STORAGE VOLUME AND RELIABILITY OF RAINWATER HARVESTING IN THE COASTAL AREAS OF BANGLADESH USING A DAILY WATER BALANCE MODEL

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ABSTRACT

Scarcity of fresh water has become a thing of concern around the world. Now, in developing countries this necessity has become a priority to be addressed like never before. Having population on the up rise in one hand and declining of fresh water resources on the other, necessity of finding an alternative source of fresh water has become the foremost priority in the world, let alone developing countries. Rainwater is one of the purest water sources on earth and harvesting rainwater has been found to be the most sustainable method of collecting fresh water. In developing countries like Bangladesh rainwater harvesting can provide an effective alternative source of fresh water, especially in the coastal areas where fresh water is scarce due to salinity in the ground water and surface water. These areas have a lot of rainfall that can be used for household and drinking purposes. Although agriculture and industrial water demand may not be fully satisfied by rainwater, drinking and household purposes may use rainwater without any question. But not too many studies have been conducted regarding this. People in this region although are using this technology but the tank sizes are not determined based upon their demand. For the purpose of storage volume and reliability analysis of rainwater harvesting in the coastal areas of Bangladesh a daily water balance model was obtained. Three daily rainfall data; Dry, Wet and Average year condition was used for developing the design curves and the reliability analysis. For the conduction of reliability analysis, catchment area and demand was increased and the results were observed from a spreadsheet. The analysis was done for household water demand only and for that reason a family of 6 members was selected as a typical family. A co-efficient factor of 0.9 was used in all these cases. In brief for a six person household scenario, almost 96% reliability can be achieved by a catchment area of 40 m^2 and a tank volume of 500 to 5000 liters in an average year condition. For a wet year condition almost

80% reliability can be achieved by a catchment area of 40 m^2 and a tank volume of 500 to 5000 liters. And for, dry years 73% reliability can be achieved for the similar condition. The analysis confirmed that rainwater can effectively meet the needs of the people in this region. More studies must be conducted on this matter but for now, it can be said that, rainwater harvesting can be more efficiently undertaken to solve the fresh water scarcity problem in the coastal areas of Bangladesh.

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CHAPTER ONE

INTRODUCTION

1.1 GENERAL

Water is currently the most important issue in the world. Increase in human activities & natural calamities, surface & ground water is becoming less palatable day by day. Water scarcity is a major problem in many developing countries. Depending upon precipitation intensity rainwater is a potential source of drinking water. Water scarcity is an increasingly severe problem worldwide due to factors such as excessive consumption of raw water, climate change, water pollution and unsustainable water resource consumption. Under these conditions, alternative forms of fresh water resource such as rainwater is being considered as attractive options to reduce potable water consumption. . One of the primary goals of WHO and its member states, is that, “All people whatever their stage of development and their social and economic conditions, have the right to have access to an adequate supply of safe drinking water.” (WHO, 2006). The fresh liquid water sources on land surfaces and in the ground constitute only about 1% of the total water on earth. These fresh water sources have been formed by condensation of water evaporated mainly from the ocean and seas. Perhaps water is the most frequently occurring substance on earth, but still evidence of recent estimate indicates that more than one billion people do not have access to safe water (World Bank, 1977). Two- third of the total surface of earth is covered by water. But the total surface water is not suitable for drinking and other purposes. Presently 2.5% of the total water of the earth is drinkable (NGO Forum, 2003)

Bangladesh is a small country with a huge population. Despite of being a riverine country and situated beside the Bay of Bengal safe drinking water is very scarce. Water borne diseases are very common in our country.

In the coastal areas the ground water and surface water is saline which is not drinkable. But we have a lot of rainfall in these regions which is a potential source of safe drinking water. This water can be used for other purposes as well.

Rain water may be used due to the following reasons:

- To reduce pressure on ground water.
- Surface water can get polluted very easily which is harmful for our health.
- To decrease water pollution.
- Rain water is necessary for places with no surface or ground water.
- Rain water contains less pathogen.
- Rain water is the ultimate form of distilled water.
- Rain water is easy to collect.
- In coastal areas the water is saline so rain water may be used for drinking or household purpose.
- Decrease of unsuitable water resource consumption.

These are the reasons why rainwater harvesting has become such an important issue. Rainwater harvesting (RWH) is a technology where surface runoff is effectively collected during yielding rain periods. In order to support such technologies RWH systems should be based on local skills, materials and equipments. Rainwater harvesting (RWH) is recognized as one of the most widely accepted solutions to save potable water. A significant number of studies reported in the literature confirm the potential of rainwater harvesting as an alternative source for saving potable water. (Opportunities in rainwater harvesting, B. Helmreich, H. Horn).

The precipitation regime is obviously considered as the key factor dominating the RWH performance. In rural areas around the world there is lack of access to potable water. In this context, the practice of rain water harvesting (RWH) is becoming important.

Satkhira is a district in South-western Bangladesh which is a part of the Khulna Division. It is located beside the Sunderbans. The tidal influence of the Bay of Bengal plays an important role in intrusion of salt in the ground water. Chemical parameters interpretation reveals that the water quality in Satkhira Municipality is mostly calcite and dolomite originated. As a result people of this area cannot rely on ground water for drinking and household purpose. Conditions like this make rainwater harvesting an eminent solution to satisfy their needs.

Current trend in the coastal areas is to use tank size of 3200 liter or 5000 liter capacity. But these tanks were not built based upon any demand studies. So, these tanks are not fully efficient. This thesis work will help to find out the tank size or storage volume actually required for a family of 6 members, to satisfy their water requirements for household purpose, according to their demand and the catchment area they have.

1.2 OBJECTIVE

- Development of a generalized storage volume vs. water demand curves (design curve) for the coastal areas of Bangladesh.
- Analysis of the rainwater harvesting system reliability using a daily water balance model.

1.3 SCOPE OF OUR STUDY

The mass curve approach was used to develop a design curves. This model was used to determine the storage volume available based upon the demand and catchment area available. The reliability of the system was determined and various comparisons were done to compute the supplementary water demand, the volume of water that will spill and the percentage of days in a year the tank will remain full. This works were done for average year, dry year and wet year conditions for different tank volumes and per capita water demand. This study will help to determine the following.

- Analyzing rainfall pattern and determining the minimum, maximum and average rainfall data to determine the tank volume of the study area.
- Determining the available storage volume to ensure supply of safe drinking water throughout the year..
- Determining the household water demand that has to be satisfied by harvested rainwater based on per capita demand of water.

- Demand curve will help to determine the volume of tank needed to satisfy the intended demand.
- Analyzing the reliability of the system would prove the sustainability of the system.
- RWH is the cheapest way to get palatable water so it may help to ensure the full efficient output of this system.

1.4 LIMITATIONS

For the purpose of this study only household water demand has been considered. Other purposes like industrial water demand and agricultural water demand has not been considered. If it were considered, the water demand would have been much higher and this process would not be sufficient for that analysis.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Water is the most important element in our daily life. Scarcity of water may lead to absolute destruction. Need of water has become a major worldwide issue in recent times. Now, due to various reasons water is getting polluted. So, proper steps have to be taken to ensure safe and sound water distribution. Modern expedition identifies that rain water harvesting is a major source of pure water. If this technique is utilized properly then a sustainable water source is achieved. Our study area is Satkhira which is one of the major regions that faces water scarcity.

Scarcity of safe drinking water has taken a serious turn in Satkhira causing immense sufferings to the town dwellers as the municipal authorities cannot supply around half of the required quantity of water. Satkhira municipal revels that, water cannot be lifted as per demand through the pumps due to decline in water table. Most of the pumps remain inoperative also due to frequent load-shedding and voltage fluctuation.

According to sources, there are 7,100 water connections for over 1,35,000 people in the municipality while the authorities are now supplying 6,300 liters of water against the demand of about 11,000 liters (Abu Ahmed, Daily Star, march 2012) . On the other hand Patients at Satkhira Hospitals and other private clinics are suffering a lot due to the scarcity of drinking water. Due to sharp fall in groundwater level, it is not possible to lift around half of the required water through pumps.

In some areas ground water is also polluted with chemicals like arsenic, dolomite, calcite etc. and intrusion of saline water is a common phenomena. So as a mean to ensure safe drinking water rain water harvesting is necessary for this region.

A significant number of studies reported in the literature confirm the potential of domestic rainwater harvesting as an alternative source for saving potable water. These studies reveal that the potential of DRWH systems ranged from 12% to 100% in potable water saving according to the specific environmental conditions (Herrmann and Schmida, 1999; Sazakli et al., 2007; Ghisietal., 2007; Zhang et al., 2009; Abdulla and Al-Shareef, 2009).

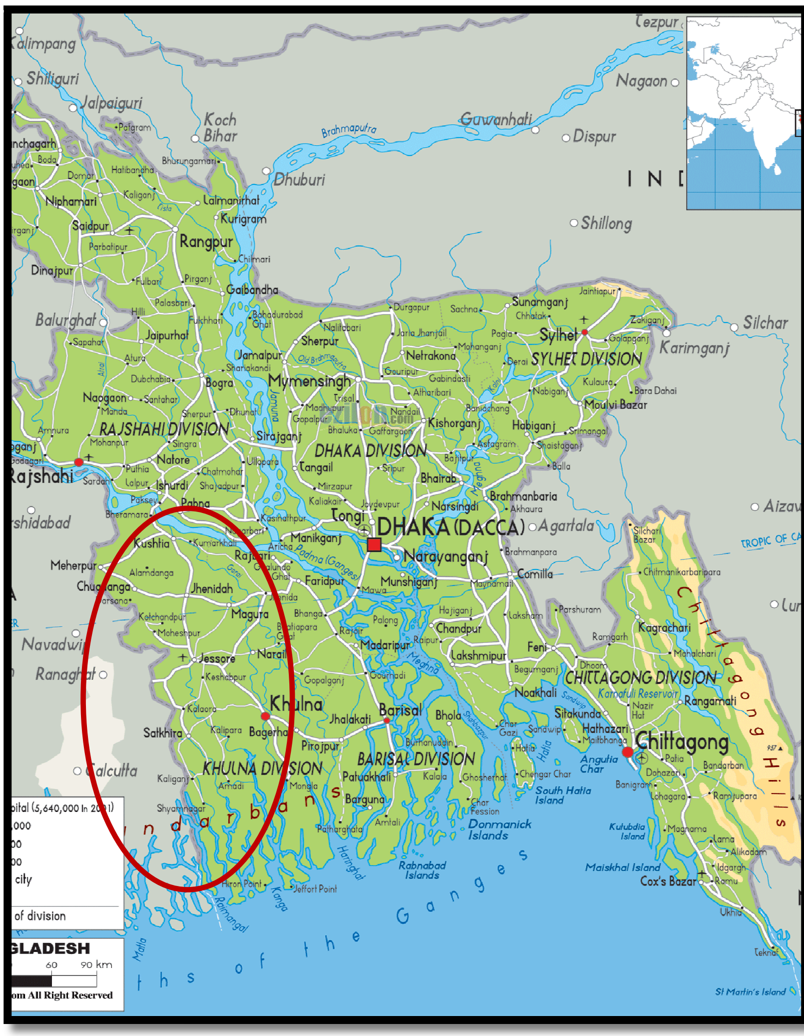

Fig (2.1) : Map of Bangladesh

2.2. RAINFALL IN BANGLADESH

Bangladesh is a country that receives a lot of rainfall due to its geographical location in the tropical areas. The rainfall distribution all over the country is not uniform. Some parts of the north-east of the country and the south eastern coastal areas receive heavy rainfall (more than 3000 mm). Other parts of the coastal area receive a moderate amount of rainfall (2400 mm to 2700 mm).

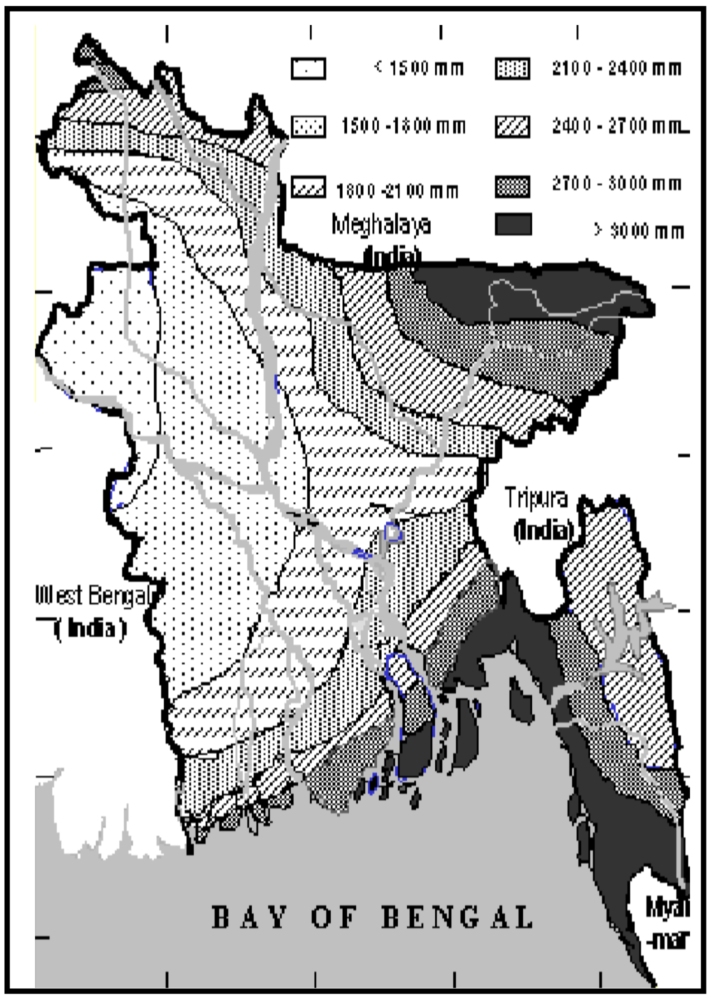

Fig (2.2): variations of average annual rainfall in Bangladesh.

2.3. TYPICAL HOUSEHOLD SIZE AND CATCHMENT AREA IN BANGLADESH

There is abundant amount of rainfall in our country. But in case of rainwater harvesting household size and available catchment area is not taken into account for determining the storage volume needed to satisfy the water demand. Distribution of household by number of persons is given below in a table.

Table 2.1: Distribution of household by number of persons (BBS, 1997)

Person per household	Household		Population	
	Number	Percentage	Number	Percentage
1	477582	2.5	477852	.5
2	1411930	7.4	2823860	2.7
3	2421613	12.7	7264839	7.0
4	3164239	16.6	12656965	12.1
5	3233789	17	16168945	15.5
6	2746566	14.4	16479396	15.8
7	2019973	10.6	14139811	13.6
8	1344665	7.1	10757320	10.3
9	840881	4.4	7567929	7.3
10+	1358975	7.2	1584827	15.2

From the table (2.1) it is seen that 15.8% of the population belongs to a household of 6 persons. 14.4% of the households have 6 persons in them, in Bangladesh. For this reasons, a household size that has 6 persons, is considered for this study.

If number of persons in a household increases there is more need of water. Rainfall is captured through the rooftop area of a house. If there is more demand more rainfall has to be captured for sustainable rain water harvesting system. So, the catchment area depends directly on the household size. Roofing size in a typical rural area for Bangladesh are given below.

Table 2.2: Roofing size in a typical rural area (Ferdausi, 2000)

Roof area < 20 m²	Roof area 20-40 m²	Roof area 40-60 m²	Roof area 60-80 m²	Roof area >100 m²
6	5	10	4	3

Most number of houses has roofing area of 10-40 m². so, for the purpose of this study roofing area of 10-50m² has been selected to develop the design curves and for 10-40 m² catchment area has been selected to determine the reliability of the system.

2.4. GEOLOGY OF THE COASTAL AREA

The geology of the coastal area is part of the overall Quaternary geology of the Bengal Basin (BAKR, 1976; MORGAN & MCINTIRE, 1959). Sediments from early Ganges-Brahmaputra-Meghna river systems were deposited over the northern and eastern parts of the basin during Pleistocene period. Tectonic movements and sea level changes between Pleistocene and recent periods have allowed deep erosion and deposition on the Pleistocene surface. Fluviatile environment of sedimentation in the southern downward area of Bengal Basin formed overlapping deltaic arcs of Ganges-Brahmaputra-Meghna river systems in recent time. The coastal belt of Khulna-Satkhira is within Ganges delta. Floodplain sediments in Satkhira coastal belt, according to borehole information drilled in the area up to a depth of 300 m are mainly composed of medium and fine sands, clay, and silty-clay and sandy clay unit. A continuous silty-clay layer of varying thickness from few centimeters to 50 m occurs at the top. The coastline is 710 km. The coastal area of Bangladesh is a part of the flat Ganges Delta, which is intersected by large tidal rivers discharging into the Bay of Bengal. The main rivers flowing through this area are Morichapr, Kholpotuar, Betna, Raimangal, Hariabhanga, Ichamati, Betrabati and Kalindi,Jamuna. For the purpose of this study, rainfall data of Satkhira rainfall station was collected from Bangladesh Meteorological Department. Satkhira is situated in the south-western part of the country and it has all the typical conditions of a coastal zone.

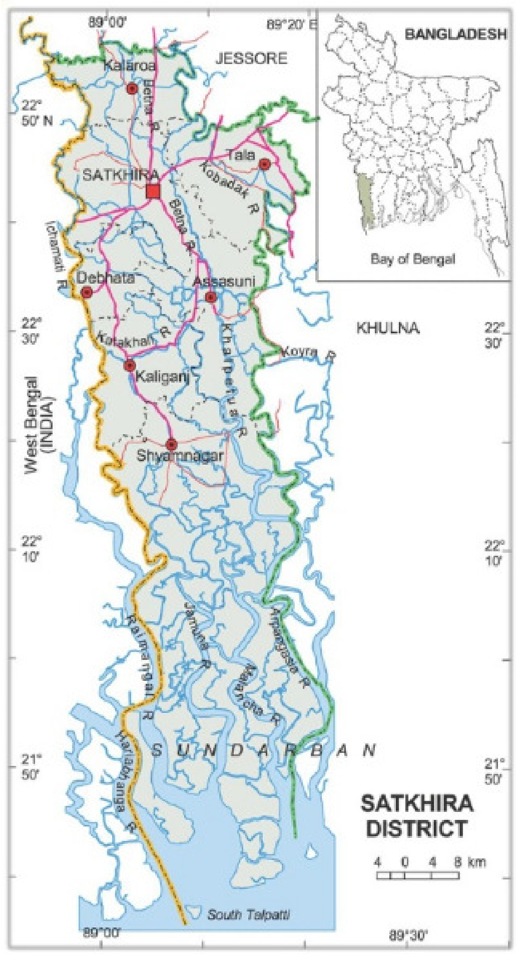

Fig (2.3): Map of Satkhira

2.5. COASTAL WATER SUPPLY SYSTEM

The whole coastal area is situated in the south east of Bangladesh. The Bay of Bengal is situated in the south of it. Sunderbans is situated in the north of it. The coastline is 710 km. The coastal area of Bangladesh is a part of the flat Ganges Delta, which is intersected by large tidal rivers discharging into the Bay of Bengal. The saline front along the 720-km coastline has encroached is greater than 100 km inland into domestic ponds, groundwater supplies, and agricultural land through various estuaries and water inlets, which are interlinked with the major rivers (Allison et al. 2003; Rahman and Bhattacharya 2006).

The coastal population of Bangladesh relies heavily on rivers, tube wells (groundwater), and ponds for washing, bathing, and obtaining drinking 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 (Rahman and Ravenscroft 2003). Approximately 20 million people living along the coast are affected by varying degrees of salinity in drinking water obtained from various natural sources [Ministry of Environment and Forest (MOEF) 2006].

The surface water in coastal area is not usable because of salt water intrusion that occurs due to influence of tide. This region is situated near to the Ganges delta. The water is not suitable for drinking, other household purpose, industrial purpose and agriculture purpose. So, the surface water cannot be used. The ground water draws huge amount of saline water and due to over use of ground water its water level is also decreasing at an alarming rate. Water supplied by the government is not enough for the people. In some cases water supply association in this region cannot supply water free of pollutions.

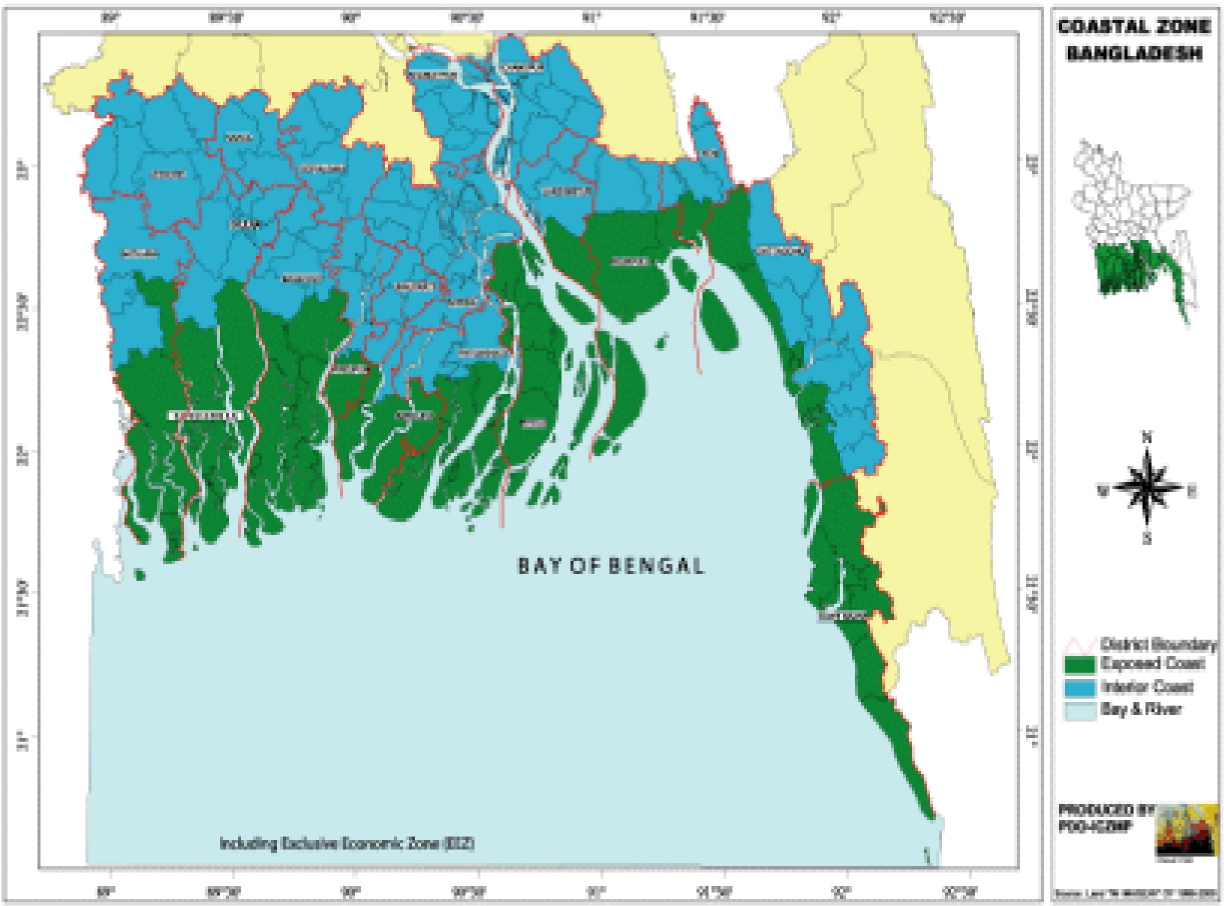

Fig (2.4): coastal area of Bangladesh

2.5.1. WATER QUALITY IN THE COASTAL AREA

Good quality coastal water is an important part of keeping our coasts healthy for the future. The water quality in the coastal area is degrading day by day due to excessive salt water intrusion in the surface and ground water. On the other hand some chemicals like arsenic, dolomite, calcite etc. also causes the pollution of ground water. Coastal water quality refers to the physical, chemical, and biological characteristics of salt and brackish water. Brackish water is a mixture of salt and freshwater, found typically in estuaries where freshwater rivers and streams mix with the tide. Deteriorating water quality can have many ecological, social, and economic effects. These include the loss of marine plant, animal and fish species. Coastal water quality is influenced by natural geological and oceanographic processes, and by human activities. The human impacts to coastal water quality come from land, shoreline, and marine activities. (*Coastal water quality*, The 2009 state of nova scotia's coast report**)**

There are many of sources of surface water in coastal area. But the water is not usable because of salt water intrusion that occurs due to influence of tide. This region is situated near to the Ganges delta. Due to salinity of surface water, pollution and contamination of water from various minerals, the water is not suitable for drinking, other household purpose, industrial purpose and agriculture purpose. So, the surface water cannot be used. Due to salt water intrusion the aquifer is also unusable. Water supplied by the government is not enough for the people.

2.5.2. WATER SUPPLY SYSTEM IN SATKHIRA

Satkhira is situated in the south east of Bangladesh. The Bay of Bengal is situated in the south of it. 36.9% of the people of this area depend on Agriculture. There are many rivers in this area such as Morichapr, Kholpotuar,Betna, Raimangal, Hariabhanga,Ichamati, Betrabati and Kalindi,Jamuna.

Ground water is another source of water. In some area people use ground water but most of the ground water aquifer is polluted with saline water, arsenic and other minerals, like dolomite, calcite etc. as a result most of the ground water is unusable. In recent times it is seen that the ground water level is decreasing at an alarming rate.

KWASA cannot supply adequate amount of water to the general people. This results in a great scarcity of water to the common people.

According to sources, there are 7,100 water connections for over 1,35,000 people in the municipality while the authorities are now supplying 6,300 liters of water against the demand of about 11,000 liters (Abu Ahmed, Daily Star, march 2012) . On the other Patients at Satkhira Hospitals and other private clinics are suffering a lot due to the scarcity of drinking water. Due to sharp fall in groundwater level, it is not possible to lift around half of the required water through pumps.

For obtaining palatable and safe water, there are some commonly used processes. These are pond sand filters, pitcher filter, and rain water harvesting. There procrsses are commonly used in

Bangladesh. Among them rain water harvesting is the most suitable for our study area. Descriptions of these processes are mentioned in the following subsections.

2.5.3. POND SAND FILTER

Pond sand filter is one of the most common water purification processes in our country. In Bangladesh, Pond Sand Filters (PSFs) are built around artificially constructed ponds, locally known as "sweet water ponds" which are replenished by rainwater during the monsoon season. In these systems, rainwater collected in these ponds, is pumped by hand into a storage tank through a filter chamber. The filter chamber is constructed in two parts, the first of which is a pre-filter packed with coconut fibers. This pre-filter reduces the turbidity of the raw water as the raw water flows into the filter chamber. The outflow from the pre-filter flows into the main body of the filter chamber through two overflow pipes. The main filter chamber consists of a layered, sand filter bed, through which the water trickles and in which impurities, including bacteria, are removed in a manner similar to slow sand filtration.

Advantages

This technology can be built to serve a large community. Use of this technology induces community cooperation in the provision of safe drinking water supplies.

Disadvantages

The major limitation of this technology is raw water storage. The pond must be large enough to ensure that it will not dry out in the dry season. It is also important to ensure that the salinity and iron content of the pond water not exceed 600 ppm and 5 ppm, respectively, at any time of the year. It is costly and is not economic for the people of coastal area who are depended on agriculture. It also requires regular maintenance.

Mohammed Aslam, Saleh Ahmed Chowdhury, Alamgeer Faridul Hoque, and *S.R. Sanwar*, Intermediate Technology Group www.unep.or.jp/ietc/publications/techpublications/techpub-8e/filtration.asp

Fig (2.5): Pond sand filter

2.5.4. PITCHER FILTERS

It is also commonly used in our country. It is basically used for drinking and cooking purpose. The filtration system consists of 3 or 4 pitchers arranged one above the other. These pitchers contain filtering materials like sand, gravels, brick chips etc. The pitcher that is kept in bottom is used for collecting water. It is a very cheap process and can hold 20 to 25 liters of water.

Advantage

It is cheap. A family with 5 to 6 people can use this 4 pitcher system. Water from pond and river can be used in this process.

Disadvantage

It cannot remove salinity form the water. It cannot destroy the micro organisms from the water. It requires regular maintenance. It is a slow process.

Fig (2.6): pitcher filters

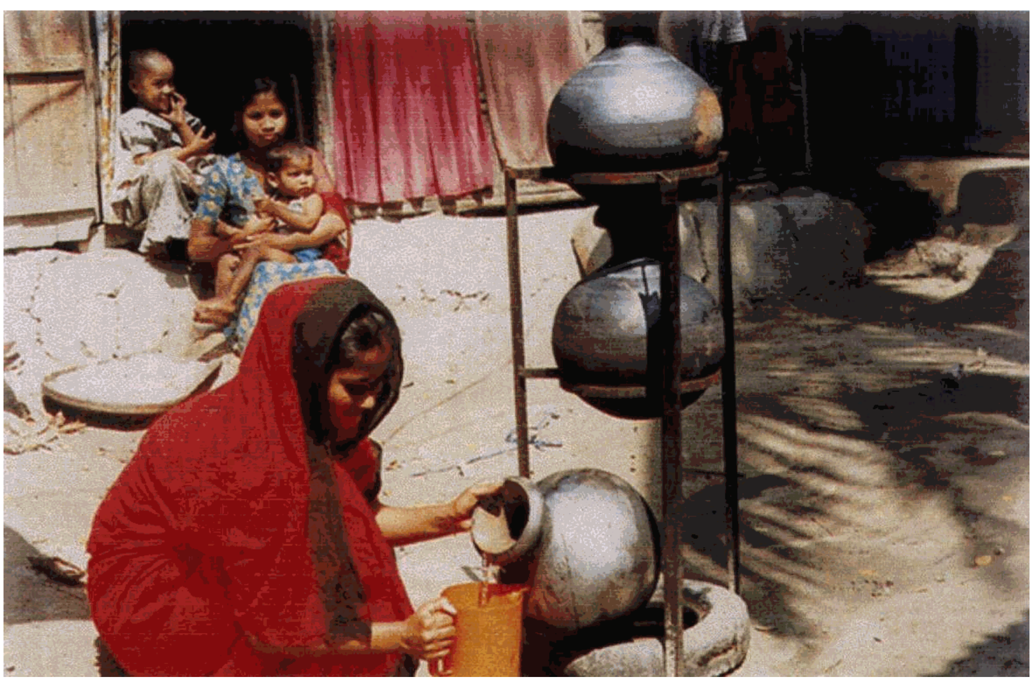

Fig (2.7): pitcher filters

2.5.5. RAIN WATER HARVESTING

Rainwater harvesting (RWH) is a technology where surface runoff is effectively collected during yielding rain periods. In order to support such technologies RWH systems should be based on local skills, materials and equipment. Harvested rainwater can then be used for rain fed agriculture or water supply for households.

Rainwater harvesting (RWH) is recognized as one of the most widely accepted solutions to save potable water in buildings. A significant number of studies reported in the literature confirm the potential of rainwater harvesting as an alternative source for saving potable water. The precipitation regime is obviously considered as the key factor dominating the RWH performance. In rural areas around the world there is lack of access to potable water. In this context, the practice of rain water harvesting (RWH) is becoming more important.

Water scarcity is a major problem in many developing countries. Depending on precipitation intensity rainwater constitutes a potential source of drinking water. In addition, its proper management could reduce water and food crisis in some of these regions. In order to support such technologies RWH systems should be based on local skills, materials and equipment. Harvested rainwater can then be used for rain fed agriculture or water supply for households. Unfortunately, rainwater might be polluted by bacteria and hazardous chemicals requiring treatment before usage.

Slow sand filtration and solar technology methods may be used to reduce the pollution. Membrane technology would also be a potential disinfection technique for a safe drinking water supply. (Opportunities in rainwater harvesting, B. Helmreich, H. Horn).

A significant number of studies reported in the literature confirm the potential of domestic rainwater harvesting as an alternative source for saving potable water. These studies reveal that the potential of DRWH systems ranged from 12% to 100% in potable water saving according to the specific environmental conditions (Herrmann and Schmida, 1999; Sazakli et al., 2007; Ghisietal., 2007; Zhang et al., 2009; Abdulla and Al-Shareef, 2009).

Fig (2.8): water harvesting system

Fig (2.9): water harvesting system

2.6. PREVIOUS WORKS ON RAIN WATER HARVESTING SYSTEM

Many works have been done all over the world regarding the rainwater harvesting. In our country studies on rain water harvesting has been done. But the coastal area has been always neglected. Conducting a proper study can ensure more efficacies regarding rainwater harvesting system. Developed countries like Australia, Italy, USA have conducted many research works on rainwater harvesting.

To determine the active storage capacity required to supply a given demand various methods may be used. Among them probability matrix method is notable which is based on Moran's Theory of storage and statistical methods (McMahon and Mein, 1978). and Mein, 1978). The choice of the analysis method is determined by the level of accuracy required and the type of storage being assessed: within-year storages that go through the full–empty–refill–spill cycle several times a year, and over-year (carry-over) storages that go through this cycle over a much longer time period, often in the order of years.

Rainwater tanks are, by and large, within year storages, the epitome being a small household rain-water tank that might fill in a single rain event and empty during a single garden watering session. (V. Grace Mitchell, July 2006, Monash University).

Behavior analysis is commonly used to assess the storage–yield–reliability relationship of a rainwater tanks (Perrens, 1975; Jenkins and Pearson, 1978; Lo and Fok,1981; Fewkes, 2000; Fewkes and Butler, 2000; Fewkes and Warm, 2000; Herrmann and Schmida, 2000; Liawand Tsai, 2004), although other methods such as the Mass Curve analysis have also been used (Schiller and Latham,1987).

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 (McMahon and Adeloye, 2005). The changes in storage volume of a finite rainwater store during a time step t are 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 account serial correlation and seasonality of inflow and demand, applies to any time step (Liaw and Tsai, 2004), and is flexible, enabling the use of any time interval and the simulation of variable demand patterns (Fewkes and Butler, 2000). In the special case of a covered rainwater tank, the incident precipitation and evaporation terms vanish.

Fewkes (1999) 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, Fewkes (2000) investigated how spatial and temporal fluctuations in rainfall alter 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.

The demand fraction (D/I),which is the ratio of annual demand to annual mean inflow, ranged from 0.25 to 2.00. The storage fraction (S/I), which is the ratio of the storage capacity to the annual mean inflow ranged from 0.005 to 0.4. Fewkes (2000) then developed a 'storage operation parameter's to transform the monthly estimates into values that correlated to those derived from a daily time step model, with the majority having a correlation coefficient of 0.9 or greater.

Fewkes and Butler (2000) built their studies on these earlier studies to investigate the relative accuracy of behavior analysis using an hourly, daily, and monthly time step and both a YAS and YBS computational operating rule, for different combinations of (D/I). Here YAS is supply after spillage and YBS is supply before spillage (V. Grace Mitchell, 2007).

The use of a YAS operating rule was found to give a conservative estimate of yield, while YBS gave the opposite result. Therefore, they recommended the use of the YAS in preference to YBS. Liaw and Tsai (2004) investigated the sensitivity of using 1-, 3-, 5-, and 10-day time intervals within a rainwater tank behavior analysis model and also concluded that shorter time intervals are required for smaller storage sizes. In contrast to Fewkes and Butler (2000), Liaw and Tsai (2004) recommend the use of the YBS operating rule in preference to YAS.

V. G. Mitchell used the same approach of the behavior model as Fewkes and Butler he also used (D/I) ratio for modeling for the prediction of rainwater tank yield for 3 regions of Australia.

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 . dixosn's (2005) model of water saving , Coombes (2007) modeling of rain water tank and Jenkins model for continuous simulations of amount of rainwater stored in the tank , are also used.

2.7. RAIN WATER HERVESTING TANKS

Rainwater tanks are installed to store rain water for later use, reducing main's water use for economic or environmental reasons and aid self-sufficiency. Stored water may be used for watering gardens, agriculture, flushing toilets, in washing machines, washing cars and also for drinking, especially when other water supplies are unavailable, expensive or of poor quality. Adequate care is taken that the water is not contaminated or the water is adequately filtered. The sizes of the tank vary from regions to regions. The area with huge rainfall should use larger tank, on the other hand the areas with scanty rainfall should use tank based on their rainfall duration and intensity.

Previously barrel shaped tanks were used. It is cheap but it has too many limitations and this type of tank is used only for drinking purpose. Plastic tanks of 208-litre area also used in some cases. Modern modular systems which are scalable, like 193 liter Rainwater HOG module and the 500 liters Stradco Aquabarrel can be used to decentralize the rainwater catchment by storing smaller volumes at each downspout. Larger tanks are commonly used where there is no access to a centralized water supply. Companies such as Solar Survival Architecture recommend 1135 liter tank for a house supporting 2 people and if the region receives 762 mm of precipitation a year. If it receives less (between 254 mm and 762mm), 2 or 3 of these 300 gallon tanks can be placed so that more rain can be gathered at times when it does rain. Also affecting tank size is predicted rainfall and rainfall variability, the higher prices for larger tanks; intended use of rainwater and typical consumption for these uses; the area of roof draining into the tank, security of supply desired.

Rainwater tanks may be constructed from materials such as plastic polyethylene, Concrete, galvanized steel, as well as fiberglass and stainless steel which are rust and chemical-resistant. Tanks are usually installed above ground, and are usually opaque to prevent the exposure of stored water to sunlight, to decrease algal bloom Tanks may be covered and have screen inlets to exclude insects, debris, animals and bird droppings. Almost all steel tanks currently produced for household rainwater collection come with a plastic inner lining to increase the life of the tank, prevent leaks and protect the water quality. Apart from rooftops, tanks may also be set up to collect rainwater from concrete patios, driveways and other impervious surfaces.

One of the greatest revolutions in the ability of harvesting rain water has been the invention of modular, scalable systems which are installable underground. These came as an evolution of a geosynthetic applications called drainage cells, which when stacked provide a void space volume which allows for the storing of water. Improved and more cost effective industrial design now allow for theoretically limitless storage of water underground. Examples of these modular structures are Atlantis Matrix Tanks used in the Manly Storm water Treatment and Re-use project of Manly Council in Australia. Filtration remove pathogens while rain water is pure it may become contaminated during collection or by collection of particulate matter in the air as it falls While rain water does not contain chlorine, contamination from airborne pollutants which settles onto rooftops may be a risk in urban or industrial areas. Certain paints and roofing materials may cause contamination also.

2.7.1 TYPES OF STORAGE TANKS

Storage tanks are constructed from different materials. Different types of storage tank is used in Bangladesh. Storage tanks are classified according to the material used. For example :

- Corrugated iron tanks
- PVC tank
- Clay rink tank
- Cement jars
- Concrete ring jars
- Ferro-cement tank
- Bamboo reinforced ferro-cement tank
- Soil-cement block tank
- Reinforced brickwork tank

CHAPTER THREE

METHODOLOGY

3.1 INTRODUCTION

The thesis mainly constitutes of two parts. First, the storage volume calculation was done by using mass curve analysis. From this storage volume calculation the design curve was computed. Next, the reliability of the system was determined. For reliability analysis, the catchment area, demand and tank size was taken into account. The volume of spilling for each combination and the supplementary water to be provided from other sources was calculated and compared with each other to determine if the work was progressing properly or not. The whole procedure is described in details in the following sections.

3.2 RAINFALL PATTERN IN BANGLADESH

Based on average annual rainfall Bangladesh has been divided into 7 different zones. There are 34 rain gauge station across the country this rain gauge stations are arranged into seven different zones mentioned earlier. In the table shown below the different rainfall zones are shown.

Satkhira, Mongla, Khulna, Bhola, Chittagong, Cox's Bazaar, Teknaf etc. are in the coastal area which are shown in the table. For the purpose of this study, rainfall data of Satkhira has been chosen which is in the zone II where average annual rainfall is 1500-1800 mm.

Table (3.1): Rain gauge station in different zones

Zones	Average annual rainfall (mm)	Rain gauge stations
Zones I	<1500	Rajshahi
Zones II	1500-1800	Ishurdi, Jessore, Satkhira, Chuadanga
Zones III	1800-2100	Bogra, Dinajpur, Faridpur, Sayedpur, Tangail, Khulna, Mongla
Zones IV	2100-2400	Barissal, Chandpur, Comilla, Dhaka, Rangpur, Mymensingh,Madaripur
Zones V	2400-2700	Bhola, Khepupara, Rangamati, Srimongal
Zones VI	2700-3000	Chittagong. Feni, Hatia, Kutubdai, Patuakhali
Zones VII	>3000	Cox's Bazaar, Shandip, Sitakunda, Sylhet, Teknaf M. Court

3.3. DETERMINIG THE AVAILABLE STORAGE VOLUME

For the purpose of available storage volume calculation first rainfall data was put in the excel sheet. Then a factor of 0.9 was selected as the system efficiency. A catchment area was selected. Multiplying these three the input volume was obtained.

Qin=C*I*A

Here, C= co-efficient of available runoff.

I= rainfall intensity in m

A= catchment area in m^2

The demand volume for a family remained constant for different per capita demands, e.g.-

Quse = 12 liters for 2lpcd

24 liters for 4lpcd

30 liters for 5lpcd

36 liters for 6lpcd

48 liters for 8lpcd

60 liters for 10lpcd

72 liters for 12lpcd

Then the usage volume was deducted from the input volume and if the value was positive then it was taken in the water storage column and if the value was negative it was put in the excess water demand column.

Qin-Quse > 0; water storage

Qin-Quse < 0; excess water demand

The water storage values are summed to get the available storage for a year. This was done using a mass curve approach. This water can be stored for use in the days without rainfall. This is the part of rainfall that is called harvested rain water.

3.4. USE OF MASS CURVE TO DEVELOP DESIGN CURVES

The storage volume calculation and development of design curves was done using a Mass Curve approach. A mass diagram is a graphical expression of cumulative inflow into the reservoir versus time which may be daily monthly or yearly. Mass curve may be used to determine the following:

(I) The storage capacity of the reservoir required to meet a particular withdrawal rate.

(II) The possible rate of withdrawal from a reservoir of specified storage capacity.

(Hydrology Principles Analysis Design, H. M. Raghunath, revised second edition)

Successful use of this method requires a minimum of 10 years of raw data the required tank can be determined using this method. This method can be graphically applied which is shown below.

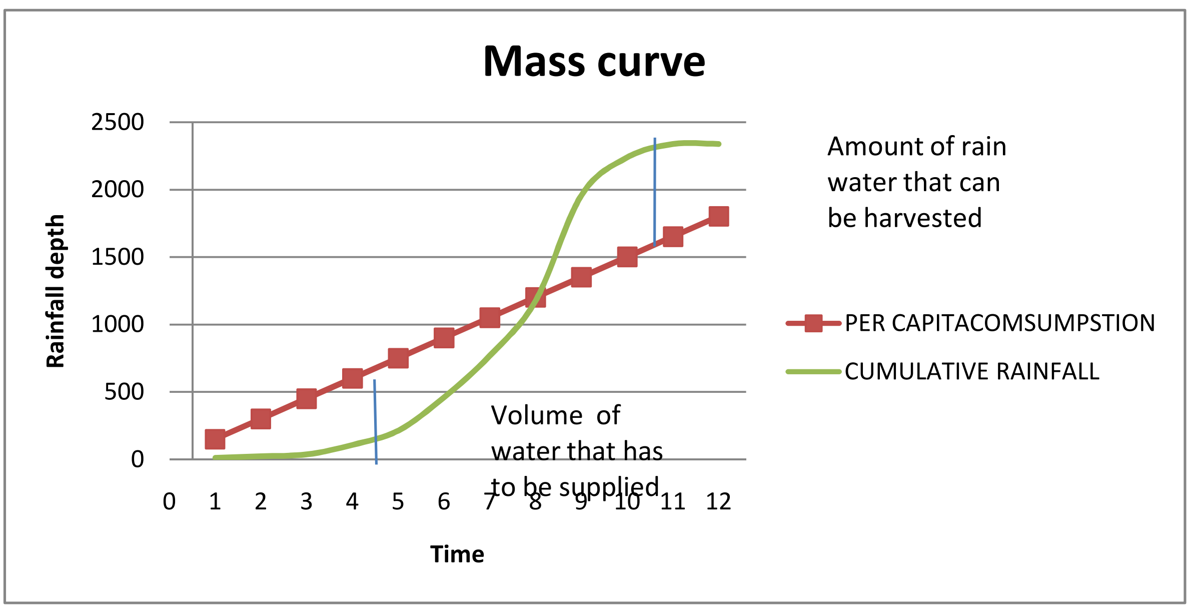

Fig (3.1): Mass curve

The sum of excess water demand for a year, obtained for different rainfall data, catchment area and per capita demand were put in an excel sheet and the desired design curve was obtained. Summation of excess water demand was plotted against the per capita demand. This is how the design curves were developed. From the design curve, a family of 6 members would be able to find out the amount of rainwater they can harvest, depending upon the catchment area they have and their demand.

Another two types of individual curves were developed which are- demand vs. catchment area and catchment area vs. available storage volume. The catchment area vs. storage volume graph shows that the curves have increasing slopes; this indicates that available storage volume increases with increase of catchment area. The demand vs. catchment area shows curves with decreasing slope, indicating a decrease of excess water demand with increase in catchment area.

These are clear indication of the analysis being done properly. The results should not have been otherwise. The Wet year Average year and Dry year curves have been developed this way. They all showed similar results.

3.5. 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,

$$\mathbf{V = Qin - Quse + V_{t-1} - Qspill}$$

Here,

V = Storage volume of the tank.

Qin = Input rainwater volume.

=Catchment area × Rainfall depth

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

Quse = Volume of water usage demand.

= Daily water use (m^3).

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

Qspill = Volume of spilled water (m^3).

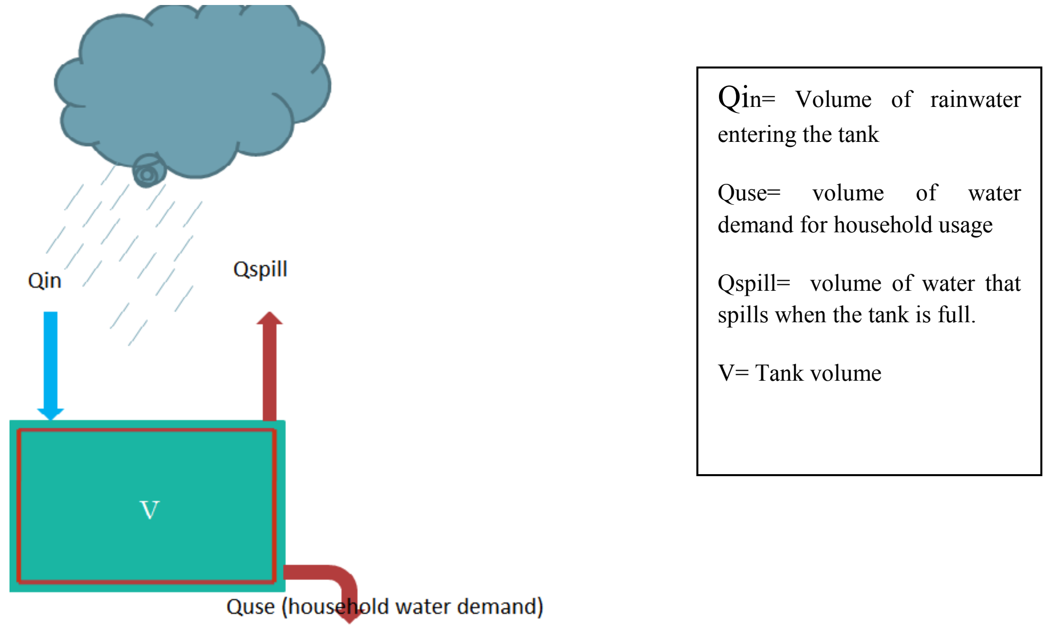

Fig (3.2): Typical rainwater harvesting features.

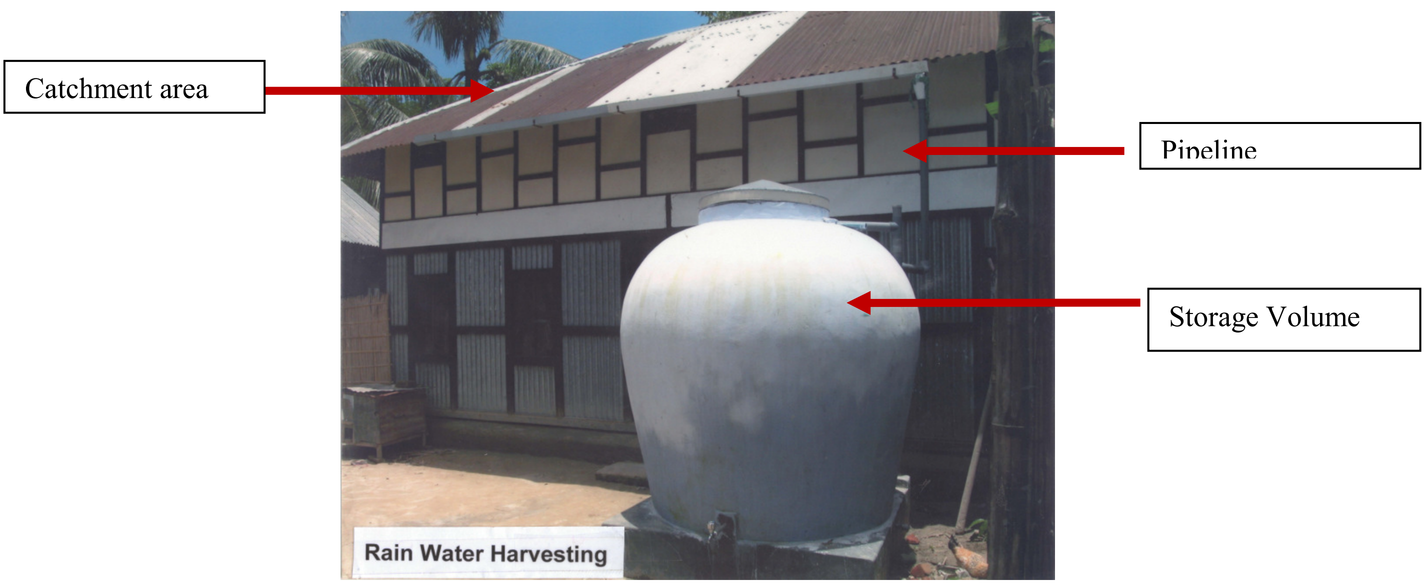

Fig (3.3): Typical rainwater harvesting system

The reliability analysis was done for the catchment areas of 10 m^2, 20m^2, 30m^2 and 40m^2. The demands considered here were 2lpcd, 5lpcd and 10lpcd. Different tank volume of 500 liters, 1000 liters, 2000 liters, 3000 liters, 4000 liters, 5000 liters was selected for analysis.

