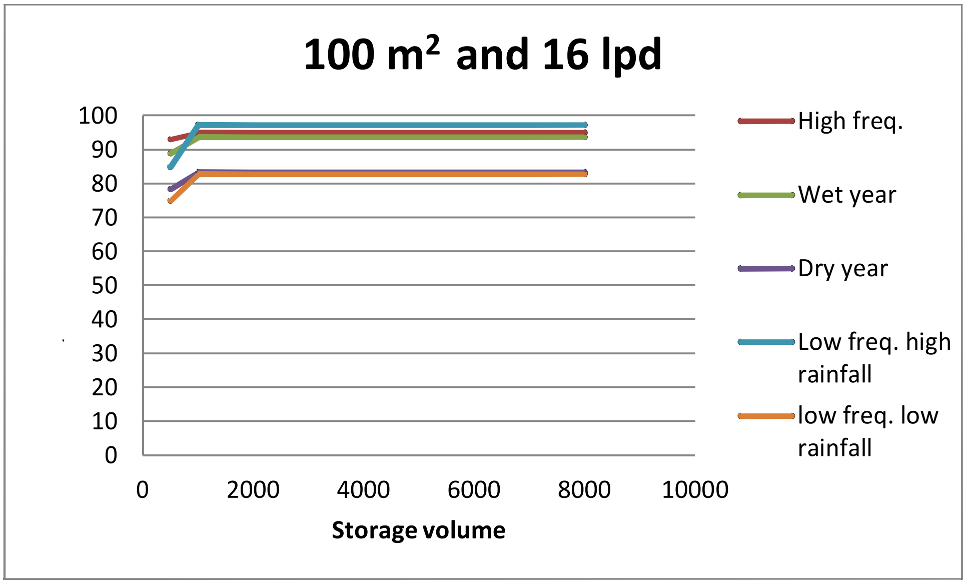
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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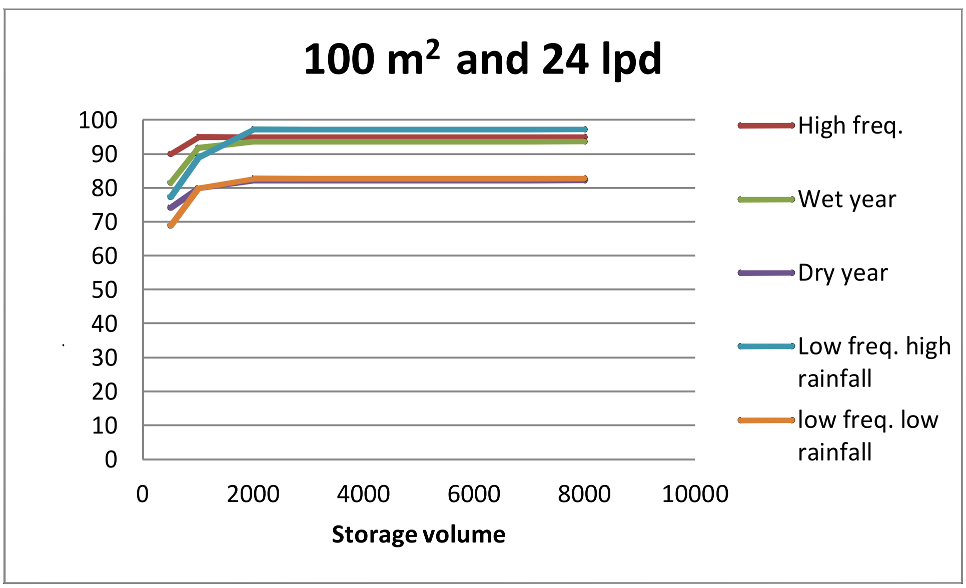
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall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Storage volume
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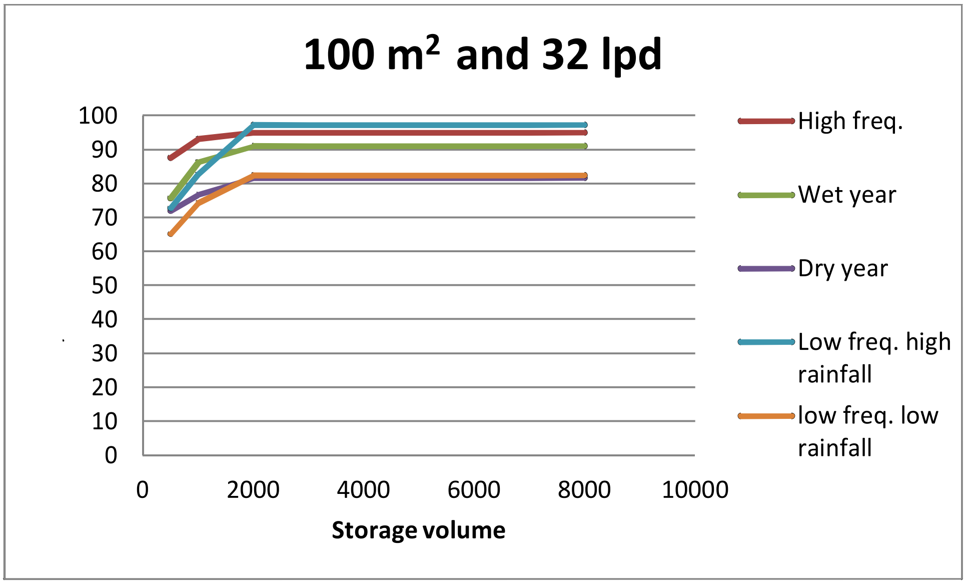
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Storage volume
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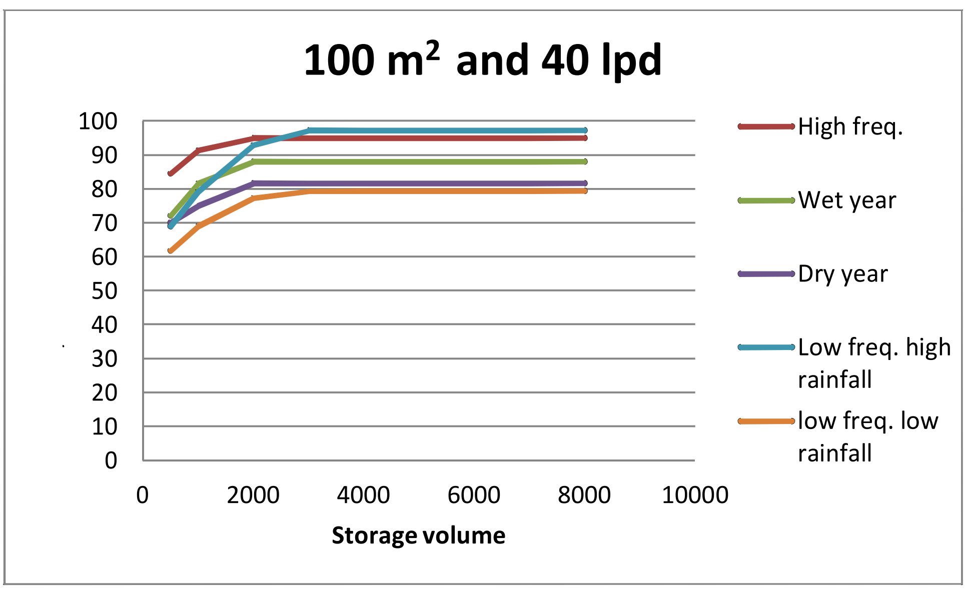
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall


100 m² and 40 lpd
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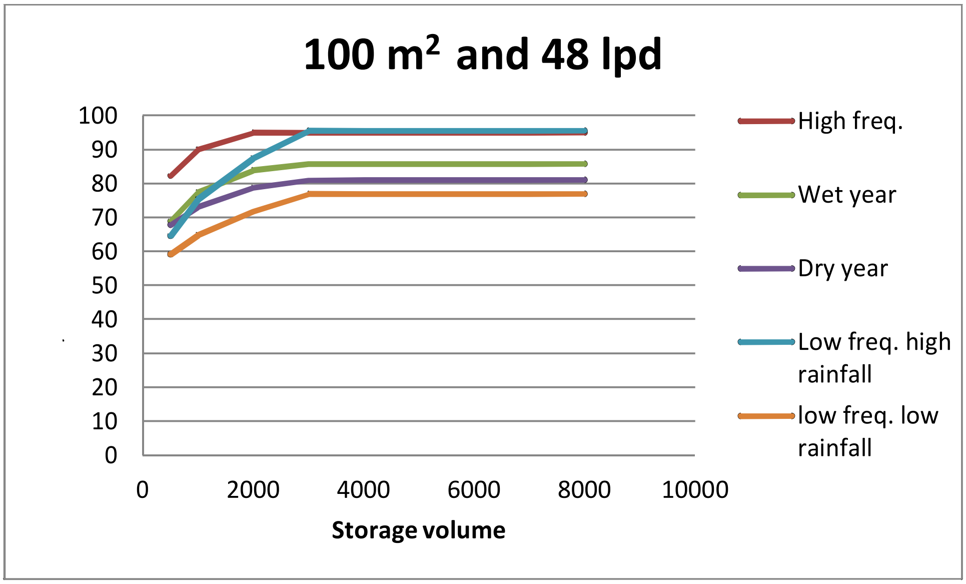
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall


100 m² and 48 lpd
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Storage volume
High freq.
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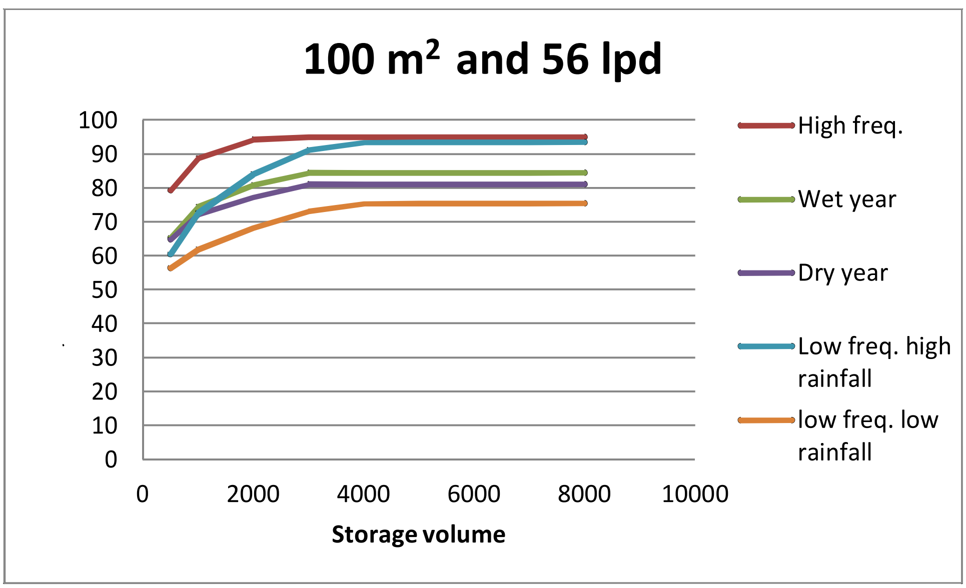
Dry year
Low freq. high rainfall
low freq. low rainfall