A typical spreadsheet for this model contained input volume (Qin), demand volume (Quse), previous day volume (Vt-1), present day water storage volume (Vt), no. of days the tank was unable to meet the demand, no. of days the tank was not full, volume of spilled water (Qspill), volume of supplementary water to be provided.

$$\mathbf{Qin=C*I*A}$$

Where, C= co-efficient or system efficiency factor

I= rainfall intensity in m

A= catchment area in m^2

Then the usage was deducted from the input and if the values were positive then it was taken in the water storage column and if the values were negative it was put in the excess water demand column

$$\mathbf{Q_{in\ (t-1)} - Q_{use\ (t-1)} = V_{(t-1)}} \qquad \text{[previous day water demand]}$$

So water storage of today will be,

$$V_t = Q_{in} - Q_{use} + V_{(t-1)}$$

Spilling occurs when storage capacity exceeds.

When,

$V1 > \text{tank size}$; there is spilling

$V1 < \text{tank size}$; there is no spilling

For, supplementary water demand or the water that has to be provided from other sources, the equation would be,

$V1 > 0$; there is no supplementary water demand

$V1 < 0$; there is supplementary water demand and the value would be;

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

3.6. 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. In other words the reliability of a rainwater catchment system is defined as the probability that the capacity of the system (i.e. the supply of rainwater) exceeds or equals the demand (consumption).

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

Reliability curves for a catchment area of different dimensions and for Wet, Dry and Average year were computed. The reliability for all these conditions increased with the increase of tank volume.

The supplementary water demand decreases with the increase of tank volume. All the results showed similarity and hence it can be said that the method was properly progressing.

In tank volume vs. spilling volume curves for different catchment area were computed. The curves had a negative slope indicating that volume of spilled water decreases as tank volume increases.

3.7. DATA COLLECTION

The whole coastal area situated in the southern part of Bangladesh has an area of 47,211 km^2 which is about 30% of the total area of Bangladesh. Satkhira was chosen due its availability of data and it has the typical conditions of a coastal region. Data of Satkhira area's rainfall was obtained from the Meteorological Department of Bangladesh. A period of 10 years was chosen for analysis (1997-2007).

3.8. DATA SELECTION:

The obtained daily rainfall data was put on Excel sheet and the maximum and minimum rainfall years were selected. The maximum rainfall year represented the Wet Year while the minimum rainfall year represented the Dry Year. Then the values were averaged and the Typical year or Average year condition was obtained. The 1999 rainfall data was selected as the Dry year data and 2004 rainfall data was chosen the Wet year data. These rainfall data were used in doing the Balance model over a Excel spreadsheet.

Then a family of 6 members was chosen to do the analysis. Various per capita water demands were selected. Water demand of 0, 2, 4, 5, 6, 8, 10 and 12 lpcd was chosen to develop the Design curves and water demand of 2, 5 and 10 lpcd was selected for balance model analysis. As for example, if per capita water demand is 2lpcd a family of 6 members would have a demand of 2*6=12 liters=0.012 m^3 of water per day.

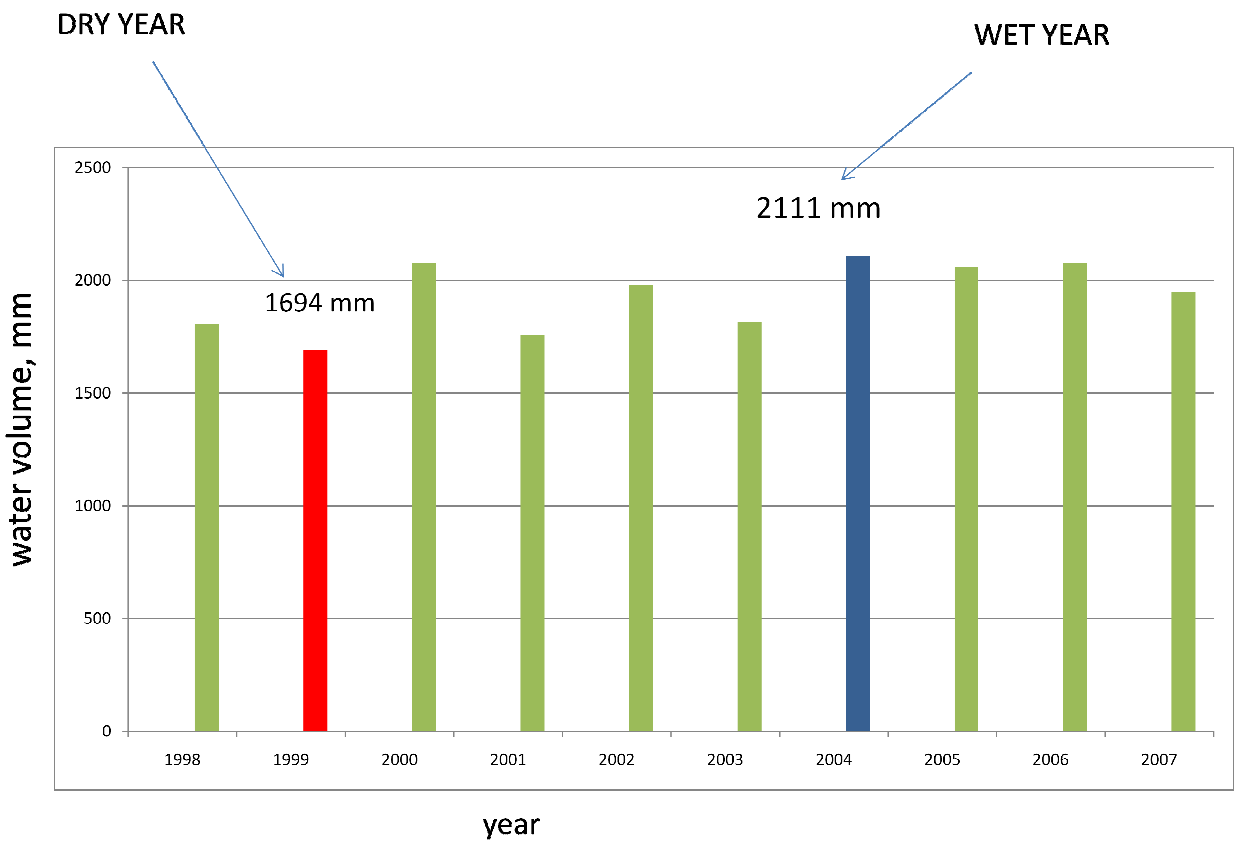

Fig (3.4): Determining the Dry and Wet

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

After development of design curves and analysis of reliability, different comparisons were being done. The comparisons were done to see the changes that occurred due to change of tank volume, change of catchment area and change of demand. These comparisons were done to assess the reliability of the system. The design curves on the other hand would be used to find out the available storage volume. The findings are described in details, in the following sections.

4.1.1 Determination of storage capacity required

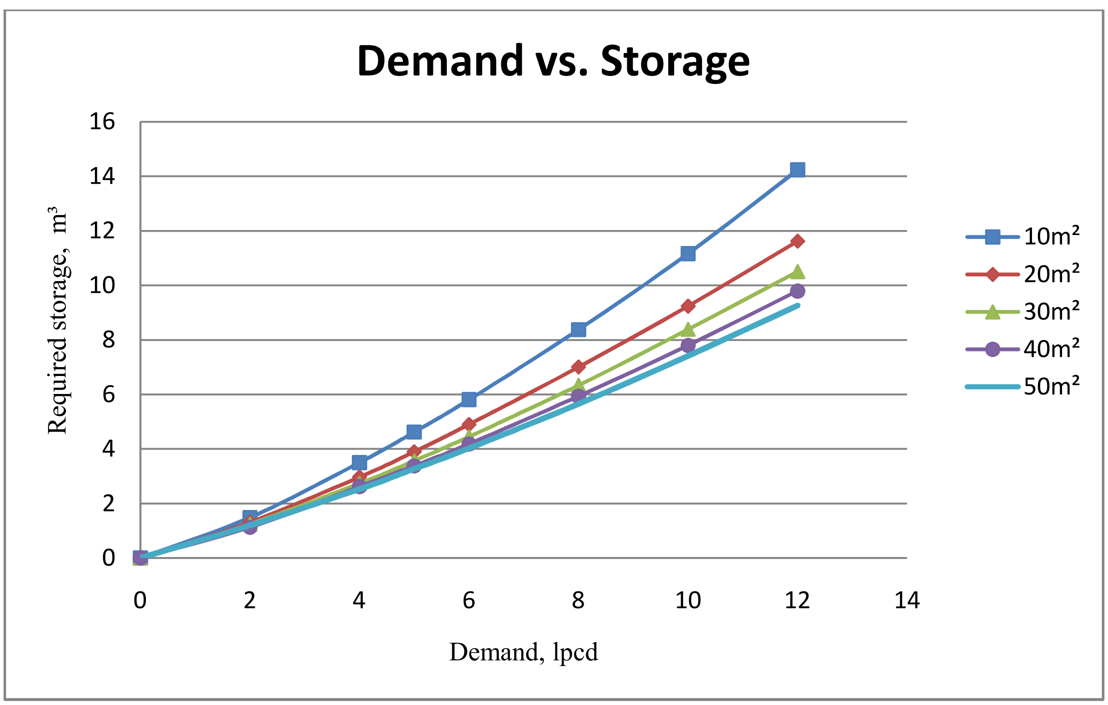

Fig (4.1): Storage capacity required for a typical year.

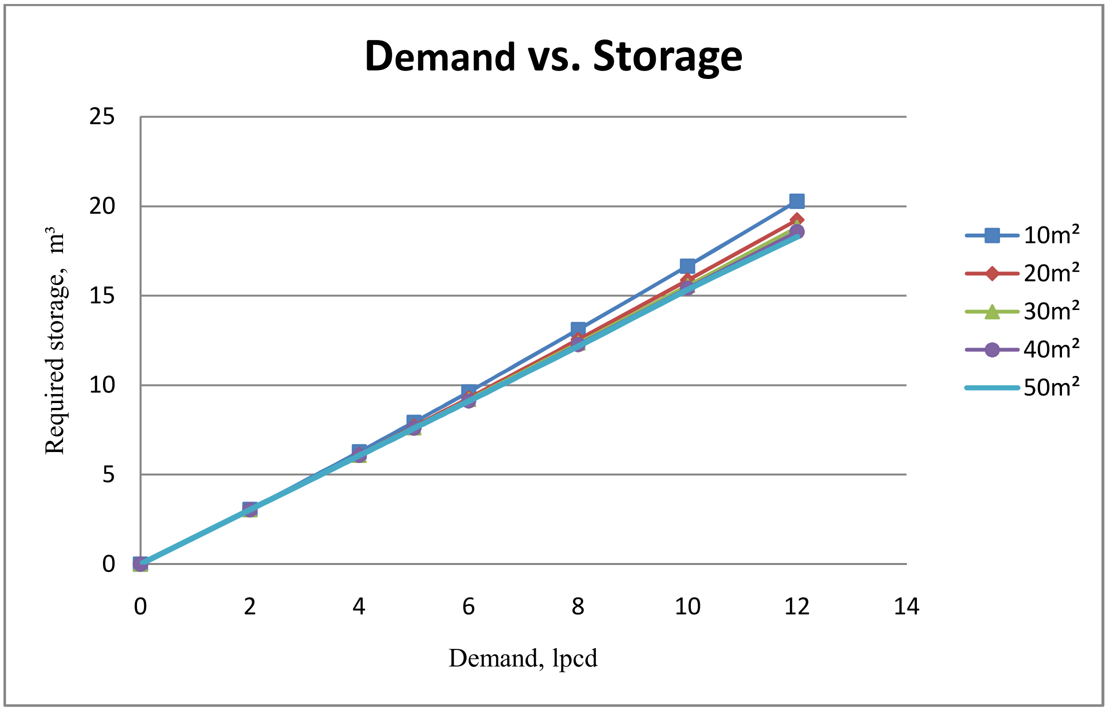

Fig (4.2): Storage capacity required for a dry year

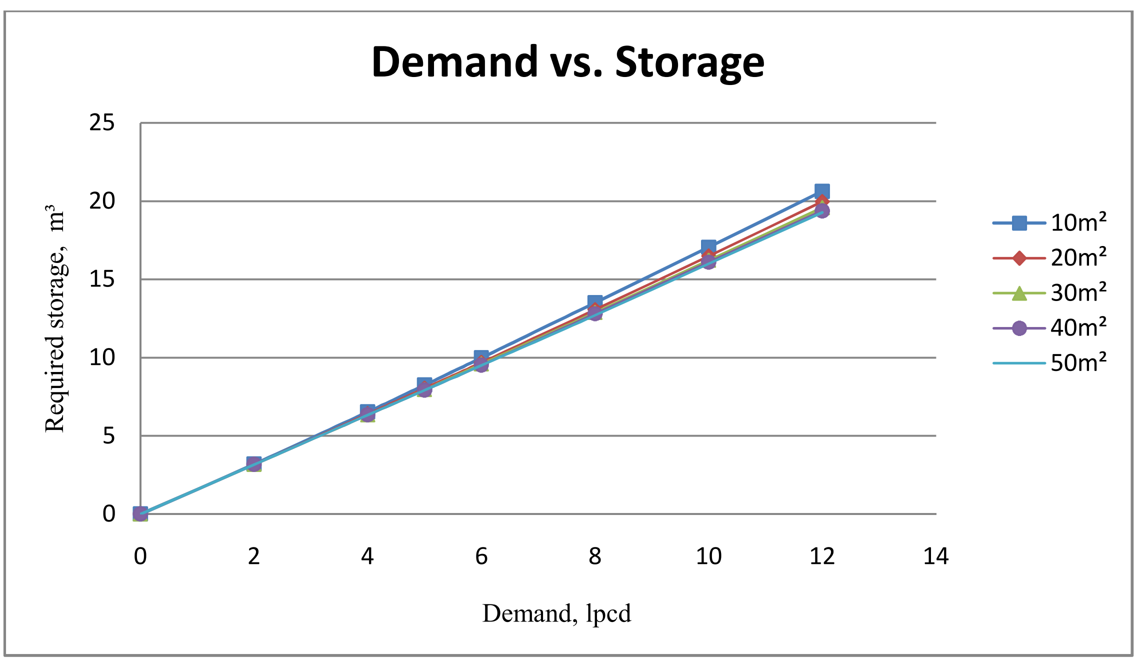

Fig (4.3): Storage capacity required for a wet year

The storage volume required for average year, wet year and dry year, for catchment areas of 10, 20, 30, 40 and 50 m² were computed based on mass curve approach, for various demands. Graphical expressions of demand vs. required storage are shown above. These graphs are computed for the demand of 2, 4, 6, 8, 10 and 12lpcd demand. From the graph of demand vs. required storage computed for a typical year wet and dry year the curves have increasing slopes, this indicates that the storage increases as the demand increases. Moreover we can see that, the curve for smaller catchment is above the bigger catchment area curves. This indicates that, if the catchment area is small more is the required storage volume necessity.

The maximum storage volume requirement for different year conditions varies with the change in catchment area. The maximum storage volume required was highest for 12lpcd demand. The maximum storage volumes required are given below.

Table (4.1): Maximum storage volume required for different catchment areas.

	Year condition	Catchment area (m²)				
		10	20	30	40	50
Maximum storage volume available (m^3)	Average	14.2416	11.6172	10.5039	9.7956	9.2655
	Dry	20.286	19.242	18.828	18.576	18.286
	Wet	20.619	19.962	19.584	19.368	19.278

4.1.2 Relationship between catchment area and demand

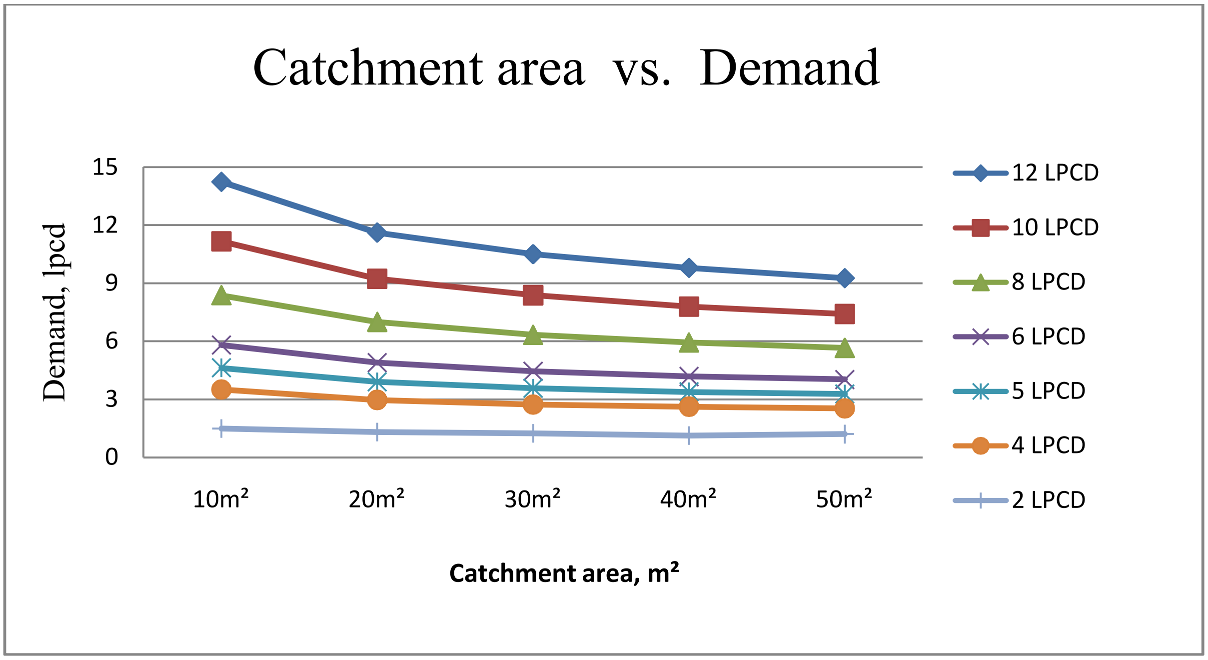

Fig (4.4): Catchment area vs. demand curves for a typical year (average year)

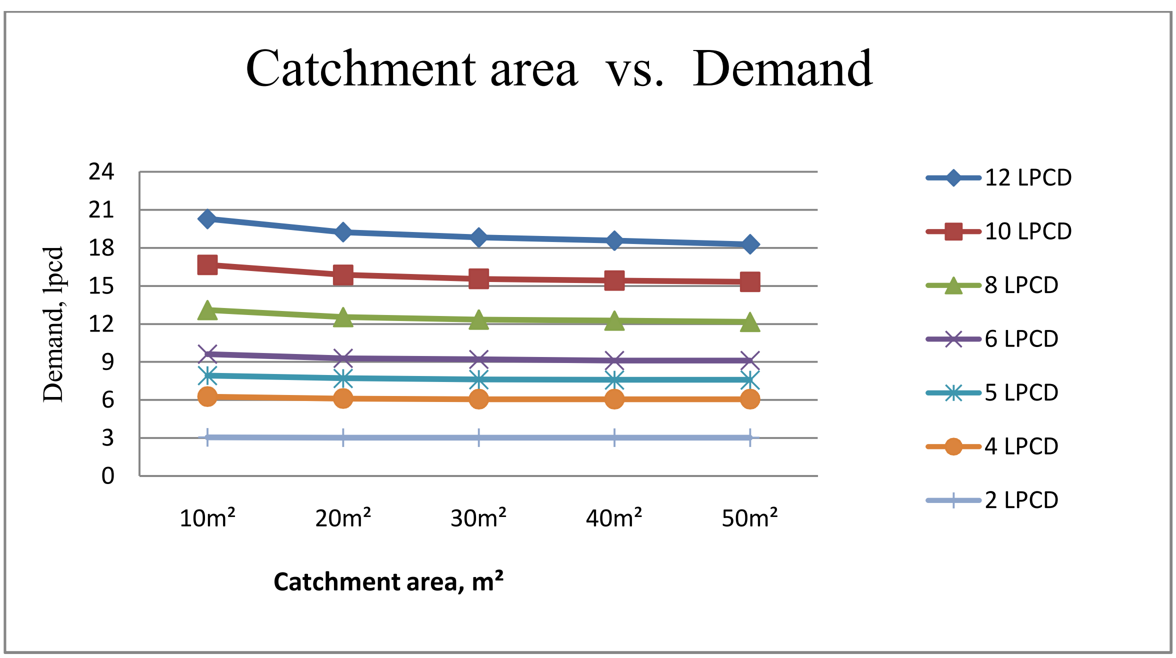

Fig (4.5): Catchment area vs. demand curves for a dry year

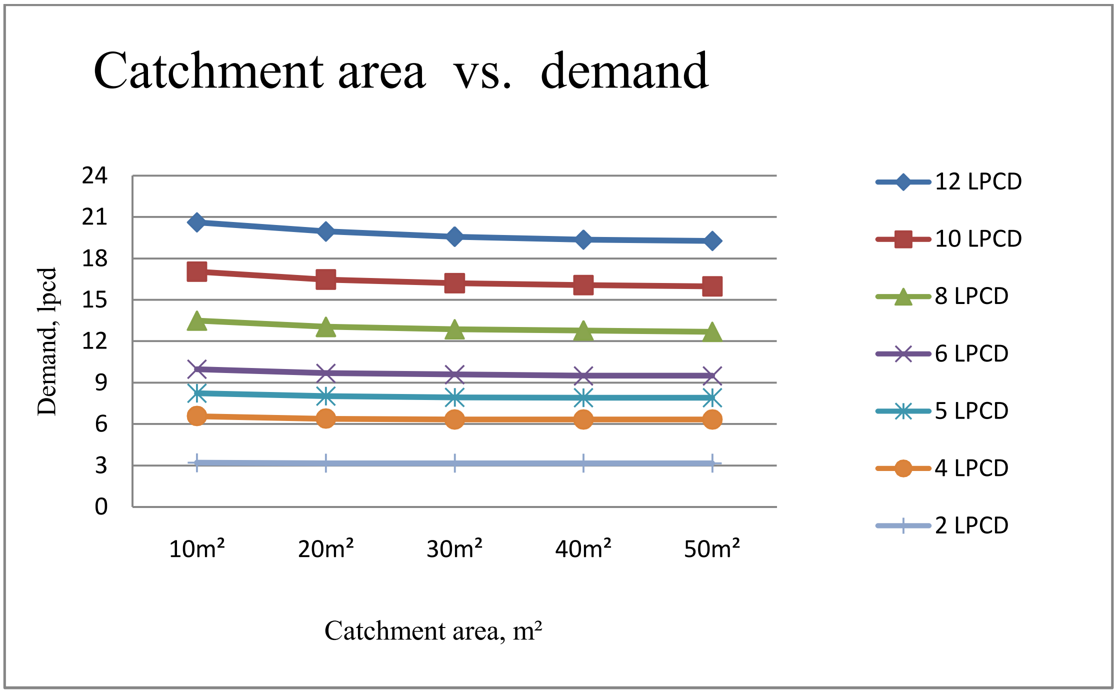

Fig (4.6): Catchment area vs. demand curves for a wet year

The catchment area vs. demand curves computed, showed that the demand of supplementary water decreased as the catchment area increased. The supplementary water demand was more for higher per capita demand.

The maximum excess water demands were for 12lpcd water demand. The maximum excess water demands for different catchment areas are given below.

Table (4.2): Maximum excess water demands for different catchment areas

Catchment area	Average year demand m^3	Dry year demand m^3	Wet year demand m^3
$10m^2$	14.2416	20.286	20.619
$20m^2$	11.6172	19.242	19.962
$30m^2$	10.5039	18.828	19.584
$40m^2$	9.7956	18.576	19.368
$50m^2$	9.2655	18.286	19.278

4.1.3. Demand and storage volume relationship

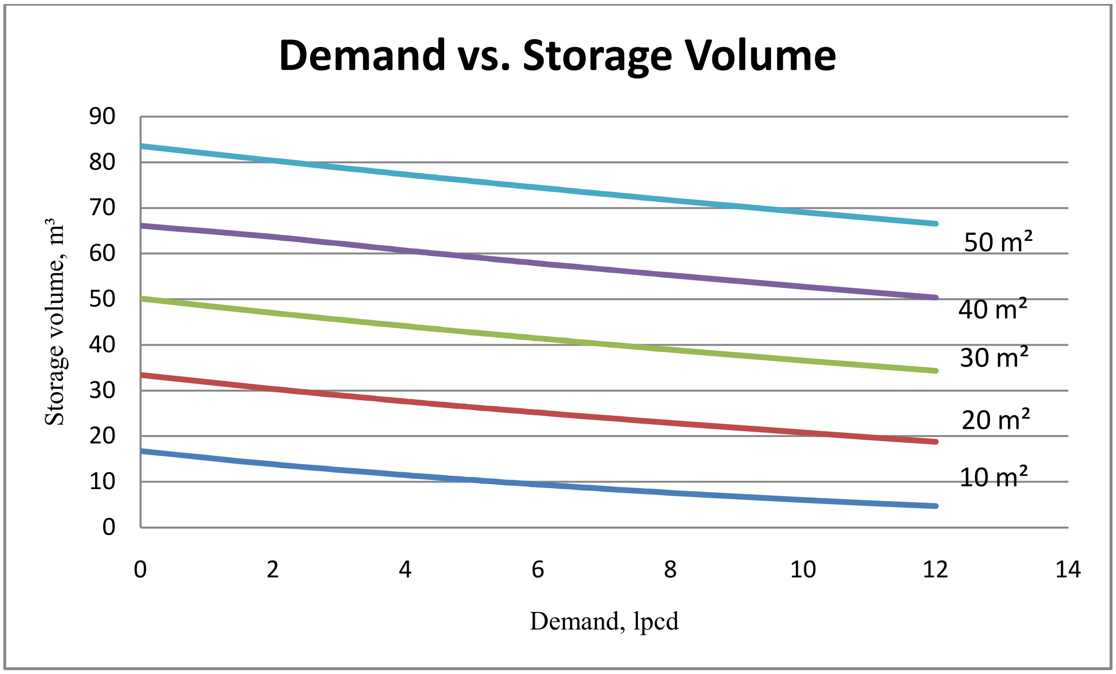

Fig (4.7): Per capita demand vs. storage volume curves for a typical year

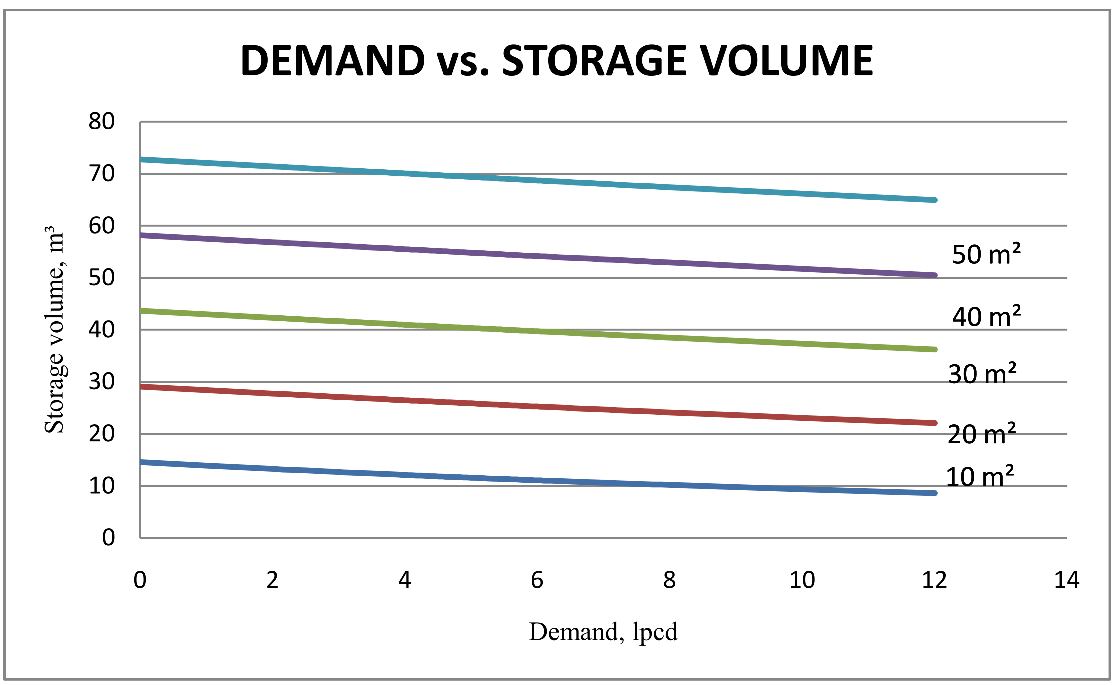

Fig (4.8): Per capita demand vs. storage volume curves for a dry year

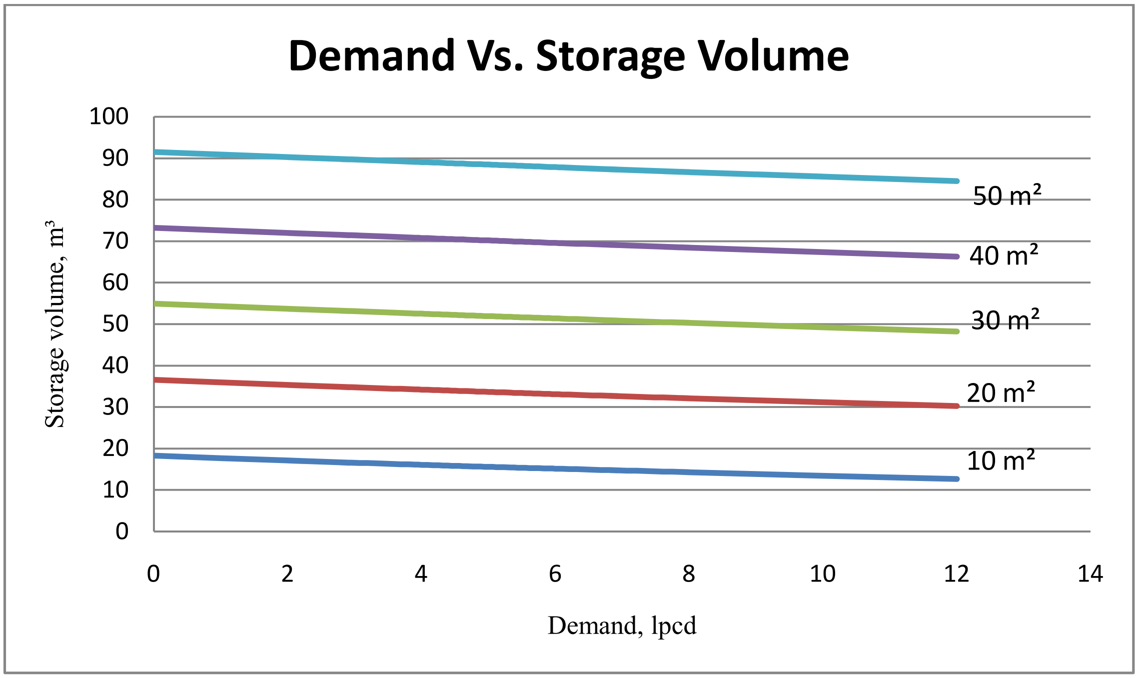

Fig (4.9): Per capita demand vs. storage volume curves for a wet year

The available storage volume for average year, wet year and dry year, for catchment areas of 10, 20, 30, 40 and 50 m² were computed based on mass curve approach, for various demands. Here the water demand is plotted against the storage volume. Graphical expressions of demand vs. storage are shown above. These graphs are computed for the demand of 2, 4, 6, 8, 10 and 12lpcd demand. Here the curves have a decreasing slope which indicates that the available storage volume is decreasing as the demand is increasing. Here we have higher storage volume for larger catchment areas for an intended demand.

The maximum storage volume requirement for different year conditions varies with the change in catchment area. The maximum storage volume required was highest for 2lpcd demand. The maximum storage volumes required are given below.

Table (4.3): Maximum available storage for different catchment areas

	Year condition	Catchment area (m^2)				
		10	20	30	40	50
Maximum storage volume available (m^3)	Average	13.8036	30.3294	46.9611	63.6348	80.319
	Dry	13.23	27.744	42.288	56.832	71.376
	Wet	17.115	35.382	53.679	71.976	90.273

4.1.4. Relationship between catchment area and storage volume

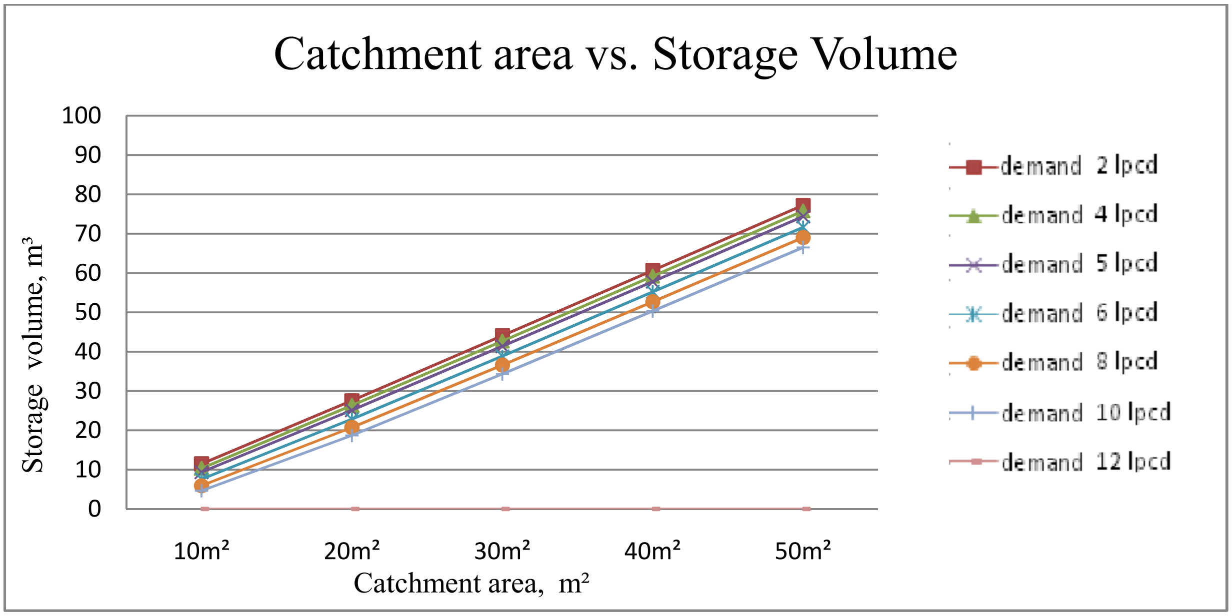

Fig (4.10): Catchment area vs. storage volume for a typical year

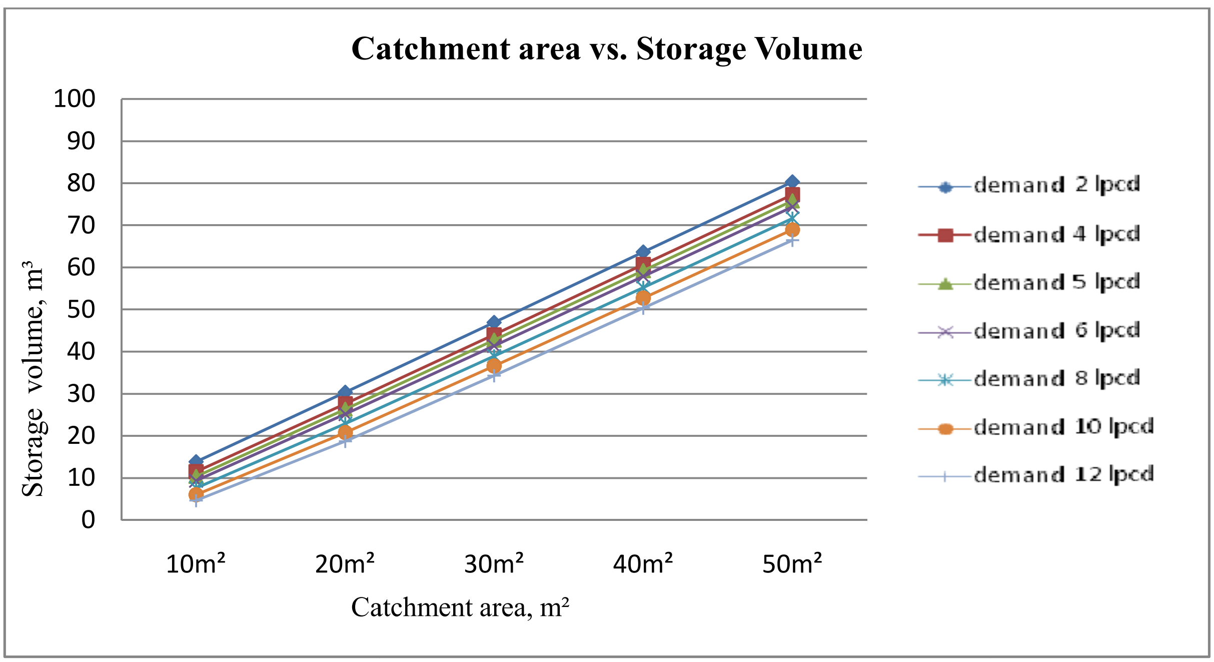

Fig (4.11): Catchment area vs. storage volume for a dry year

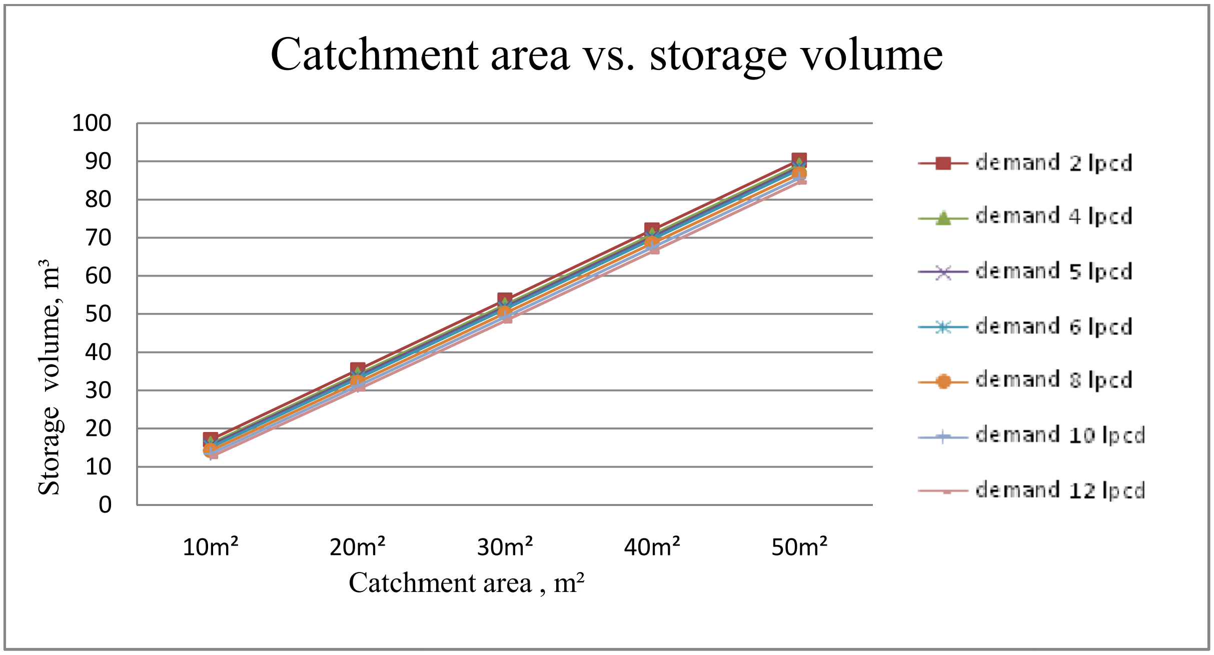

Fig (4.12): Catchment area vs. storage volume for a wet year

The catchment area vs. storage volume has curves with increasing slopes. This indicates that the storage volume increases with the increase of catchment area. From this curve we can see that the storage volume is highest for the wet year. Moreover, we can see, as the demand increases the storage volume decreases.

Table (4.4): maximum available storage volume for different catchment areas

Catchment area	Average year storage, (m^3)	Dry year storage, (m^3)	Wet year storage, (m^3)
$10m^2$	13.8036	13.23	18.297
$20m^2$	30.3294	24.744	36.594
$30m^2$	46.9611	42.288	54.891
$40m^2$	63.6348	56.832	73.188
$50m^2$	80.319	71.376	91.485

4.2. COMPARISON GRAPHS OF RELIABILITY

The reliability of the system was determined, using a water balance model. Comparisons were done among 2, 5 and 10lpcd demand, catchment aeras of 10, 20, 30 and 40 m² and for tank volume of 1000, 2000, 3000, 4000 and 5000 Liters. For different combinations, the findings are described below.

4.2.1. Reliability comparison for 2lpcd demand

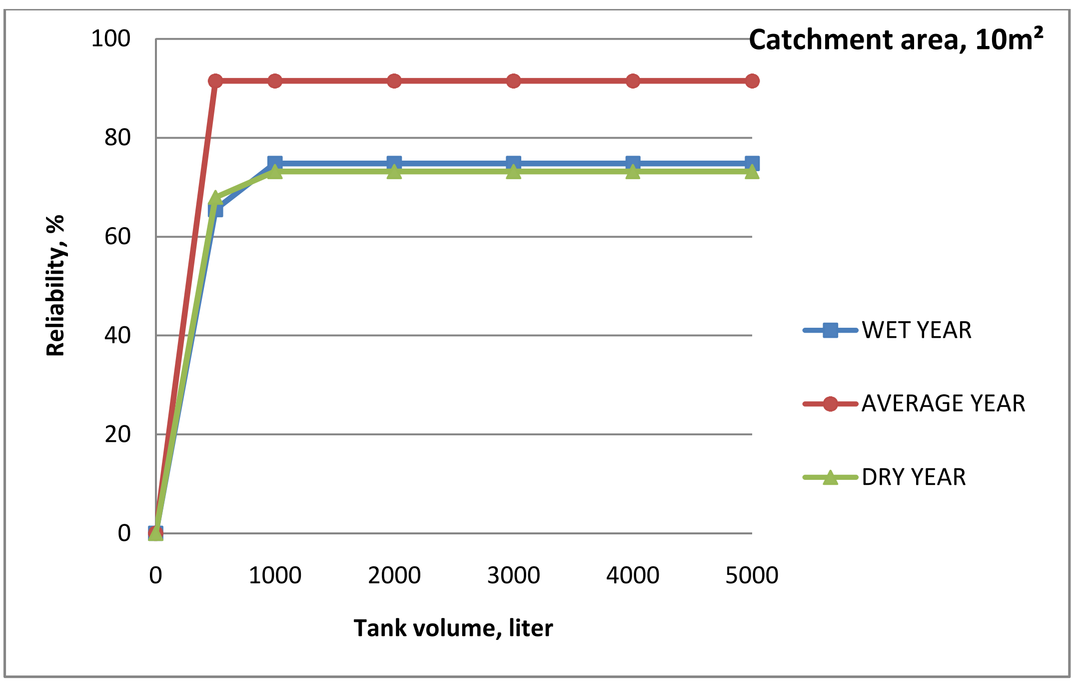

Fig (4.13): Reliability curve for 2lpcd demand and 10 m² catchment area

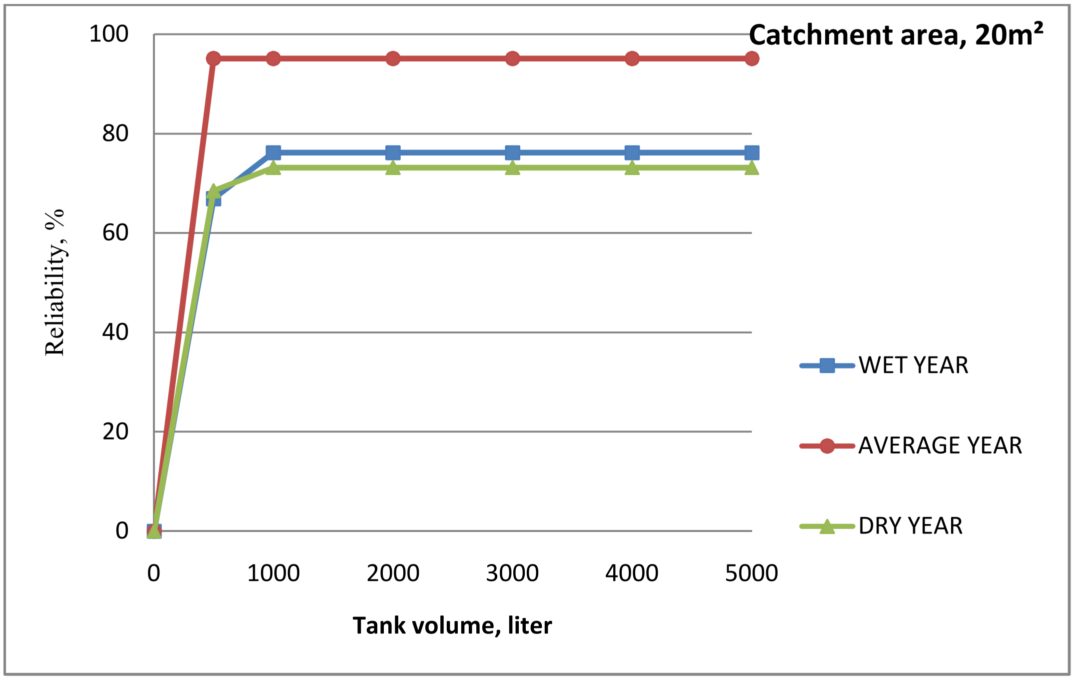

Fig (4.14): Reliability curve for 2lpcd demand and 20 m² catchment area

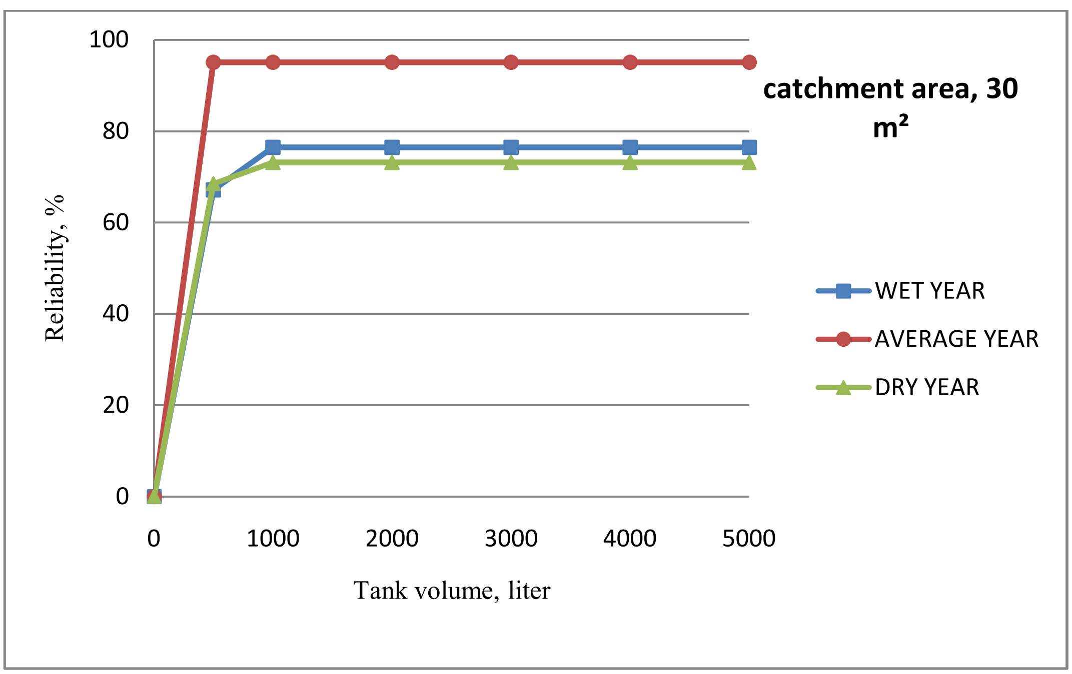

Fig (4.15): Reliability curve for 2lpcd demand and 30 m² catchment area

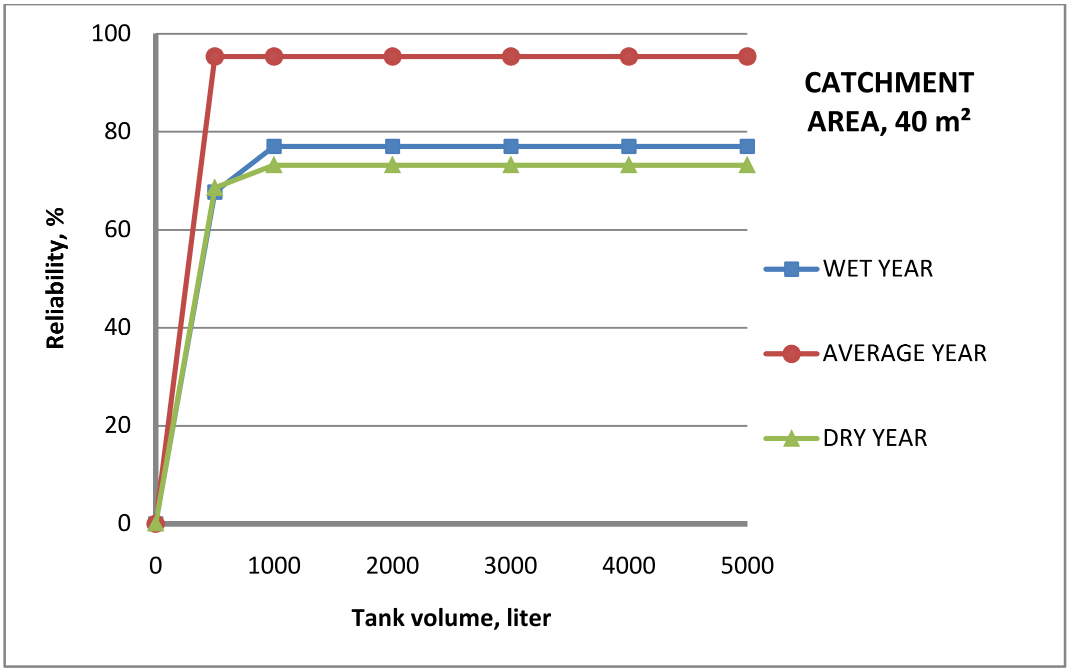

Fig (4.16): Reliability curve for 2lpcd demand and 40 m² catchment area

2lpcd is a low demand and for this reason the reliability for different catchment area is than the higher demands. In all the graphs the reliability increases as the tank volume increases. Reliability for the wet year is higher than the dry year in all cases.

A table showing the maximum reliability achieved for which tank volume is shown below, when the demand was 2lpcd.

Table (4.5): Maximum reliability for different tank sizes when the demand is 2lpcd

Catchment area (m^2)	Average year		Dry year		Wet year	
	Reliability (%)	Tank size (Liter)	Reliability (%)	Tank size (Liter)	Reliability (%)	Tank size (Liter)
10	91.52	500	73.2	1000	74.8	1000
20	95.06	500	73.2	1000	76.2	1000
30	95.06	500	73.2	1000	76.5	1000
40	95.4	500	73.2	1000	77	1000

4.2.2. Reliability comparison for 5lpcd demand

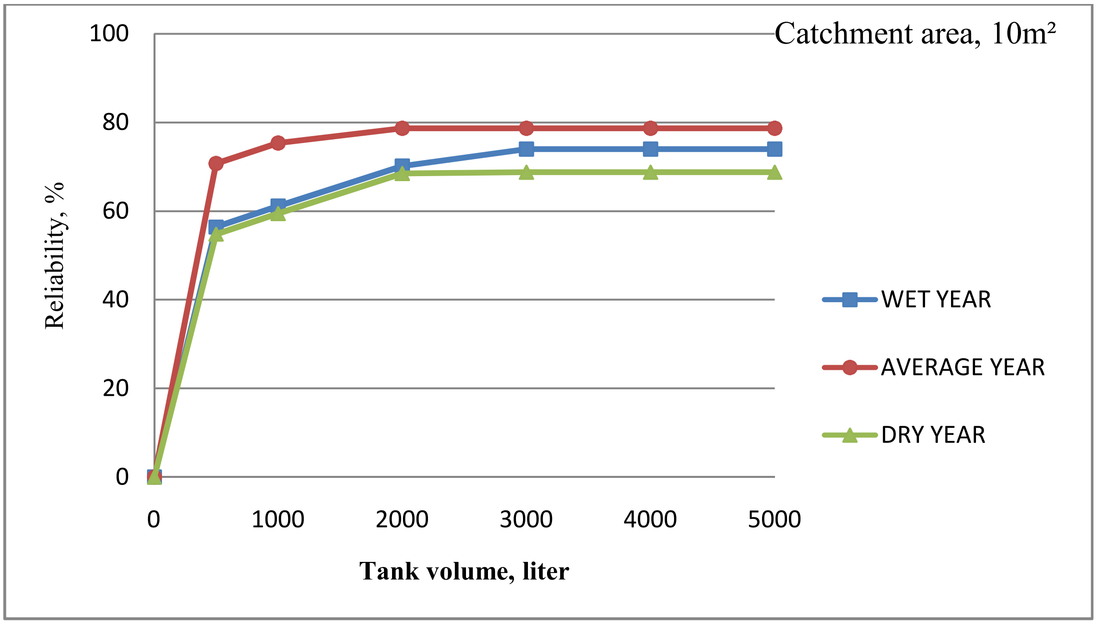

Fig (4.17): Reliability curve for 5lpcd demand and 10 m² catchment area

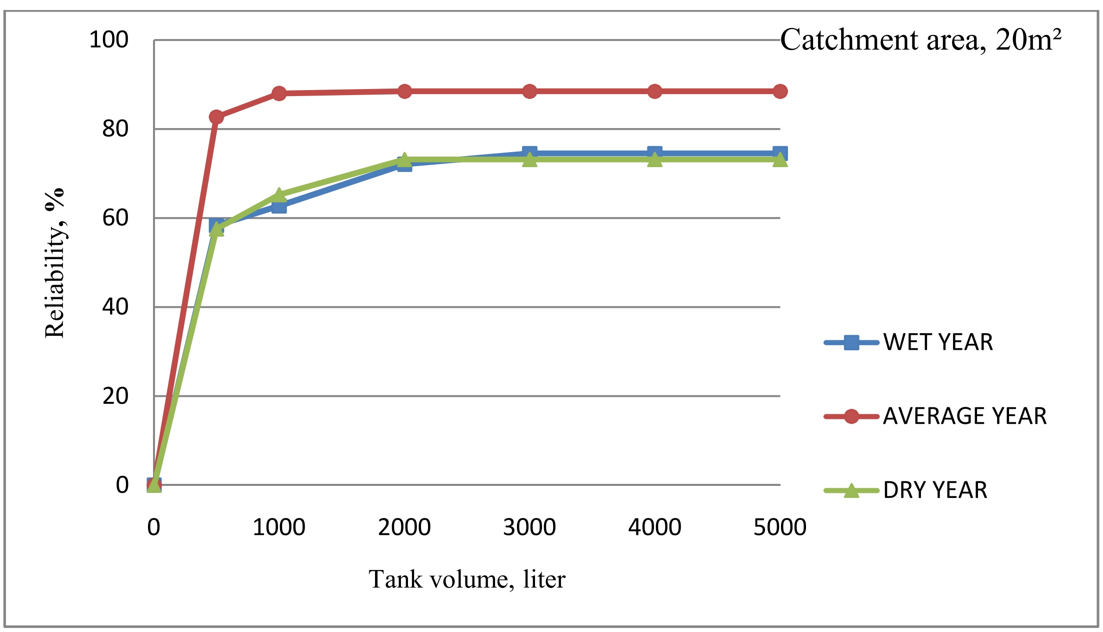

Fig (4.18): Reliability curve for 5lpcd demand and 20 m² catchment area

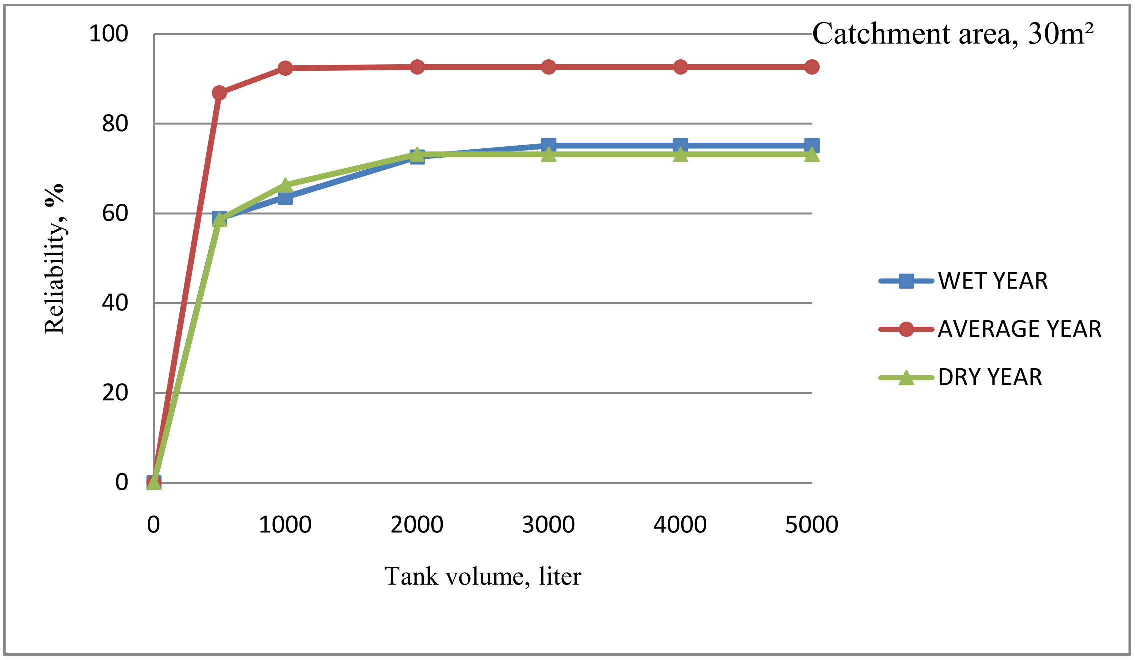

Fig (4.19): Reliability curve for 5lpcd demand and 30 m² catchment area

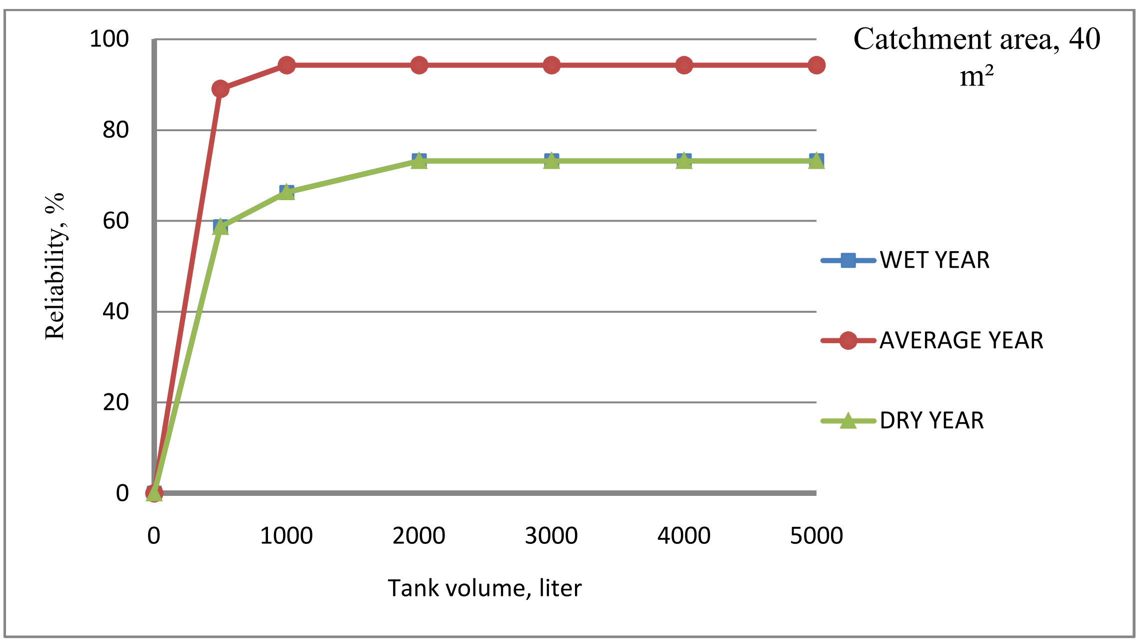

Fig (4.20): Reliability curve for 5lpcd demand and 40 m² catchment area

5lpcd is a higher demand than 2lpcd and so the reliability here is lesser than the reliability before. But in this case also, the reliability increased as the tank volume was increased and the reliability for wet year is higher than the dry year in all the cases.

A table showing the maximum reliability achieved for which tank volume is shown below, when the demand was 5lpcd.

Table (4.6): Maximum reliability for different tank sizes when the demand is 5lpcd

Catchment area (m^2)	Average year		Dry year		Wet year	
	Reliability (%)	Tank size (Liter)	Reliability (%)	Tank size (Liter)	Reliability (%)	Tank size (Liter)
10	78.7	2000	68.8	3000	73.8	3000
20	88.5	2000	73.2	2000	74.5	3000
30	92.6	2000	73.2	2000	75.1	3000
40	92.3	1000	73.2	2000	73.2	2000

4.2.3. Reliability comparison for 10lpcd demand

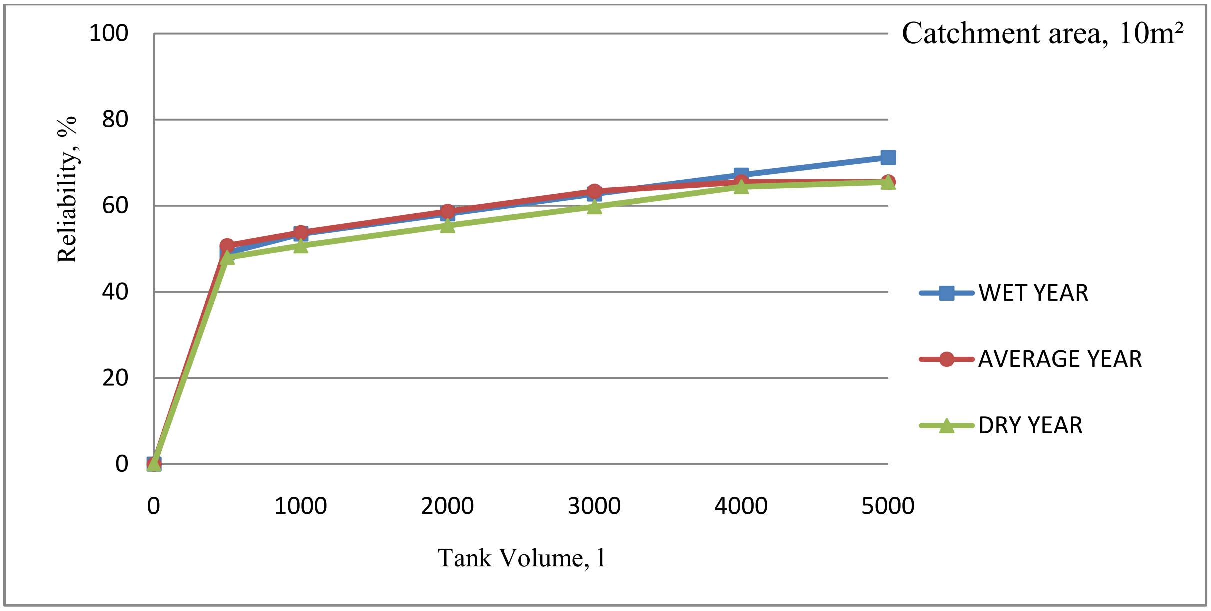

Fig (4.21): Reliability curve for 10lpcd demand and 10 m² catchment area

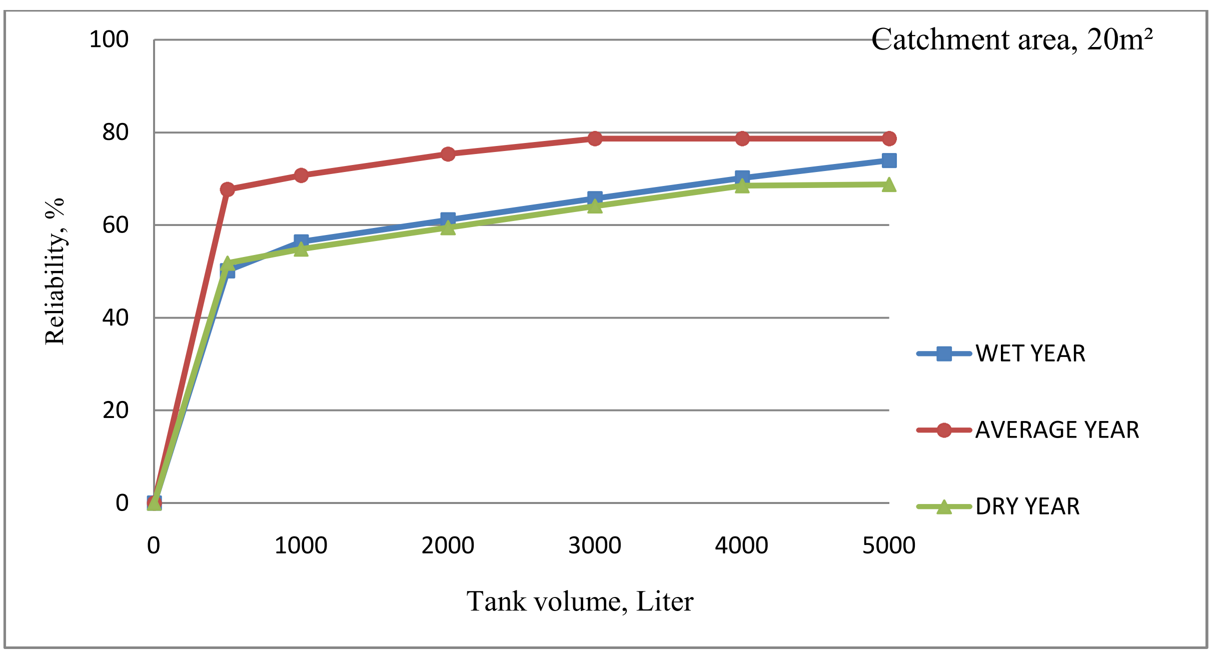

Fig (4.22): Reliability curve for 10pcd demand and 20 m² catchment area

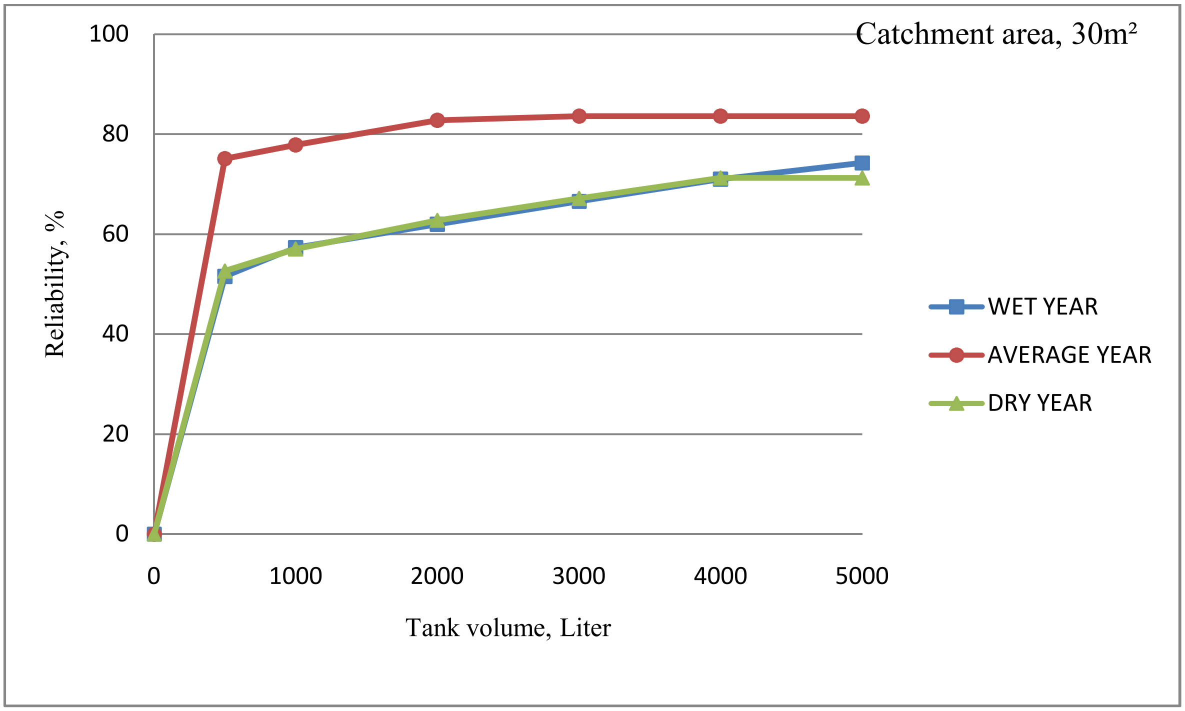

Fig (4.23): Reliability curve for 10lpcd demand and 30 m² catchment area

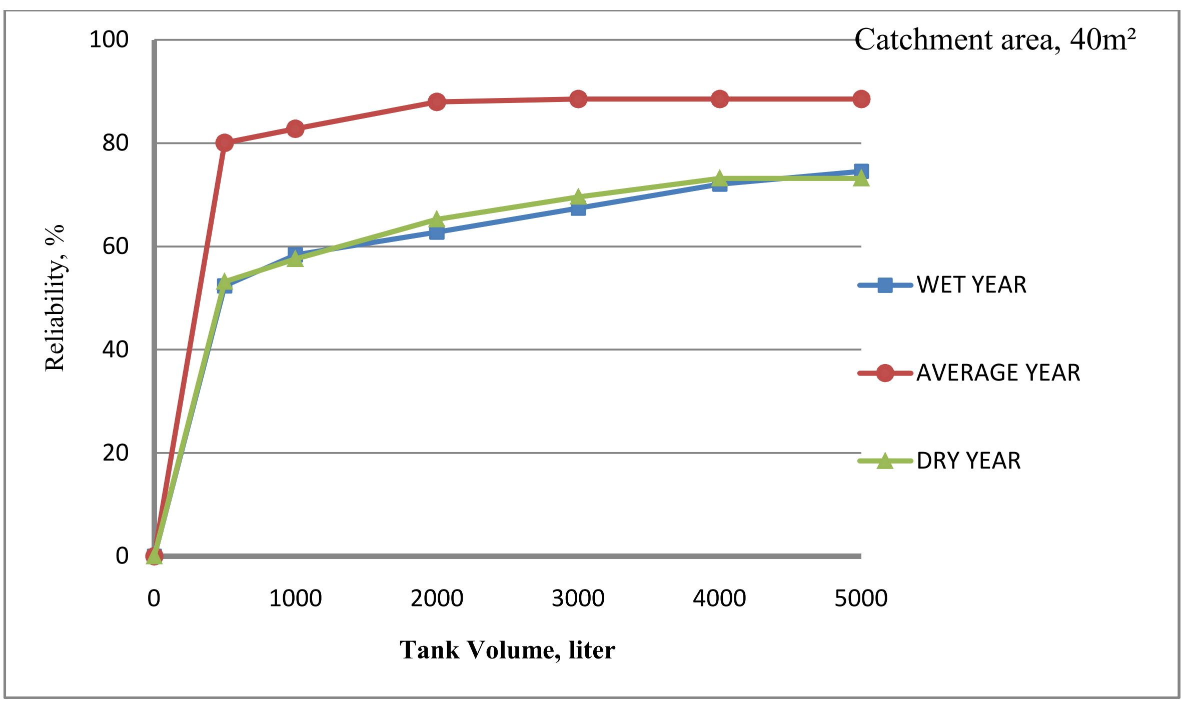

Fig (4.24): Reliability curve for 10lpcd demand and 40 m² catchment area

10lpcd is a much higher demand than 2 or 5lpcd. The reliability here is much lower than before. But, like before the wet year reliability is higher than dry year reliability.

A table showing the maximum reliability achieved for which tank volume is shown below, when the demand was 10lpcd.

Table (4.7): Maximum reliability for different tank sizes when the demand is 10lpcd

Catchment area (m^2)	Average year		Dry year		Wet year	
	Reliability (%)	Tank size (Liter)	Reliability (%)	Tank size (Liter)	Reliability (%)	Tank size (Liter)
10	65.5	4000	65.5	5000	71.3	5000
20	78.7	3000	68.8	5000	74	5000
30	83.6	3000	71.3	4000	74.4	5000
40	88.5	3000	73.2	4000	74.6	5000

4.3. COMPARISON GRAPHS OF SPILLING

Spilling occurs when available storage is higher than the tank volume. Comparisons were done among 2, 5 and 10lpcd demand, catchment aeras of 10, 20, 30 and 40 m² and for tank volume of 1000, 2000, 3000, 4000 and 5000 Liters. For different combinations, the findings are described below.

4.3.1. Spilling comparison for 2lpcd demand

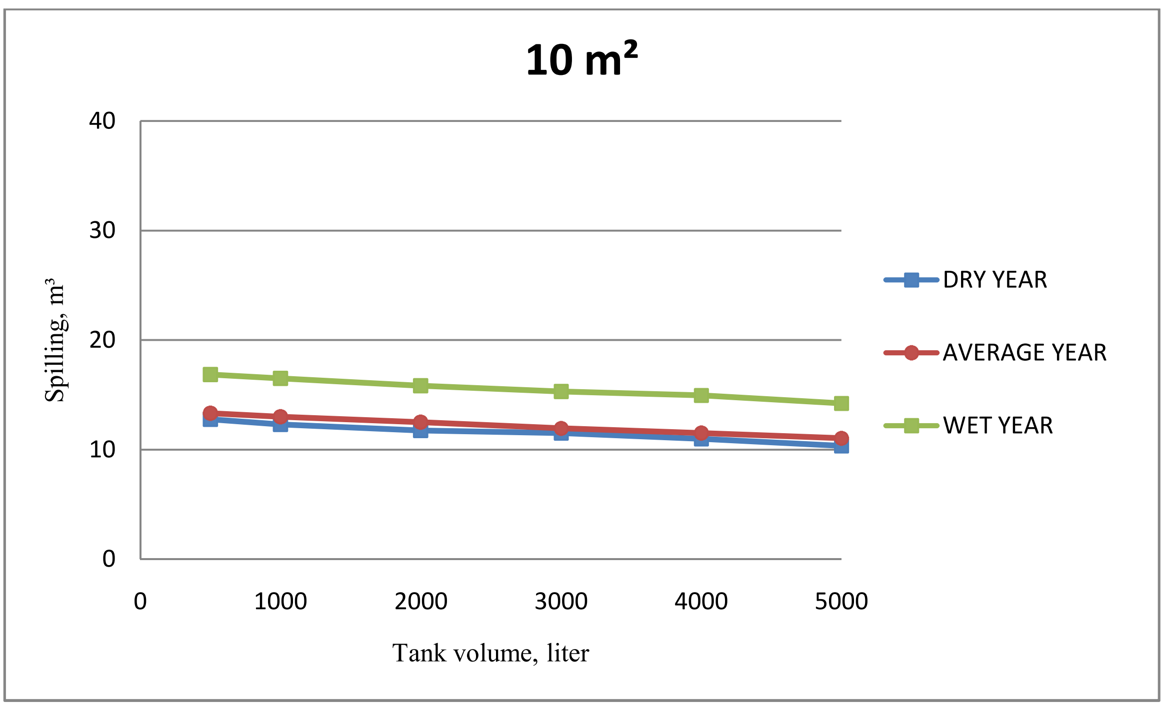

Fig (4.25): Spilling for 2lpcd demand and 10 m² catchment area

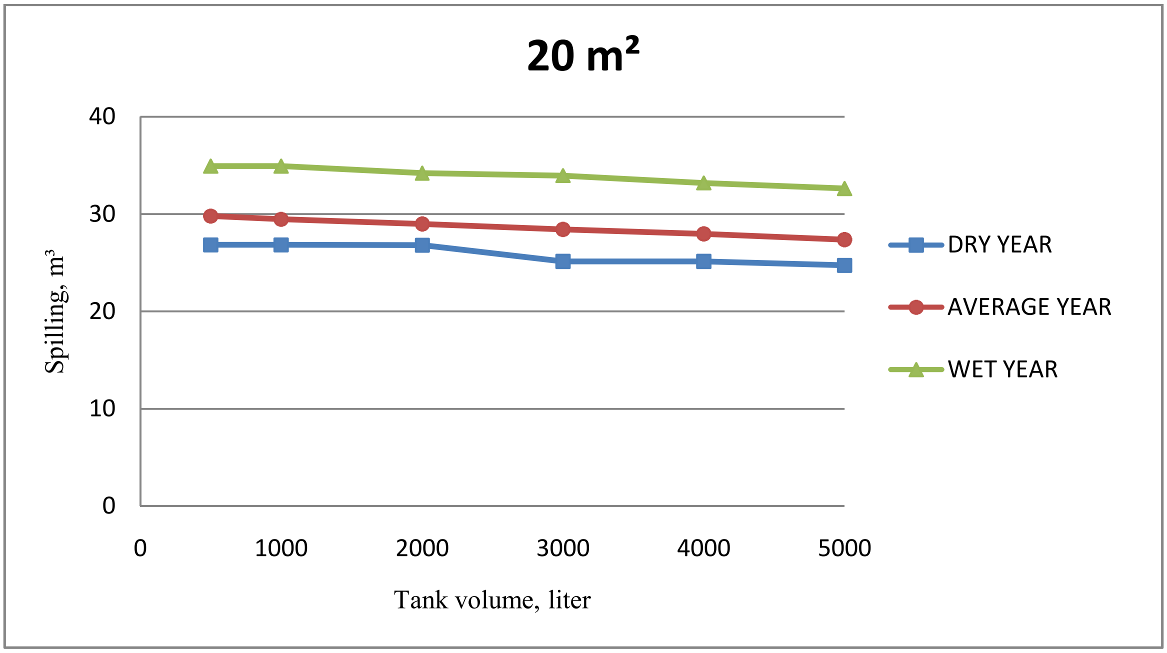

Fig (4.26): Spilling for 2lpcd demand and 20 m² catchment area

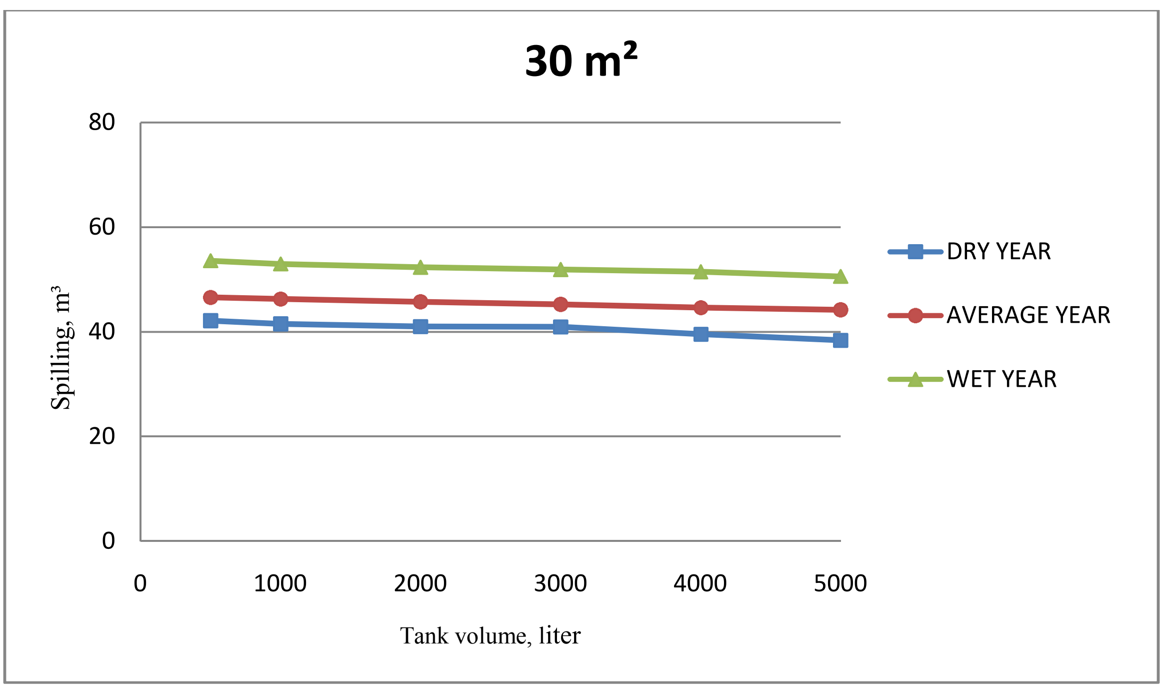

Fig (4.27): Spilling for 2lpcd demand and 30 m² catchment area

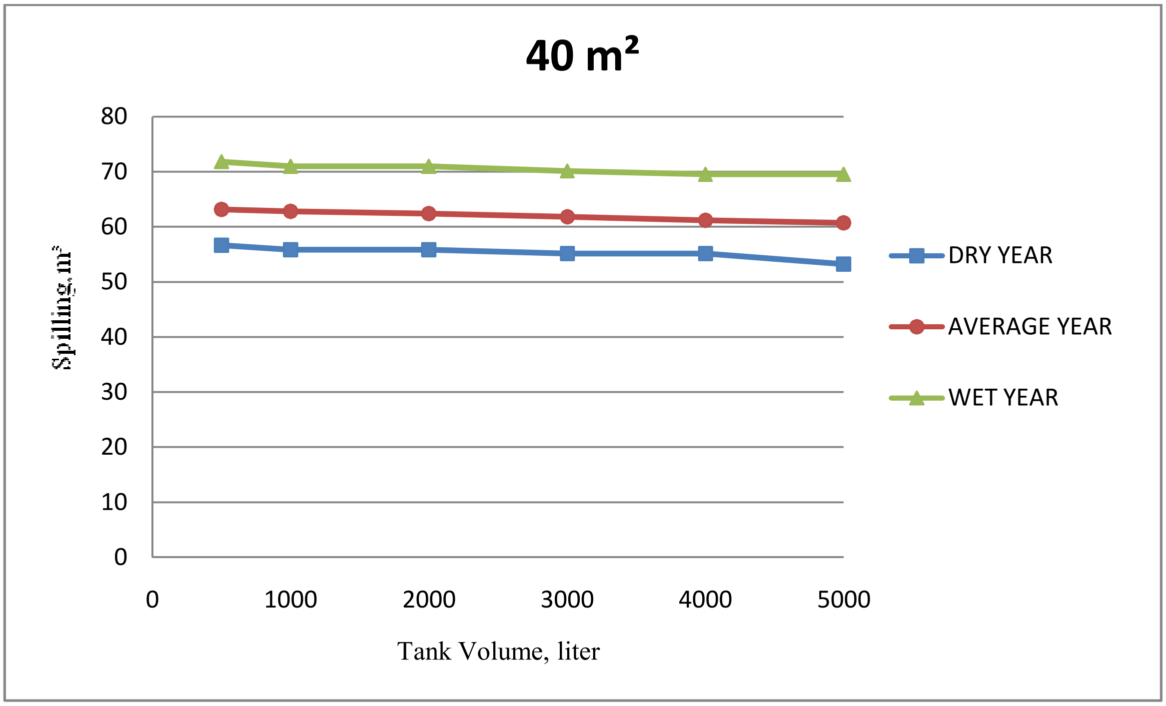

Fig (4.28): Spilling for 2lpcd demand and 40 m² catchment area

Spilling vs. tank volume curves show that spilling volume decreases as the tank volume increases. Moreover, the spilling volume increases as the catchment area increases. This happens because; more storage volume is available if the catchment area is higher. 2lpcd is a low demand so; the spilling volume is very high in all cases. The wet year has the most amount of spilling in these cases.

Maximum spilling occurs when tank volume is least. The catchment areas used in this study are 500-5000 liters. So, in this study the maximum spilling occurred for 500 liter tank size in all cases. A table showing maximum spilling for 2lpcd is shown below.

Table (4.8): Maximum spilling for different tank sizes when the demand is 2lpcd

Catchment area (m^2)	Average year		Wet year		Dry year	
	Spilling (m^3)	Tank size (Liter)	Spilling (m^3)	Tank size (Liter)	Spilling (m^3)	Tank size (Liter)
10	13.3	500	16.9	500	12.3	500
20	29.9	500	35	500	26.9	500
30	46.6	500	53.6	500	43	500
40	63.2	500	72	500	56.8	500

4.3.2. Spilling comparison for 5lpcd demand

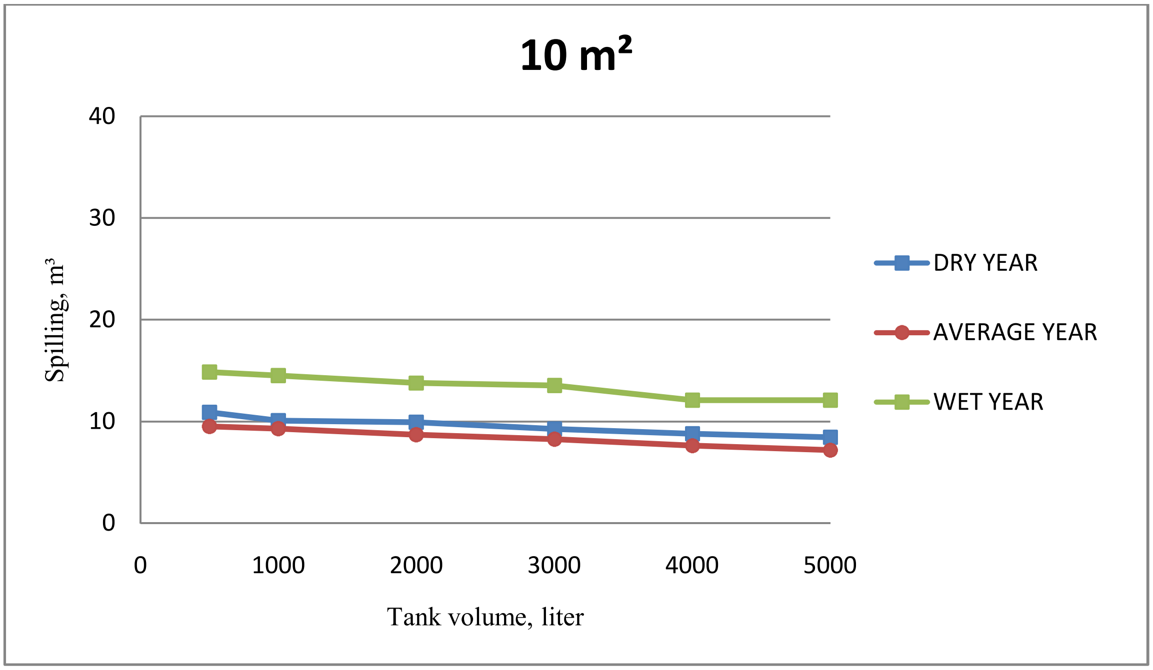

Fig (4.29): Spilling for 5lpcd demand and 10 m² catchment area

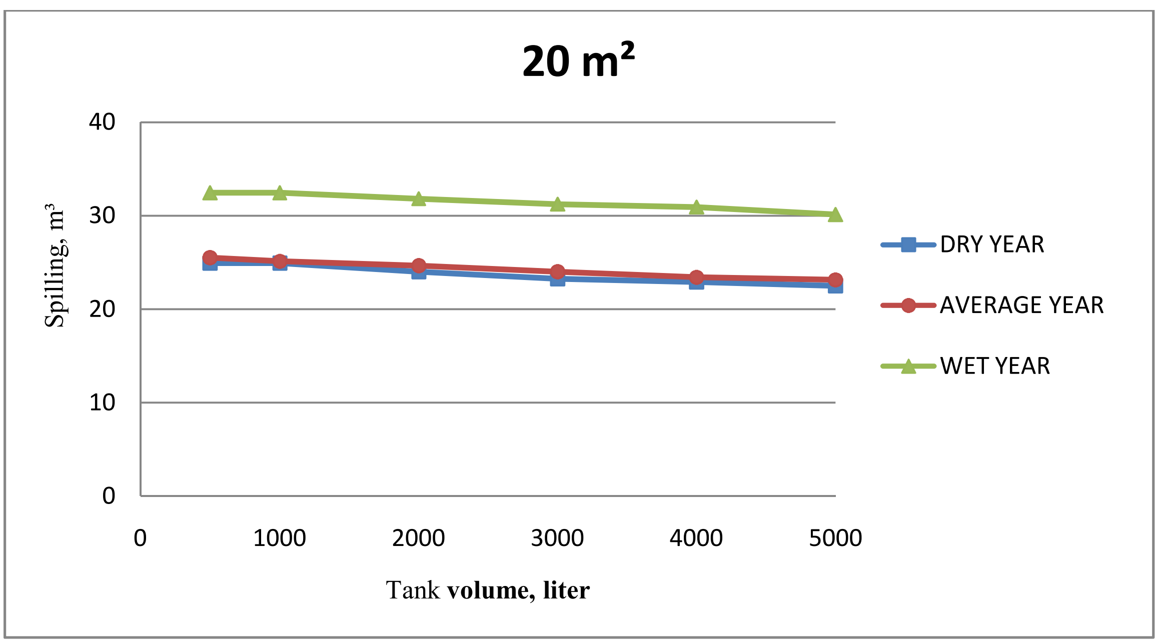

Fig (4.30): Spilling for 5lpcd demand and 20 m² catchment area

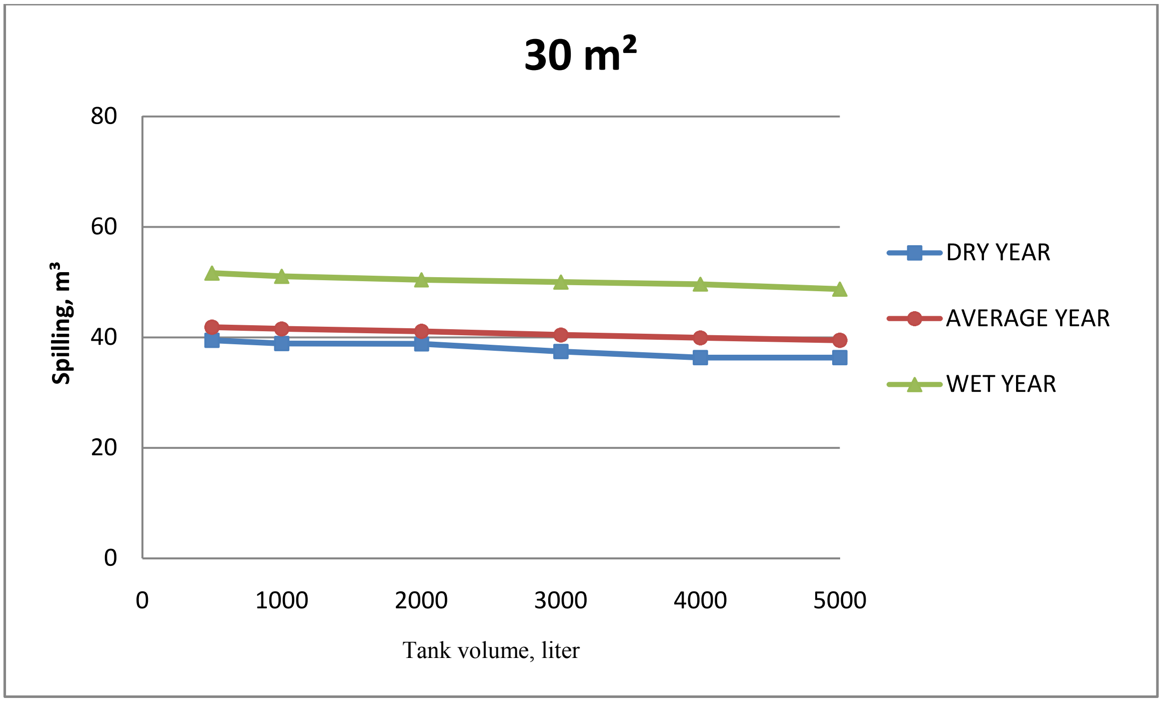

Fig (4.31): Spilling for 5lpcd demand and 30 m² catchment area

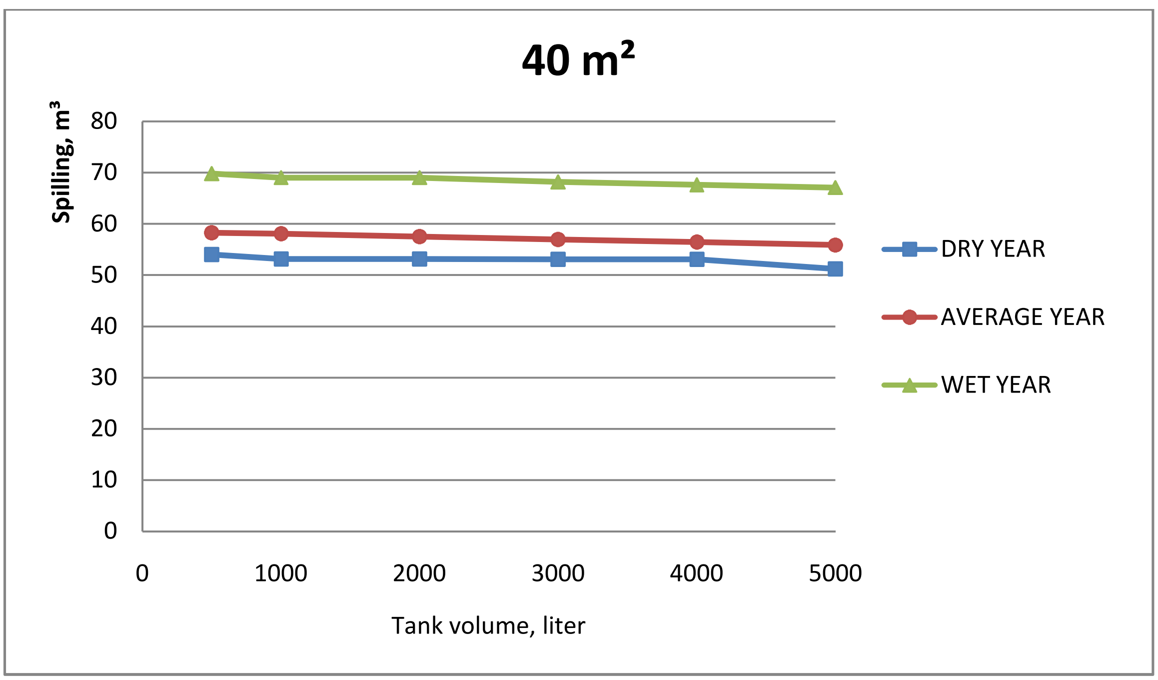

Fig (4.32): Spilling for 5lpcd demand and 40 m² catchment area

The spilling curves for 5lpcd demand are lower than before. Here also, the spilling increases with the increase of catchment area. Wet year has the most spilling volume then the other years.