100 m² and 56 lpd
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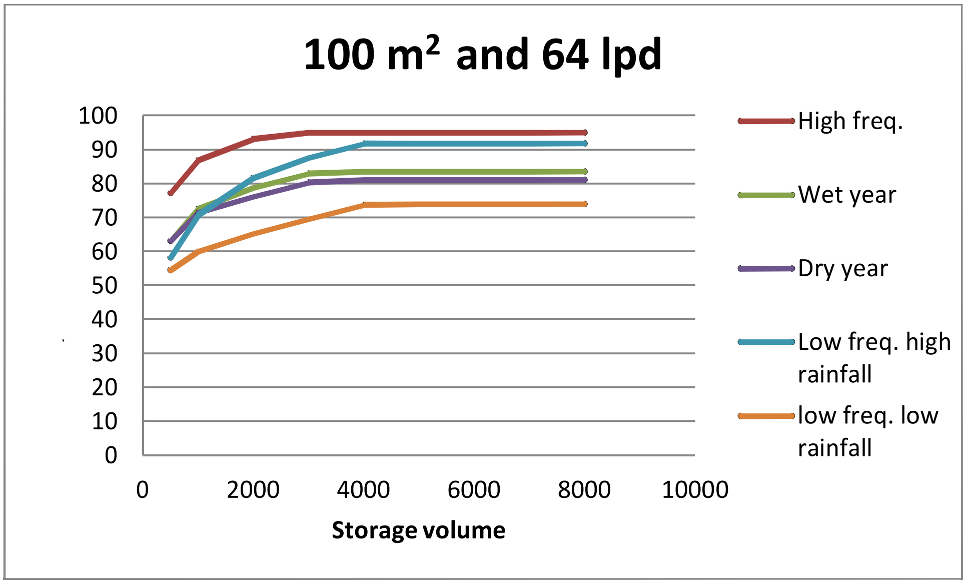
Storage volume
High freq.
Wet year
Dry year
Low freq. high rainfall
low freq. low rainfall

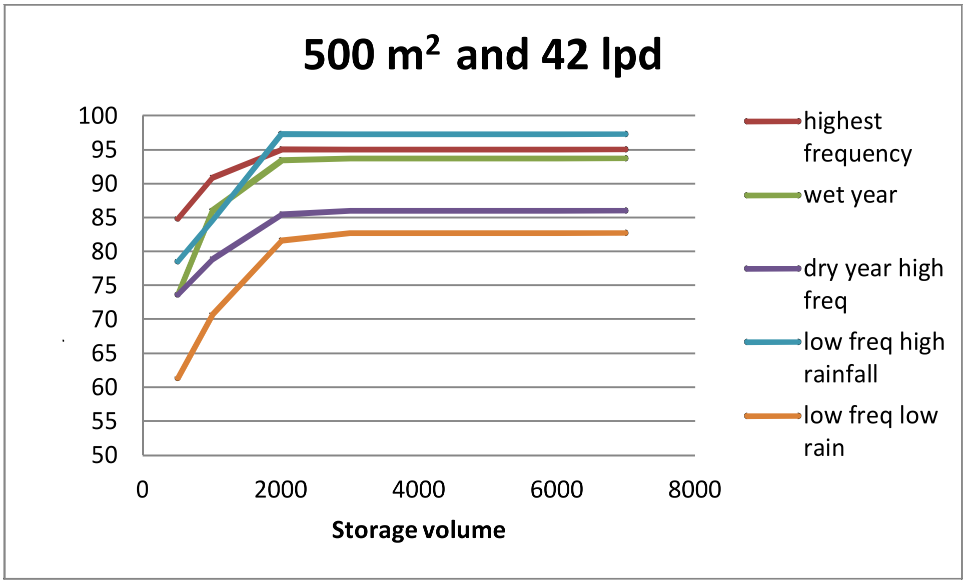


A. Catchment area, Daily demand and Reliability:

Reliability of the rwh system indicates direct relationship with the catchment area. As the catchment area increased the reliability increases. In case of demand if the demand increased the reliability of the storage tank decreased. The graphs indicate that the assumed catchment area with respect to the demand shows varied range of reliability depending on the rainfall pattern. However, there is a constant reliability after the increasing of storage volume for a particular year. It is due to the reason that in daily basis model there is an extended dry period at the starting of the year, which results the same reliability over a large change in storage volume. Over the dry period, the occasional daily rainfall is very small. Therefore, unless a very large catchment area is used for our standard demand, there will be no change in reliability over the increase of catchment area.

Figure: 6.81

Reliability analysis for large catchment:



The graph indicates the change in the reliability. The change may indicate a sudden change in reliability for some year but the reliability for some years remains unchanged. It is because there were no occasional high intensity rainfalls in the dry season of those years and as in case of daily basis calculation the initial dry season come first at the yearly calendar in Bangladesh. Therefore, the increased catchment area does not contribute the increment of reliability.

B. Relation between reliability and rainfall pattern

The graphs are analyzed on the basis 5 rainfall pattern. The year with the highest frequency of rainfall, wet year, dry year, low frequency but high total rainfall and low frequency and low rainfall. These patterns with the relation of reliability will help us understand how the storage tank behaves during the different rainfall pattern. It will also indicate the type of daily basis rainfall we should consider during the preparation of design curve.

It is very important to note that, when the demand is low compared to the catchment area the reliability tends to be higher in the higher rainfall year rather than the higher frequency. This is because when the demand is low, once there is high rainfall to fulfill the tank (which volume is much larger than the daily demand) the stored water can be used for a longer period without the need of frequent rainfall.

For same storage volume and within our standard demand and catchment area, we received higher reliability in the highest frequency year rather than the wet year .In every case we received lowest reliability in Year with low frequency with low Rainfall that has a higher total rainfall than the dry year.

C. Limitation of the study

From the behavior analysis, we get that with the increase of storage volume the reliability increases. Nevertheless, the reliability remains constant after a certain change in volume and in daily basis model often found out that the constant reliability is lower than the 100%. Therefore, it is very hard to determine the storage volume for which the daily basis model will have 100% reliability. For the very sensitive operation like drinking and cooking water supply in the coastal area, it is very important to identify the minimum storage volume that will give 100% reliability when it will be in operation for a period of more than one year.

Chapter Seven

Operational Reliability

7.1 OPERATIONAL RELIABILITY CONCEPT:

If same rainfall (pattern, intensity) is repeated for an infinite year of time period then for a constant demand (D) and catchment area (A); the minimum storage of tank (V) for which it will operate with 100% reliability for the rest of the time period once it is filled fully, should be taken as minimum design volume for rainwater harvesting for the particular rainfall.

7.2 DETRMINATION OF MINIMUM STORAGE VOLUME:

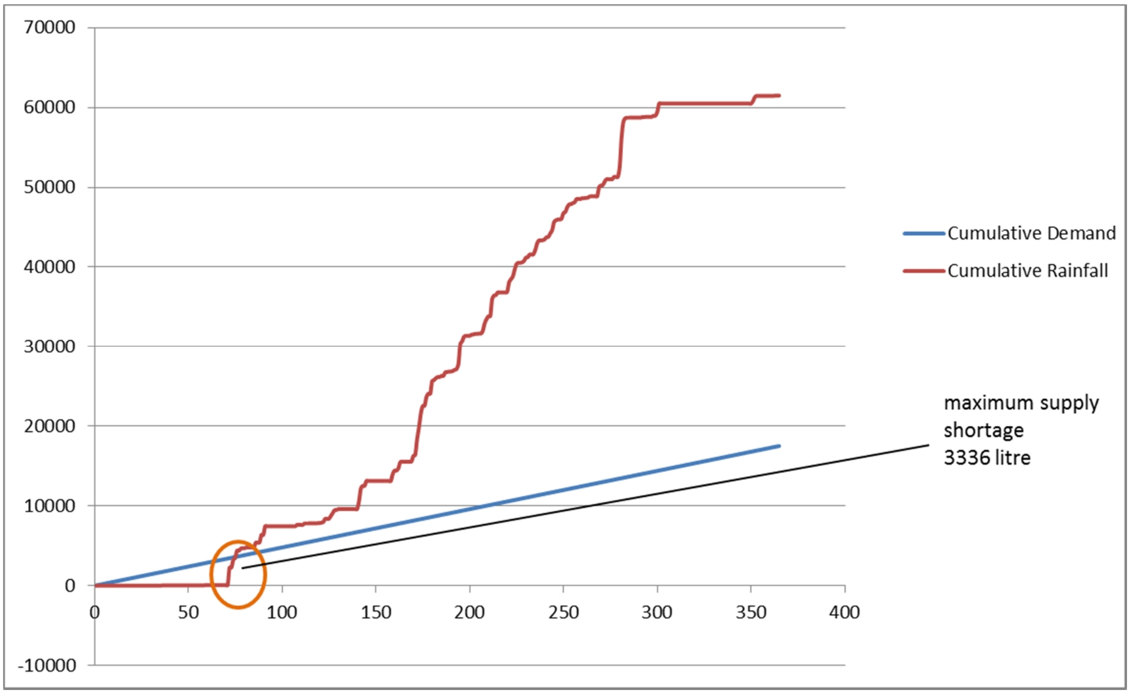
A simple approach can be made to determine the minimum storage volume of tank for 100% operational reliability by the combination of Mass curve analysis and a mass balance sheet prepared with the water balance model. The whole process can be divided into 2 steps.