Maximum spilling occurs when tank volume is least. The catchment areas used in this study are 500-5000 liters. So, in this study the maximum spilling occurred for 500 liter tank size in all cases. A table showing maximum spilling for 5lpcd is shown below

Table (4.9): Maximum spilling for different tank sizes when the demand is 5lpcd

Catchment area (m^2)	Average year		Wet year		Dry year	
	Spilling (m^3)	Tank size (Liter)	Spilling (m^3)	Tank size (Liter)	Spilling (m^3)	Tank size (Liter)
10	9.6	500	14.9	500	10.9	500
20	25.5	500	32.5	500	25	500
30	41.9	500	51.7	500	39.5	500
40	58.3	500	79.8	500	54.1	500

4.3.3. Spilling comparison for 10lpcd demand

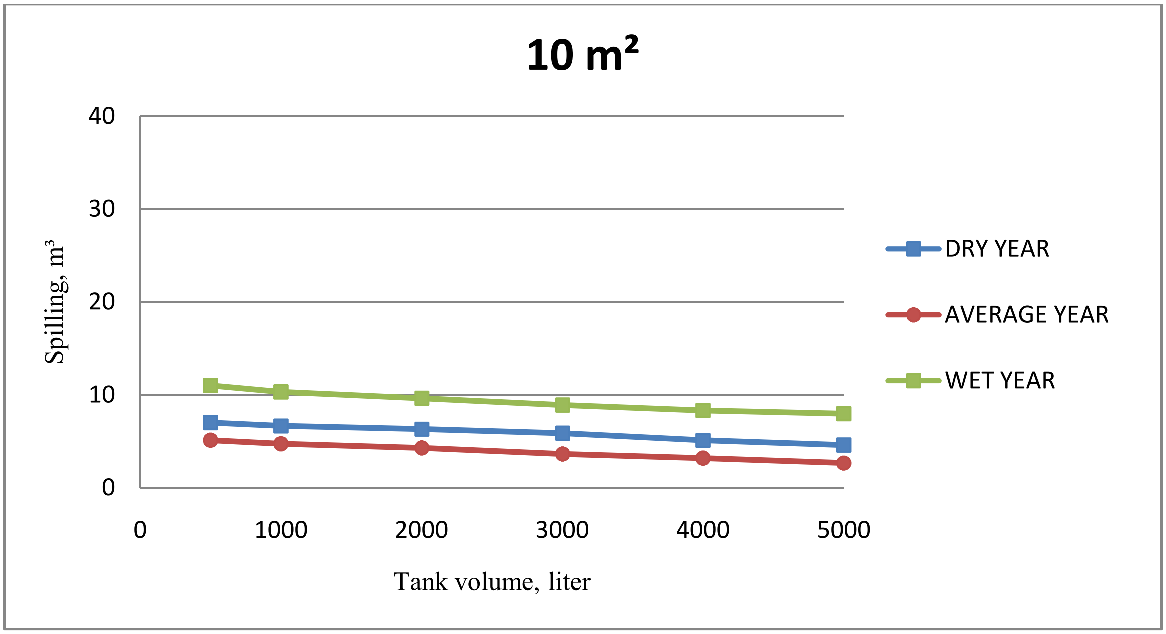

Fig (4.33): Spilling for 10lpcd demand and 10 m² catchment area

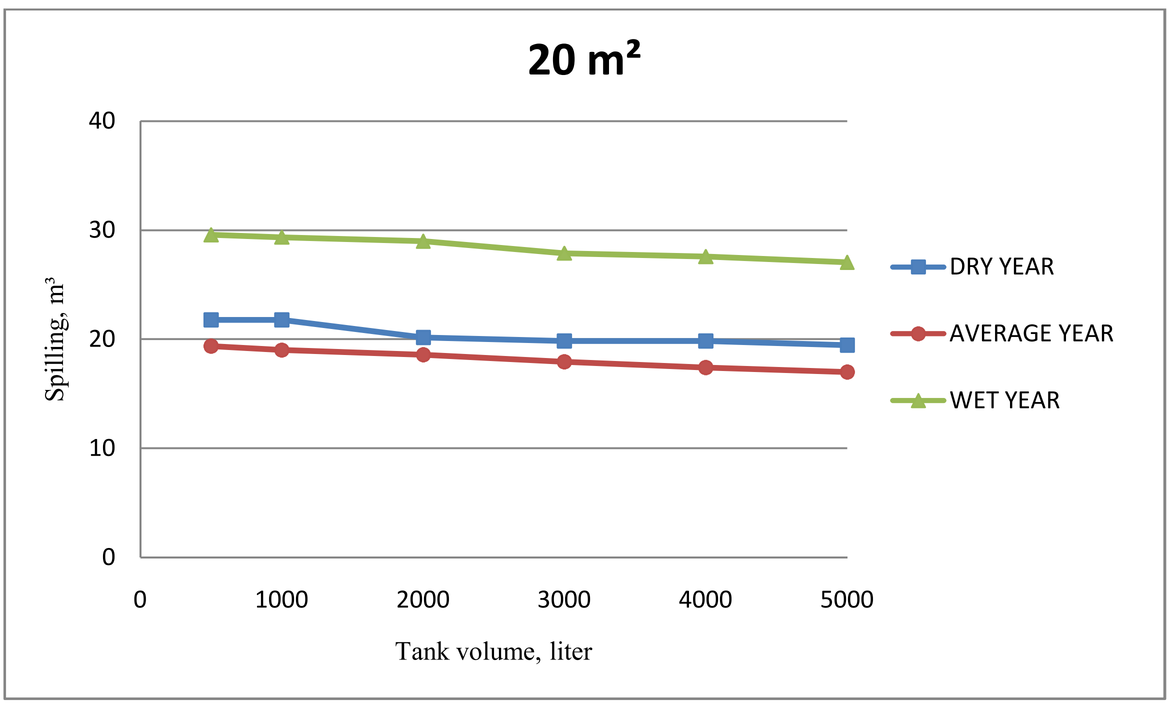

Fig (4.34): Spilling for 10lpcd demand and 20 m² catchment area

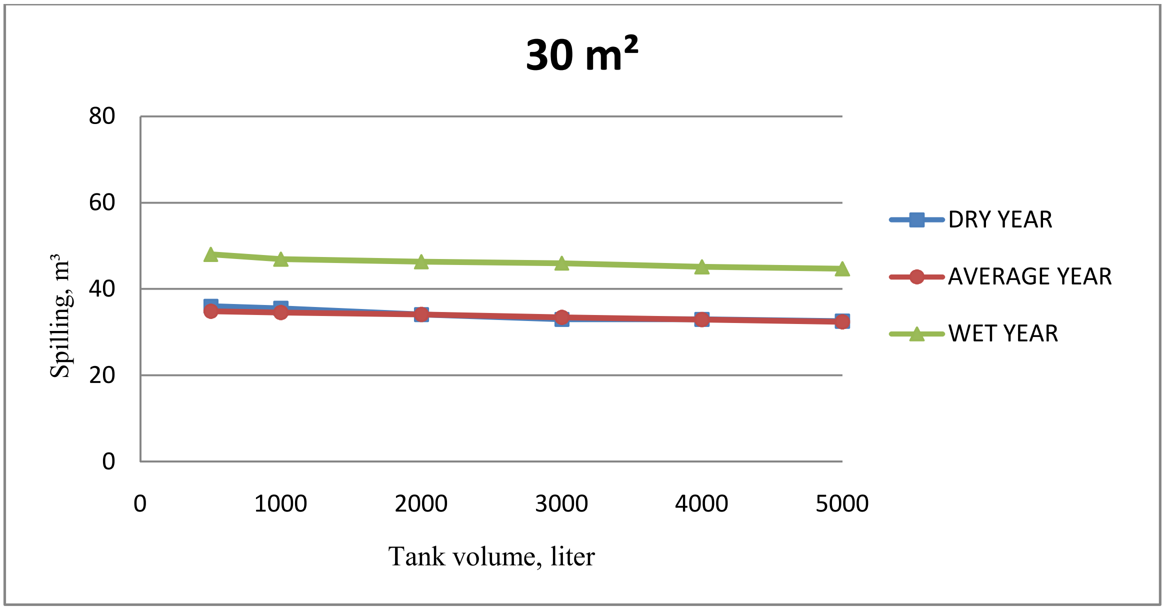

Fig (4.35): Spilling for 10lpcd demand and 30 m² catchment area

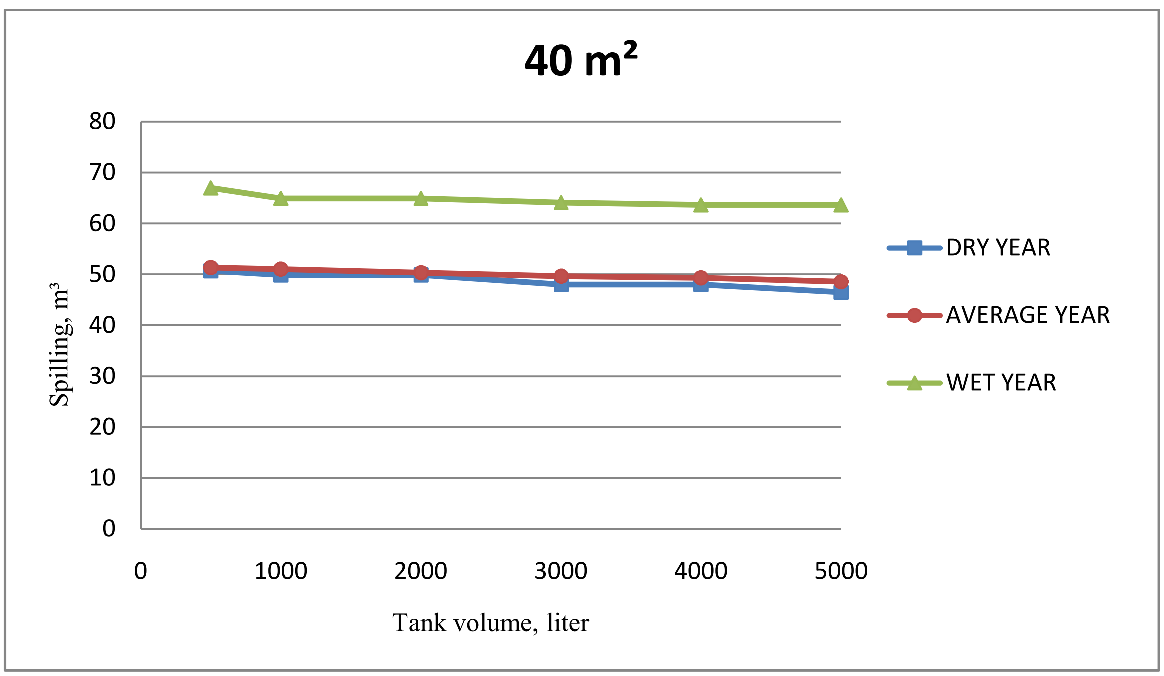

Fig (4.36): Spilling for 10lpcd demand and 40 m² catchment area

Spilling volume is lower than before for 10lpcd demand. Here also, the spilling increases with the increase of catchment area. Wet year has the most spilling volume then the other years.

Maximum spilling occurs when tank volume is least. The catchment areas used in this study are 500-5000 liters. So, in this study the maximum spilling occurred for 500 liter tank size in all cases. A table showing maximum spilling for 10lpcd is shown below

Table (4.10): Maximum spilling for tank sizes when the demand is 10lpcd

Catchment area (m^2)	Average year		Wet year		Dry year	
	Spilling (m^3)	Tank size (Liter)	Spilling (m^3)	Tank size (Liter)	Spilling (m^3)	Tank size (Liter)
10	5.1	500	11	500	7	500
20	19.4	500	9.6	500	21.8	500
30	34.9	500	48.1	500	36	500
40	51.3	500	67	500	50.8	500

4.3. COMPARISON GRAPHS OF SUPPLEMENTARY WATER DEMAND

The supplementary water demand is the water volume that has to be provided from another source. This water is not from the rainwater tank in use. Comparisons of supplementary water demand for different combinations of conditions are computed and assessed. Variables in this case are catchment area, demand and tank volume.

4.3.1. Supplementary water demand comparison for 2lpcd demand

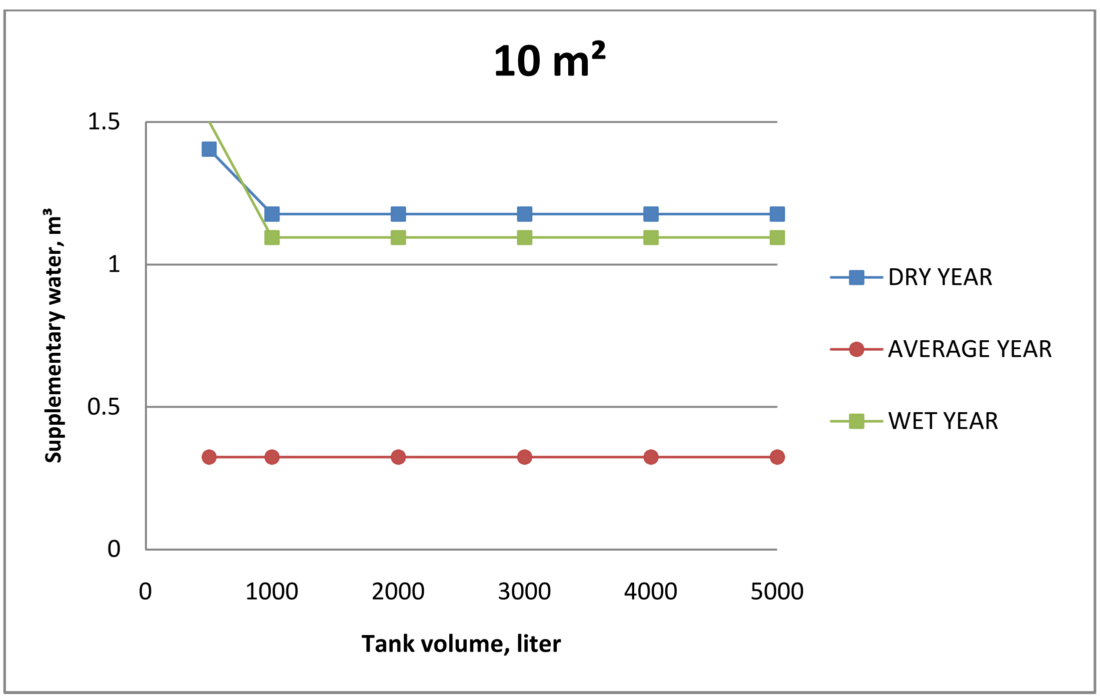

Fig (4.37): Supplementary water demand for 2lpcd demand and 10 m² catchment area

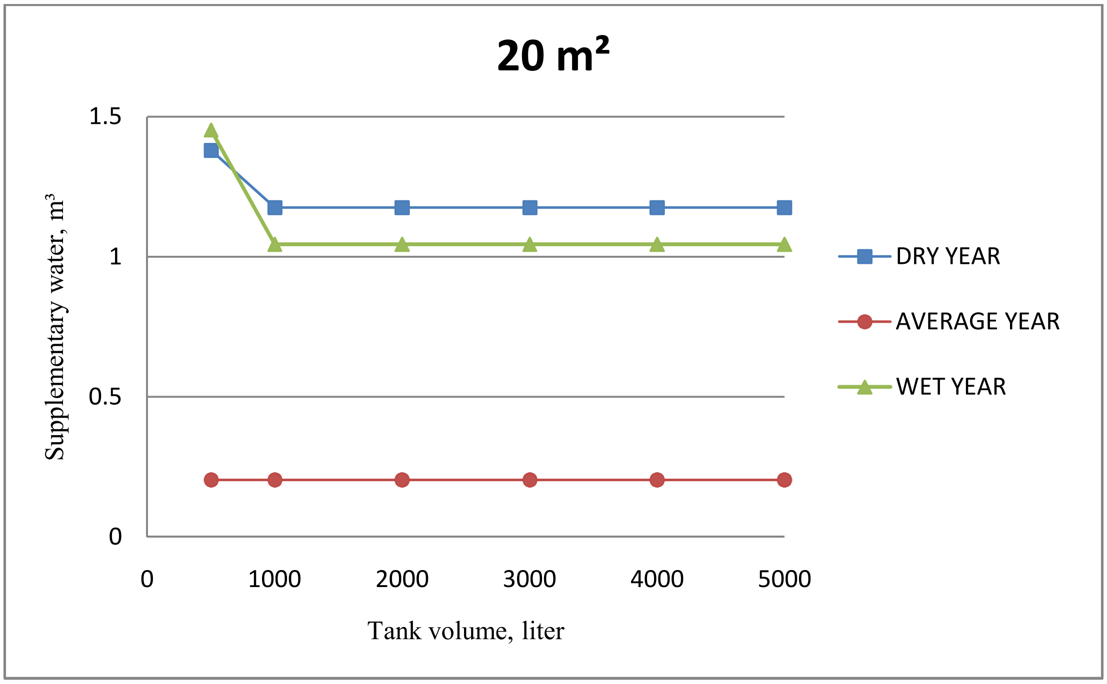

Fig (4.38): Supplementary water demand for 2lpcd demand and 20 m² catchment area

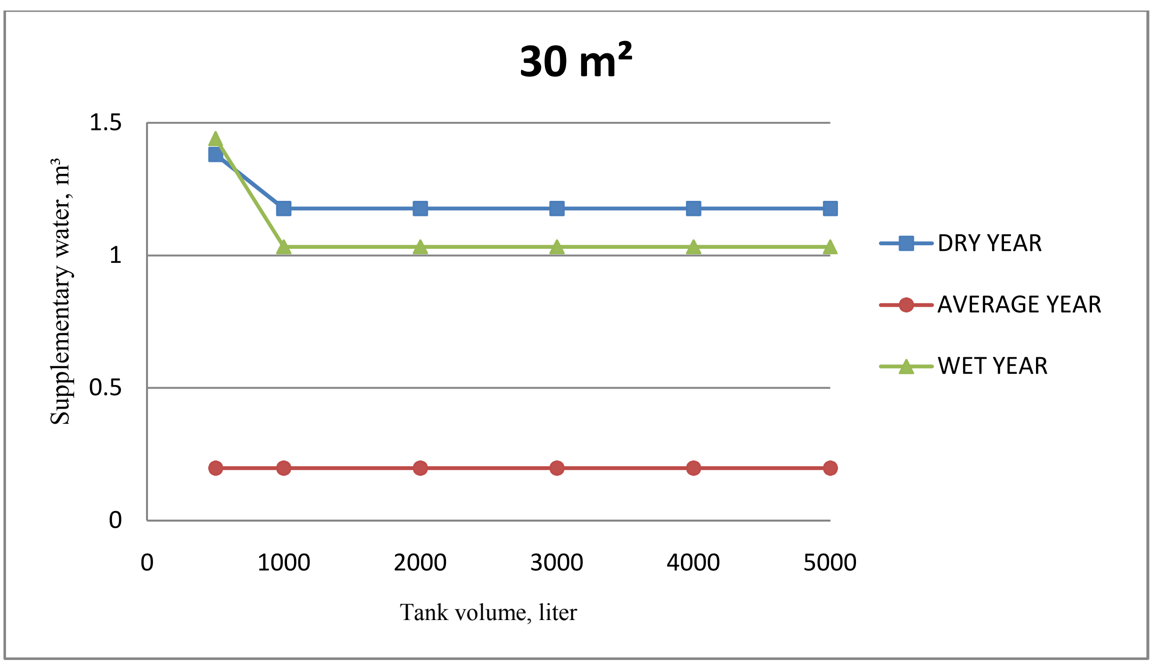

Fig (4.39): Supplementary water demand for 2lpcd demand and 10 m² catchment area

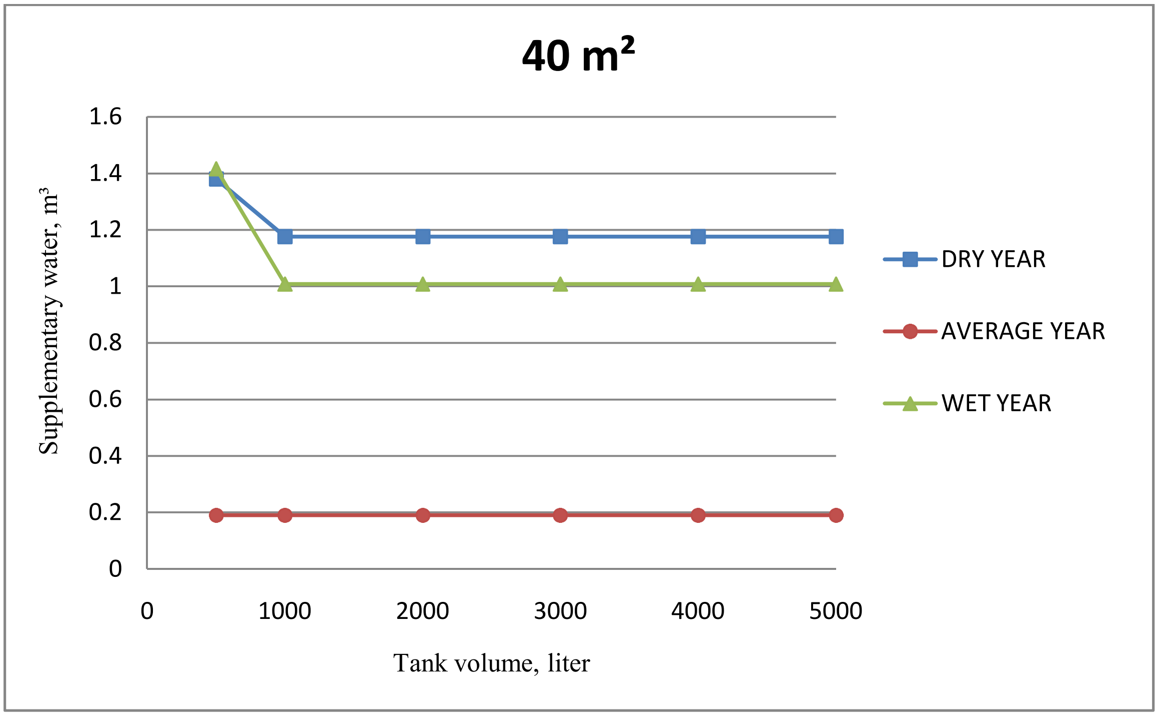

Fig (4.40): Supplementary water demand for 2lpcd demand and 10 m² catchment area

The supplementary water demand for 2 lpcd demands for various catchment areas and tank volume are shown here. Supplementary water demand is highest for dry years. This happens because there is less storage volume available.

The maximum supplementary water demand is shown below. The maximum supplementary water demand is the highest volume of water that has to be supplied from other sources.

The less the supplementary water demand, the higher is the reliability of the system. The minimum supplementary water demand is also shown below.

The maximum and minimum supplementary water demand for different tank sizes when the demand is 2lpcd are given below in tables.

Table (4.11): Maximum supplementary water demand for different tank sizes when the demand is 2lpcd

Catchment area (m^2)	Average year		Wet year		Dry year	
	Supplementary Water demand (m^3)	Tank size (Liter)	Supplementary Water demand (m^3)	Tank size (Liter)	Supplementary Water demand (m^3)	Tank size (Liter)
10	0.33	500	1.4	500	1.18	1000
20	0.21	500	1.45	500	1.38	1000
30	0.2	500	1.44	500	1.38	1000
40	0.19	500	1.416	500	1.38	5000

Table (4.12): Minimum supplementary water demand for different tank sizes when the demand is 2lpcd

Catchment area (m^2)	Average year		Wet year		Dry year	
	Supplementary Water demand (m^3)	Tank size (Liter)	Supplementary Water demand (m^3)	Tank size (Liter)	Supplementary Water demand (m^3)	Tank size (Liter)
10	0.323	500	1.095	1000	1.76	1000
20	0.203	500	1.04	1000	1.17	1000
30	0.197	500	1.03	1000	1.176	1000
40	0.1908	500	1.008	1000	1.176	1000

4.3.2. Supplementary water demand comparison for 5lpcd demand

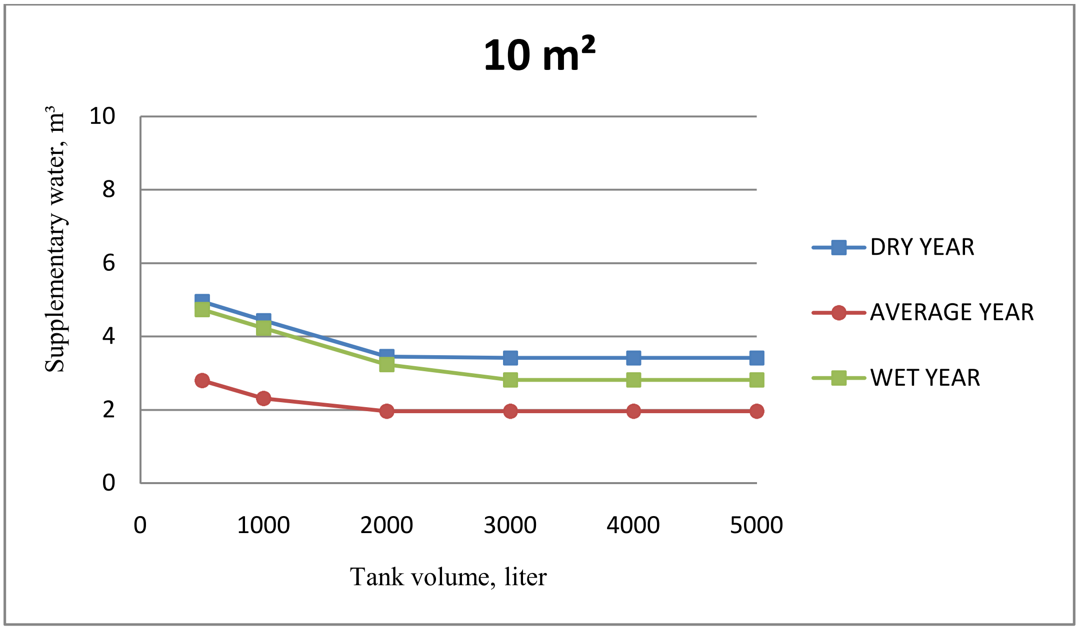

Fig (4.41): Supplementary water demand for 5lpcd demand and 10 m² catchment area

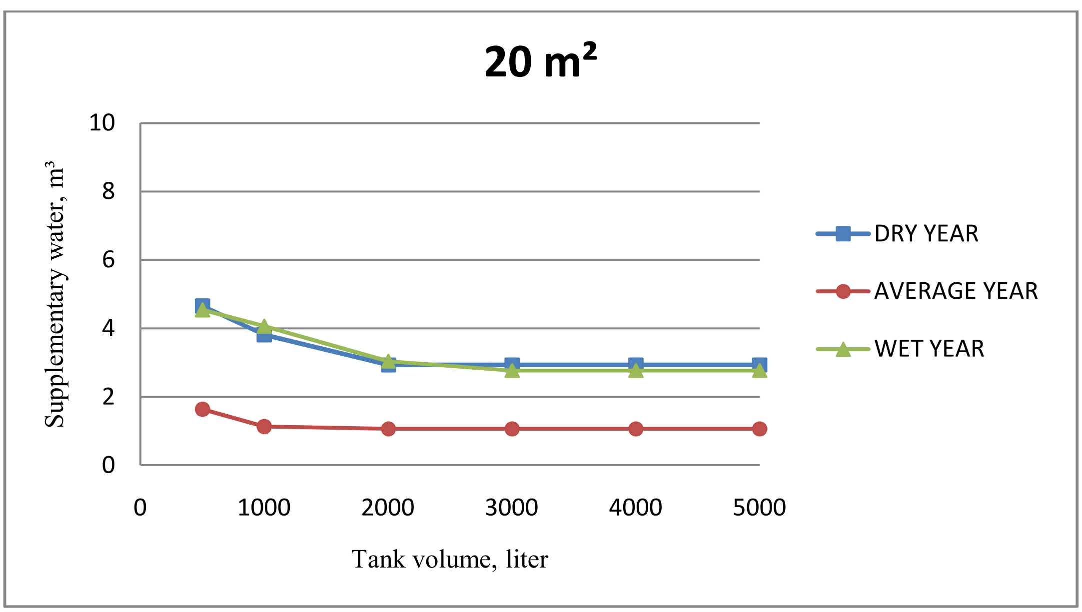

Fig (4.42): Supplementary water demand for 5lpcd demand and 20 m² catchment area

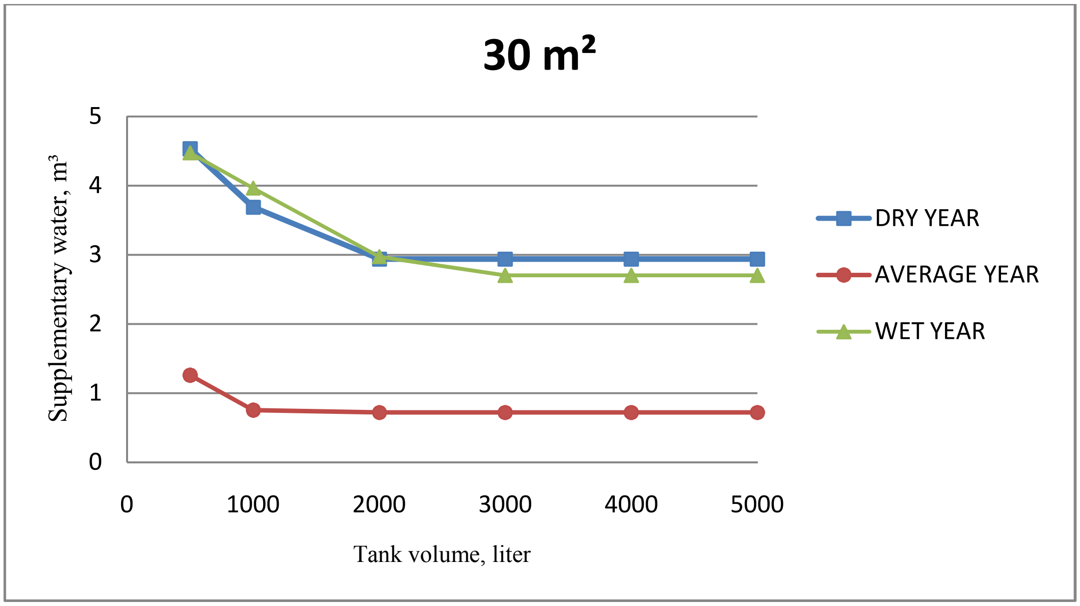

Fig (4.43): Supplementary water demand for 5lpcd demand and 30 m² catchment area

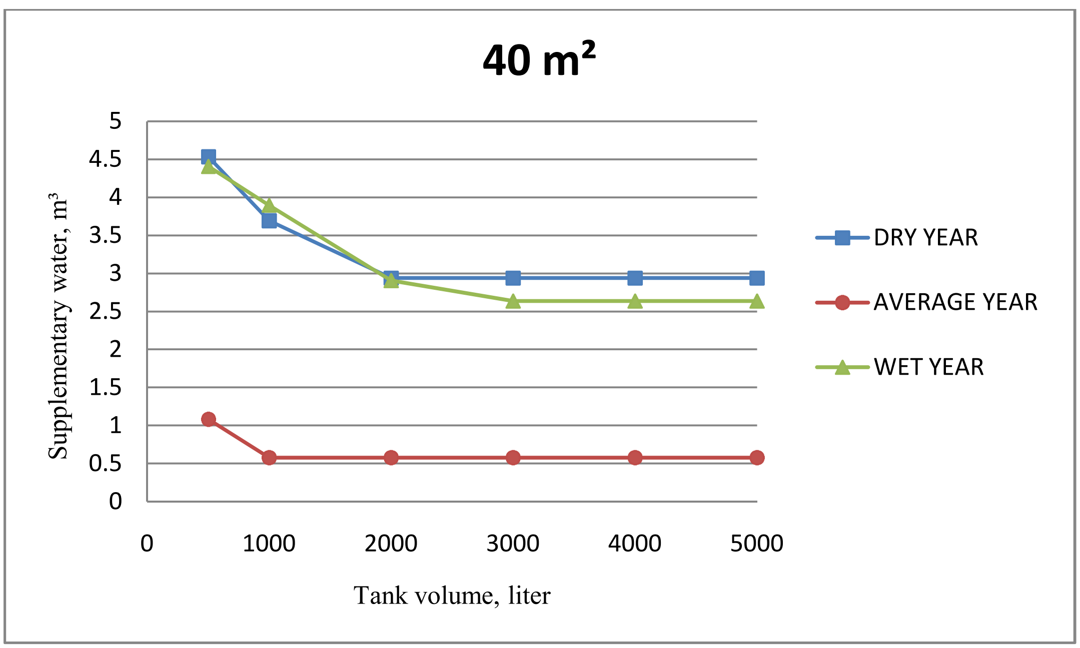

Fig (4.44): Supplementary water demand for 5lpcd demand and 40 m² catchment area

The supplementary water demand for 5lpcd demand shows almost the same result as before. The demand is higher than before in this case.

The maximum supplementary water demand is shown below. The maximum supplementary water demand is the highest volume of water that has to be supplied from other sources.

The less the supplementary water demand, the higher is the reliability of the system. The minimum supplementary water demand is also shown below.

The maximum and minimum supplementary water demand for different tank sizes when the demand is 5lpcd are given below in tables.

Table (4.13): Maximum supplementary water demand for different tank sizes when the demand is 5lpcd

Catchment area (m^2)	Average year		Wet year		Dry year	
	Supplementary Water demand (m^3)	Tank size (Liter)	Supplementary Water demand (m^3)	Tank size (Liter)	Supplementary Water demand (m^3)	Tank size (Liter)
10	2.76	500	4.73	500	4.95	500
20	1.63	500	4.5	500	4.65	500
30	1.25	500	4.4	500	4.5	500
40	1.08	500	4.4	500	4.5	500

Table (4.14): Minimum supplementary water demand for different tank sizes when the demand is 5lpcd

Catchment area (m^2)	Average year		Wet year		Dry year	
	Supplementary Water demand (m^3)	Tank size (Liter)	Supplementary Water demand (m^3)	Tank size (Liter)	Supplementary Water demand (m^3)	Tank size (Liter)
10	1.9	2000	2.8	2000	3.45	2000
20	1.06	3000	2.72	3000	2.94	3000
30	0.72	2000	2.703	3000	2.94	2000
40	0.57	1000	2.6	3000	2.9	2000

4.3.3. Supplementary water demand comparison for 10lpcd demand

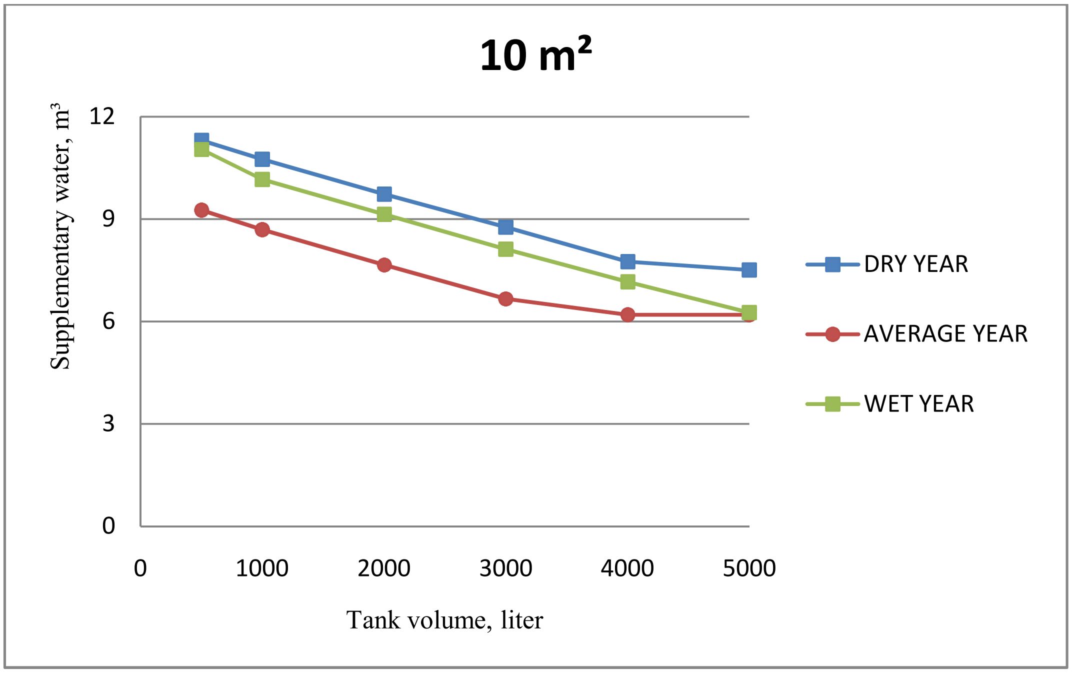

Fig (4.45): Supplementary water demand for 5lpcd demand and 40 m² catchment area

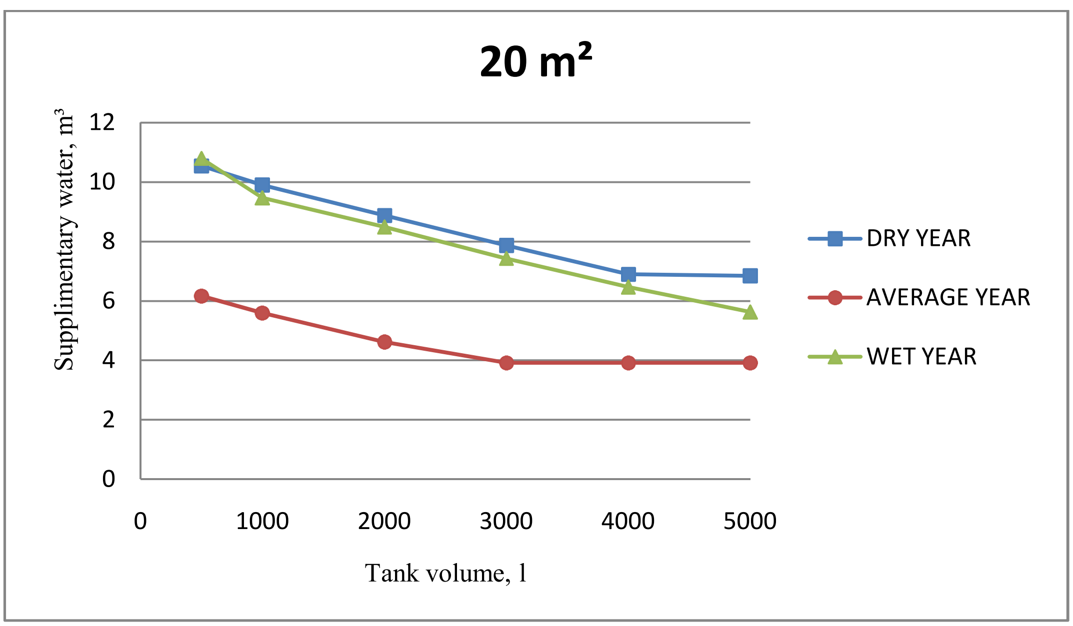

Fig (4.46): Supplementary water demand for 5lpcd demand and 40 m² catchment area

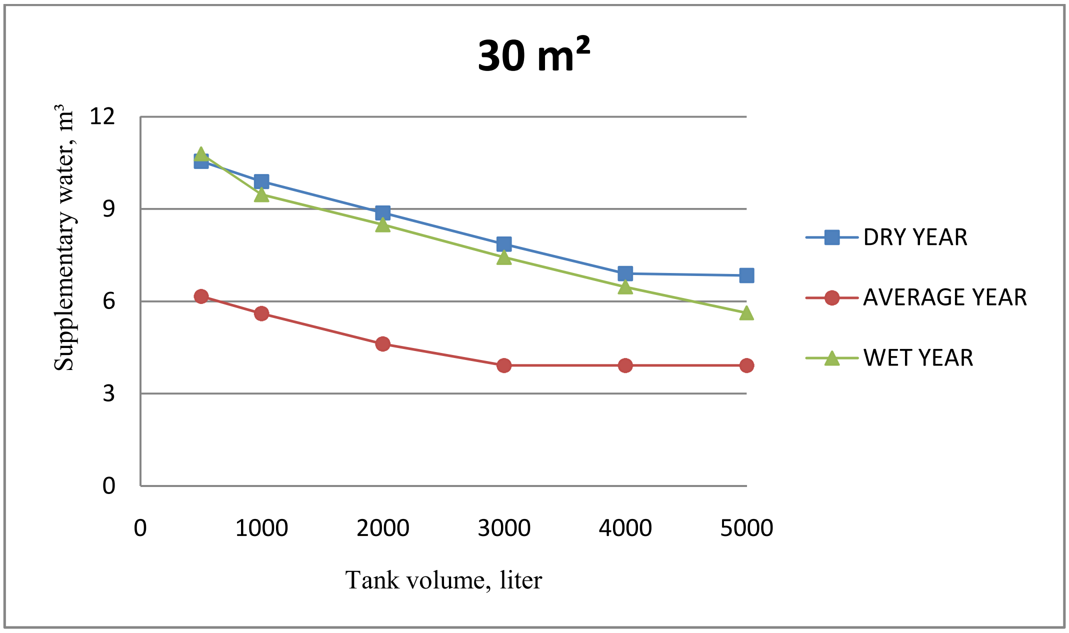

Fig (4.47): Supplementary water demand for 5lpcd demand and 40 m² catchment area

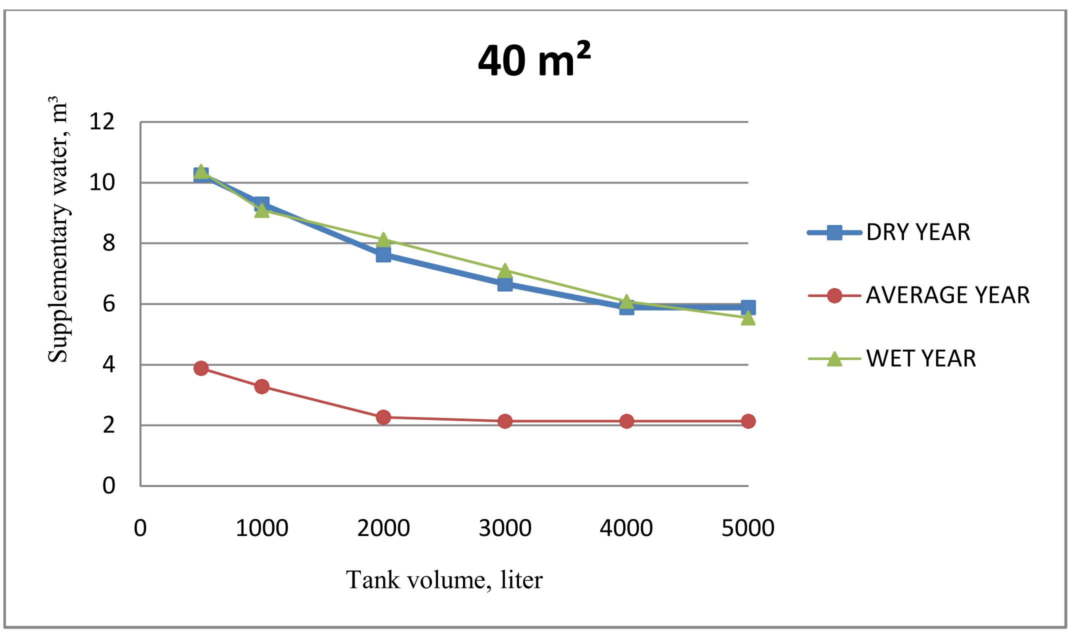

Fig (4.48): Supplementary water demand for 5lpcd demand and 40 m² catchment area

The supplementary water demand is higher than before but it decreases as the tank volume increases. The graphs show similar results for all the combinations of conditions.

The maximum supplementary water demand is shown below. The maximum supplementary water demand is the highest volume of water that has to be supplied from other sources.

The less the supplementary water demand, the higher is the reliability of the system. The minimum supplementary water demand is also shown below.

The maximum and minimum supplementary water demand for different tank sizes when the demand is 10lpcd are given below in tables.

Table (4.15): Maximum supplementary water demand for different tank sizes when the demand is 10lpcd

Catchment area (m^2)	Average year		Wet year		Dry year	
	Supplementary Water demand (m^3)	Tank size (Liter)	Supplementary Water demand (m^3)	Tank size (Liter)	Supplementary Water demand (m^3)	Tank size (Liter)
10	9.25	500	11.04	500	11.3	500
20	6.16	500	10.79	500	10.54	500
30	4.6	500	10.5	500	10.3	500
40	3.8	500	10.3	500	10.2	500

Table (4.16): Minimum supplementary water demand for different tank sizes when the demand is 10lpcd

Catchment area (m^2)	Average year		Wet year		Dry year	
	Supplementary Water demand (m^3)	Tank size (Liter)	Supplementary Water demand (m^3)	Tank size (Liter)	Supplementary Water demand (m^3)	Tank size (Liter)
10	6.18	4000	6.2	5000	7.5	5000
20	3.92	3000	5.62	5000	6.8	5000
30	2.9	3000	5.5	5000	6.3	5000
40	2.13	3000	5.5	5000	5.8	4000

4.4. COMPARISON GRAPHS FOR WET, DRY AND AVERAGE YEARS

The reliability, supplementary water demand, percentage of days the will be full and spilling volume were compared for the per capita demand of 2, 5 and 10lpcd. These comparisons were done to assess the reliability of the system. The comparisons are given according to different catchment areas,

4.4.1. COMPARISON GRAPHS

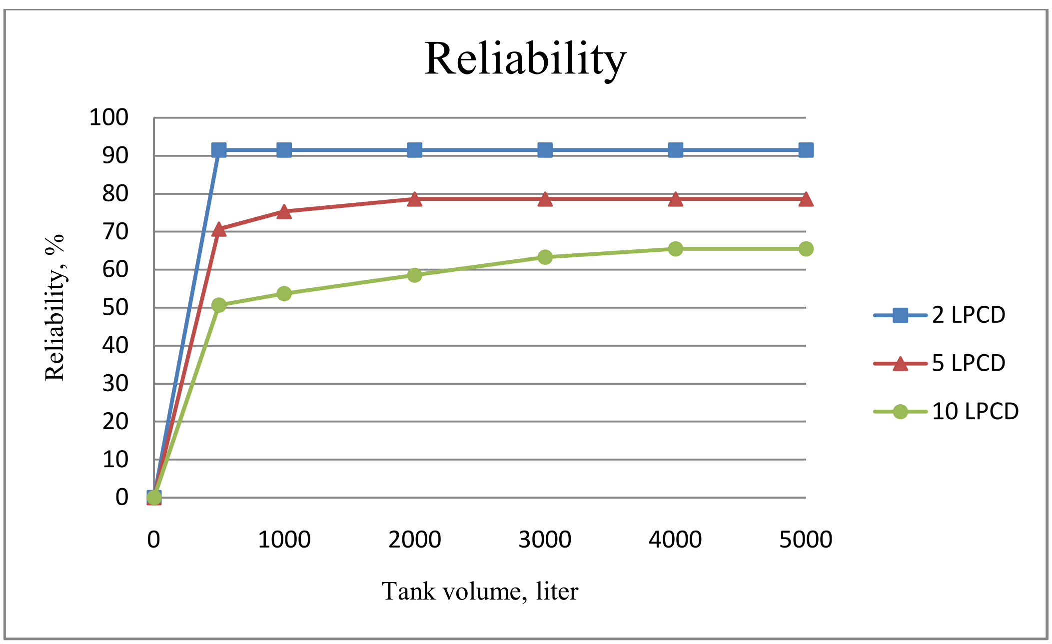

Fig (4.49): Reliability vs. Tank volume (10 m² for average year)

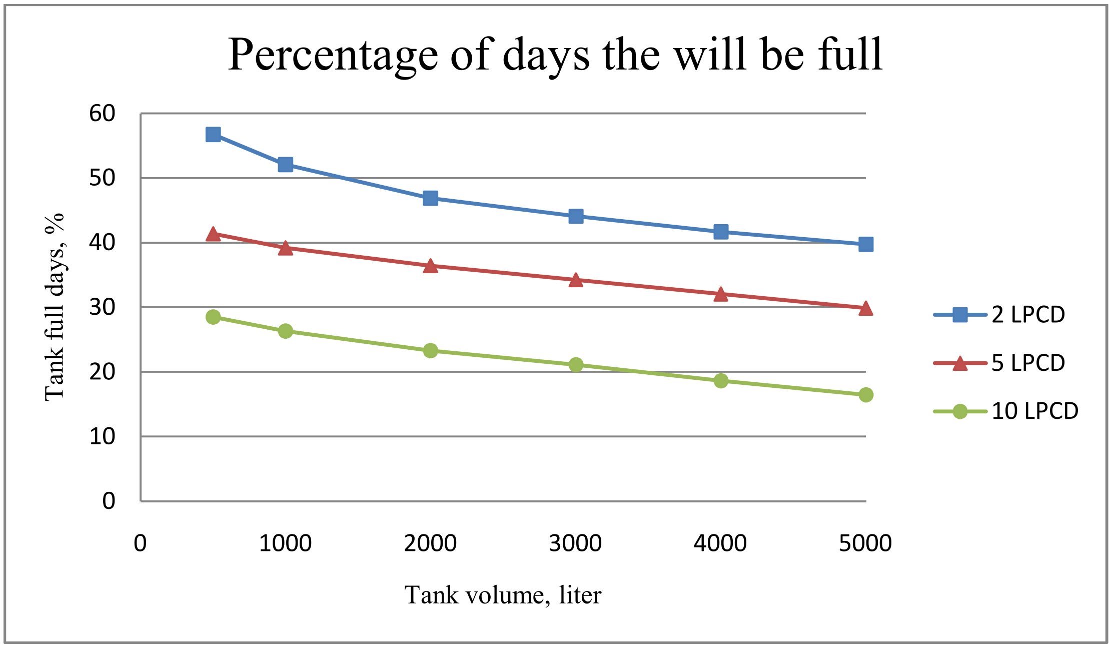

Fig (4.50): Tank volume vs. Tank full days (10 m² for average year)

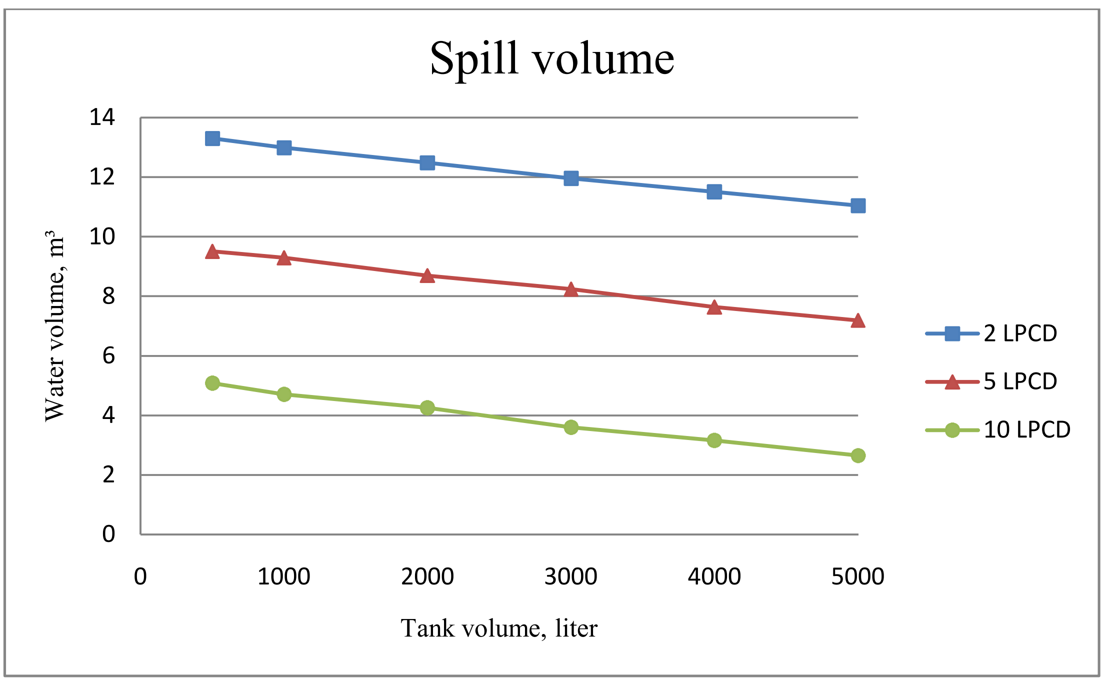

Fig (4.51): Spill volume (10 m² for average year)

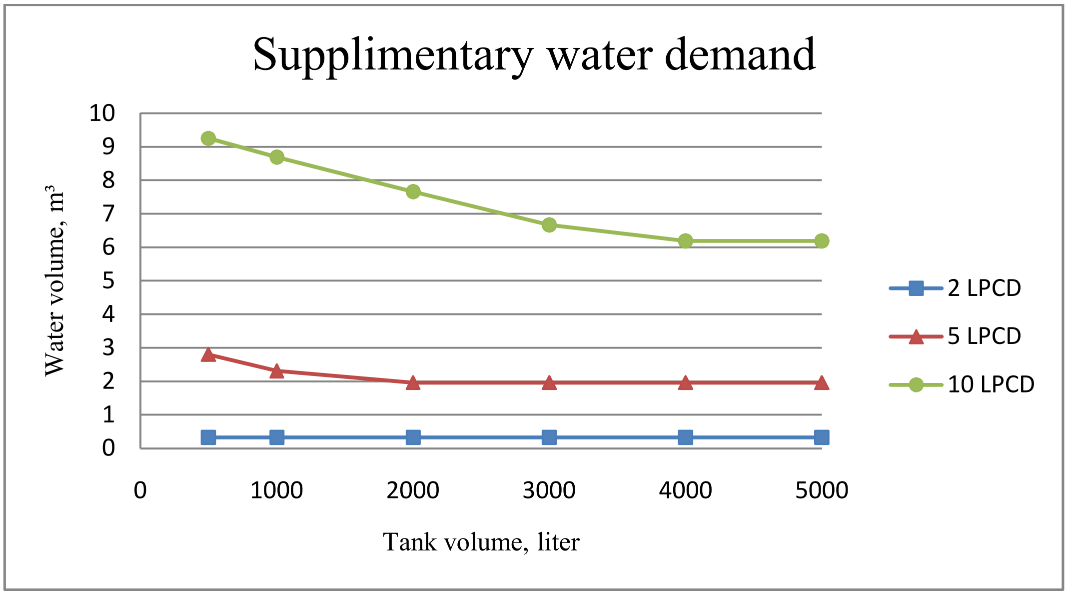

Fig (4.52): Supplementary water demand (10 m² for average year)

10 m² is a small catchment area so the storage volume is very small in quantity. For demand of 2, 5 and 10lpcd the reliability decreases along with the increase of demand. The reliability increases as the tank volume increases.