A. Mass curve analysis

A highest demand-supply lag should be calculated from the mass curve analysis. It is important that the mass curve analysis should be prepared starting from any period. The following mass curve has been prepared from January 2003. If there is no supply shortage throughout the analysis then it is to be taken as zero and should move to second step.

Figure: 7.1

Mass curve analysis:



B. Water balance model sheet

A water balance model on excel sheet has to be prepared by the following theories. The daily basis model should start from the same day as it was started in the mass-curve analysis. The basic composition of the excel formula is described below:

Rainfall intensity, I (mm) = Historic data

Co-efficient, C = .9 (assuming 10% loss, can be varied)

Catchment area, A (m^2) = 40 (variable input for simulation)

Volume of Total Rainwater Q (L) = **I*C*A**

Volume of water used, D (Lpd) = 48 (variable input for simulation)

Storage volume from previous day V_{t-1} = Maximum supply shortage found from Mass curve analysis in case of **1st** day, for **other days** if $V_t < 0$, **0** otherwise $V_{t-1} = V_t$ of previous day

Volume of the tank, T (L) = 1000, 2000,3000,4000,5000 and cont. (Variable input for simulation)

Volume of water storage today, V_t = if, $V_{t-1} + Q - D < T$ then, $V_t = V_{t-1} + Q - D$

Otherwise, $V_t = T$

Supplementary Water Volume, V_{other} = if, $V_t > 0$, $V_{other} = 0$

Otherwise, $V_{other} = -(V_{t-1} + Q - D)$

Reliability Calculation tool, X = if, $V_{other} > 0$, then, **X= 1**

Otherwise **X= 0**

Reliability, $R_e = (P/N) * 100\%$

N= no of days in a year.

U= no of days tank was unable to meet the demand, $U = \sum X$

P= N-U

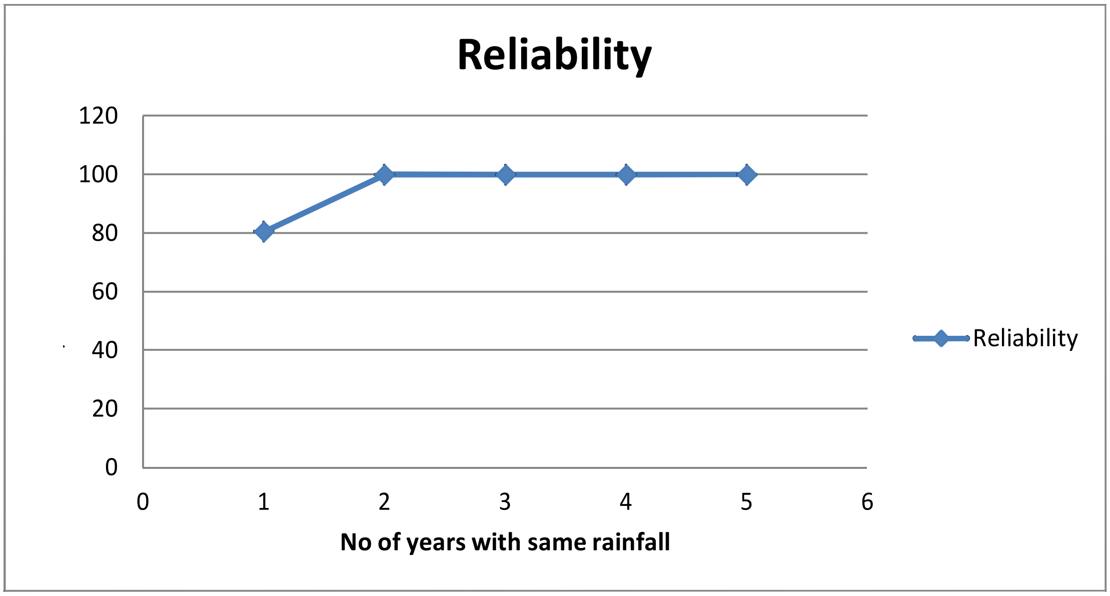
Now a Volume of the tank is to be determined which fulfill the following requirement-

1. A reliability of 100%
2. V_{t-1} of the 1st day = V_t of the last day of the year cycle = Maximum supply shortage found from Mass curve analysis.

For the year 2003 (40 catchment area, 48 lpd demand), the minimum volume that meets the above requirement is 5400 liter. Now a five-year operation chart is prepared by repeating the rainfall of 2003.

Figure: 7.2

Operational reliability for repeated rainfall:



The graph shows that if the rainfall pattern and intensity stays unchanged then for a constant catchment area of 40 sq. and a demand of 48 lpd the tank of 5400 liter will operate with 100% reliability once it fulfill its initial supply shortage.

Since we found lowest reliability in the year 2006 i.e. Year with low frequency with low Rainfall, so the year 2006 is considered for the preparation of design curve of 100% reliability for that period.

7.3 RESULTS AND DISCUSSIONS:

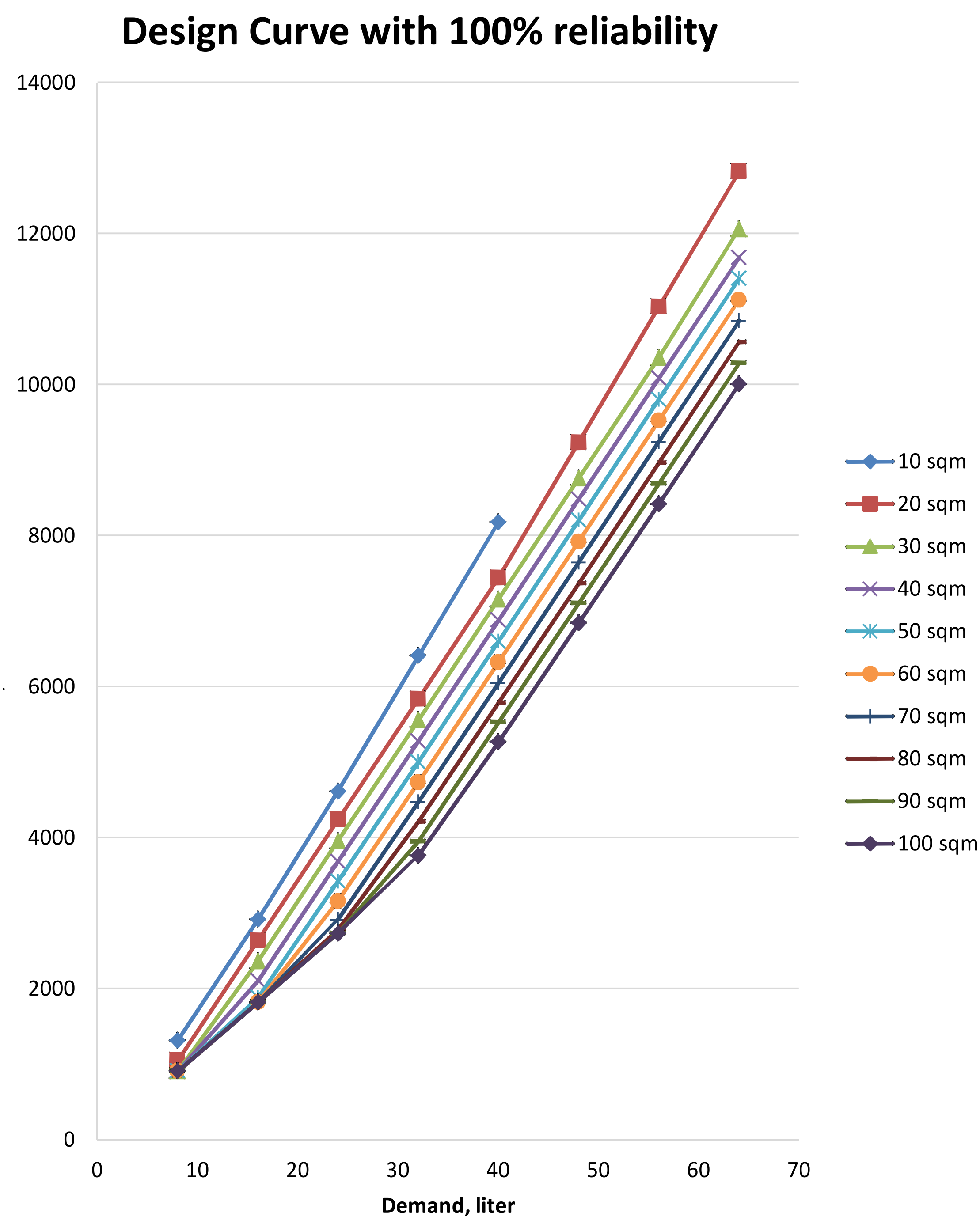
Table: 7.1

Minimum storage volume based on 100% operational reliability concept for the year 2006

Catchment Area (m^2)	Demand(litre)							
	8	16	24	32	40	48	56	64
10	1321	2921	4620	6412	8184			
20	1054	2642	4242	5842	7448	9240	11032	12824
30	912	2369	3963	5563	7163	8763	10363	12068
40	912	2108	3684	5284	6884	8484	10084	11684
50	912	1884	3423	5005	6605	8205	9805	11405
60	912	1824	3162	4738	6326	7926	9526	11126
70	912	1824	2916	4477	6053	7647	9247	10847
80	912	1824	2784	4216	5792	7368	8968	10568
90	912	1824	2736	3955	5531	7107	8689	10289
100	912	1824	2736	3768	5270	6846	8422	10010

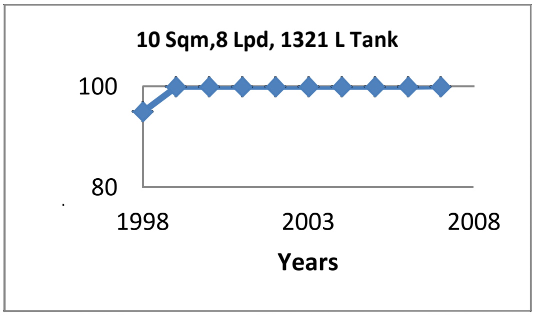
Figure: 7.3

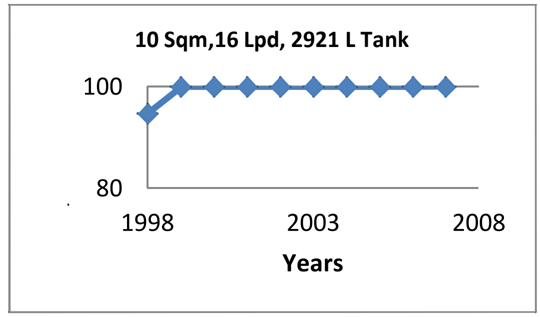
Design curve with 100% reliability for the year 1998-2007 (Mongla Area)