The percentage of days the tank remains full decreases as the demand increases. It also decreases as the tank volume increases.

The spill volume decreases as the tank volume increases. It also decreases as the demand increases.

The volume of water that has to be provided from other sources decreases as the tank volume increases. But the water volume increases as the demand increases.

All the comparison values are shown in the appendix section B.

4.4.2. COMPARISON GRAPHS FOR 20 m²

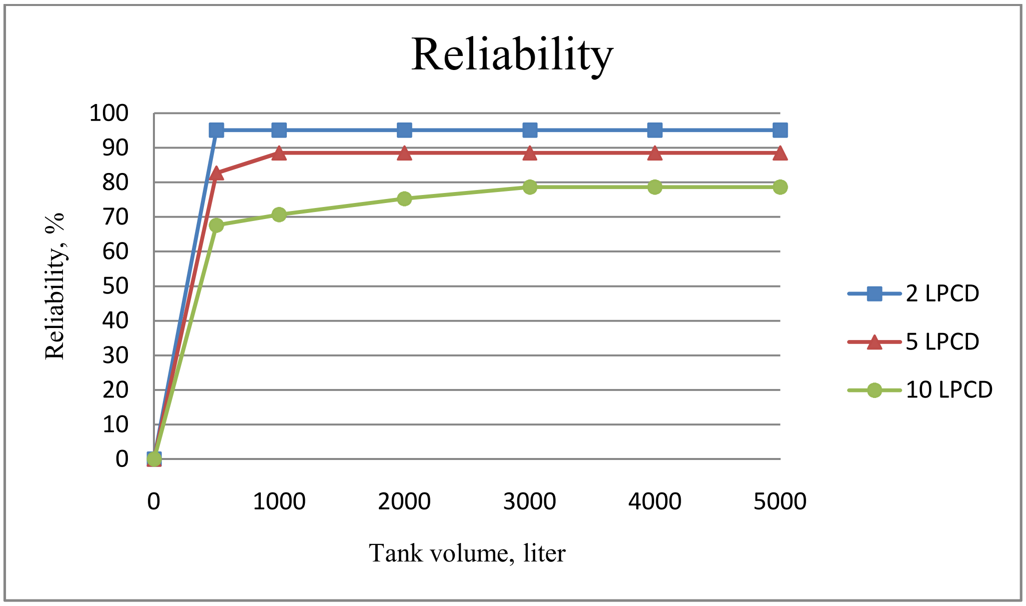

Fig (4.53): Reliability vs. Tank volume (20 m² for average year)

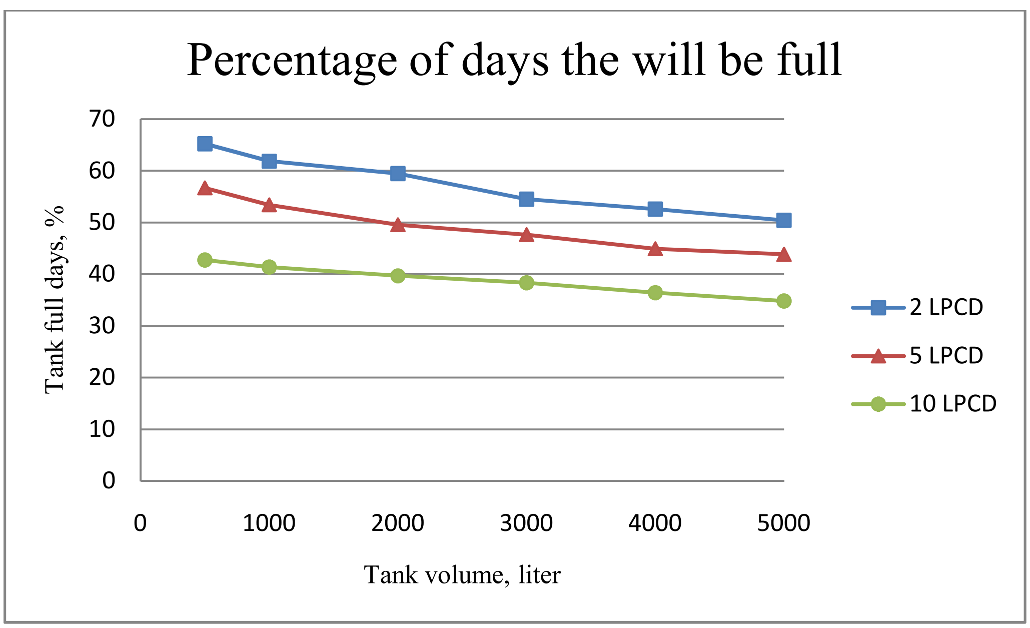

Fig (4.54): Tank volume vs. Tank full days (20 m² for average year)

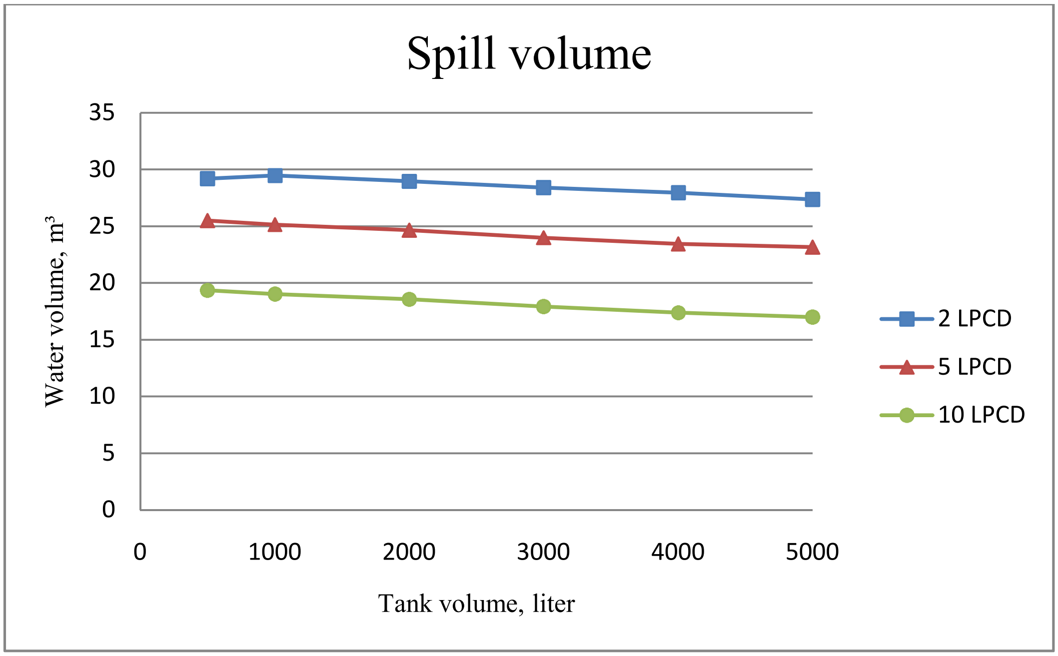

Fig (4.55): Spill volume (20 m² for average year)

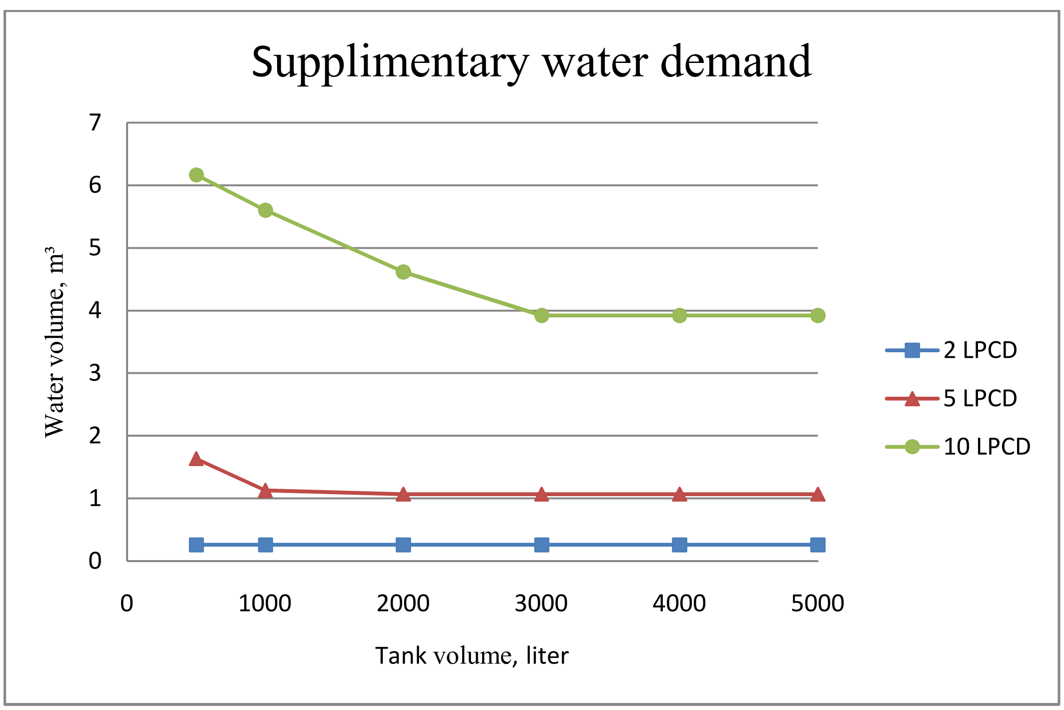

Fig (4.56): Supplementary water demand (20 m² for average year)

20 m² is a small catchment area so the storage volume is very small in quantity. For demand of 2, 5 and 10lpcd the reliability decreases along with the increase of demand. The reliability increases as the tank volume increases.

The percentage of days the tank remains full decreases as the demand increases. It also decreases as the tank volume increases.

The spill volume decreases as the tank volume increases. It also decreases as the demand increases.

The volume of water that has to be provided from other sources decreases as the tank volume increases. But the water volume increases as the demand increases.

All the comparison values are shown in the appendix section B.

4.4.3. COMPARISON GRAPHS FOR 30 m²

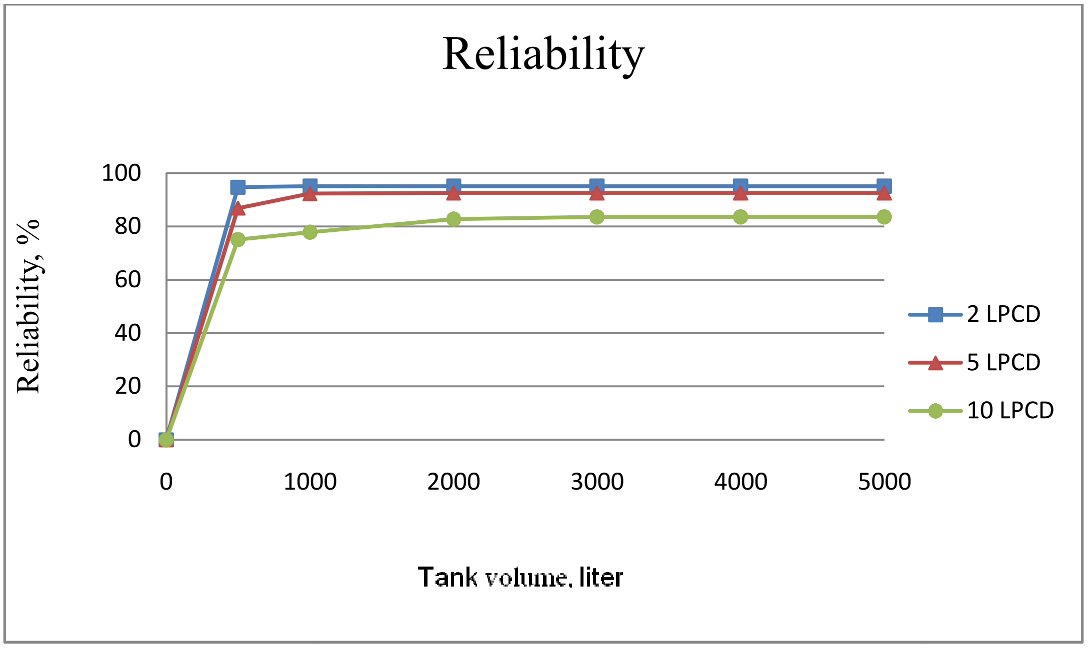

Fig (4.57): Reliability vs. Tank volume (30 m² for average year)

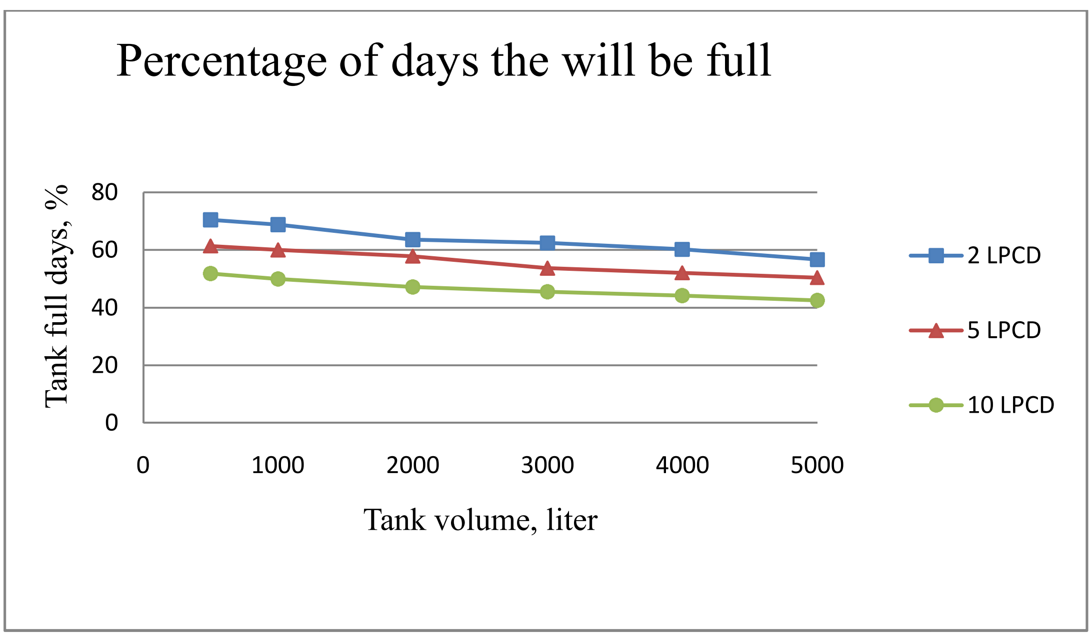

Fig (4.58): Tank volume vs. Tank full days (30 m² for average year)

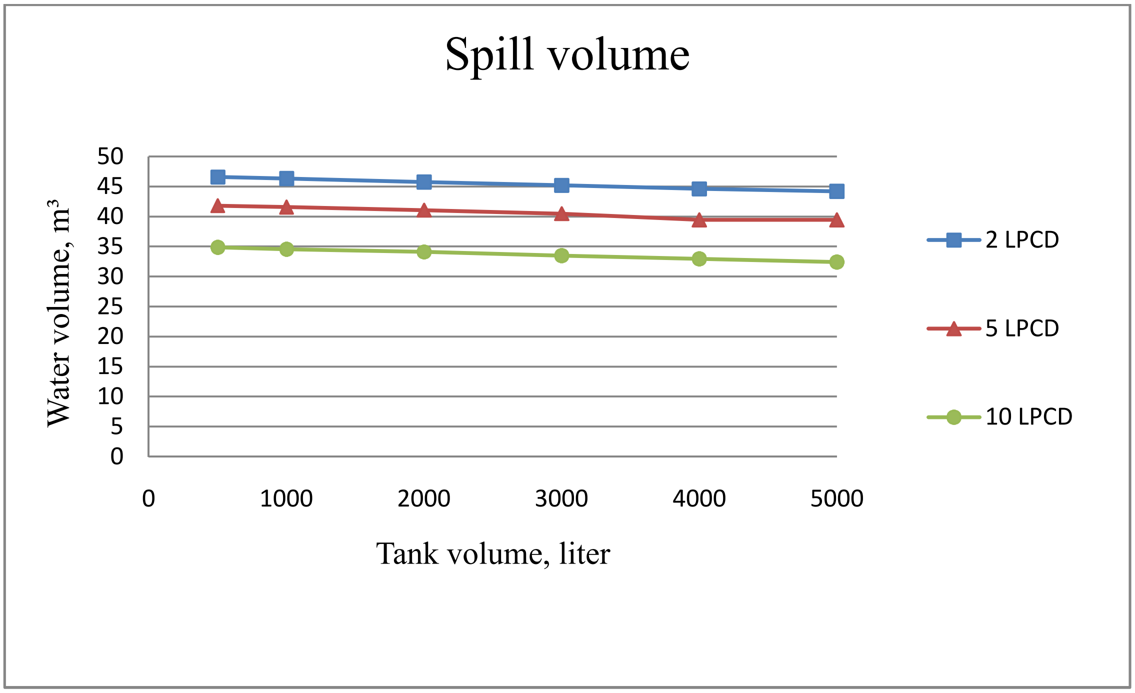

Fig (4.59): Spill volume (30 m² for average year)

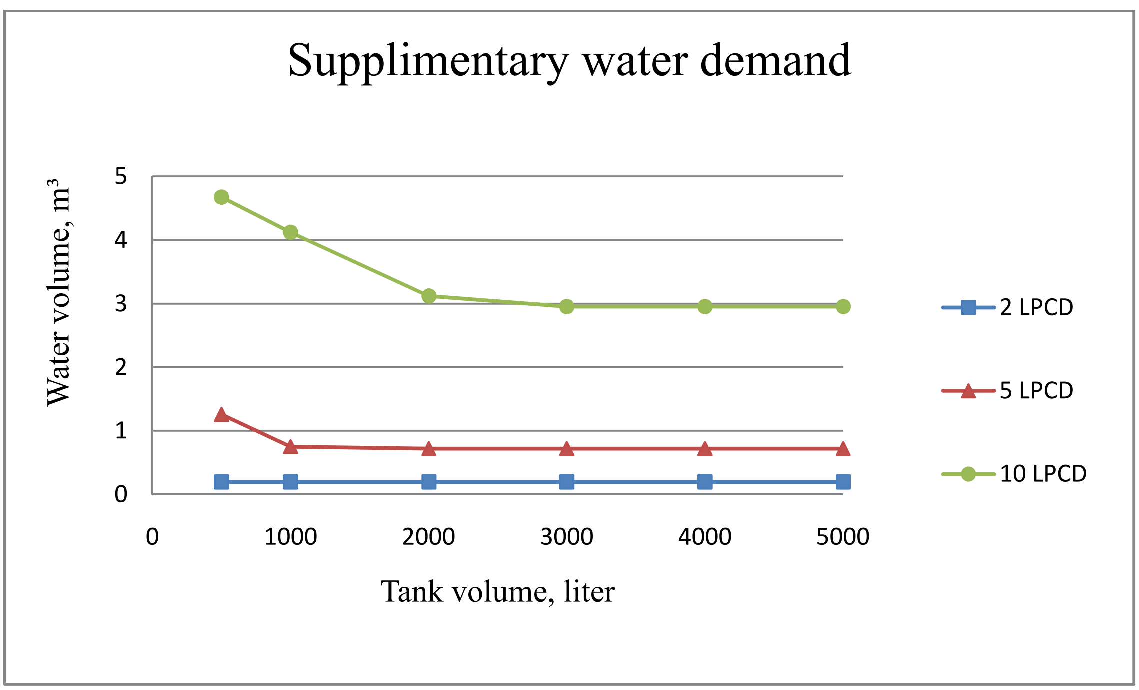

Fig (4.60): Supplementary water demand (30 m² for average year)

30 m² is a rather large catchment area so the storage volume is partially large in quantity. For demand of 2, 5 and 10lpcd the reliability decreases along with the increase of demand. The reliability increases as the tank volume increases.

The percentage of days the tank remains full decreases as the demand increases. It also decreases as the tank volume increases.

The spill volume decreases as the tank volume increases. It also decreases as the demand increases.

The volume of water that has to be provided from other sources decreases as the tank volume increases. But the water volume increases as the demand increases.

All the comparison values are shown in the appendix section B.

4.4.4. COMPARISON GRAPHS FOR 40 m^2

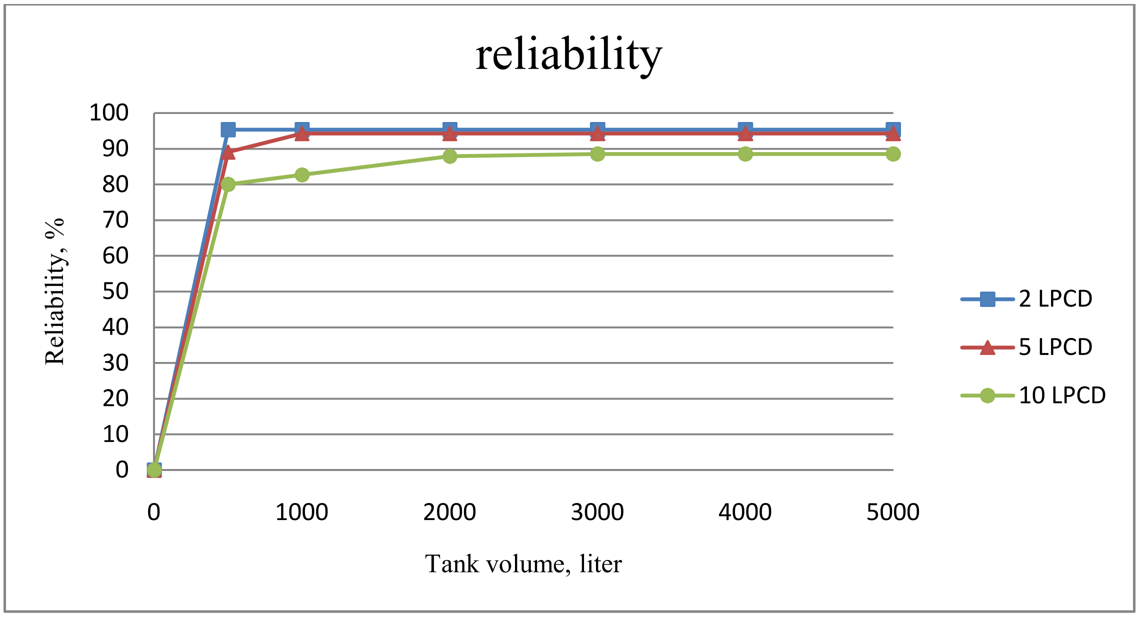

Fig (4.61): Reliability vs. Tank volume (40 m^2 for average year)

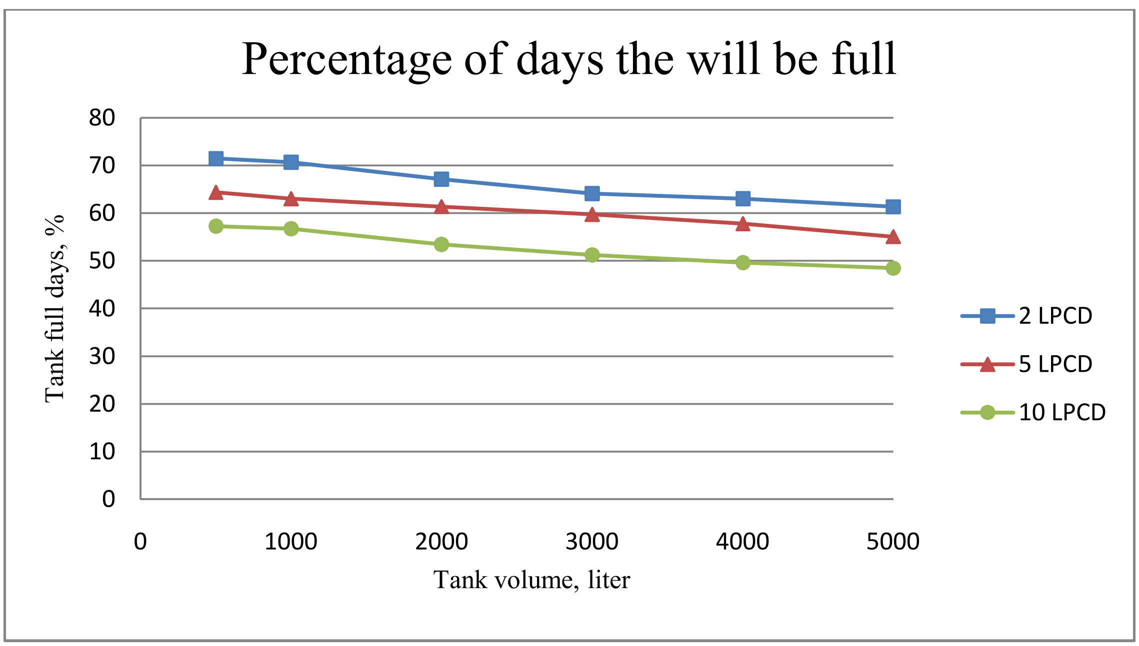

Fig (4.62): Tank volume vs. Tank full days (40 m^2 for average year)

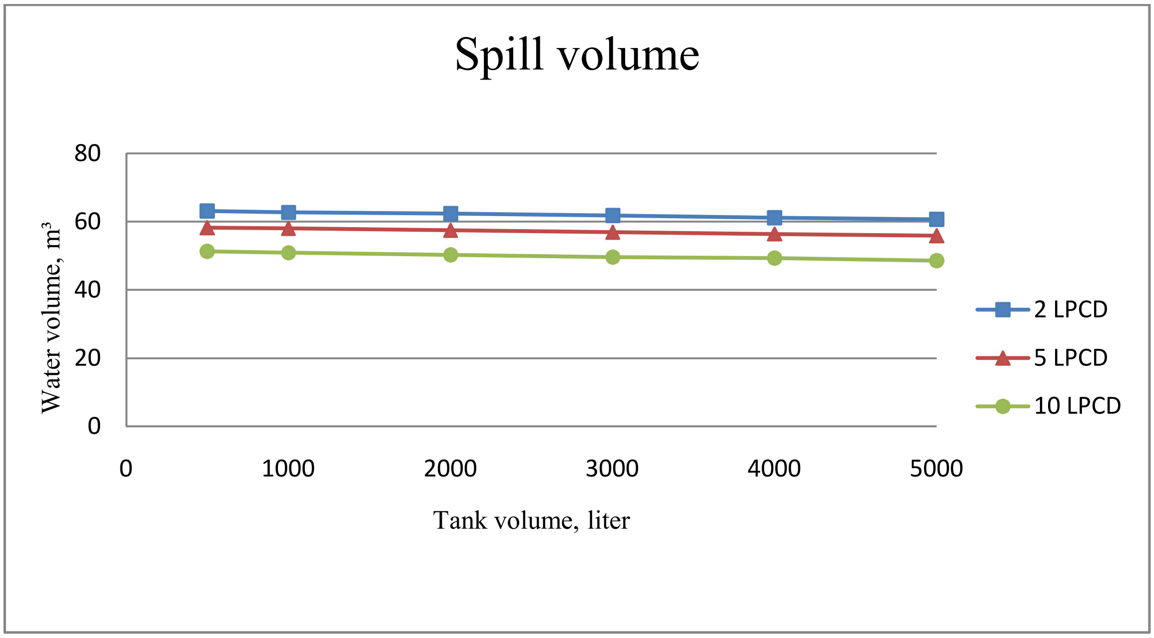

Fig (4.63): Spill volume (40 m² for average year)

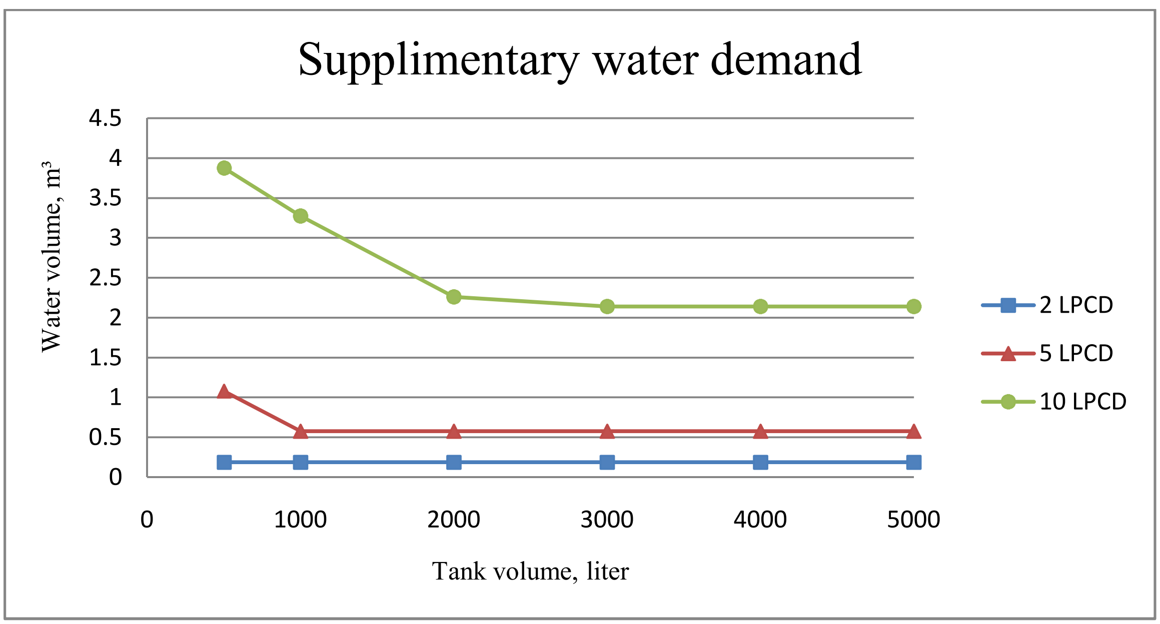

Fig (4.64): Supplementary water demand (40 m² for average year)

40 m² is a large catchment area so the storage volume is large in quantity. For demand of 2, 5 and 10lpcd the reliability decreases along with the increase of demand. The reliability increases as the tank volume increases.

The percentage of days the tank remains full decreases as the demand increases. It also decreases as the tank volume increases.

The spill volume decreases as the tank volume increases. It also decreases as the demand increases.

The volume of water that has to be provided from other sources decreases as the tank volume increases. But the water volume increases as the demand increases.

All the comparison values are shown in the appendix section B.

4.4.5. COMPARISON GRAPHS FOR 10 m² (DRY YEAR)

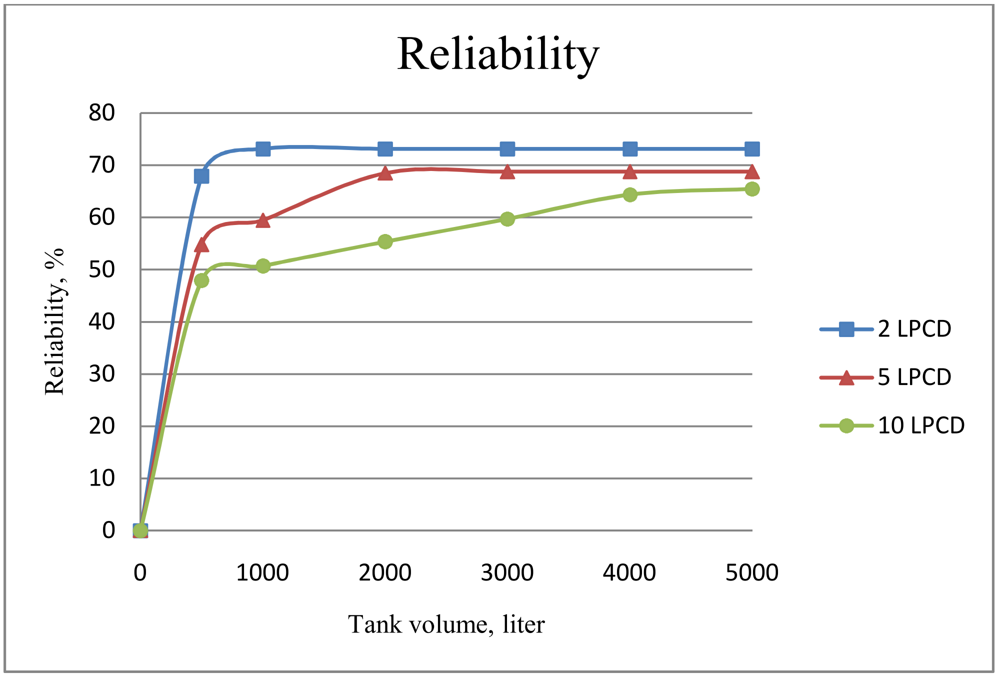

Fig (4.65): Reliability vs. Tank volume (10 m² for dry year)

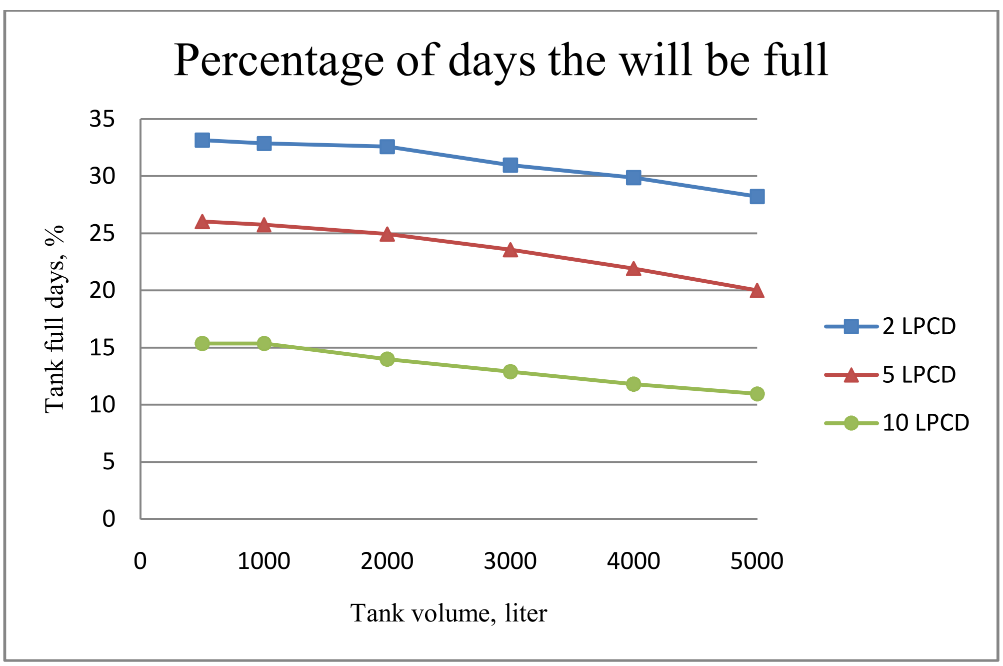

Fig (4.66): Tank volume vs. Tank full days (10 m² for dry year)

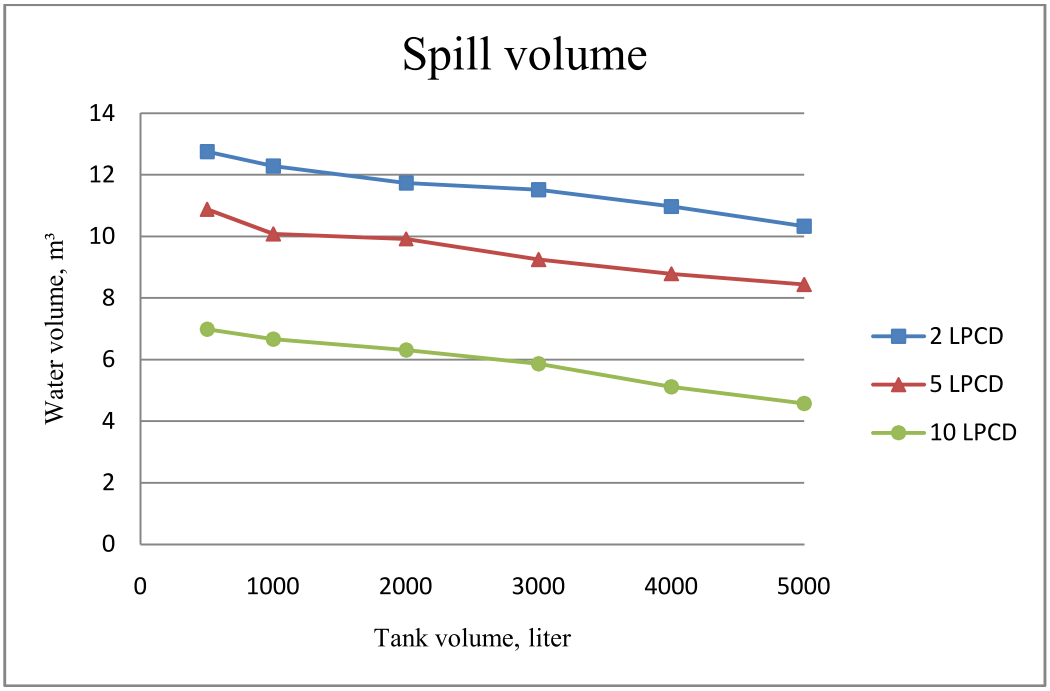

Fig (4.67): Spill volume (10 m² for dry year)

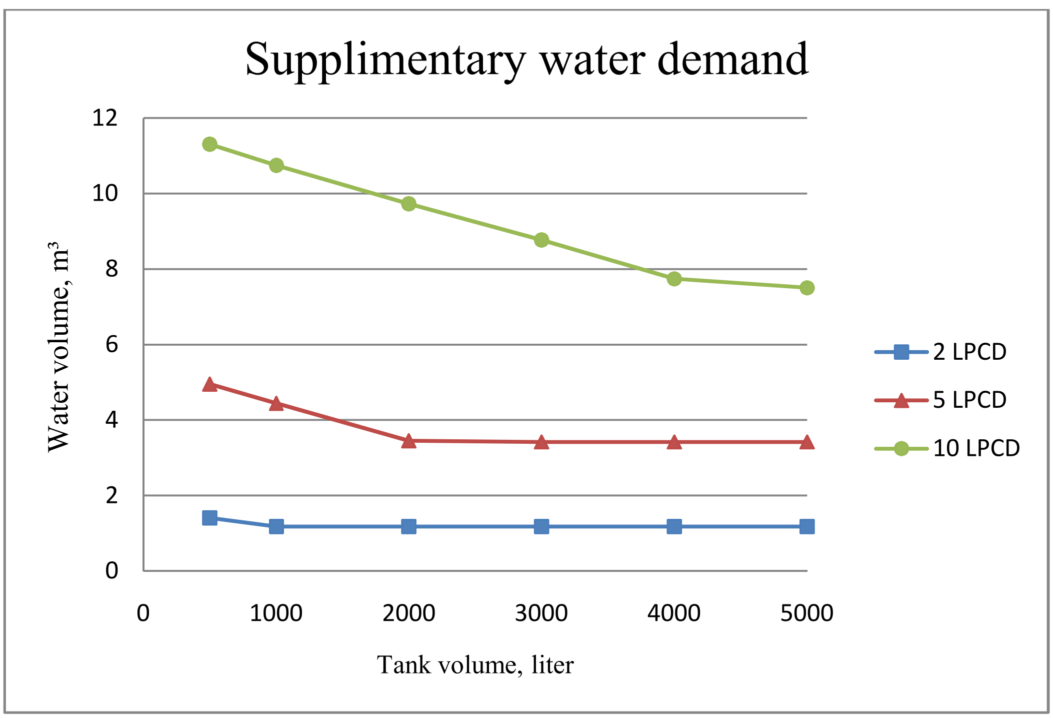

Fig (4.68): Supplementary water demand (10 m² for dry year)

For dry years the amount of rainfall is less. So the available storage volume is very low. 10 m^2 is a small catchment area so the storage volume is small in quantity. For demand of 2, 5 and 10lpcd the reliability decreases along with the increase of demand. The reliability increases as the tank volume increases.

The percentage of days the tank remains full decreases as the demand increases. It also decreases as the tank volume increases.

The spill volume decreases as the tank volume increases. It also decreases as the demand increases.

The volume of water that has to be provided from other sources decreases as the tank volume increases. But the water volume increases as the demand increases.

All the comparison values are shown in the appendix section B.

4.4.6. COMPARISON GRAPHS FOR 20 m²

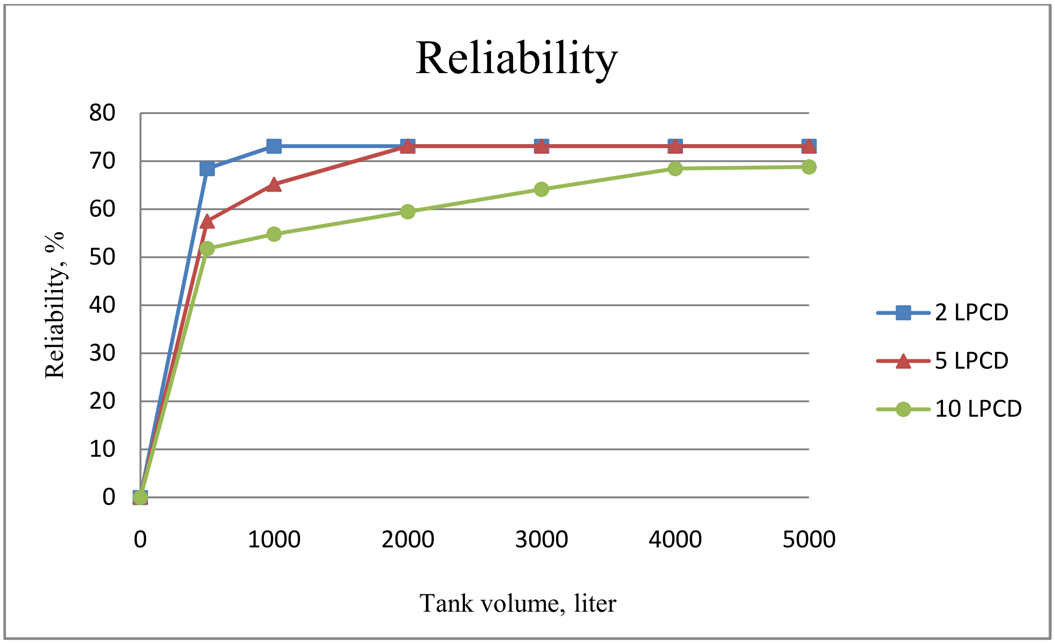

Fig (4.69): Reliability vs. Tank volume (20 m² for dry year)

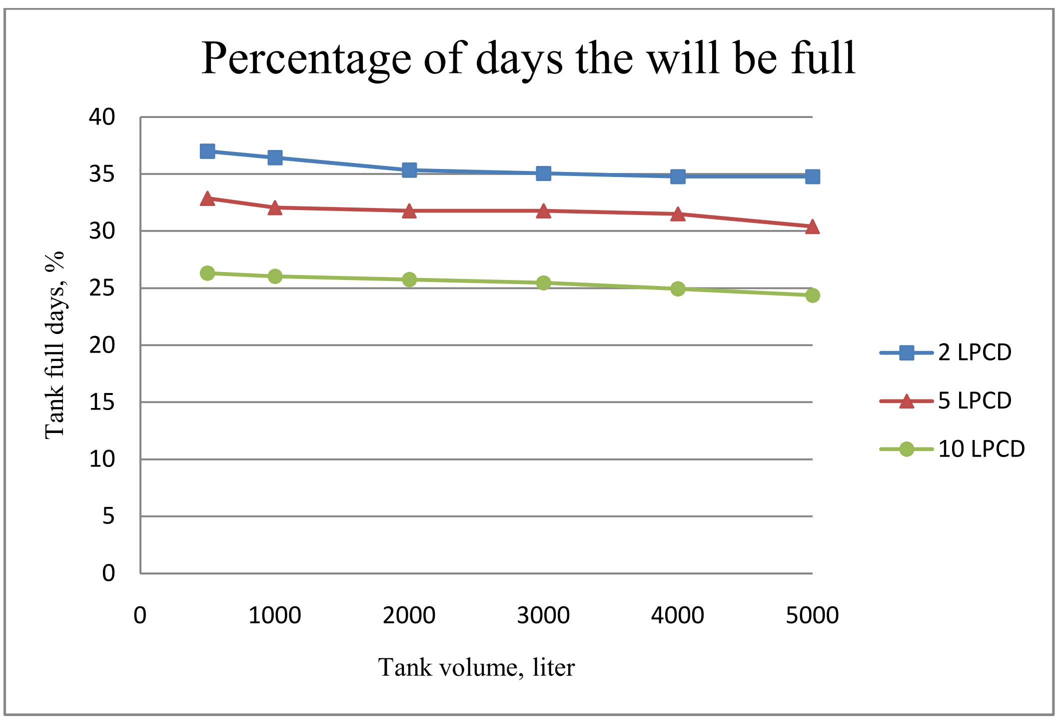

Fig (4.70): Tank volume vs. Tank full days (20 m² for dry year)

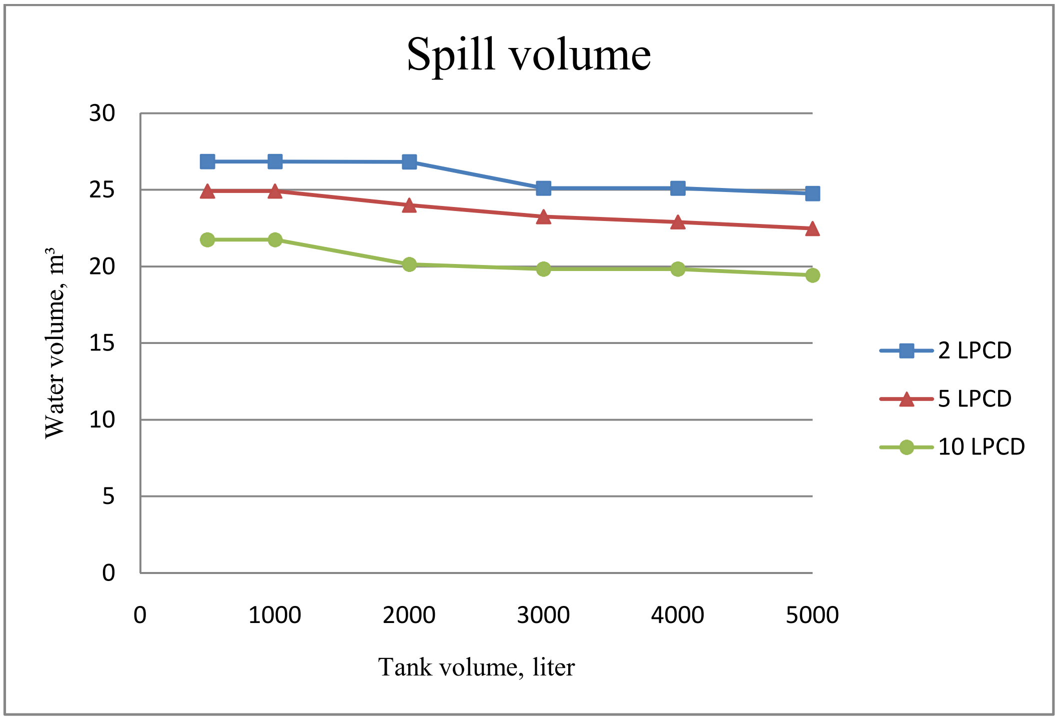

Fig (4.71): Spill volume (20 m² for dry year)

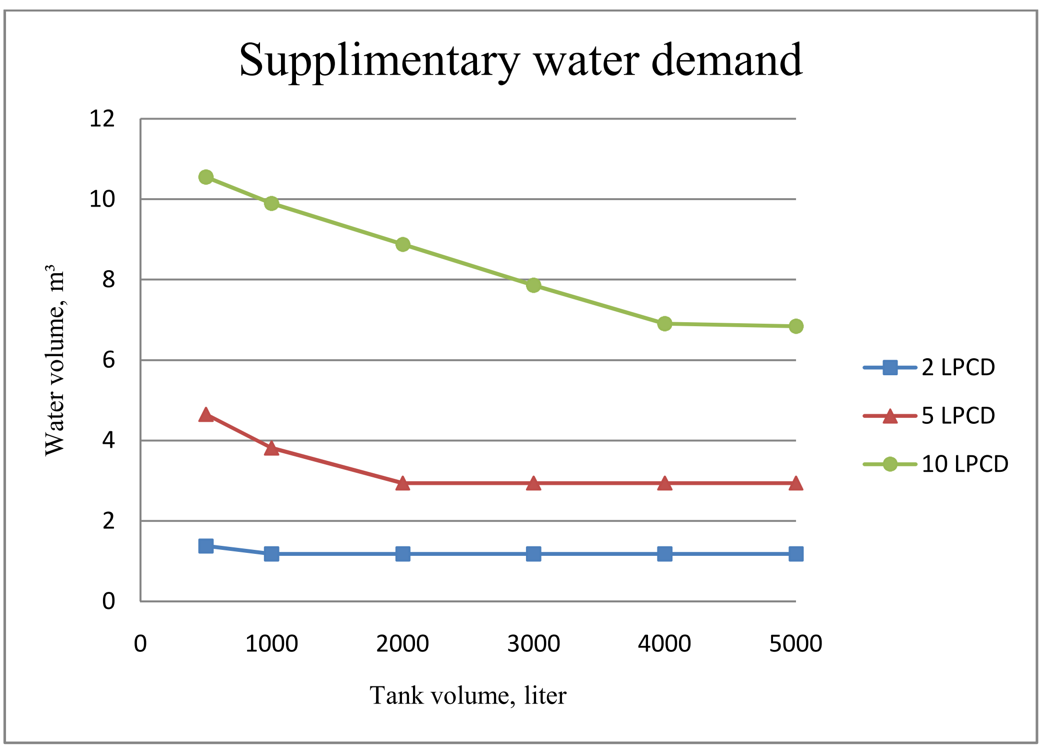

Fig (4.72): Supplementary water demand (20 m² for dry year)

For dry years the amount of rainfall is less. So the available storage volume is very low. 20 m^2 is a small catchment area so the storage volume is small in quantity. For demand of 2, 5 and 10lpcd the reliability decreases along with the increase of demand. The reliability increases as the tank volume increases.