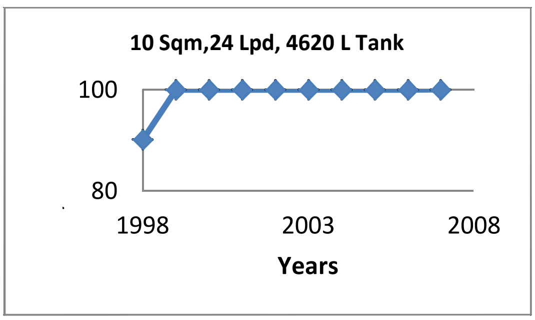


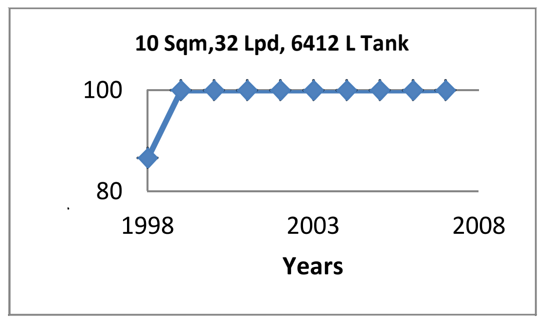
Figures: 7.4 -7.79

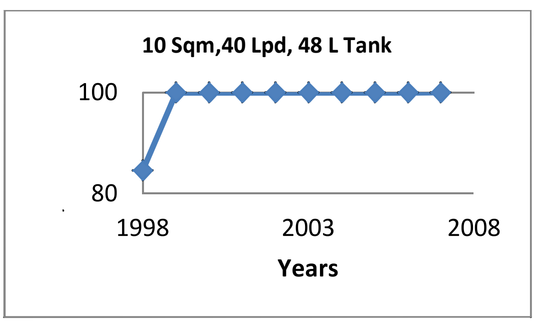
RESULTING OPERATIONAL RELIABILITY CURVE (1998-2007) USING THE STORAGE VOLUME FROM DESIGN CURVE:

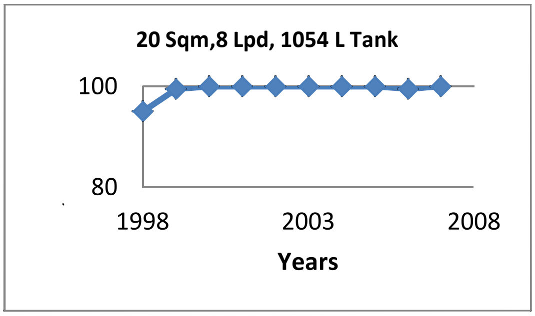








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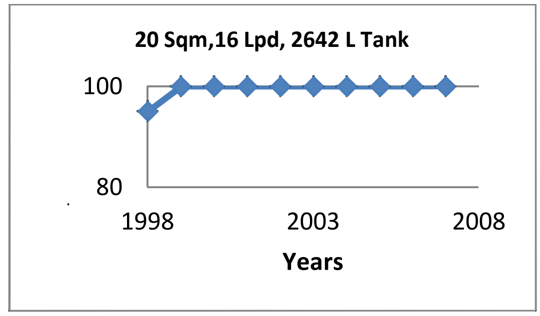
1998
2003
2008
Years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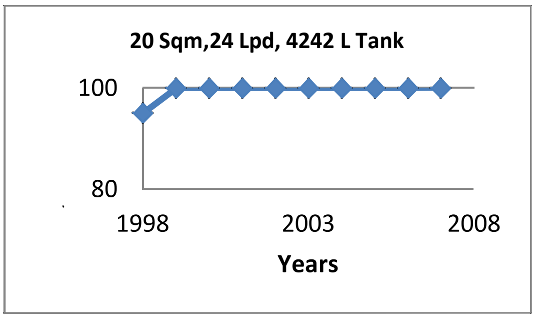
Years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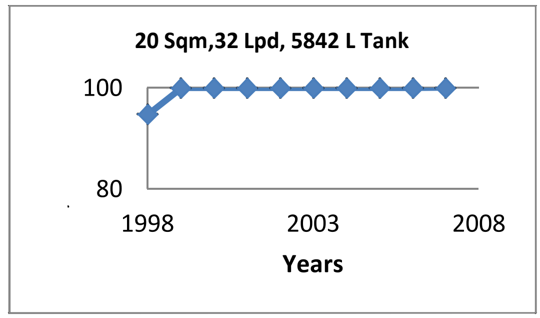
2003
2008
Years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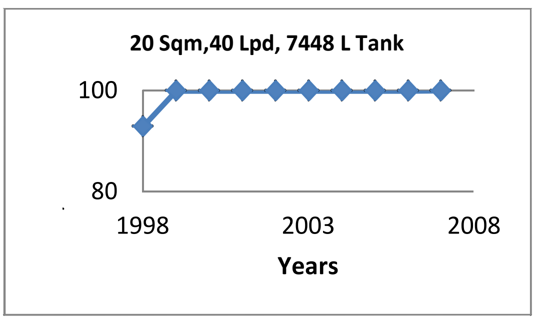
2003
2008
Years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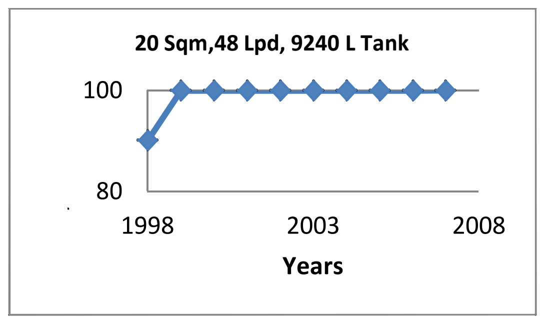
1998
2003
2008
Years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1998
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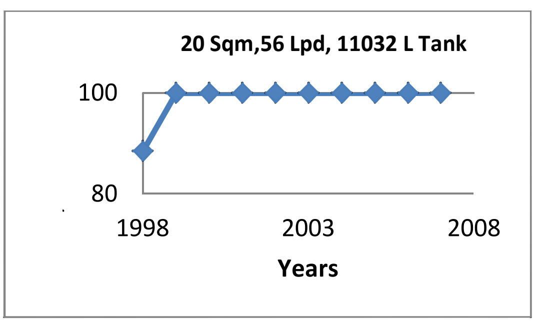
Years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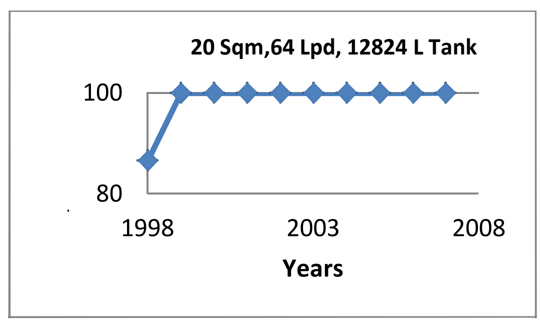
1998
2003
2008
Years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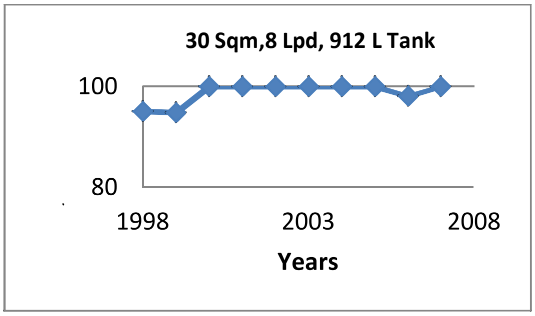
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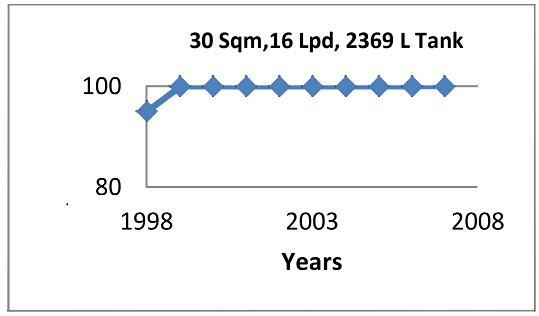
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2003
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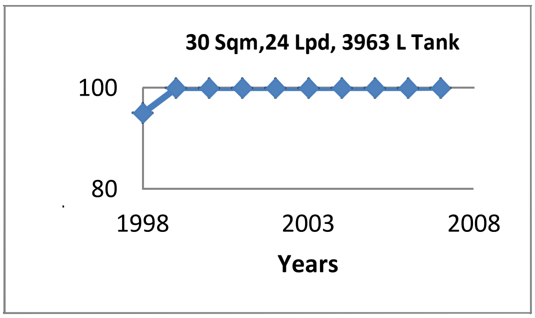
Years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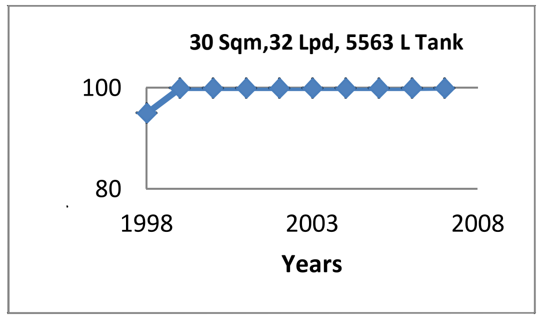
2008
Years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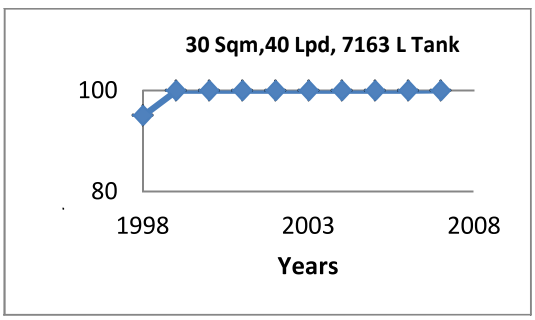
1998
2003
2008
Years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1998
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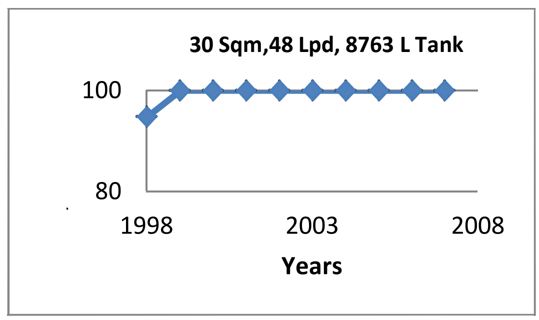
Years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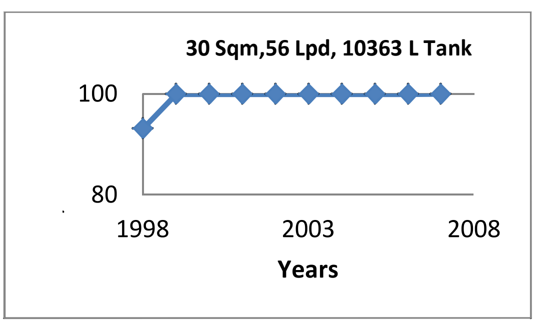
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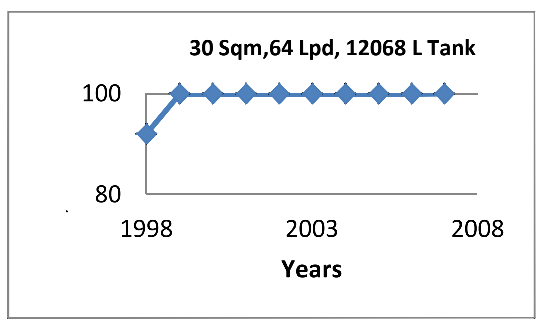
Years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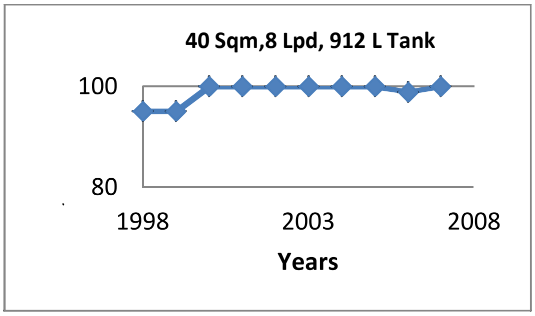
Years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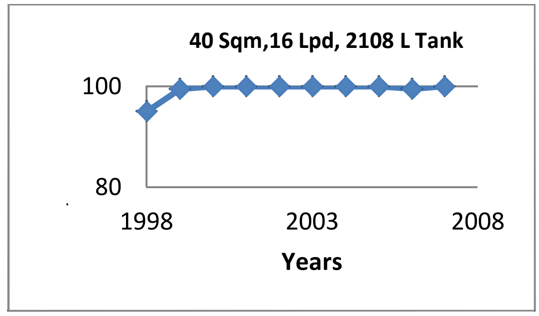
1998
2003
2008
Years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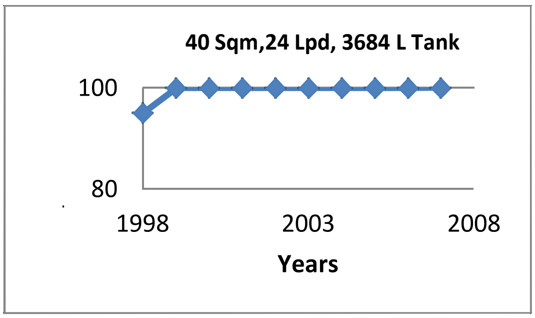
80
1998
2003
2008
Years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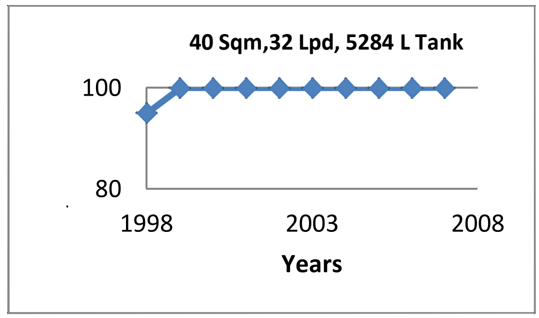
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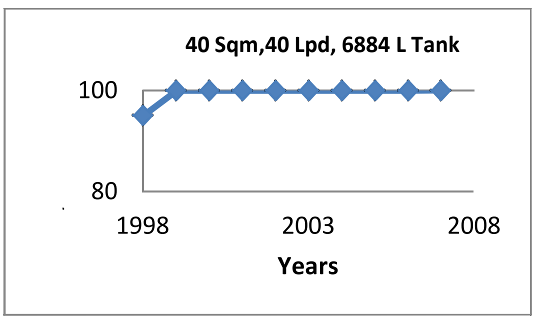
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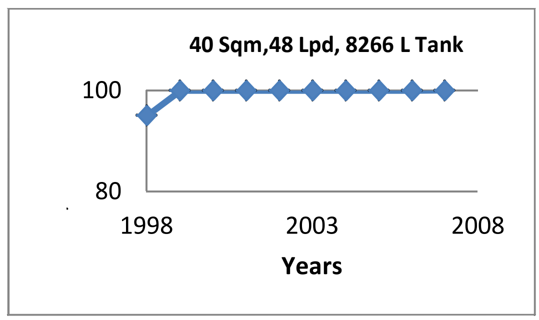
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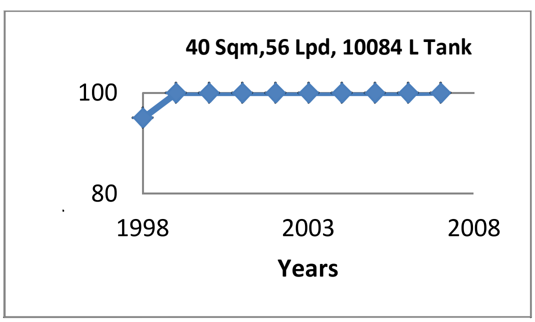