The percentage of days the tank remains full decreases as the demand increases. It also decreases as the tank volume increases.

The spill volume decreases as the tank volume increases. It also decreases as the demand increases.

The volume of water that has to be provided from other sources decreases as the tank volume increases. But the water volume increases as the demand increases.

All the comparison values are shown in the appendix section B.

4.4.7. COMPARISON GRAPHS FOR 30 m²

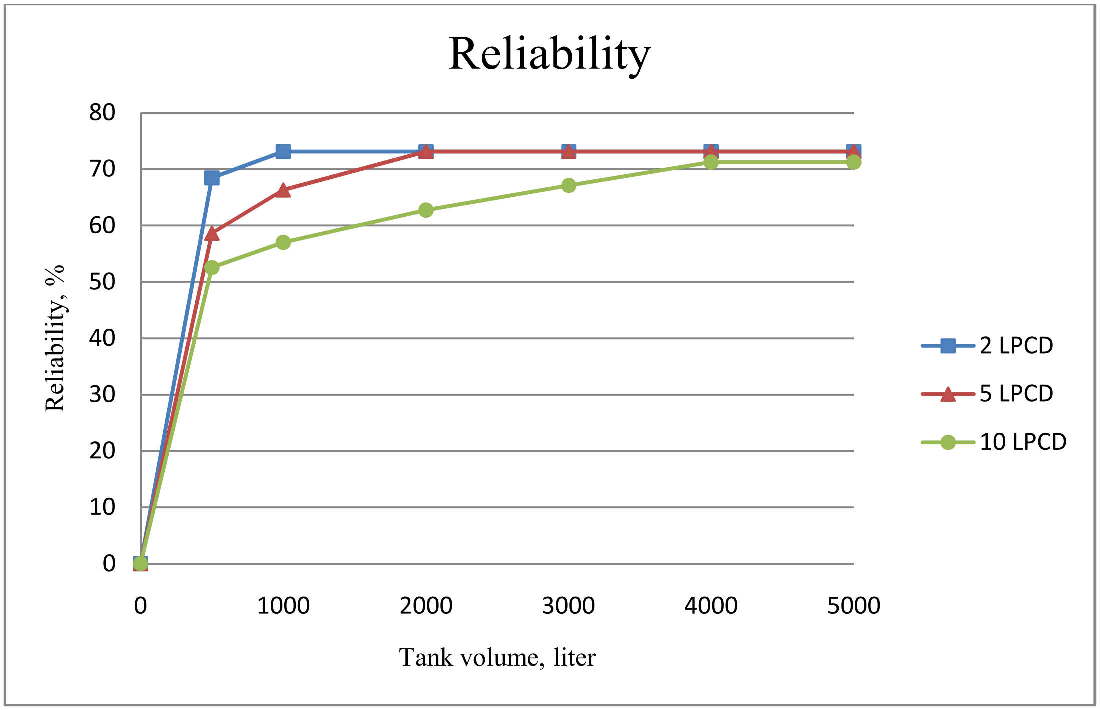

Fig (4.73): Reliability vs. Tank volume (30 m² for dry year)

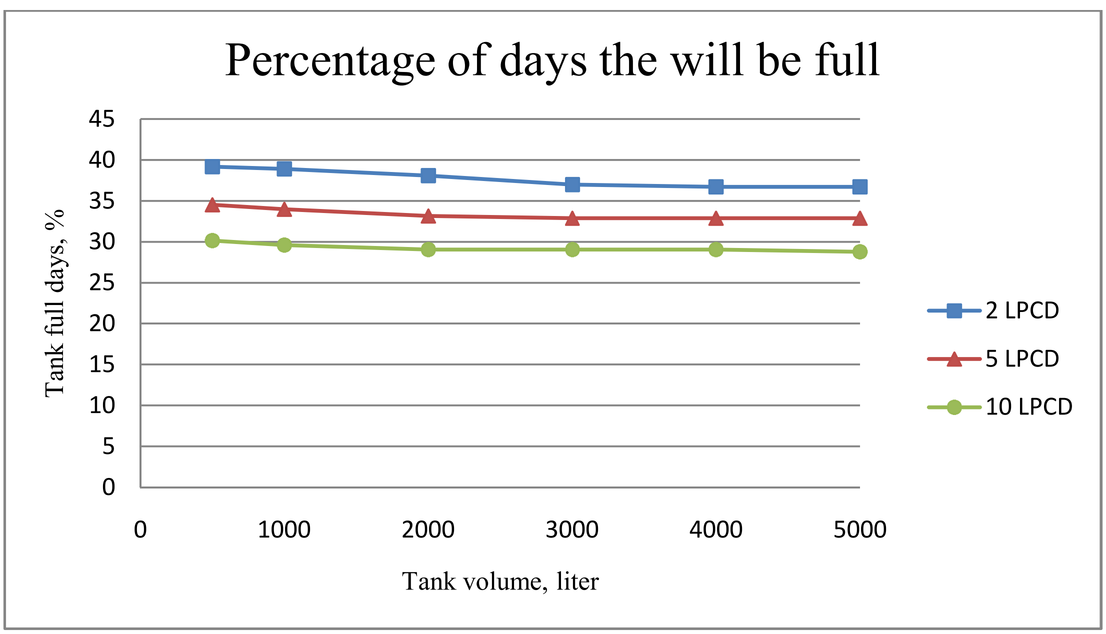

Fig (4.74): Tank volume vs. Tank full days (30 m² for dry year)

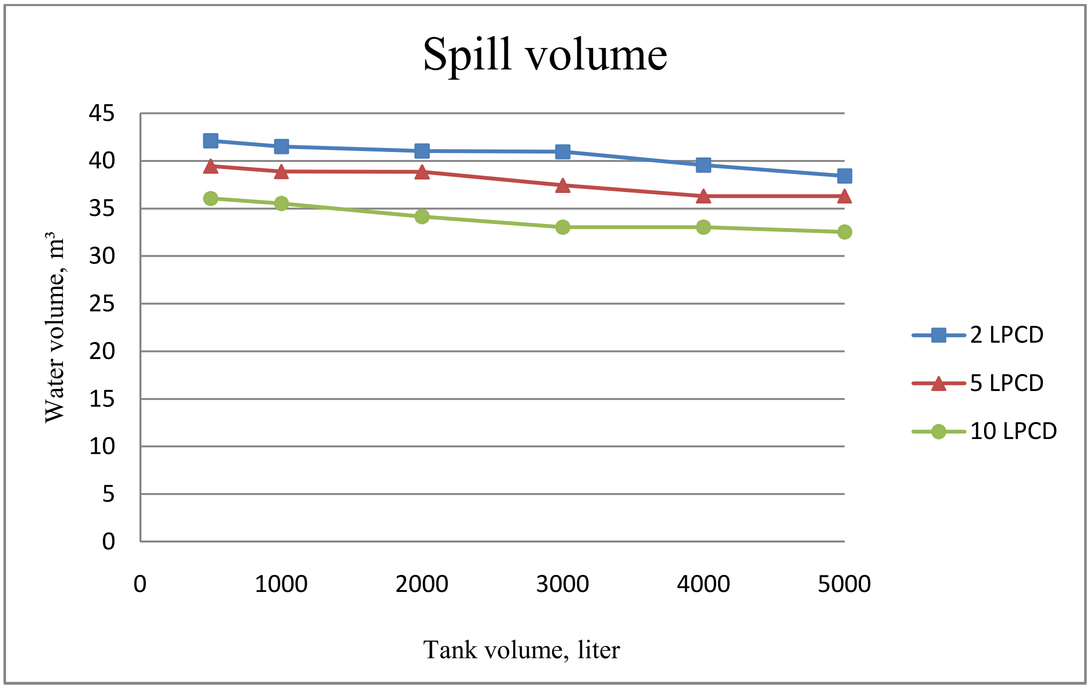

Fig (4.75): Spill volume (30 m² for dry year)

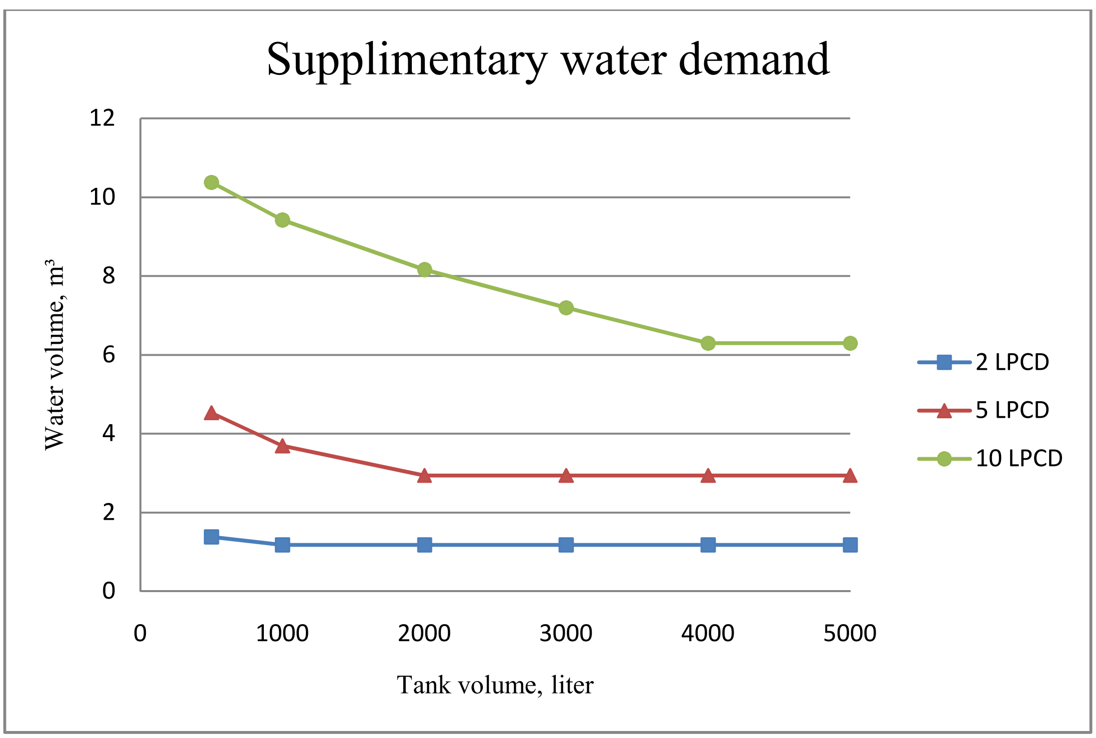

Fig (4.76): Supplementary water demand (30 m² for dry year)

For dry years the amount of rainfall is less. So the available storage volume is very low. 30 m^2 is rather large catchment area so the storage volume is small in quantity. For demand of 2, 5 and 10lpcd the reliability decreases along with the increase of demand. The reliability increases as the tank volume increases.

The percentage of days the tank remains full decreases as the demand increases. It also decreases as the tank volume increases.

The spill volume decreases as the tank volume increases. It also decreases as the demand increases.

The volume of water that has to be provided from other sources decreases as the tank volume increases. But the water volume increases as the demand increases.

All the comparison values are shown in the appendix section B.

4.4.8. COMPARISON GRAPHS FOR 40 m²

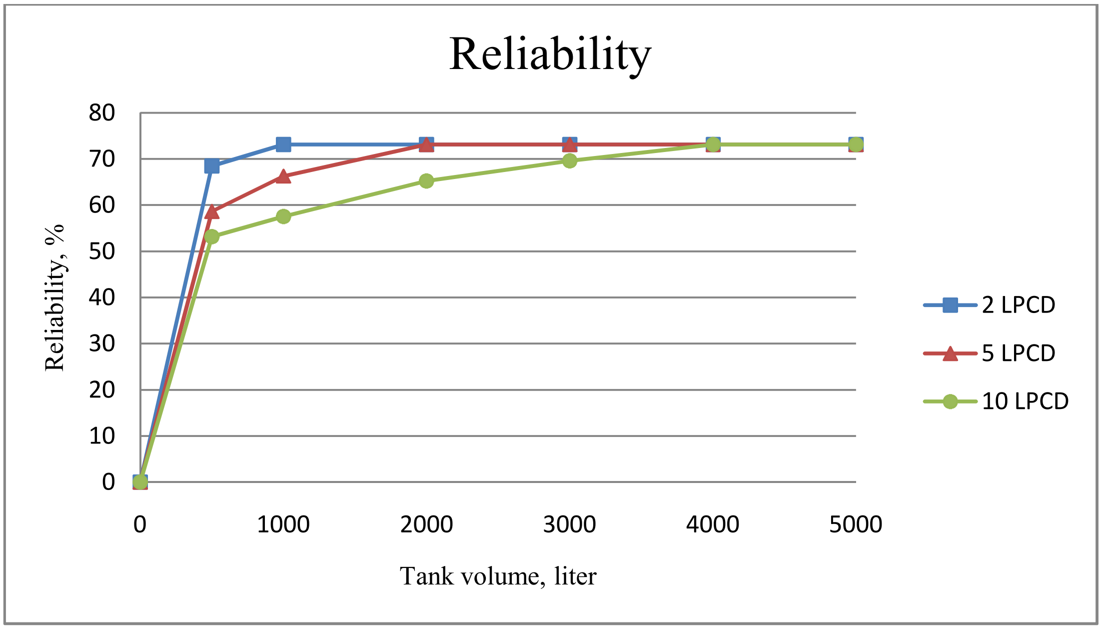

Fig (4.77): Reliability vs. Tank volume (40 m² for dry year)

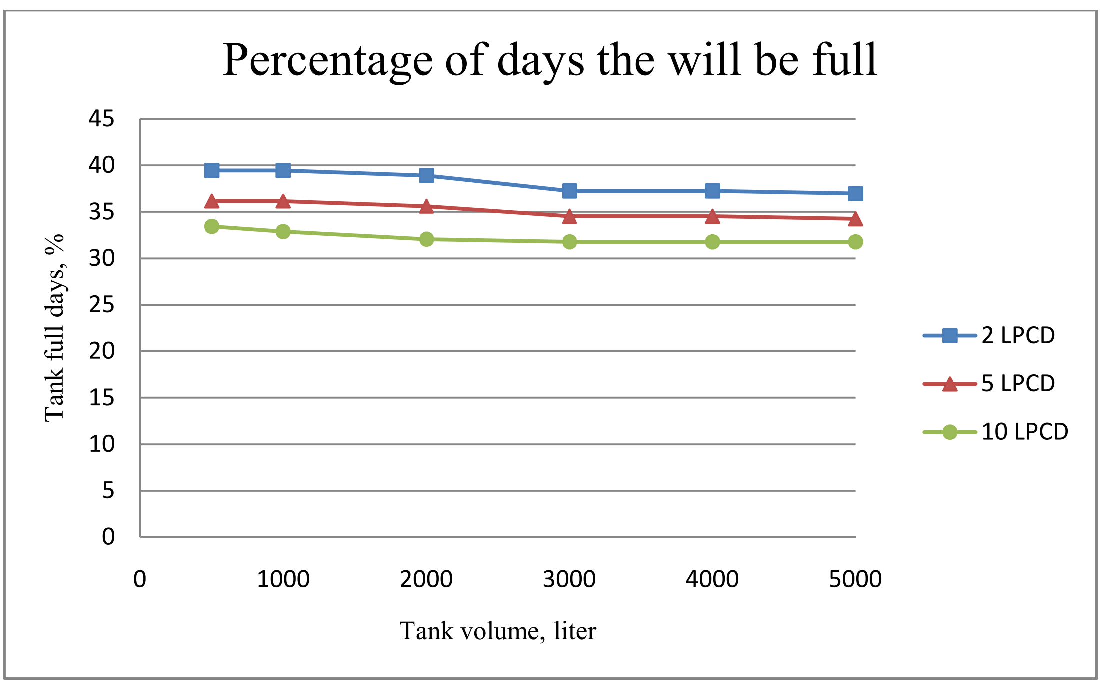

Fig (4.78): Tank volume vs. Tank full days (40 m² for dry year)

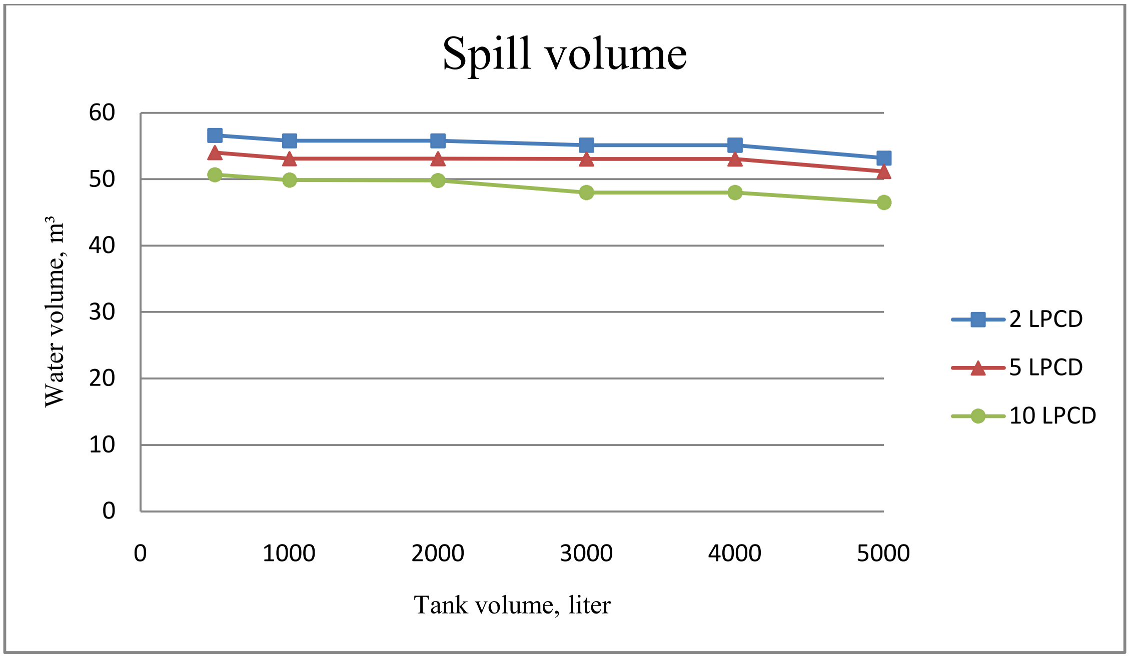

Fig (4.79): Spill volume (40 m² for dry year)

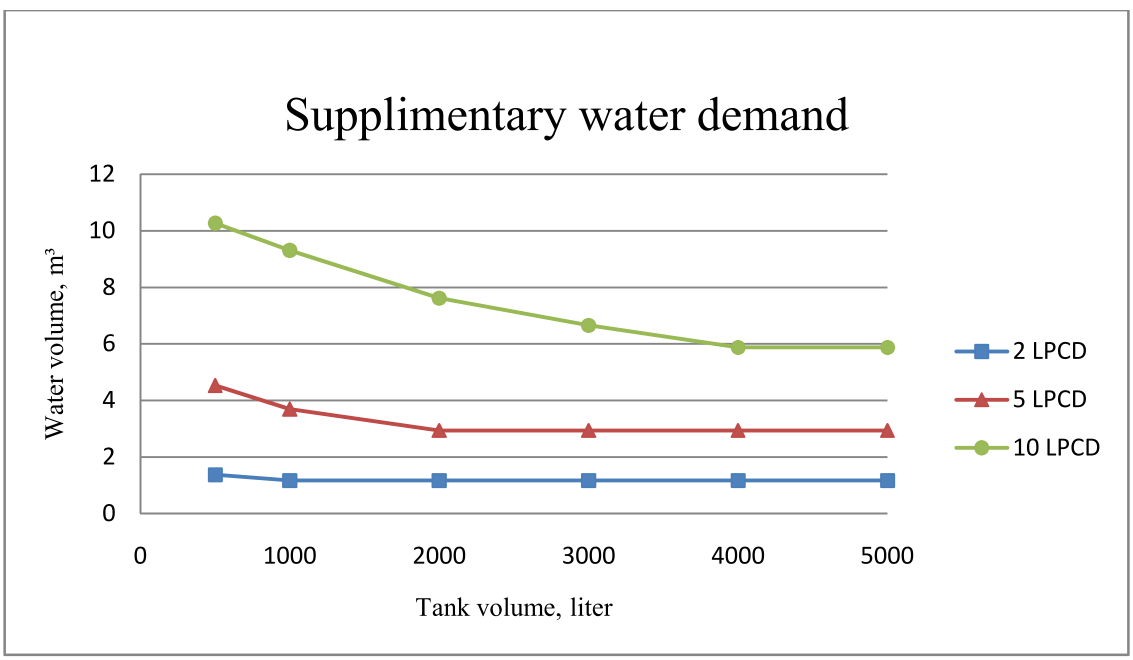

Fig (4.80): Supplementary water demand (40 m² for dry year)

For dry years the amount of rainfall is less. So the available storage volume is very low. 40 m^2 is large catchment area so the storage volume is large in quantity. For demand of 2, 5 and 10lpcd the reliability decreases along with the increase of demand. The reliability increases as the tank volume increases.

The percentage of days the tank remains full decreases as the demand increases. It also decreases as the tank volume increases.

The spill volume decreases as the tank volume increases. It also decreases as the demand increases.

The volume of water that has to be provided from other sources decreases as the tank volume increases. But the water volume increases as the demand increases.

All the comparison values are shown in the appendix section B.

4.4.9. COMPARISON GRAPHS FOR 10 m² (WET YEAR)

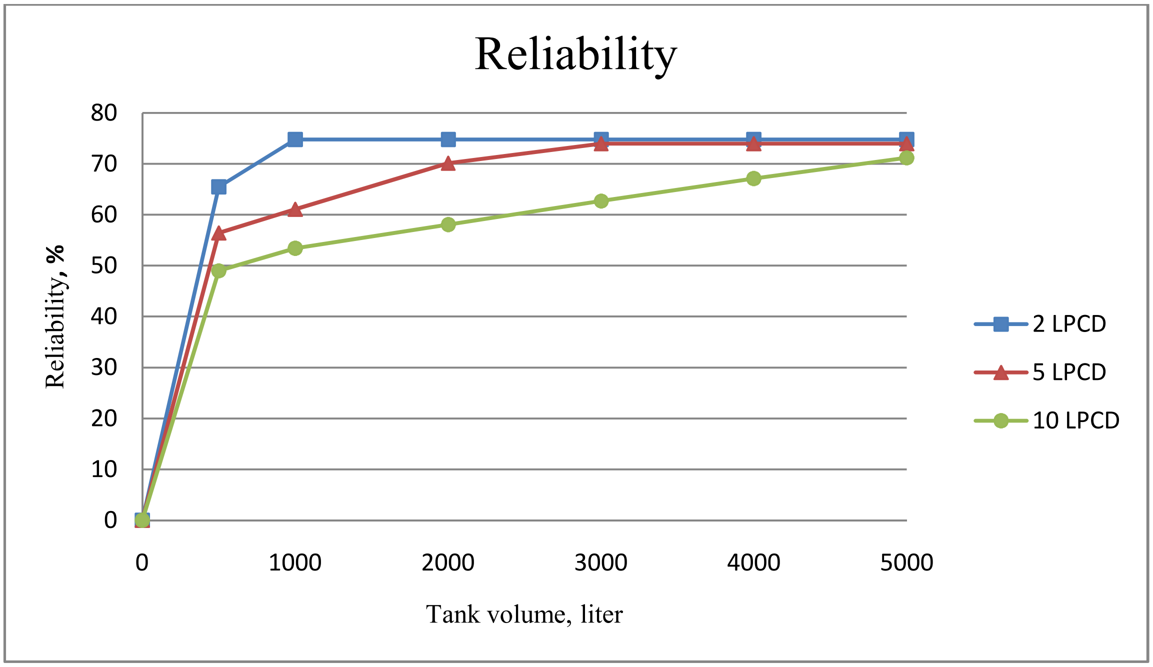

Fig (4.81): Reliability vs. Tank volume (10 m² for wet year)

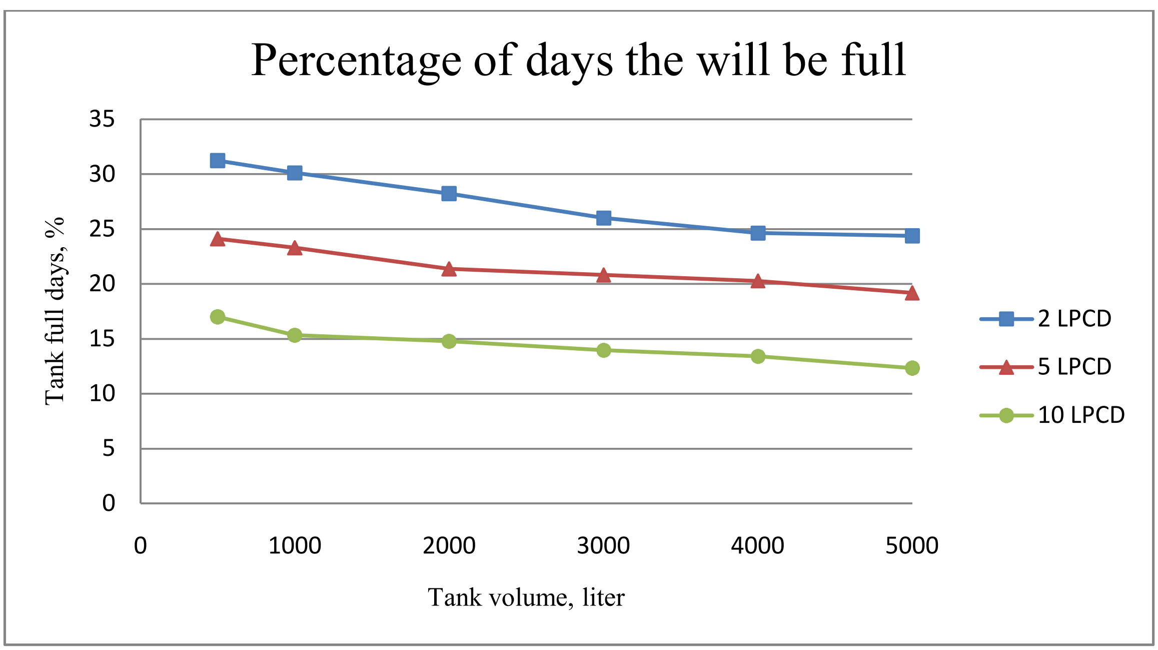

Fig (4.82): Tank volume vs. Tank full days (10 m² for wet year)

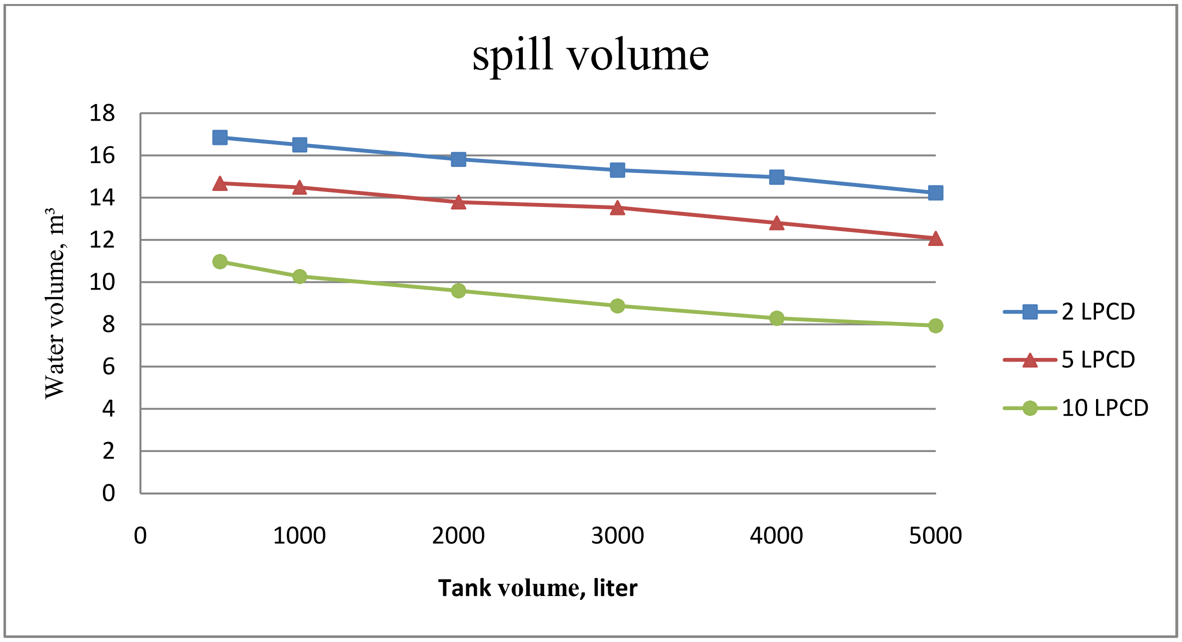

Fig (4.83): Spill volume (10 m² for wet year)

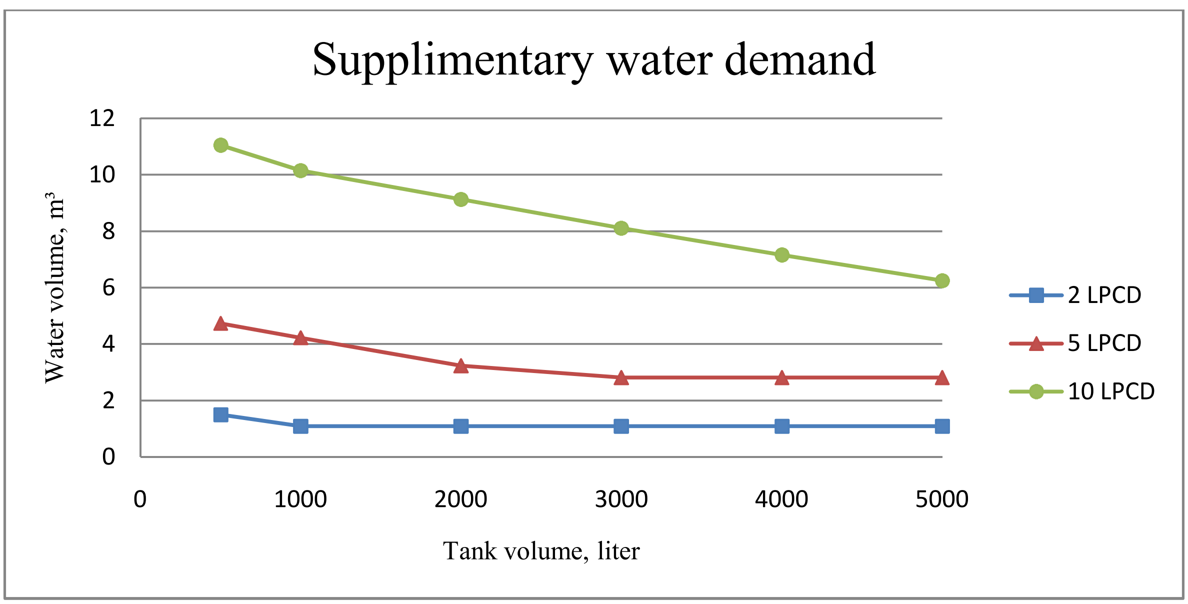

Fig (4.84): Supplementary water demand (10 m² for wet year)

For wet years the amount of rainfall is very high. So the available storage volume is very high. 10 m^2 is small catchment area so the storage volume is small in quantity. For demand of 2, 5 and 10lpcd the reliability decreases along with the increase of demand. The reliability increases as the tank volume increases.

The percentage of days the tank remains full decreases as the demand increases. It also decreases as the tank volume increases.

The spill volume decreases as the tank volume increases. It also decreases as the demand increases.

The volume of water that has to be provided from other sources decreases as the tank volume increases. But the water volume increases as the demand increases.

All the comparison values are shown in the appendix section B.

4.4.10. COMPARISON GRAPHS FOR 20 m²

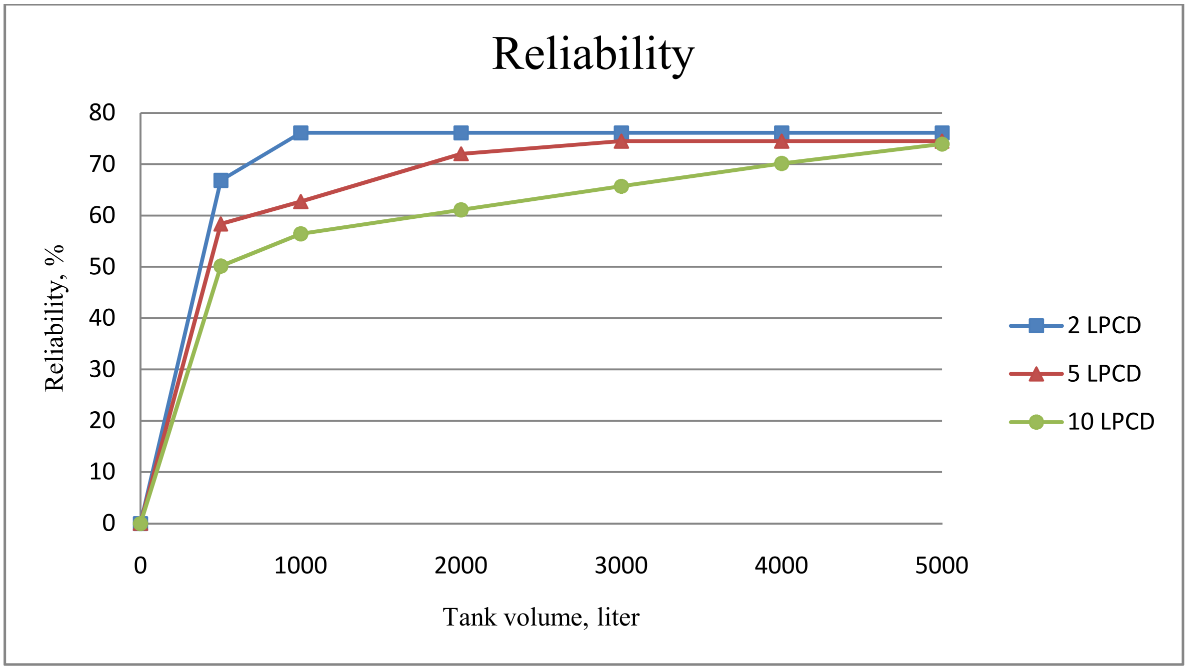

Fig (4.85): Reliability vs. Tank volume (20 m² for wet year)

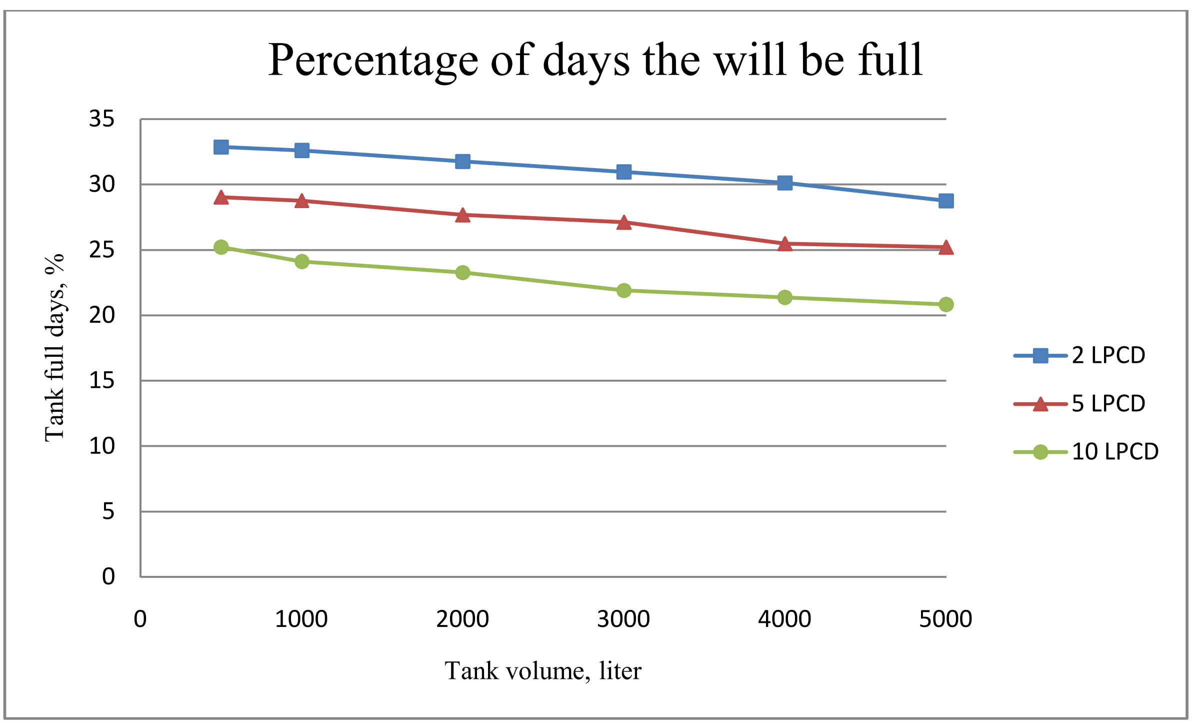

Fig (4.86): Tank volume vs. Tank full days (20 m² for wet year)

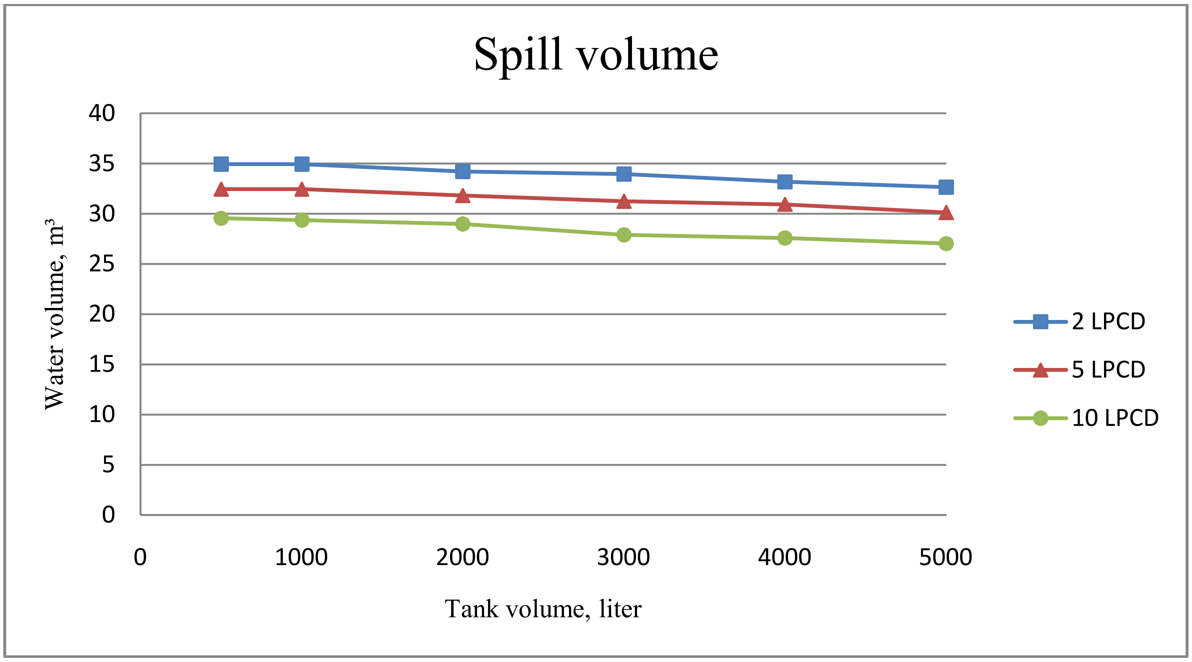

Fig (4.87): Spill volume (20 m² for wet year)

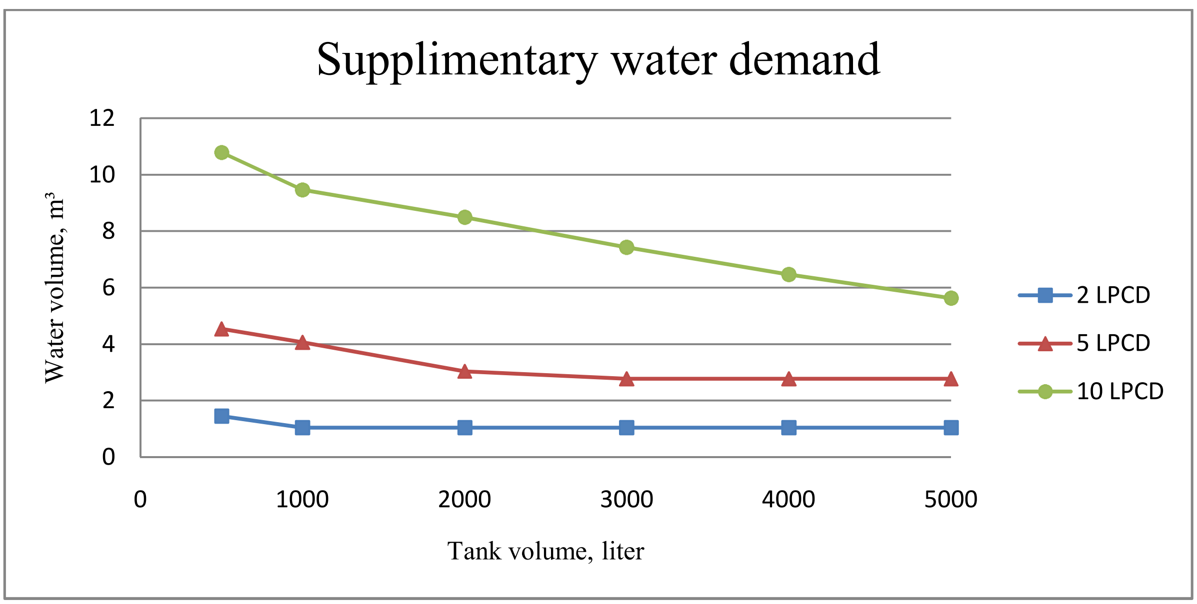

Fig (4.88): Supplementary water demand (20 m² for wet year)

For wet years the amount of rainfall is very high. So the available storage volume is very high. 20 m^2 is small catchment area so the storage volume is small in quantity. For demand of 2, 5 and 10lpcd the reliability decreases along with the increase of demand. The reliability increases as the tank volume increases.

The percentage of days the tank remains full decreases as the demand increases. It also decreases as the tank volume increases.

The spill volume decreases as the tank volume increases. It also decreases as the demand increases.

The volume of water that has to be provided from other sources decreases as the tank volume increases. But the water volume increases as the demand increases.

All the comparison values are shown in the appendix section B.

4.4.11. COMPARISON GRAPHS FOR 30 m²

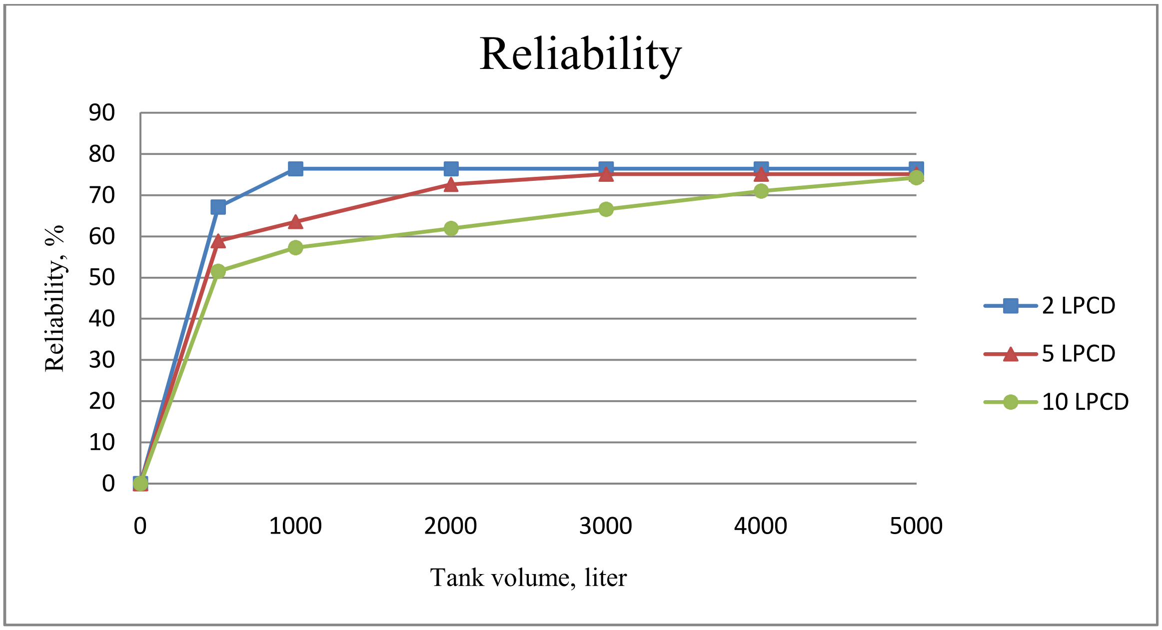

Fig (4.89): Reliability vs. Tank volume (30 m² for wet year)

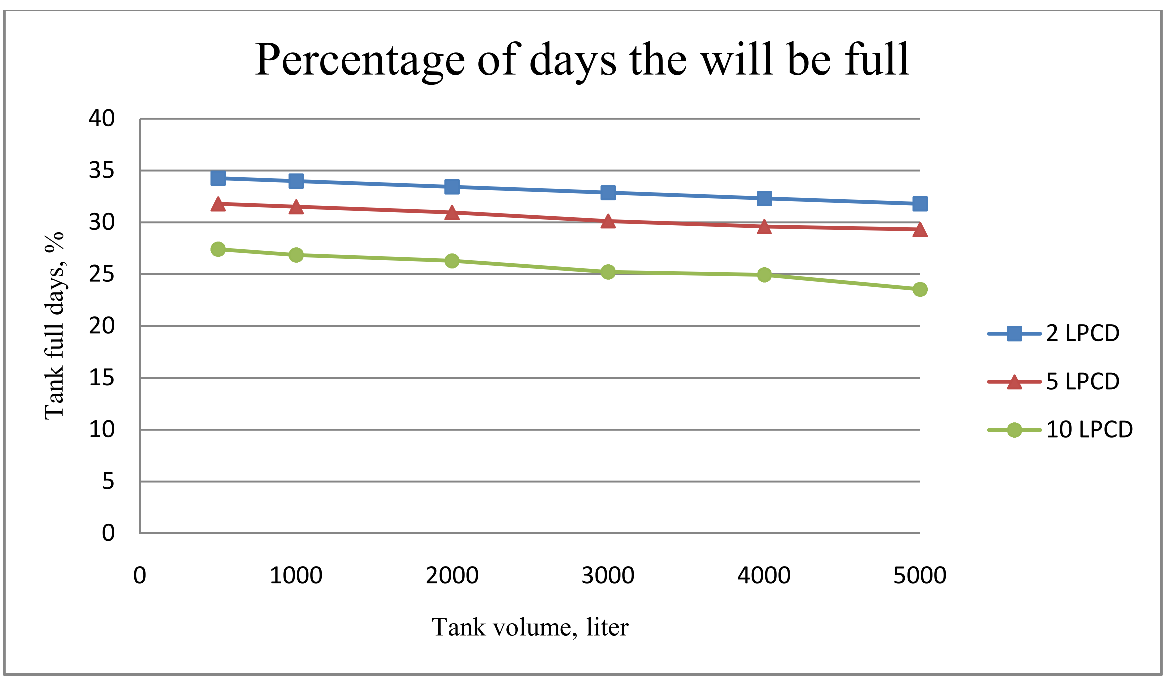

Fig (4.90): Tank volume vs. Tank full days (30 m² for wet year)

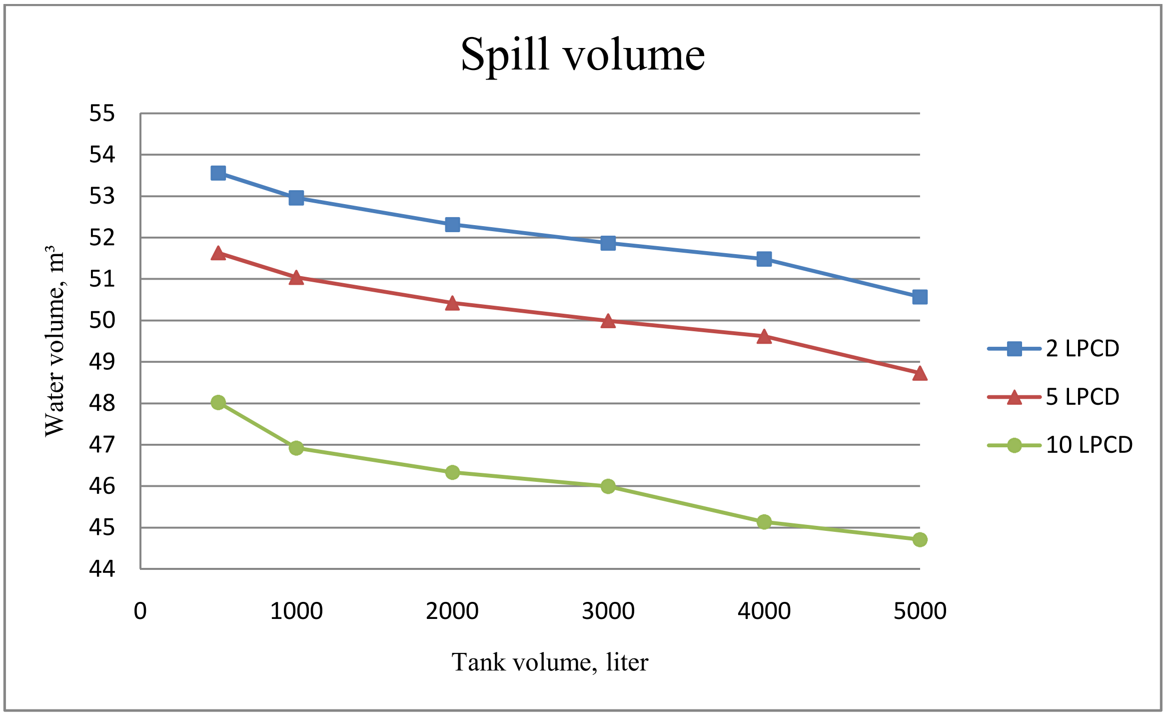

Fig (4.91): Spill volume (30 m² for wet year)

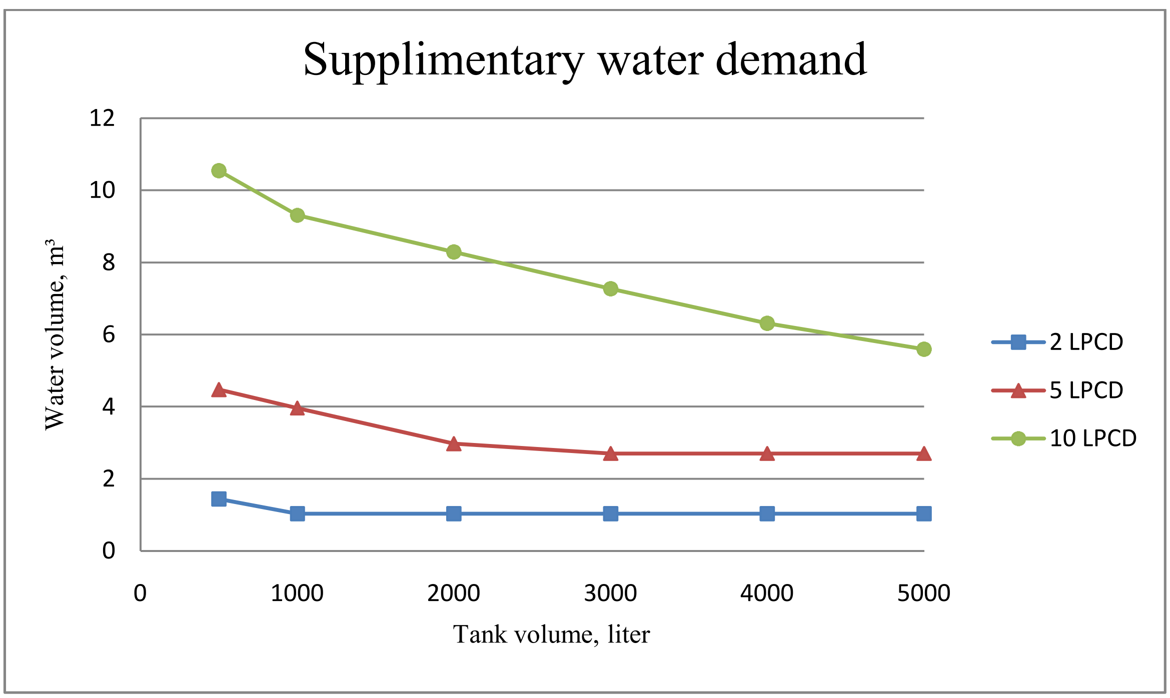

Fig (4.92): Supplementary water demand (30 m² for wet year)

For wet years the amount of rainfall is very high. So the available storage volume is very high. 30 m^2 is a large catchment area so the storage volume is also large in quantity. For demand of 2, 5 and 10lpcd the reliability decreases along with the increase of demand. The reliability increases as the tank volume increases.

The percentage of days the tank remains full decreases as the demand increases. It also decreases as the tank volume increases.

The spill volume decreases as the tank volume increases. It also decreases as the demand increases.

The volume of water that has to be provided from other sources decreases as the tank volume increases. But the water volume increases as the demand increases.

All the comparison values are shown in the appendix section B.

4.4.12. COMPARISON GRAPHS FOR 40 m²

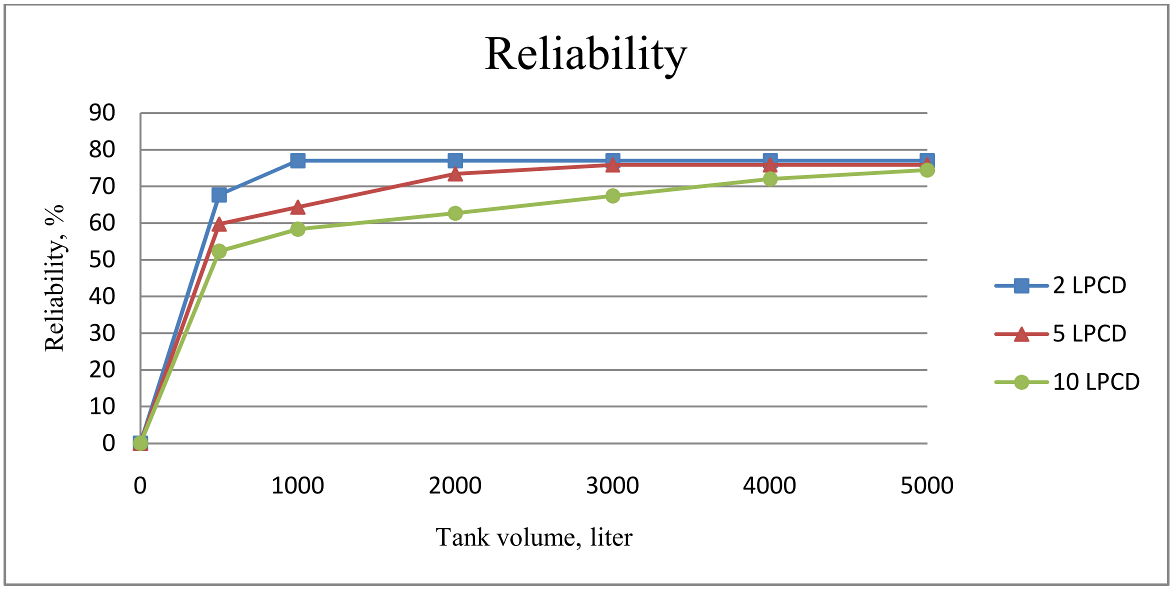

Fig (4.93): Reliability vs. Tank volume (40 m² for wet year)

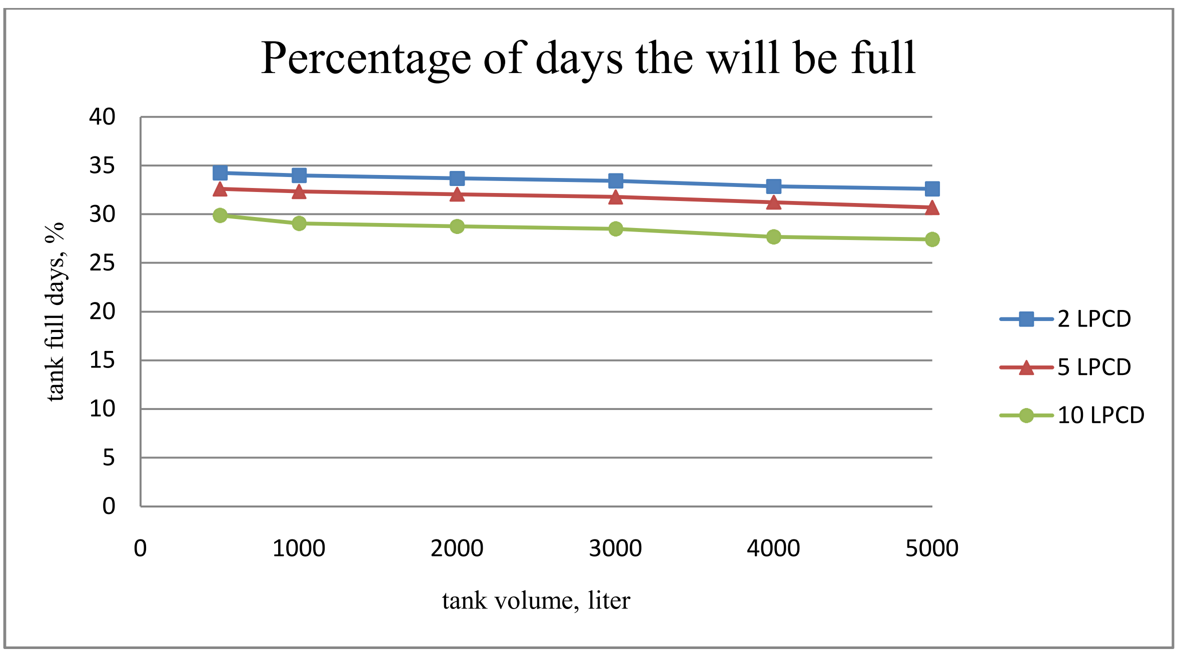

Fig (4.94): Tank volume vs. Tank full days (40 m² for wet year)

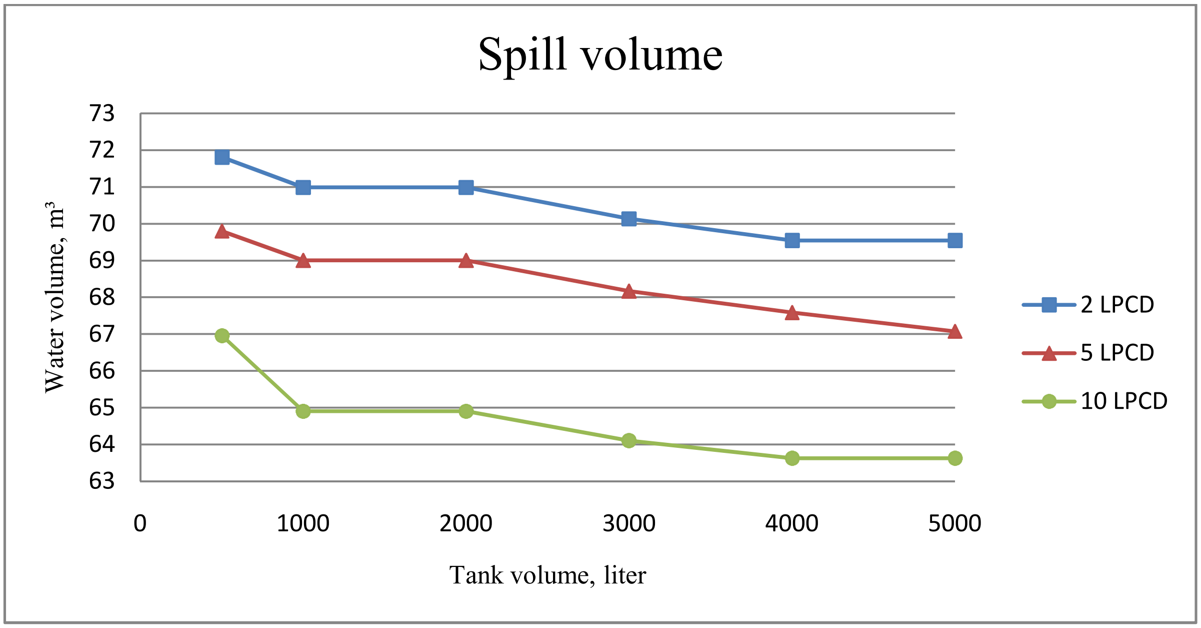

Fig (4.95): Spill volume (40 m² for wet year)

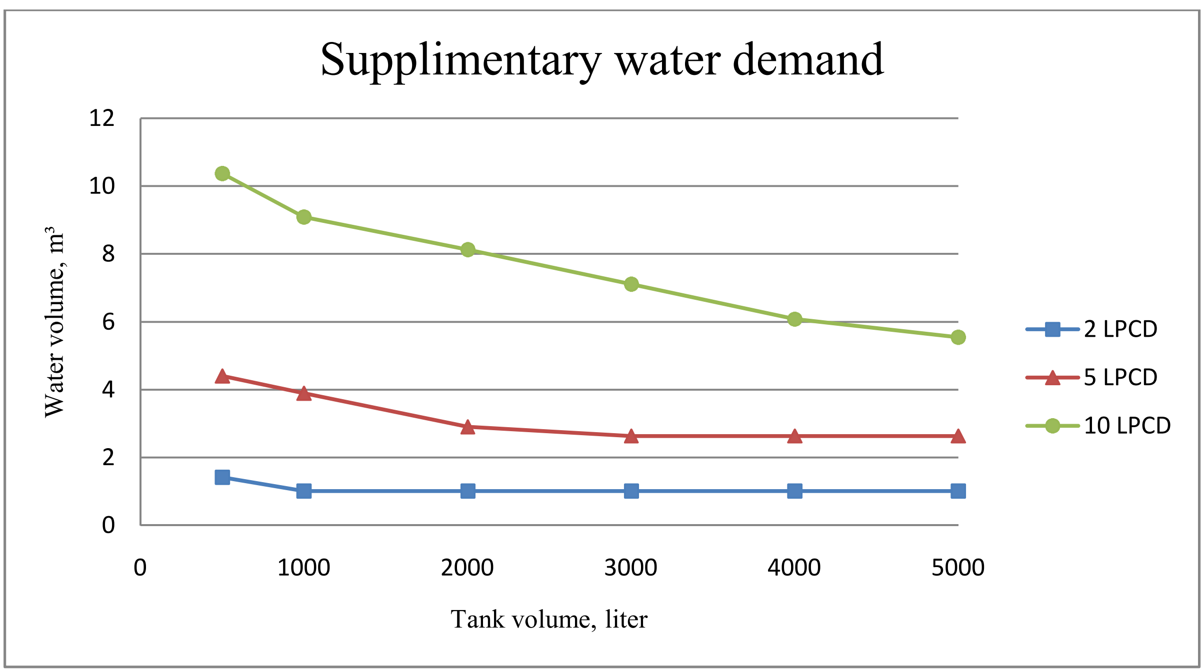

Fig (4.96): Supplementary water demand (40 m² for wet year)

4.5. DISCUSSIONS

4.5.1. DESIGN CURVES

The design curves showed good results. It can be effectively used for determining the tank volume required for a family of 6 members.

All the relationship between storage volume, catchment area and demand proved that the method proceeded properly.

4.5.2. RELIABILITY

The reliability of the system proved it to be well enough for use. The reliability was close to 100% in some cases. As catchment area and tank volume was increased the reliability increased properly. This reliability would increase and ultimately become 100% reliable if the procedure was carried over for a number of consecutive years. Nevertheless, the reliability was satisfactory and can be said that the system is reliable. The tank volumes of 500 liter are about 95% reliable for 2lpcd demand where the catchment area was 30m². This was achieved for an average year condition. This was the maximum reliability achieved in the whole study. For, 5lpcd demand maximum reliability achieved was about 93% where the demand was 30m² and tank volume was 2000 liters. For, 10lpcd demand, about 88.5% reliability was achieved where catchment area was 40m² and tank volume was 3000 liters. For dry years, about 73.2% reliability was achieved for 30m² catchment areas and 2000 liter tank volume where demand was 5 and 10lpcd. For wet year, maximum reliability achieved was 77% where catchment area was 40m² and tank volume was 1000 liters for 2lpcd demand.

4.5.3. SPILLING

The spilled volume was considerable and if tank volume increased the spilling decreased. This water can be used if the efficiency of the system could be increased. This water can also be used in other places. The highest spilling was found for 2lpcd demand; catchment area of $40m^2$ and it was for tank volume 500 liter. The maximum spill volume was $72m^3$. The minimum spill volume was $5.1m^3$ where catchment area was $10m^2$, demand 10lpcd and tank volume was 500 liters.

4.5.4. SUPPLEMENTARY WATER DEMAND

The volume of water that has to provided from another source depends largely upon the reliability. If reliability increases the supplementary water demand would decrease. This excess water has to be satisfied by ground or surface water which has a treatment cost and so this volume of water is costly. The maximum supplementary water demand of 11.3 m^3 was found for dry year condition. There the volume of tank was 500 liters and catchment area was $10m^2$. The minimum demand was 0.19 m^3 for a 500 liter tank and catchment area of 40 m^2. it was found for average condition.

CHAPTER FIVE
CONCLUSION

5. CONCLUDING REMARKS

The results of this study show that, proper use of demand curve has to be applied to make an assessment of actual requirement of tank size. This has to be done for more efficacies. The tank will then be more effective for the people there. The comparisons done to make sure, the progression was in the right direction or not, gave a positive feedback. They showed that the demand curve is more or less adequate for determining the available storage for a typical family of six persons with various demands.

The reliability analysis showed that, the tank volumes for different catchment areas and demand are more or less adequate. This was also compared using different combinations of conditions and the results came out very positively. The tank volumes of 500 liter are about 95% reliable for 2lpcd demand where the catchment area was 30m². This was achieved for an average year condition. This was the maximum reliability achieved in the whole study. For, 5lpcd demand maximum reliability achieved was about 93% where the demand was 30m² and tank volume was 2000 liters. For, 10lpcd demand, about 88.5% reliability was achieved where catchment area was 40m² and tank volume was 3000 liters. For dry years, about 73.2% reliability was achieved for 30m² catchment areas and 2000 liter tank volume where demand was 5 and 10lpcd. For wet year, maximum reliability achieved was 77% where catchment area was 40m² and tank volume was 1000 liters for 2lpcd demand.

The spilling volume increases with the increase of catchment area but for the same per capita demand, the spilling volume increases if storage volume is higher. The highest spilling was found for 2lpcd demand; catchment area of 40m^2 and it was for tank volume 500 liter. The maximum spill volume was 72m^3. The minimum spill volume was 5.1m^3 where catchment area was 10m^2, demand 10lpcd and tank volume was 500 liters.

The supplementary water demand, which is the water that has to be provided from another source to meet the demand, decreases if the tank volume is increased. It also decreases if the catchment area is increased. For any intended demand of water, the supplementary water demand decreases if rainfall is higher. The maximum supplementary water demand of 11.3 m^3 was found for dry year condition. There the volume of tank was 500 liters and catchment area was 10m^2. The minimum demand was 0.19 m^3 for a 500 liter tank and catchment area of 40 m^2. it was found for average condition.

The coastal areas of Bangladesh need to have proper and analyzed rainwater harvesting system and properly calculated tank volume. It is high time, there should be proper studies conducted for rainwater harvesting. With an increase in population and aquifers getting deeper beneath the ground there is only one viable option left for the people of those areas to get safe water for drinking which is rainwater harvesting.

The analysis that has been done here shows that rainwater harvesting can be effectively used as a viable option to provide fresh water. The design curve may be effectively used for determining a tank volume or tank size according to the demand of the people. The reliability analysis of the system also was promising and showed that the system would be sufficient to meet the demands of the people. The tank size or storage volume currently provided is not based upon any studies and so it is not effectively serving the purpose. The efficiency is not very high and it is also due to the fact that no proper studies have been done when preparing the tank size. The tank volume is determined according to the convenience of the company. But it is clear from this analysis that tank volume should be determined based upon the demand of the users.

As promising as the results of this analysis might be, there are still some factors that may retard the efficiency of the system. Nevertheless, it is clear that, Rainwater Harvesting in the coastal areas is a promising option for the people there.

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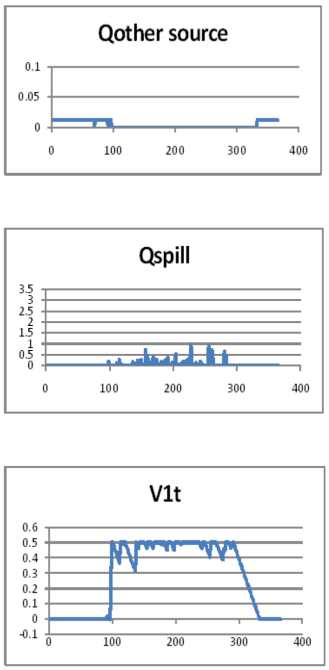
APPENDIX

WET YEAR

10 m² 2 lpcd

500 L



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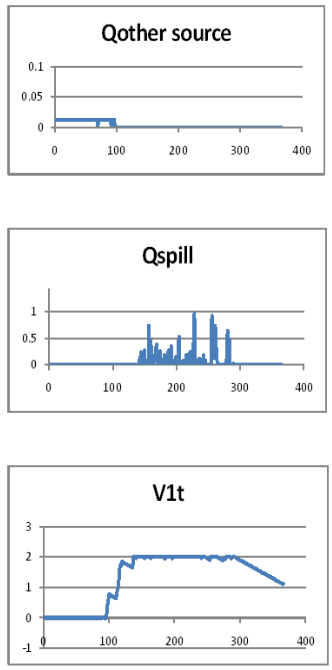

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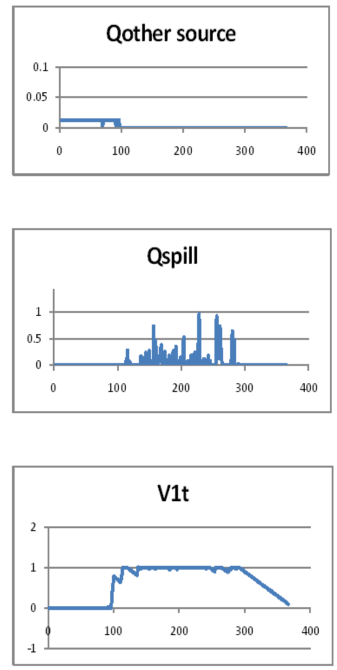

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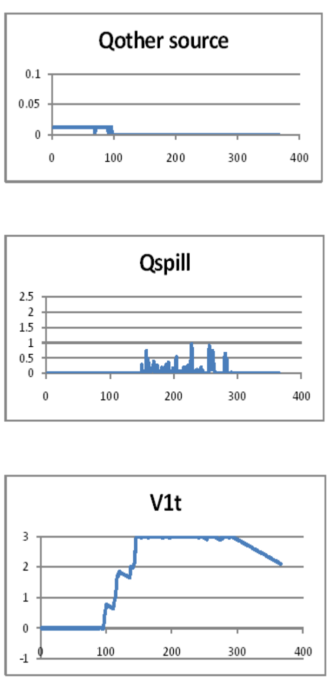

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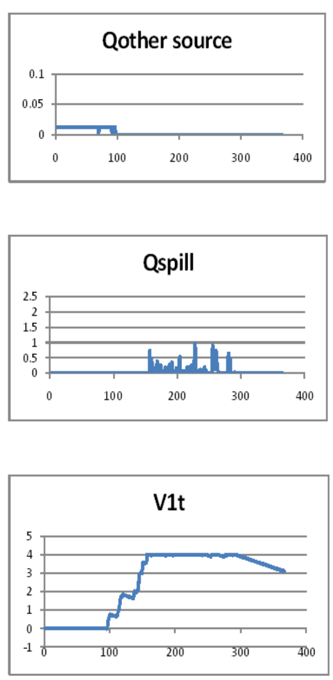

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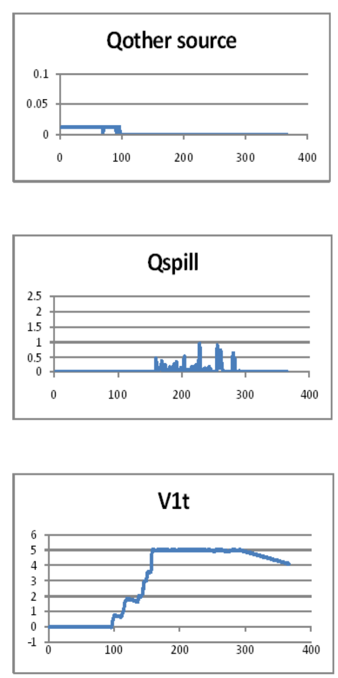
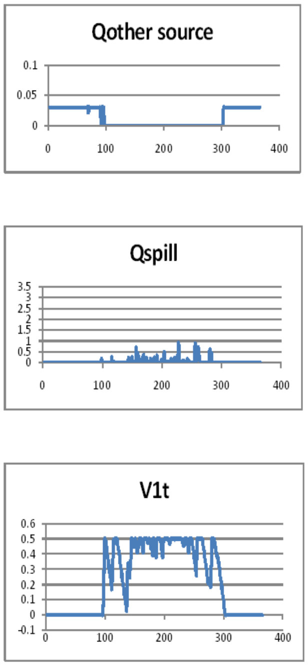


10 m² 5 lpcd

500 L



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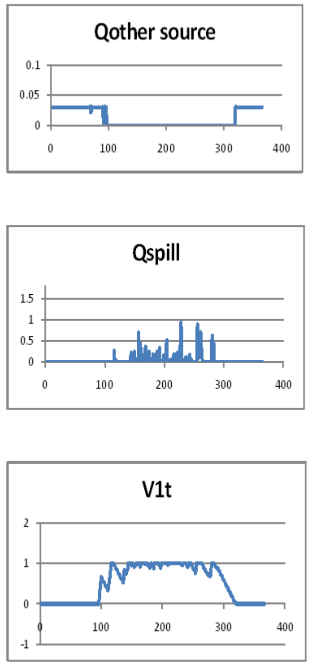

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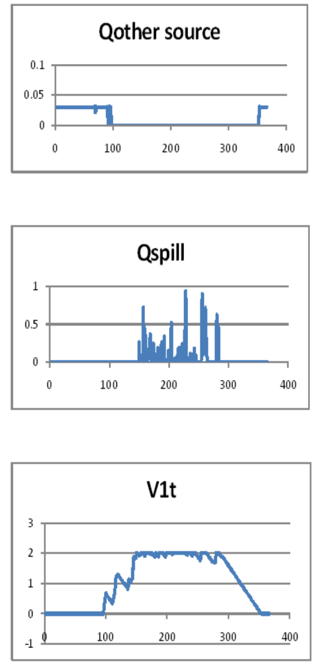

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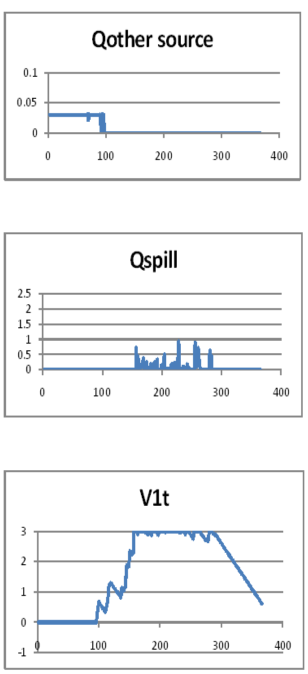

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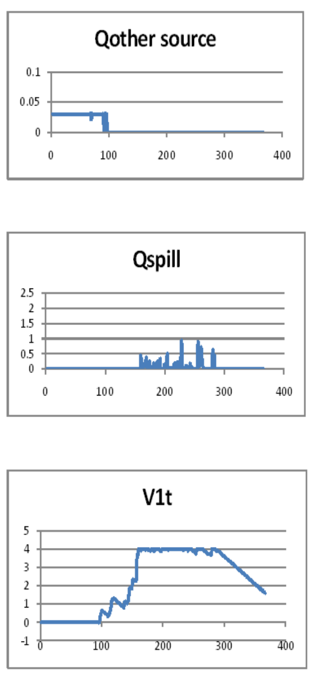

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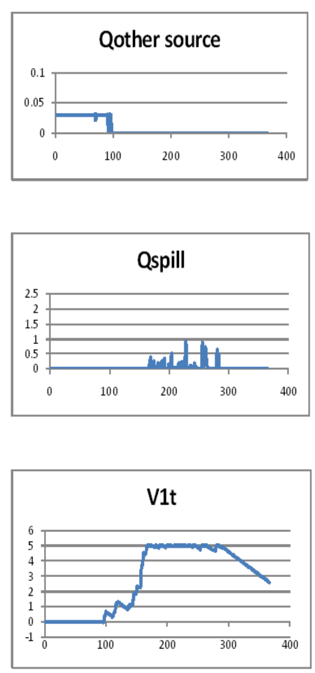

10 m² 10 lpcd

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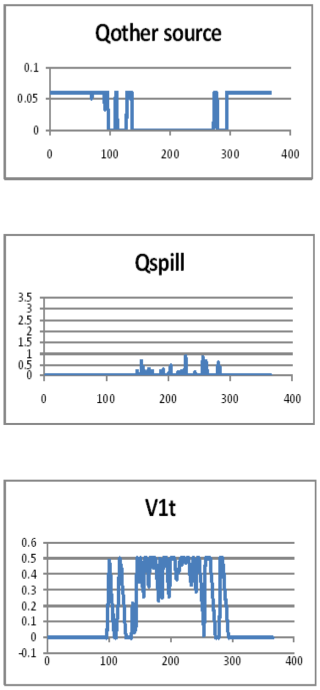

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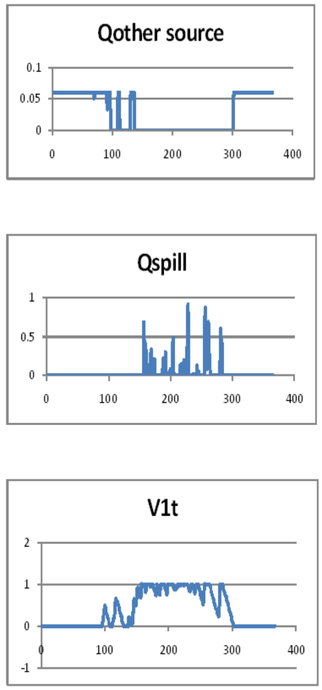

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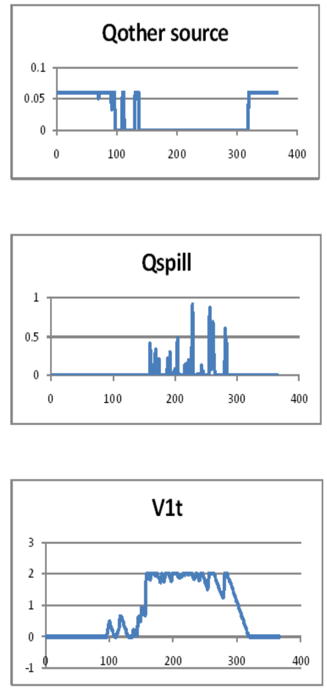

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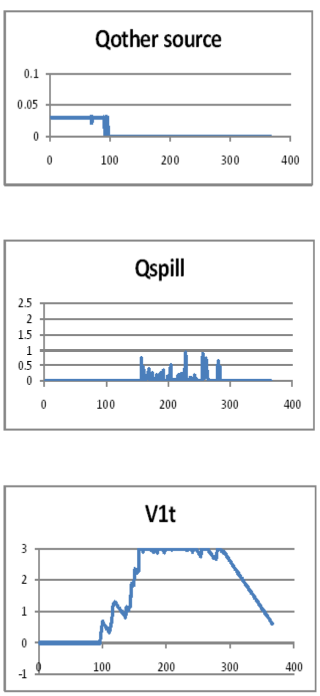

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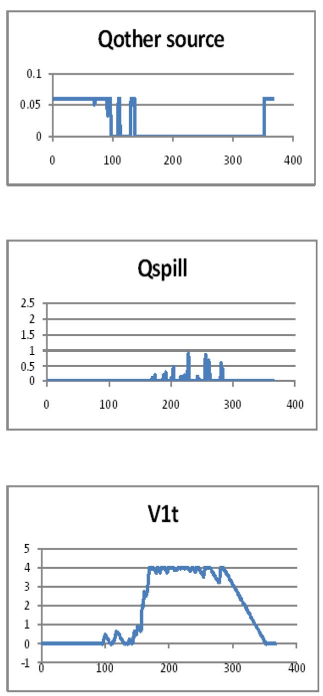

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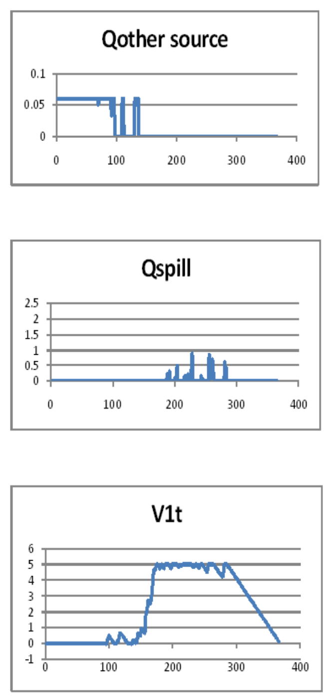

20 m² 2 lpcd

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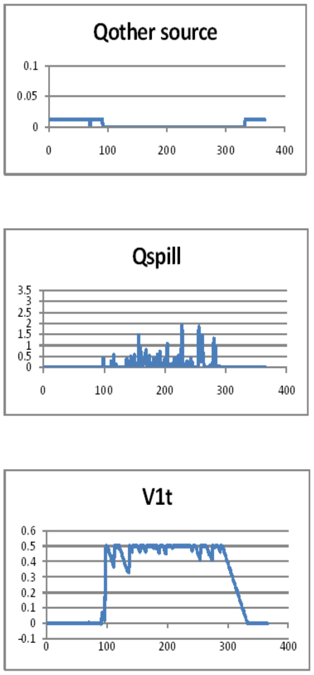

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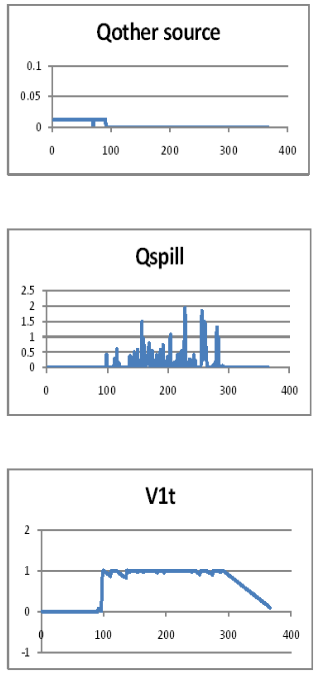

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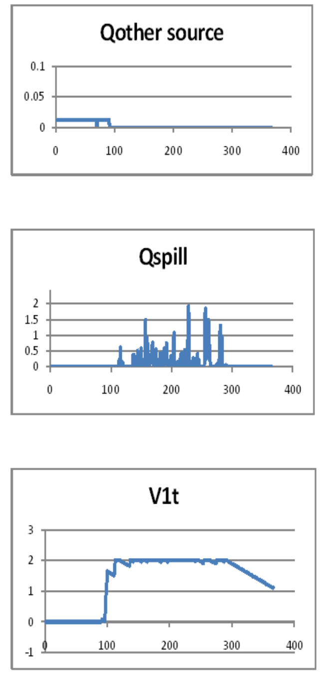

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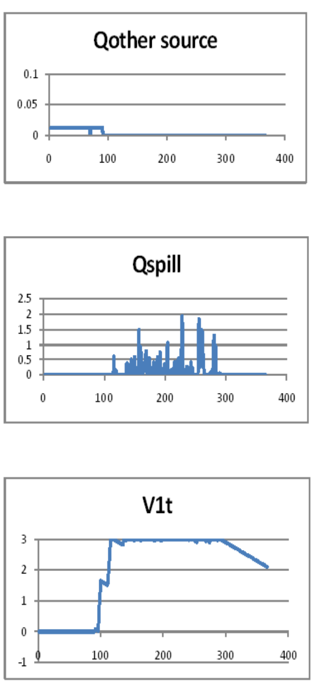

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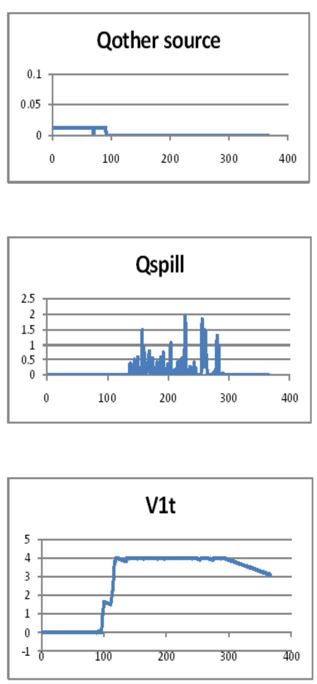

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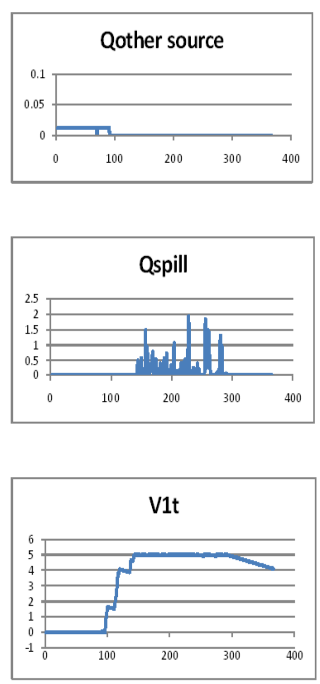

20 m² 5 lpcd

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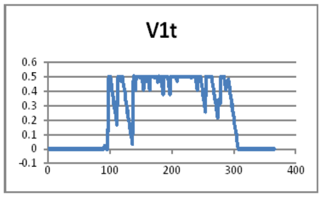

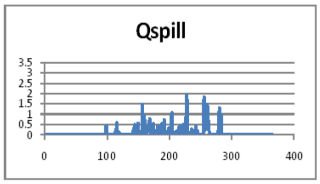

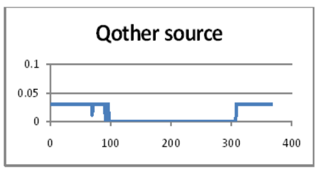

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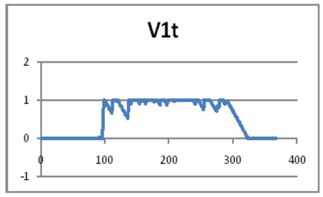

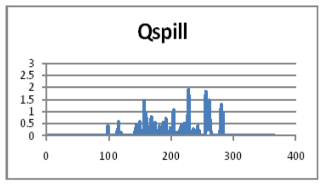

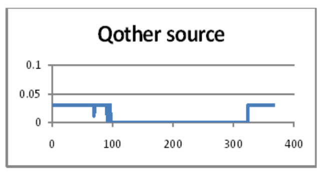

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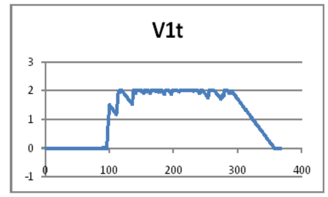

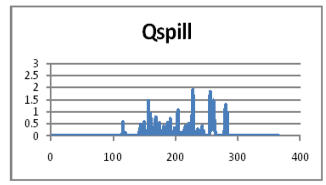

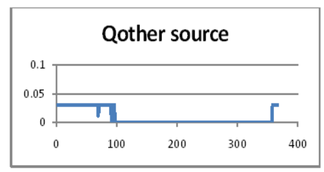

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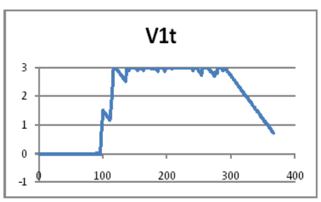

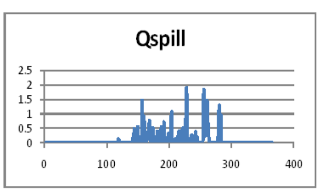

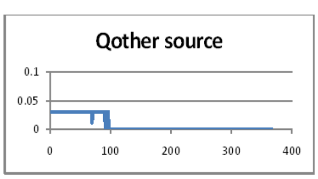

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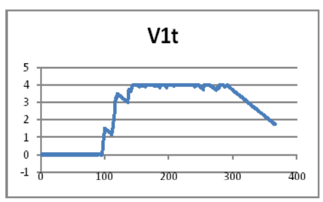

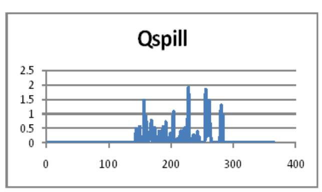

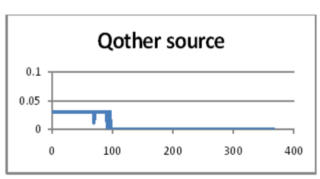

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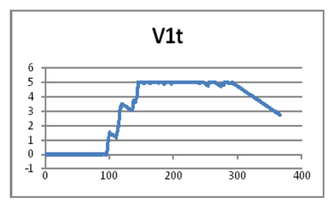
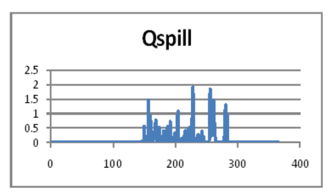
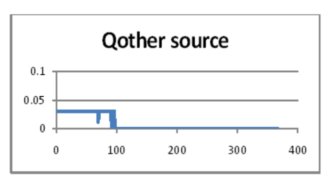
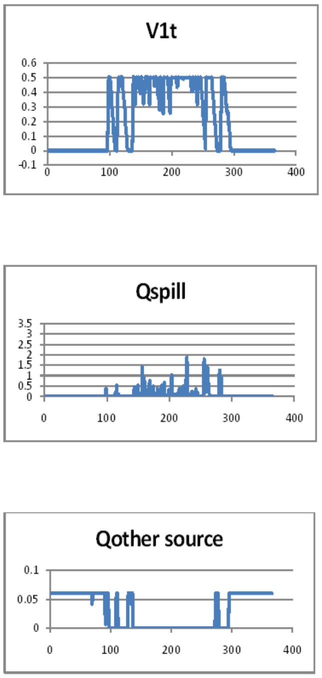






20 m² 10 lpcd

500 L



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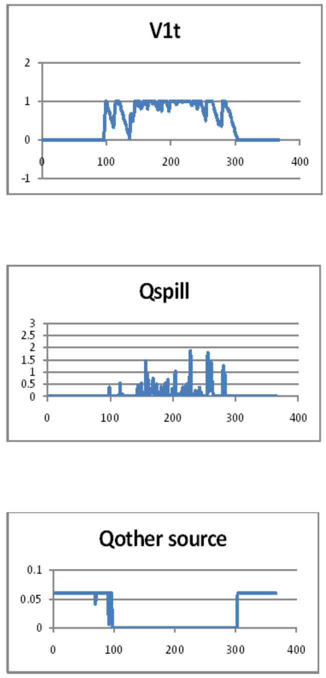

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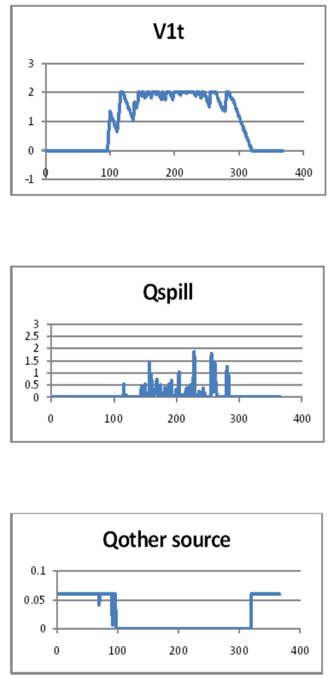

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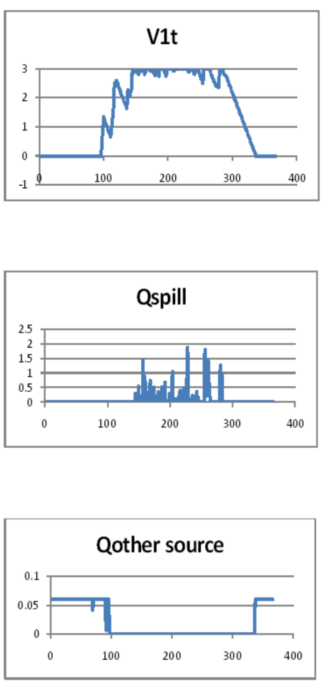

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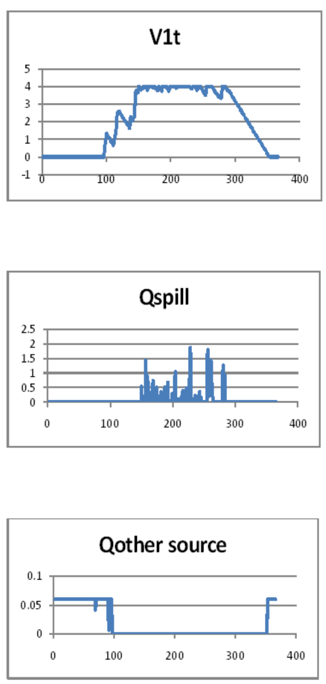

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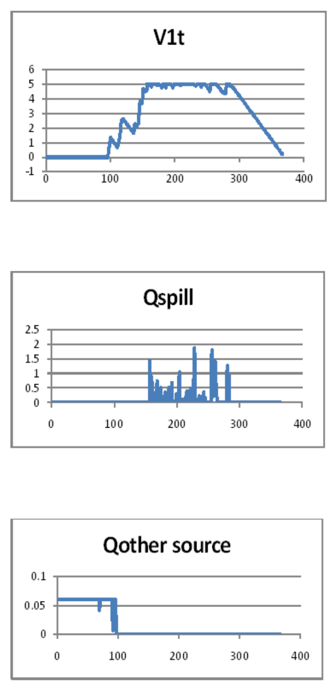
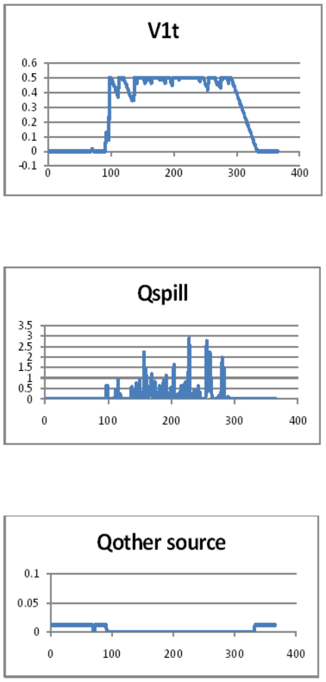


30 m² 2 lpcd

500 L



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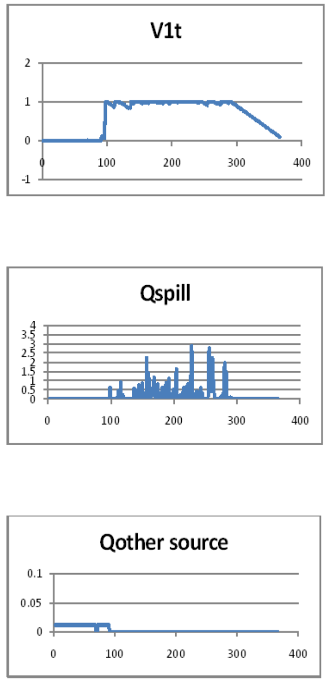

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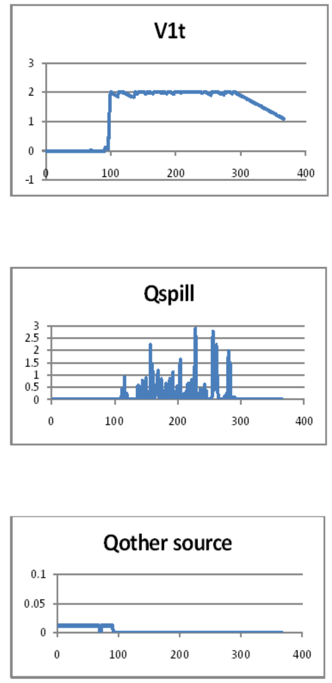