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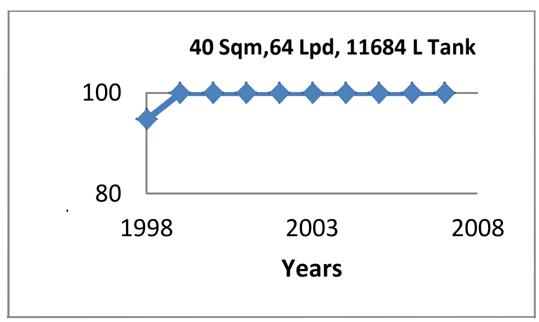
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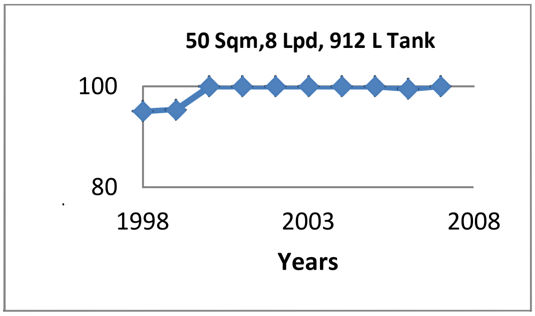
Years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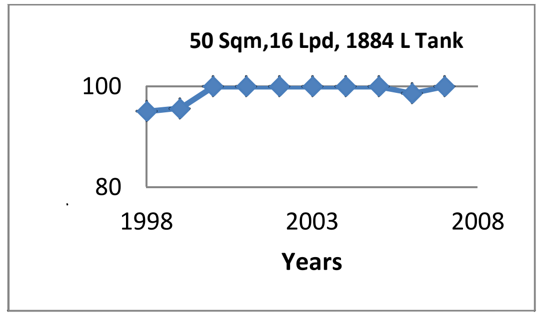
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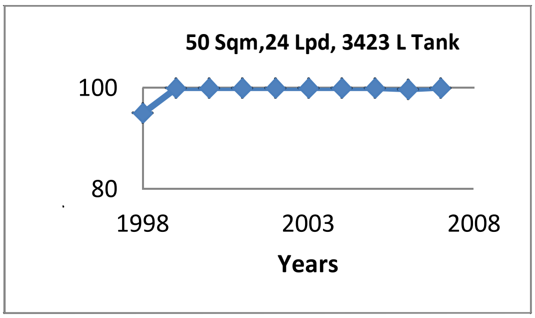
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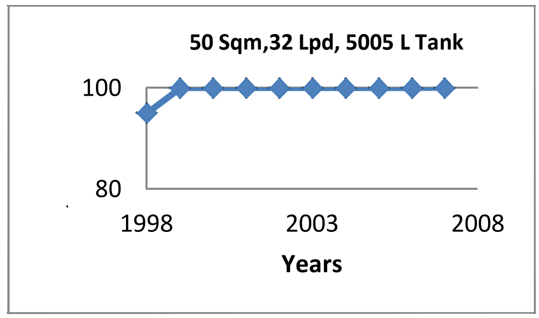
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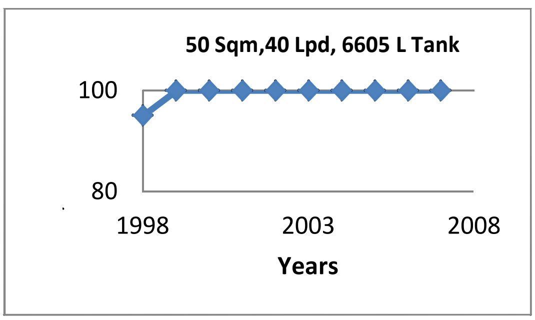
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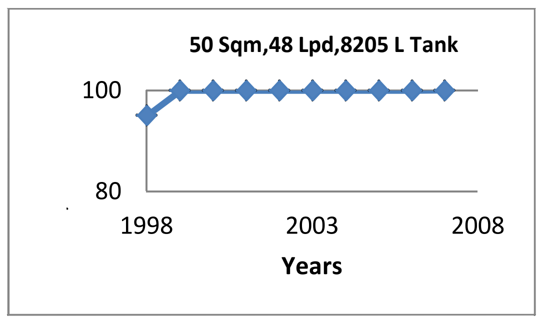
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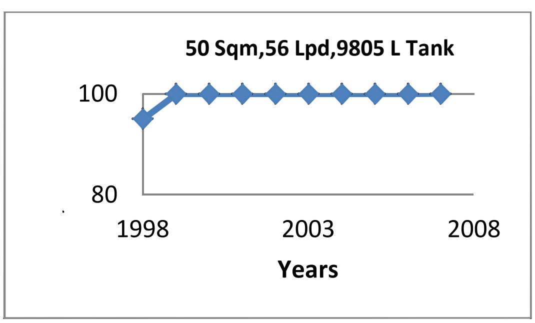
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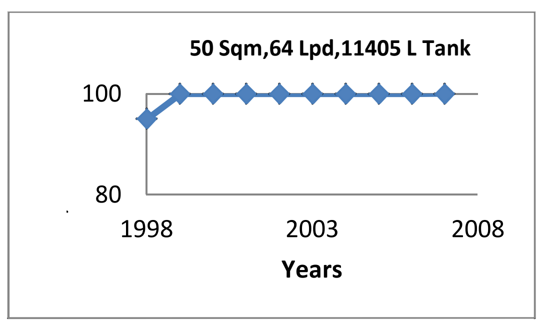
Years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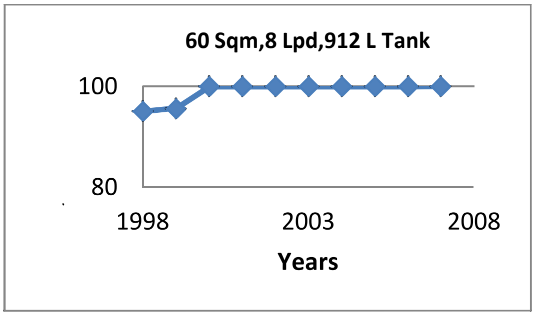
2003
2008
Years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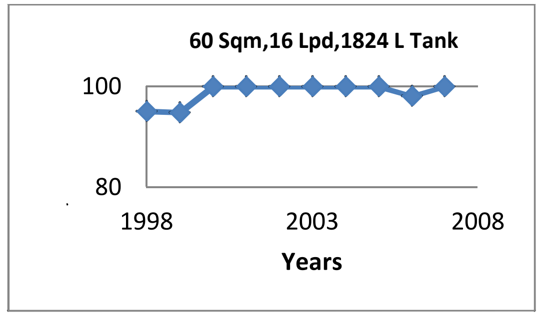
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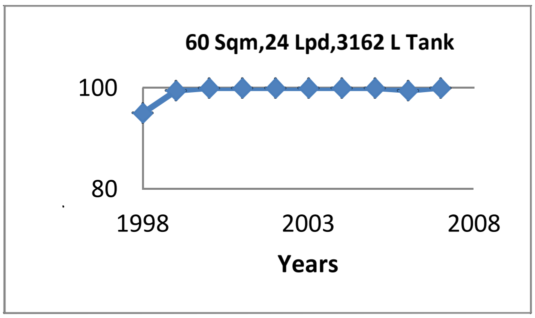
Years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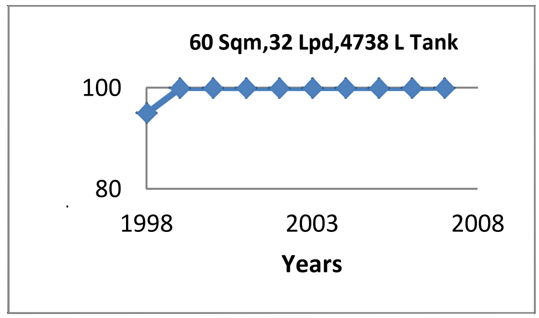
1998
2003
2008
Years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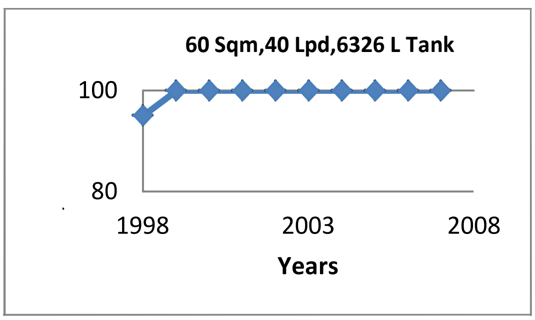
2008
Years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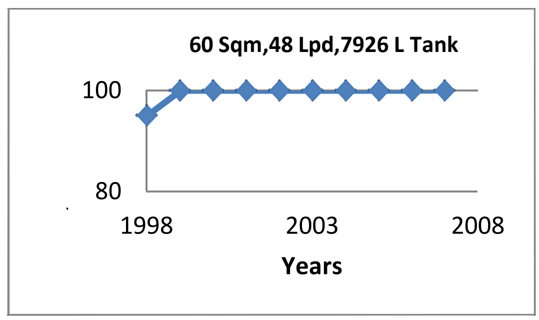
2008
Years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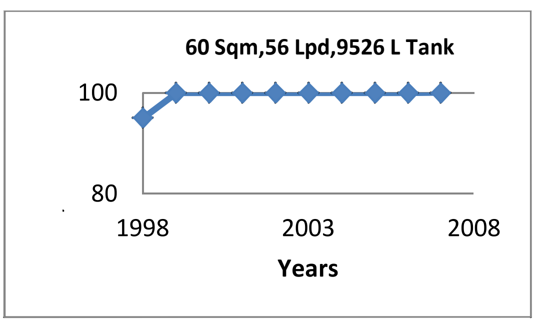
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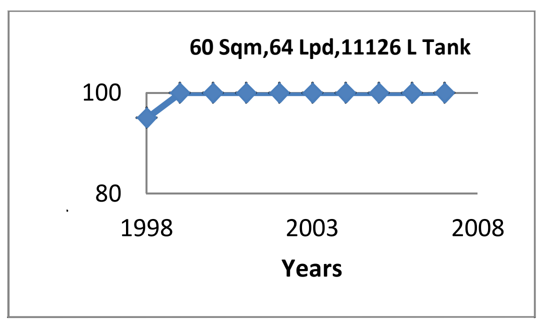
2008
Years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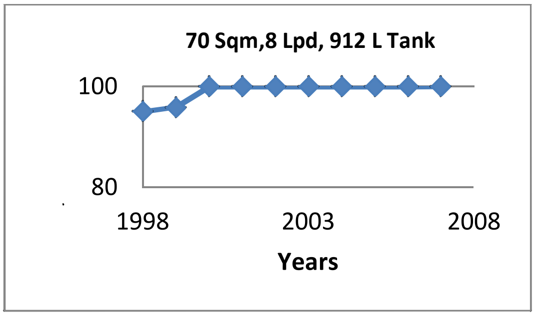
1998
2003
2008
Years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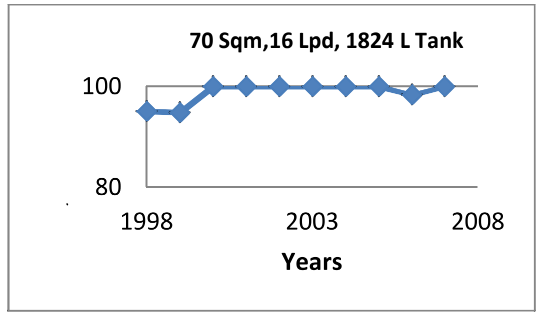
1998
2003
2008
Years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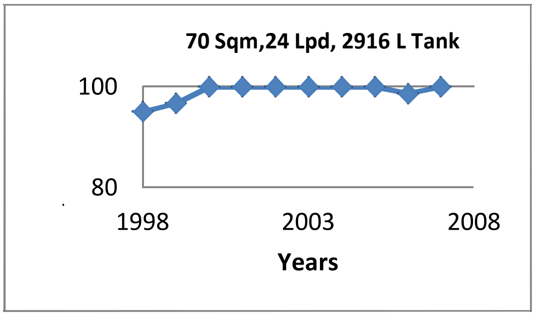
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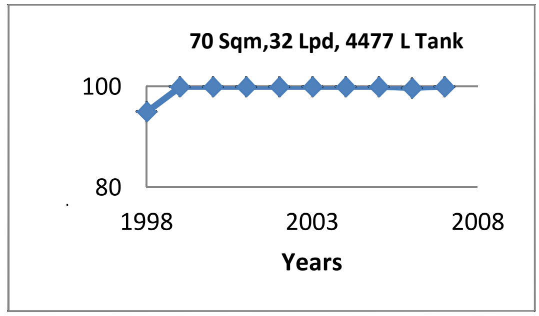
2003
2008
Years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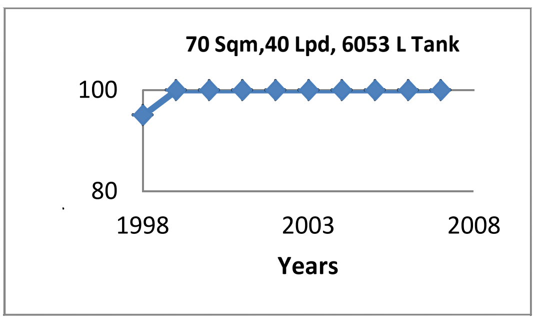
2008
Years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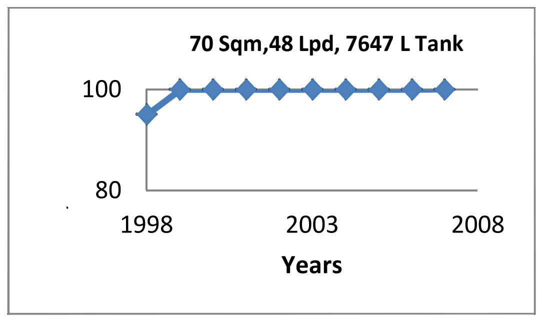
Years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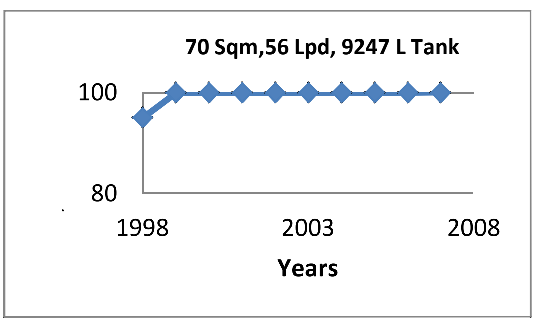
2003
2008
Years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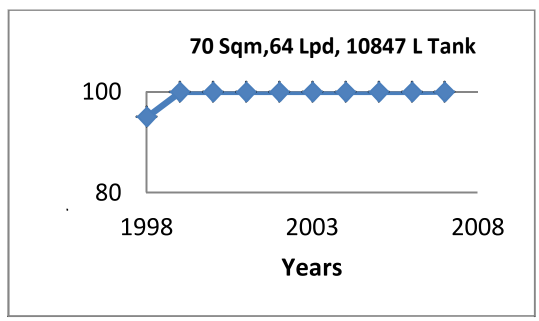
1998
2003
2008
Years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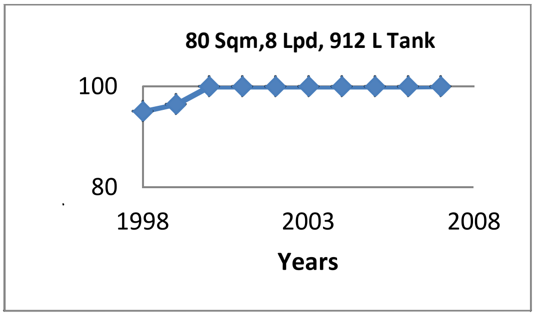
2008
Years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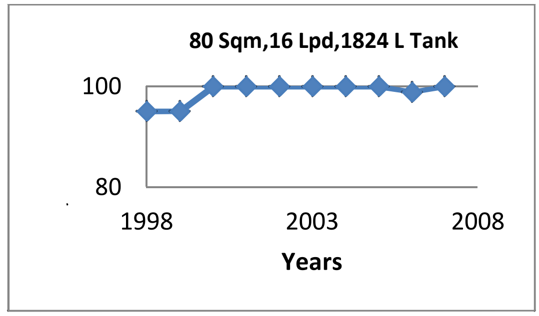
1998
2003
2008
Years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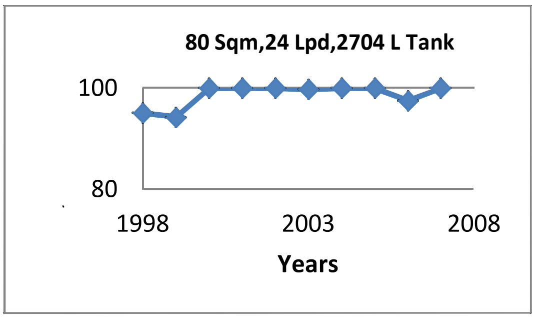
1998
2003
2008
Years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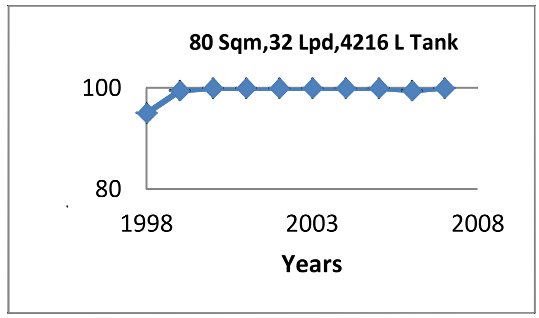
1998
2003
2008
Years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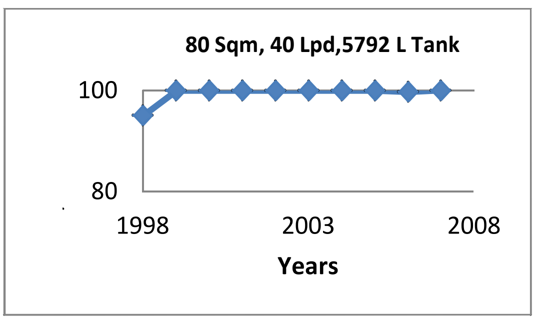
2003
2008
Years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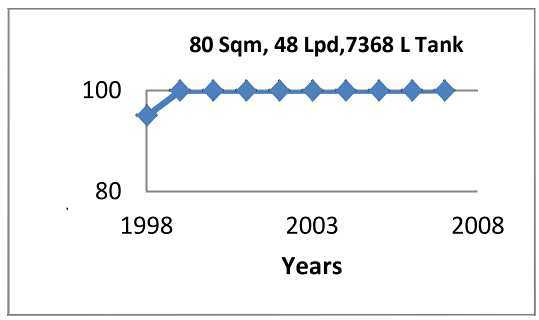
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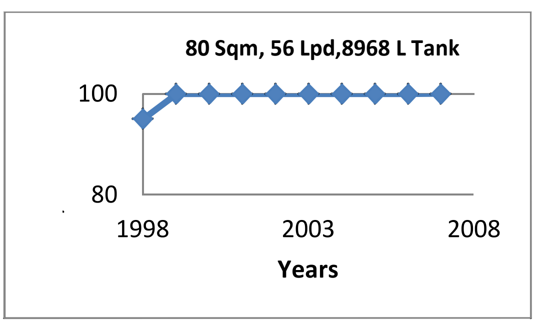
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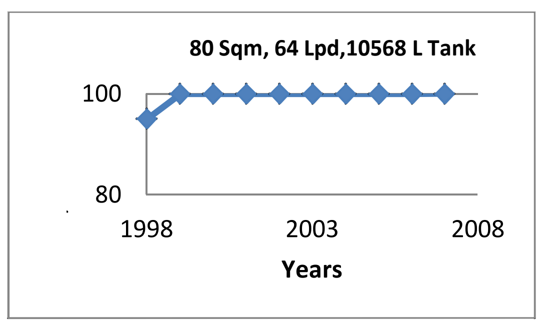
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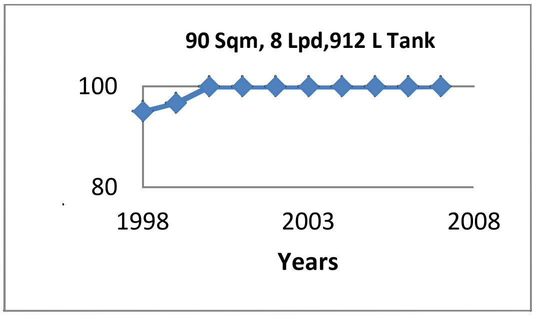
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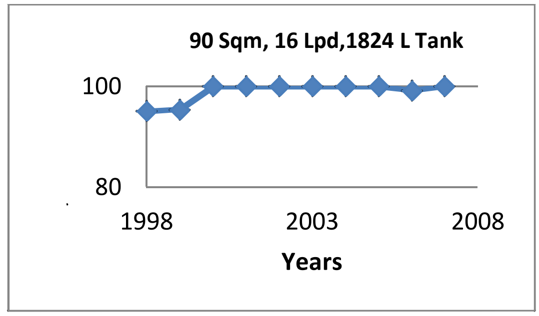
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2008
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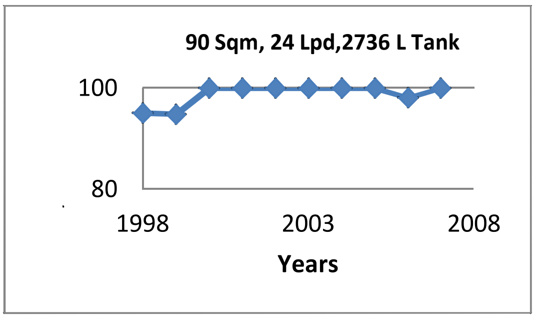
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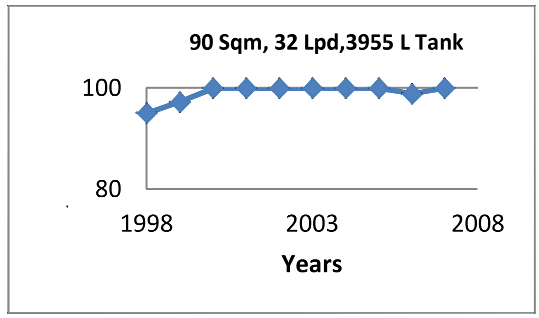
2008
Years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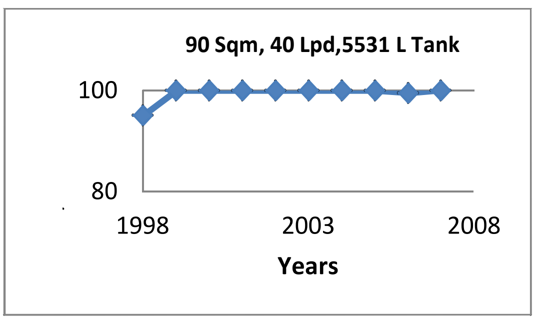
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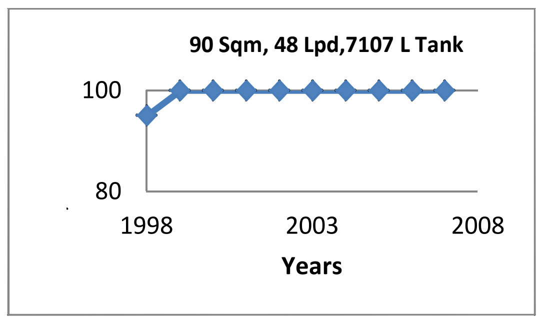
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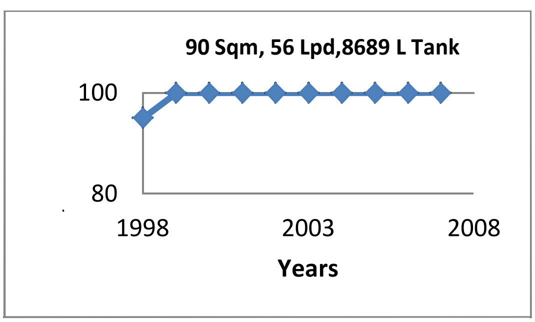
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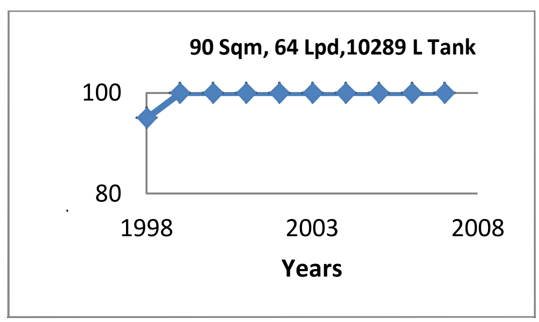
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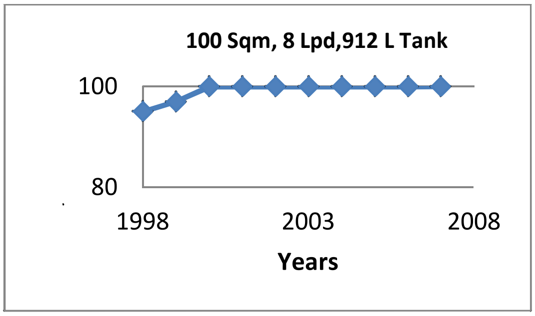
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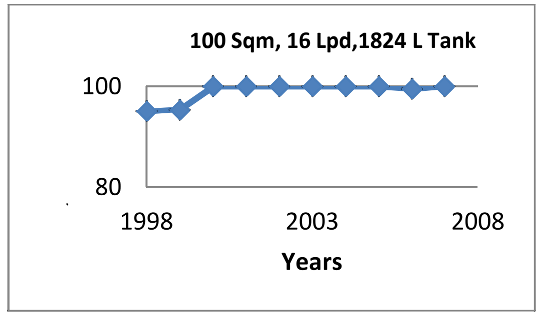
Years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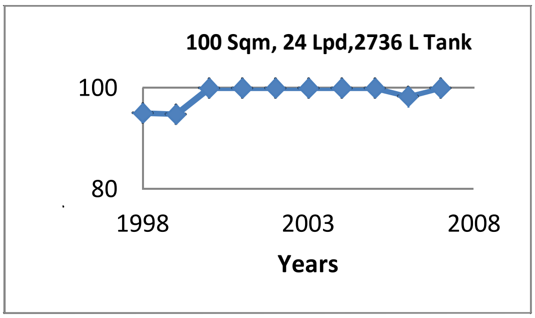
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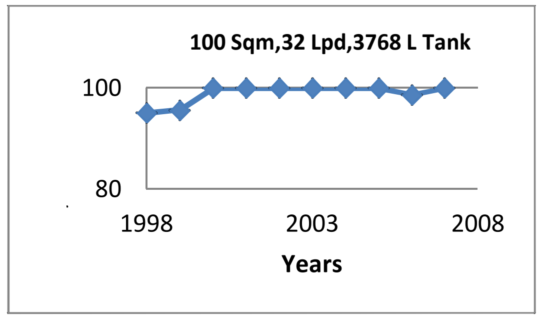
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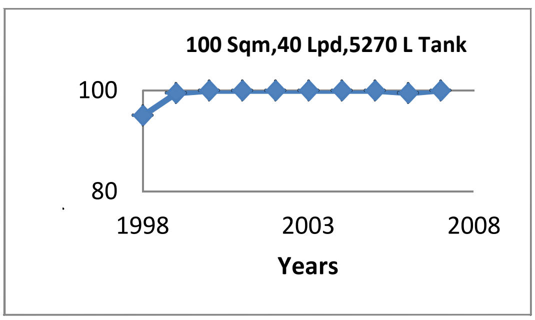
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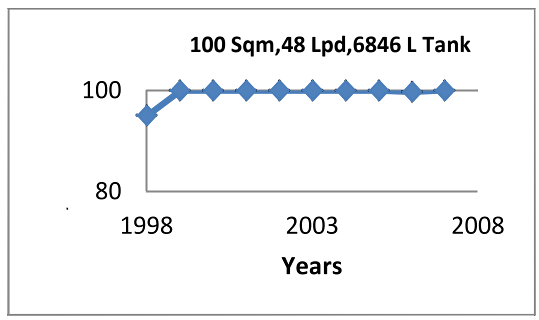
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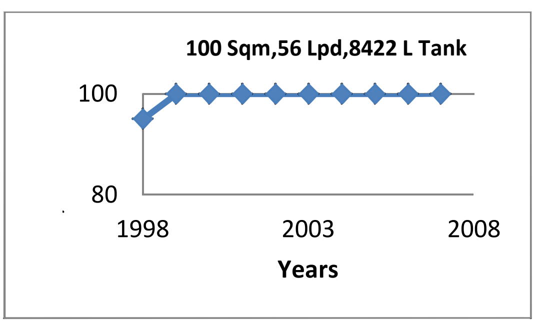
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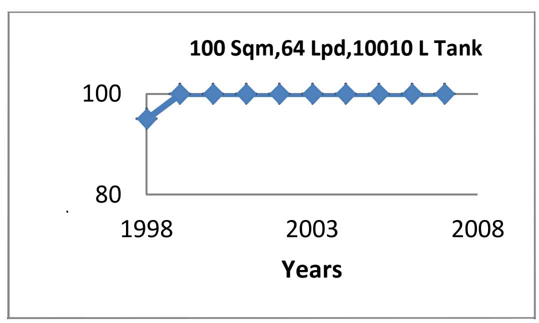
100 Sqm,64 Lpd,10010 L Tank
100
80
1998
2003
2008
Years

A. Findings from graphs:

In the most cases, the minimum storage obtained from the design curve fulfilled the expected reliability of 100% in the 10-year operation. The only exception was when Catchment Area/Demand ratio was very low. In those cases, the occasional rainfall in the dry period of the designed year (in this case 2006) contributed an extended storage of water in the tank that caused some alteration from the expected outcomes.

Table: 7.2

Comparison of design storage volume from mass curve analysis and operational reliability concept:

Catchment	Demand(litre)															
	8		16		24		32		40		48		56		64	
	Mass curve	Opra. relia	Mass curve	Op.relia	Mass curve	Op.relia	Mass curve	Op.relia	Mass curve	Op. relia	Mass curve	Op. relia	Masscurve	Op. relia	Mass curve	Op. relia
10	801	1321	1809	2921	2817	4620	3825	6412	4833	8184	5841		6849		7857	
20	594	1054	1602	2642	2610	4242	3618	5842	4626	7448	5634	9240	6642	11032	7650	12824
30	504	912	1395	2369	2403	3963	3411	5563	4419	7163	5427	8763	6435	10363	7443	12068
40	504	912	1188	2108	2196	3684	3204	5284	4212	6884	5220	8484	6228	10084	7236	11684

50	504	912	1018	1884	1989	3423	2997	5005	4005	6605	5013	8205	6021	9805	7029	11405
60	504	912	1008	1824	1782	3162	2790	4738	3798	6326	4806	7926	5814	9526	6822	11126
70	504	912	1008	1824	1590	2916	2583	4477	3591	6053	4599	7647	5607	9247	6615	10847
80	504	912	1008	1824	1512	2784	2376	4216	3384	5792	4392	7368	5400	8968	6408	10568
90	504	912	1008	1824	1512	2736	2169	3955	3177	5531	4185	7107	5193	8689	6201	10289
100	504	912	1008	1824	1512	2736	2036	3768	2970	5270	3978	6846	4986	8422	5994	10010

References

Works Cited-Chapter 1

(1.). Retrieved from www.rainwaterharvesting.org/whatiswh.html

(2.). Retrieved from https://en.wikipedia.org/wiki/Water_scarcity

(3.). Retrieved from http://en.wikipedia.org/wiki/Rainwater_harvesting

(4.). Retrieved from http://www.unep.or.jp/ietc/publications/urban/urbanenv-2/9.asp

(5.). Retrieved from http://data.worldbank.org/indicator/AG.LND.PRCP.MM?order=wbapi_data_value_2011+wbapi_data_value+wbapi_data_value-first&sort=desc

(2012). *THE UNITED NATIONS WORLD WATER DEVELOPMENT REPORT 4.* United Nations Educational Scientific and Cultural Organization,UNESCO.

Gazeta, R. (2010). Retrieved from http://waterforum.ru/eng/news/923/

Works Cited-Chapter 2

A. Campisano, C. M. (11-16 September 2011). Regional evaluation of the performance of rooftop rain water harvesting systems for domestic use. *12nd International Conference on Urban Drainage.* Porto Alegre/Brazil.

Dixon, A. M. (1999). Water saving potential of domestic water reuse systems using greywater and rainwater in combination.

Fewkes, A. (2004). The Modelling and Testing of a Rainwater Catchment System in the UK.

Fewkes, A. (November 2000). Method of modelling the performance of rainwater collection systems in the United Kingdom.

Matt Basinger, F. M. (2010). A rainwater harvesting system reliability model based on nonparametric stochastic rainfall generator. *Journal of Hydrology*.

S. Ward*, F. A. (2008). Rainwater harvesting: model-based design evaluation . *11th International Conference on Urban Drainage, Edinburgh, Scotland, UK.*

Works Cited-Chapter 3

Aneire Ehmar Khan, A. I. (n.d.). Drinking Water Salinity and Maternal Health in Coastal Bangladesh: Implications of Climate Change.

Geography of Bangladesh. (n.d.). Retrieved from wikipedia: en.wikipedia.org/wiki/Geography-of-Bangladesh

M.Feroze Ahmed, M. M. (june,2000). *Water Supply & Sanitation* (1st ed.).

Mohammed Fazlul Karim, N. M. (n.d.). *SEA LEVEL RISE IN THE BAY OF BENGAL: ITS IMPACTS AND ADAPTATIONS IN BANGLADESH.*

Mongla Upazilla. (n.d.). Retrieved from Wikipedia: en.wikipedia.org/wiki/mongla-upazilla

Sayma Khanom, M. S. (n.d.). SALINITY CONSTRAINTS TO DIFFERENT WATER USES IN COASTAL AREA OF BANGLADESH:A CASE STUDY.

Shakil A. Ferdausi, M. W. (2000). Rainwater Harvesting for application in rural Bangladeh.