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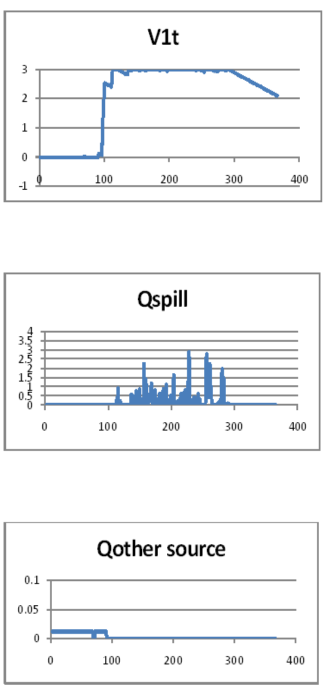

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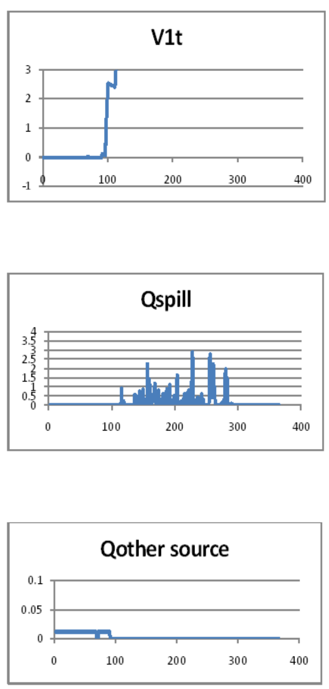

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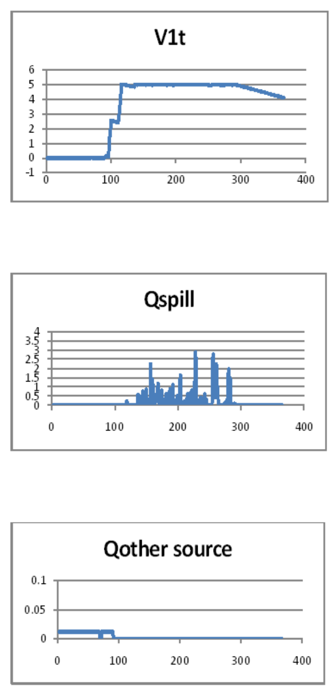

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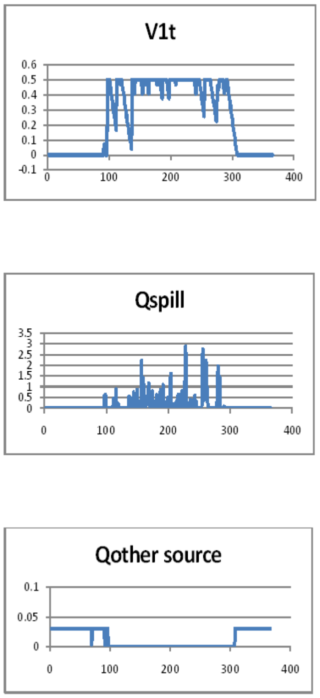

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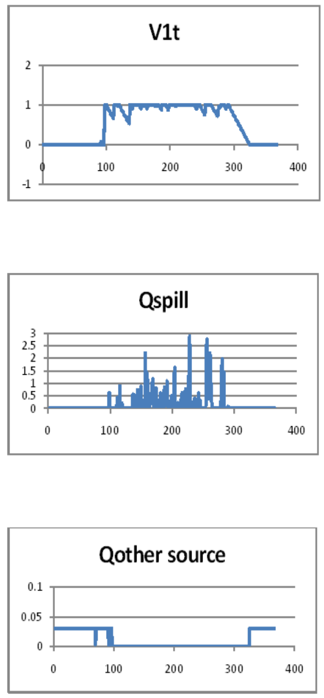

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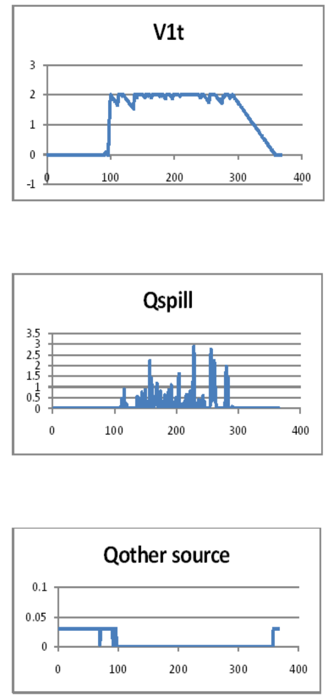

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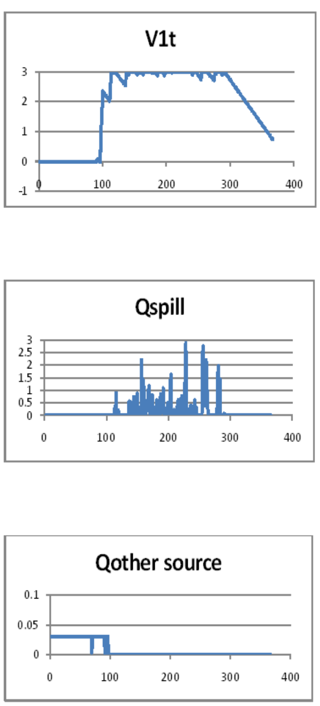

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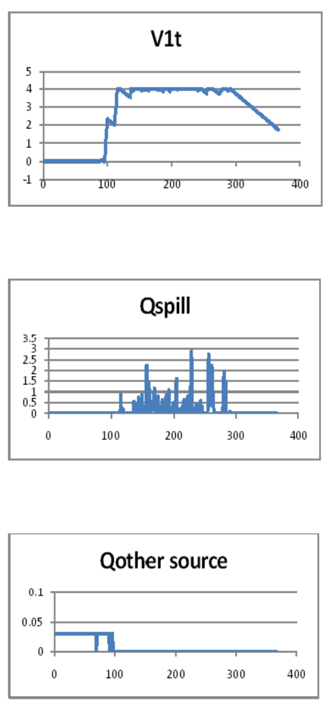

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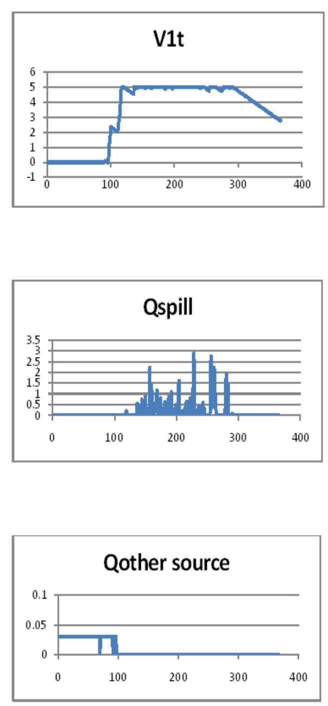

30 m² 10 lpcd

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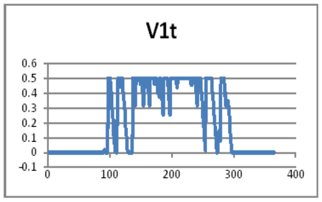

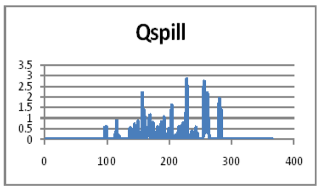

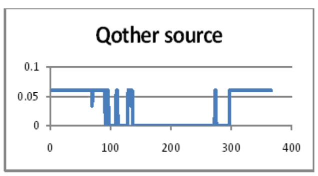

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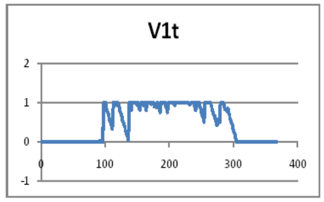

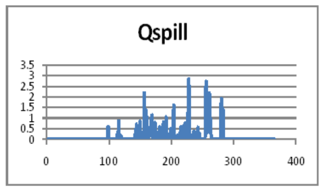

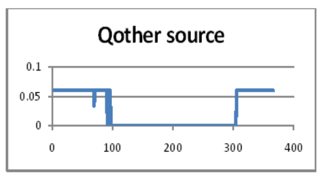

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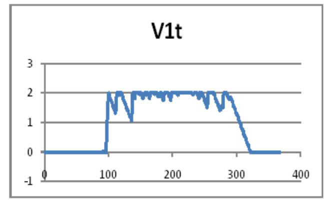

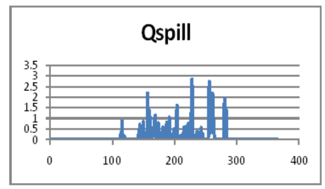

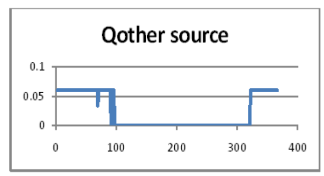

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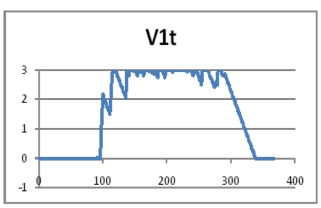

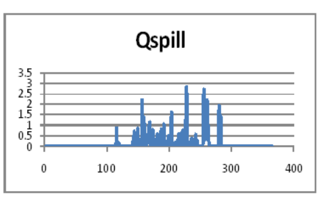

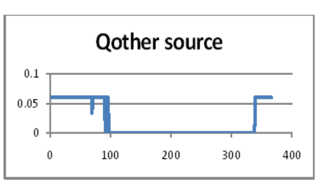

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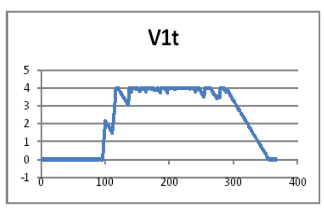

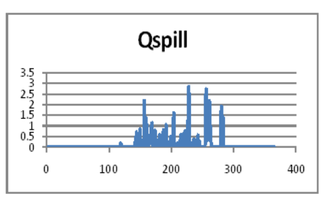

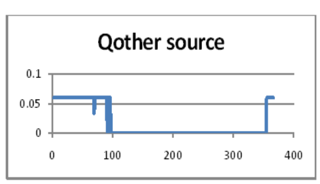

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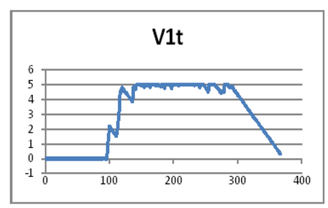

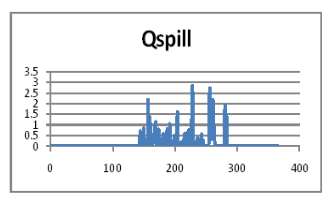

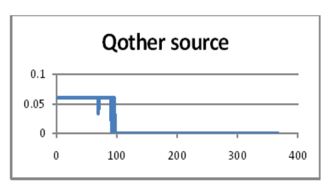

40 m² 2 lpcd

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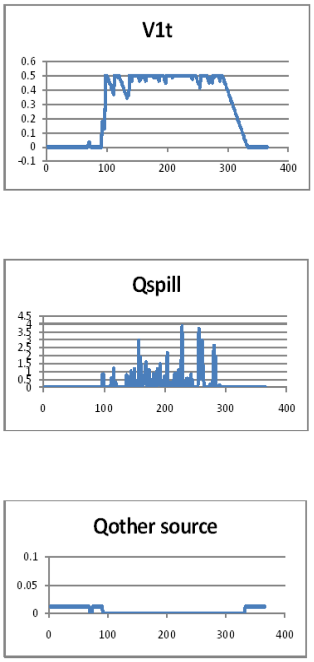

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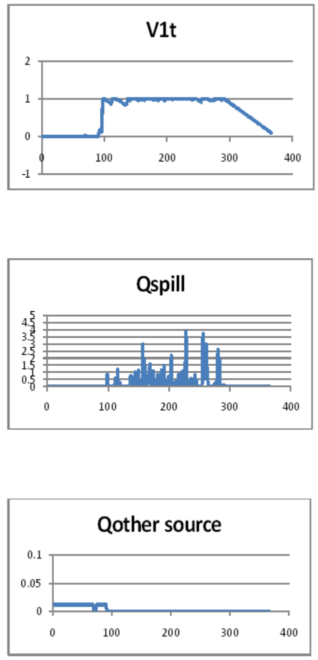

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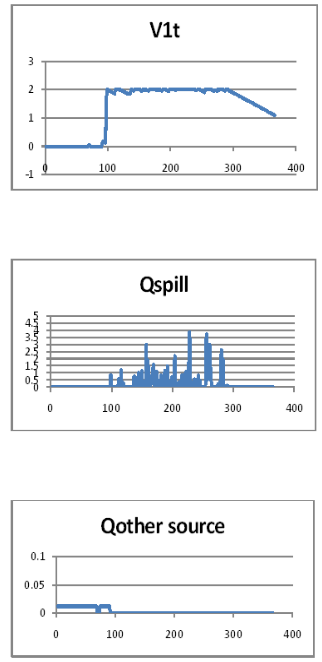

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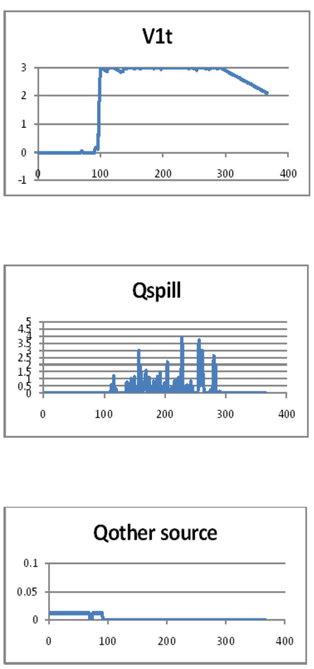

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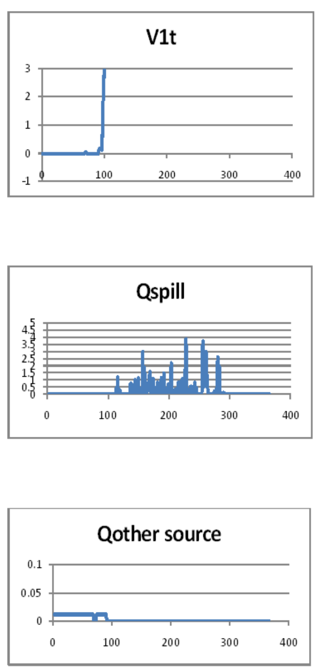

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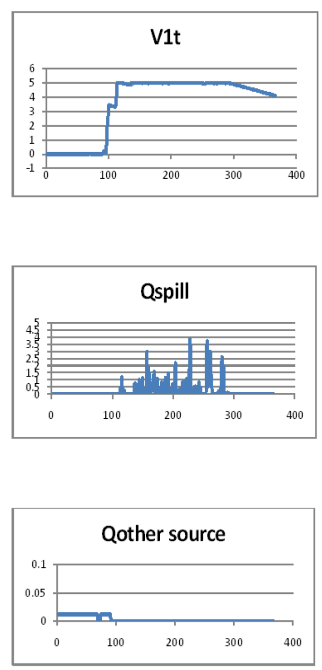
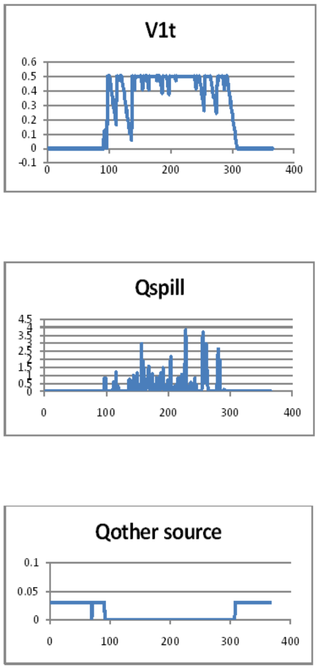


40 m² 5 lpcd

500 L



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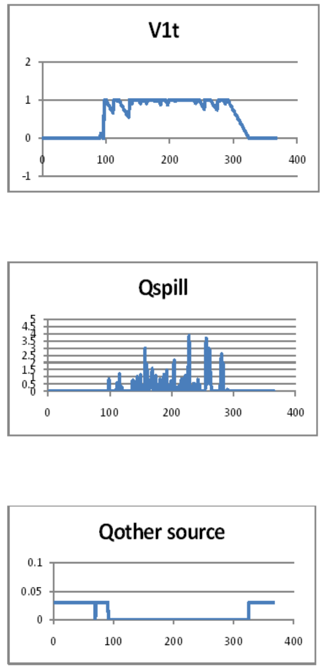

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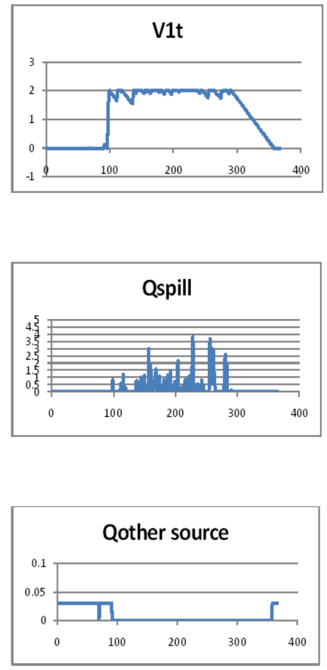

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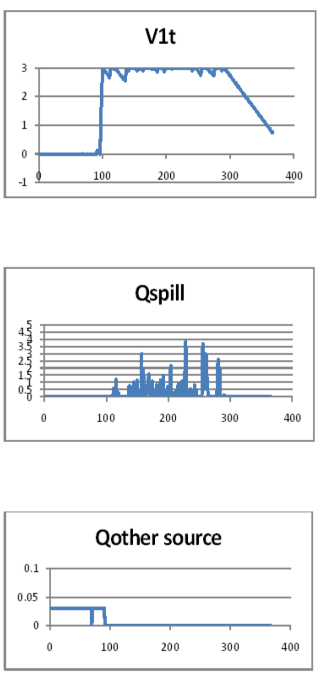

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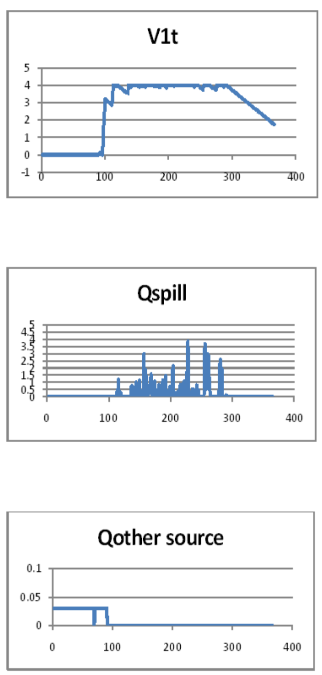

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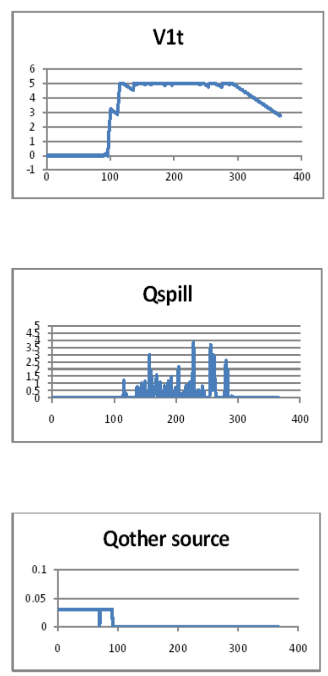

40 m² 10 lpcd

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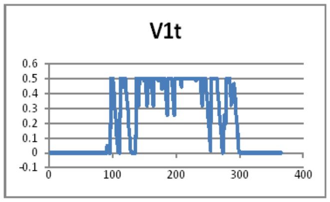

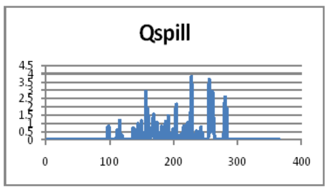

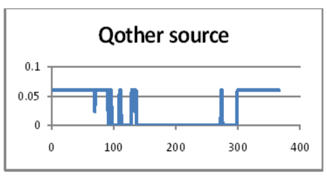

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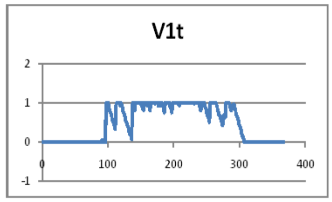

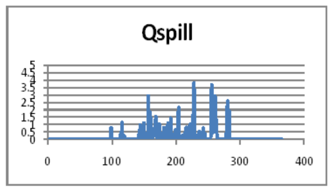

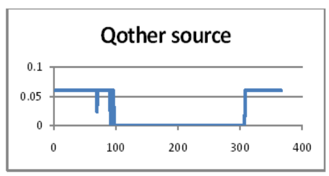

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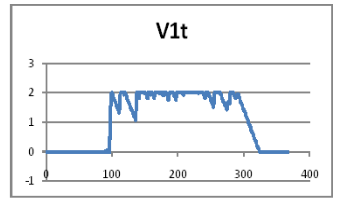

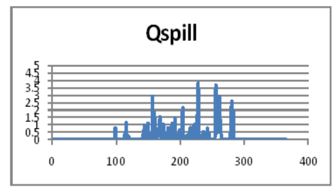

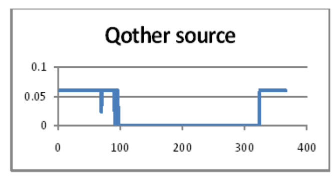

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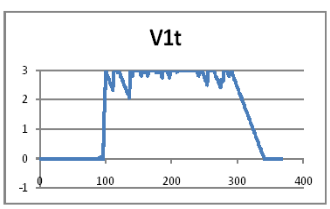

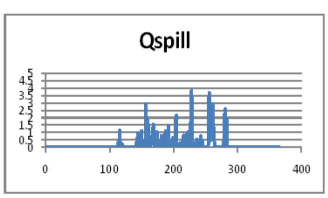

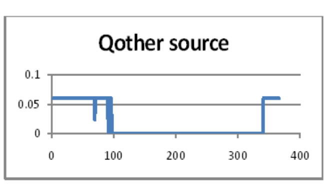

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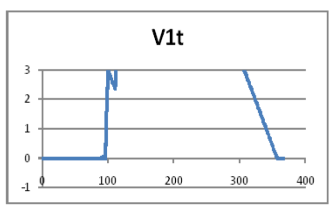

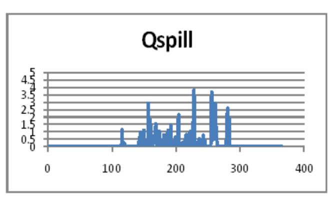

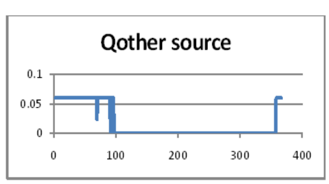

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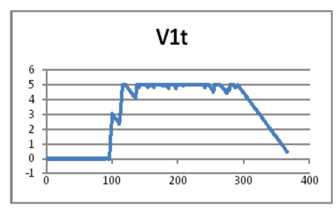
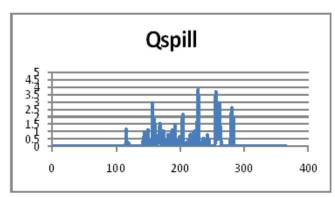
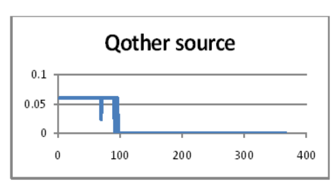


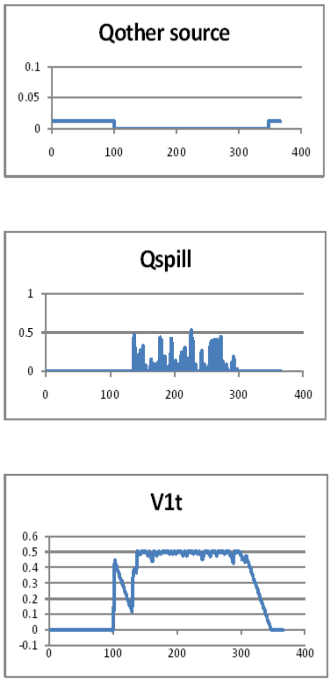




GRAPH
(DRY YEAR)

10 m² 2 lpcd

500 L



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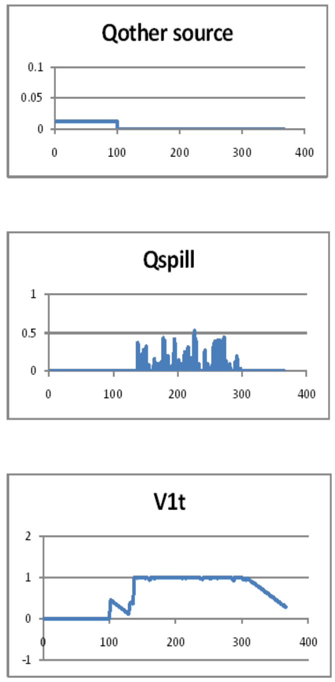

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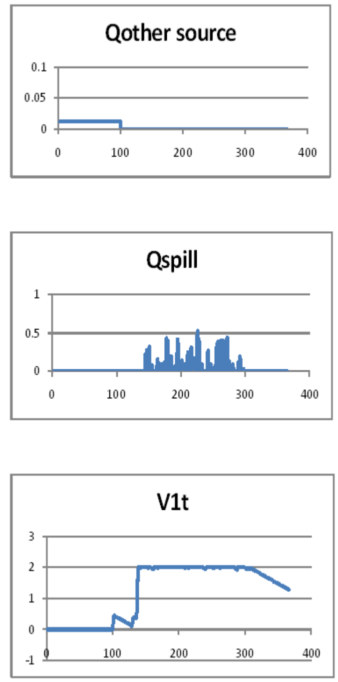

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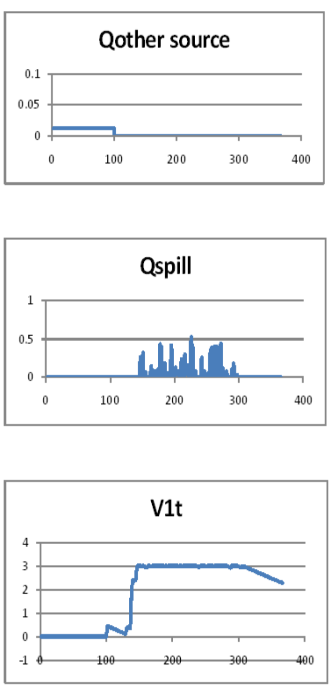

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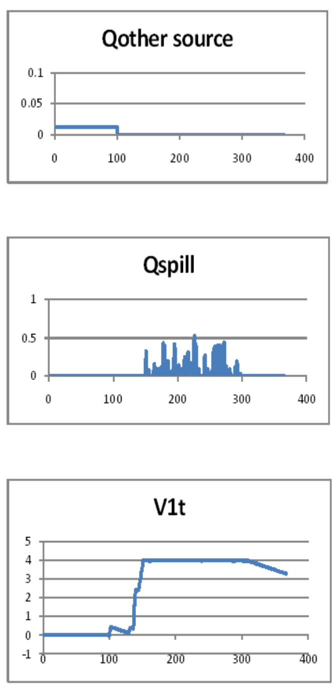

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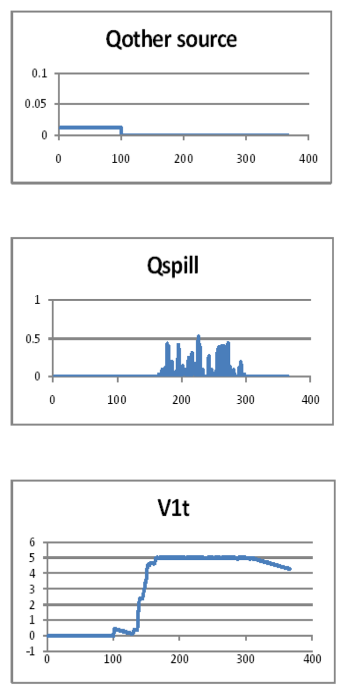
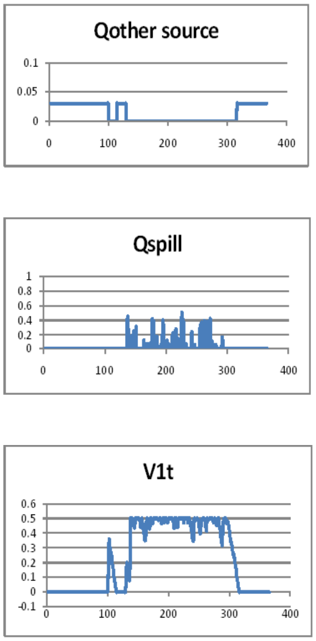


10 m² 5 lpcd

500 L



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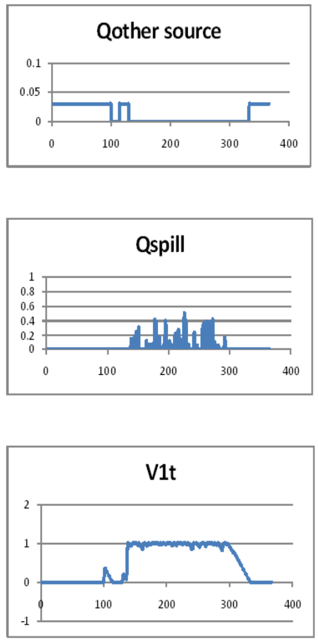

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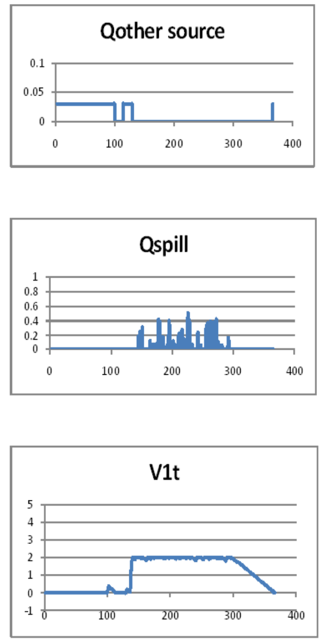

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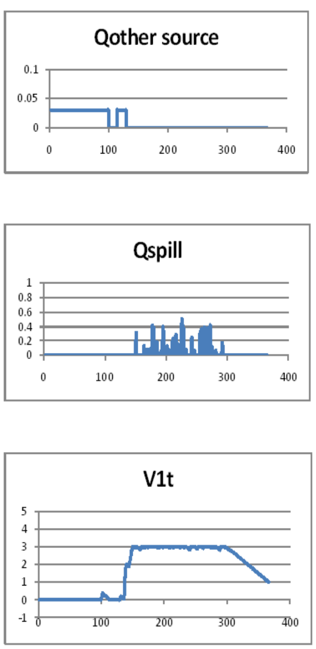

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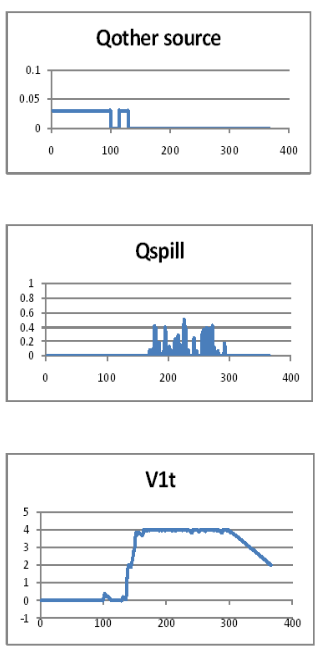

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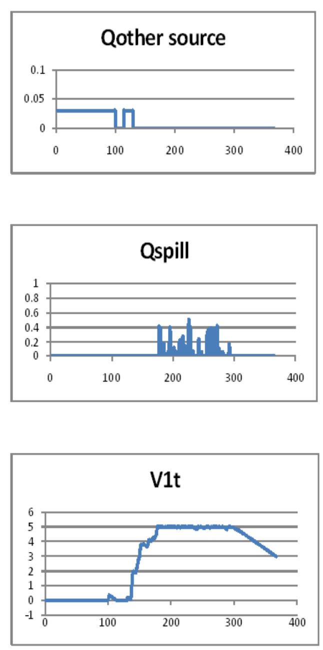
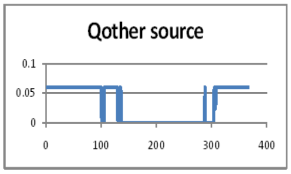
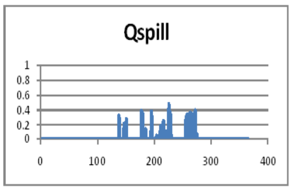
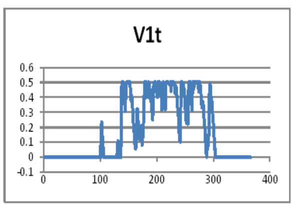


10 m² 10 lpcd

500 L







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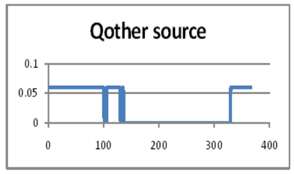

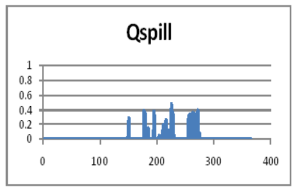

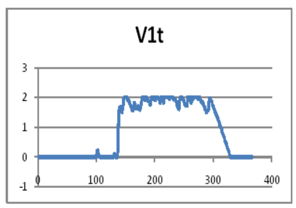

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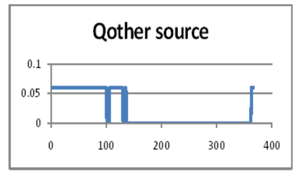

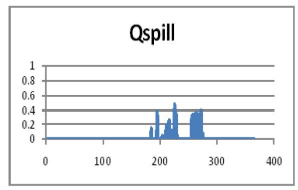

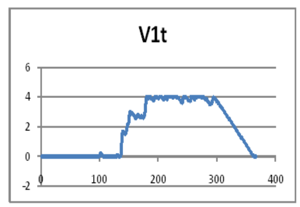

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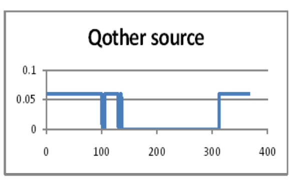

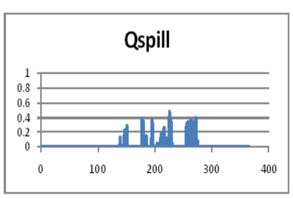

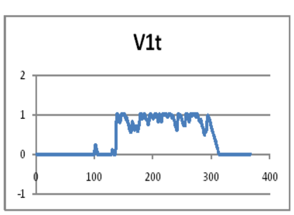

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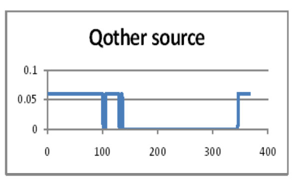

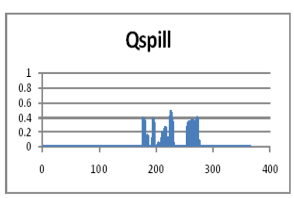

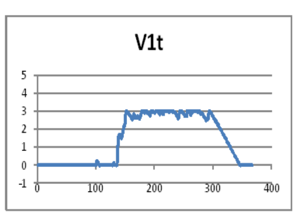

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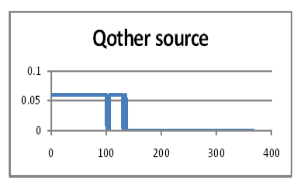

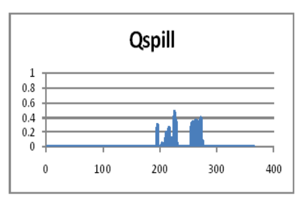

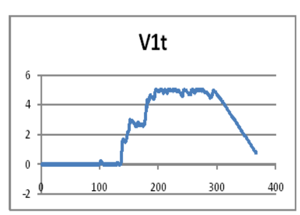

20 m² 5 lpcd

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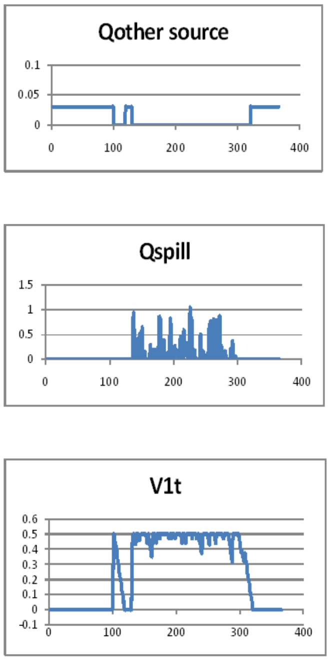

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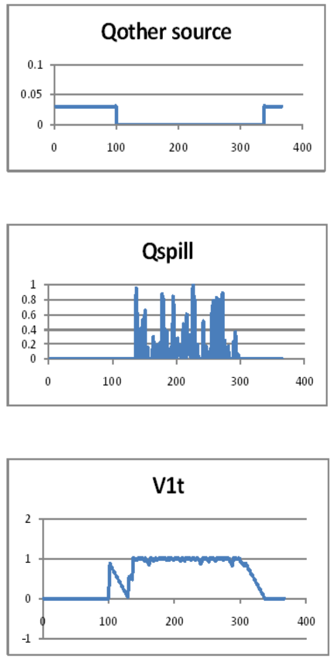

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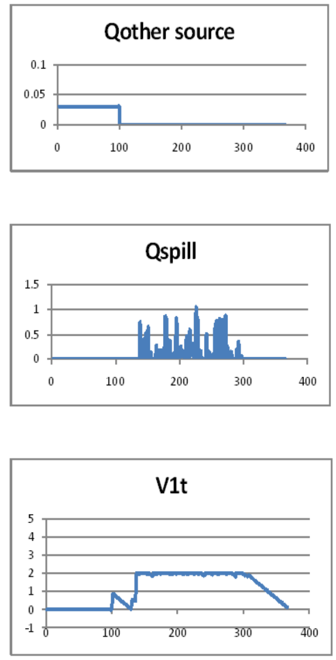

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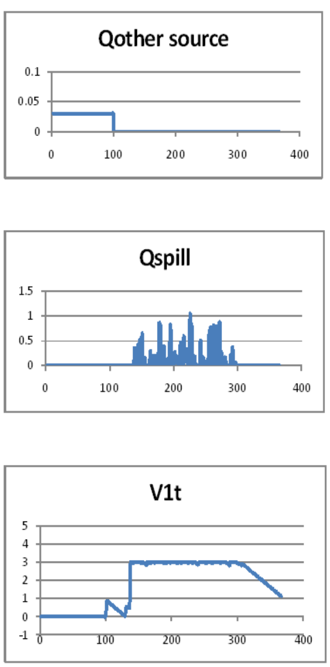

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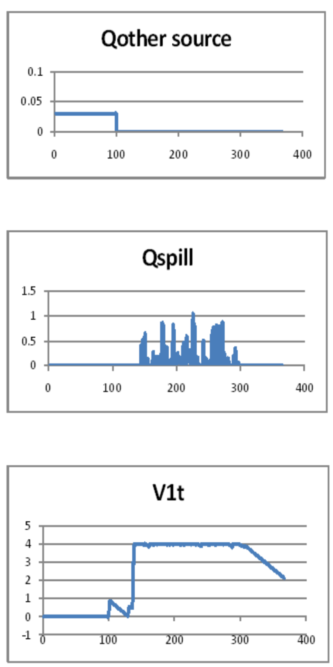

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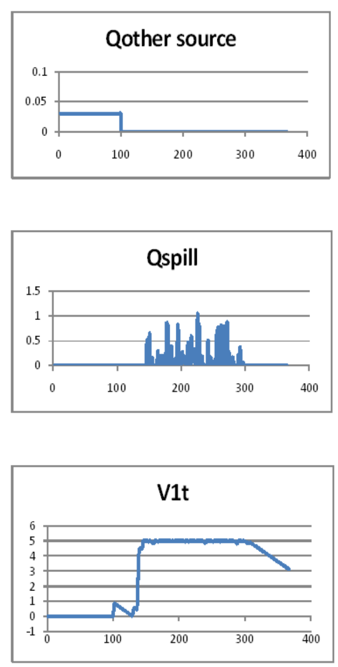

20m² 2 lpcd

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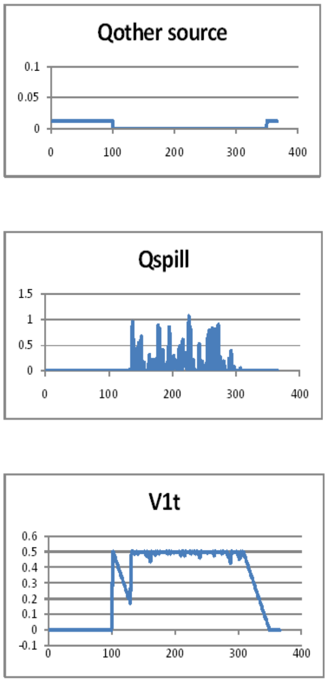

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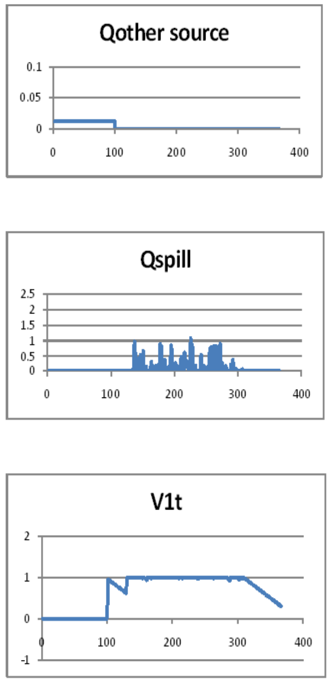

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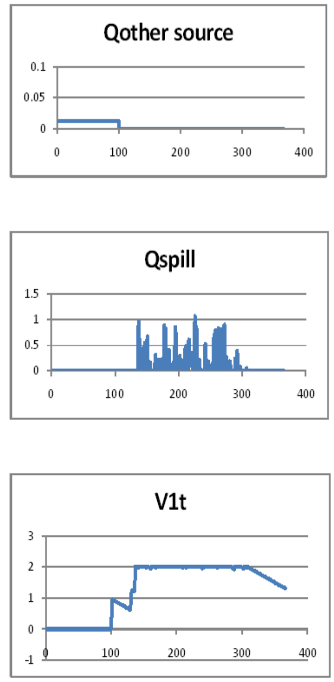

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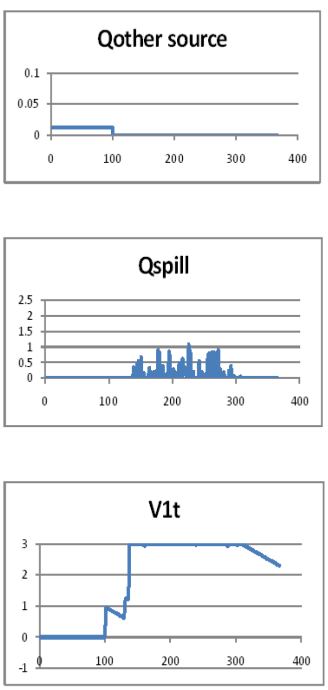

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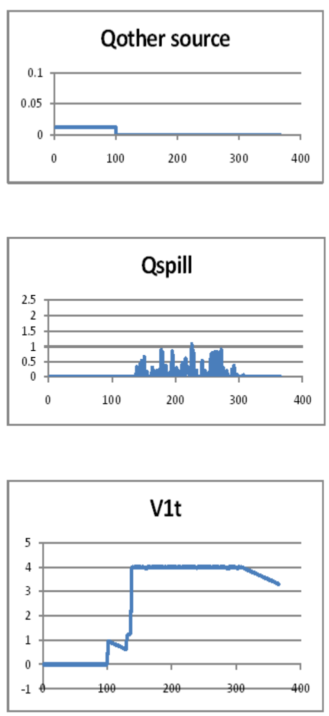

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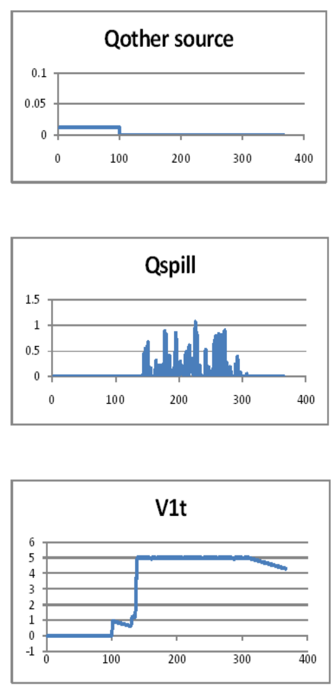

20m² 10 lpcd

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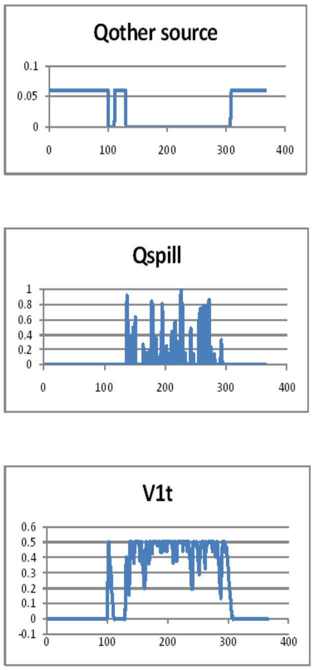

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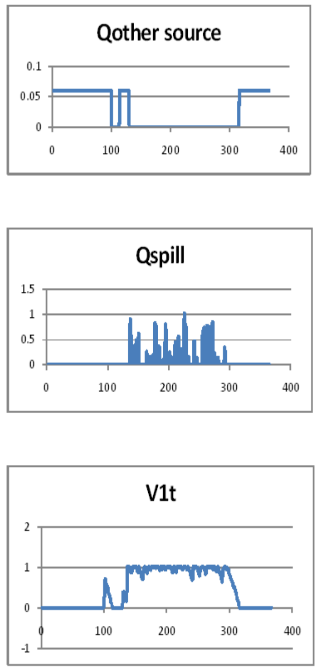

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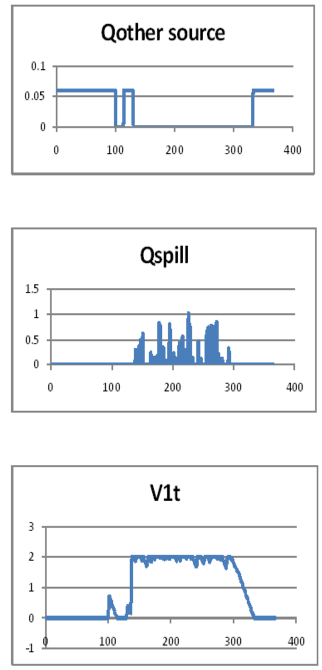

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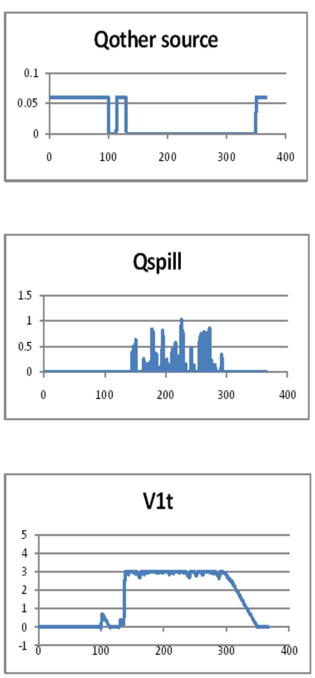

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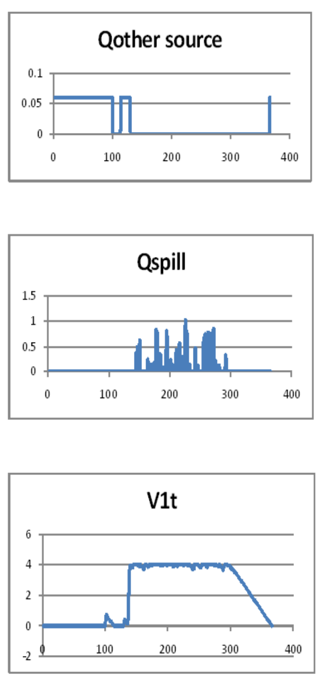

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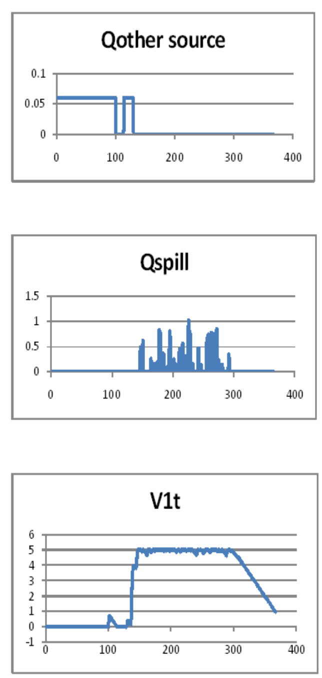

30 m² 2 lpcd

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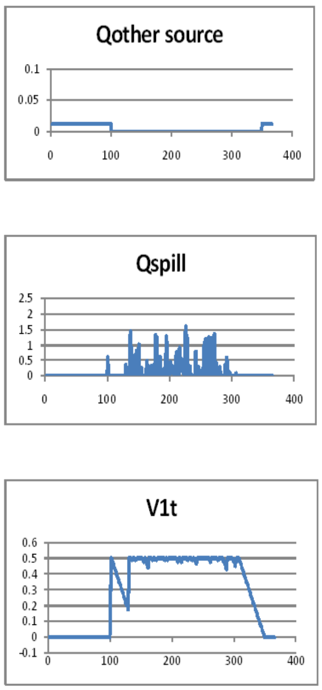

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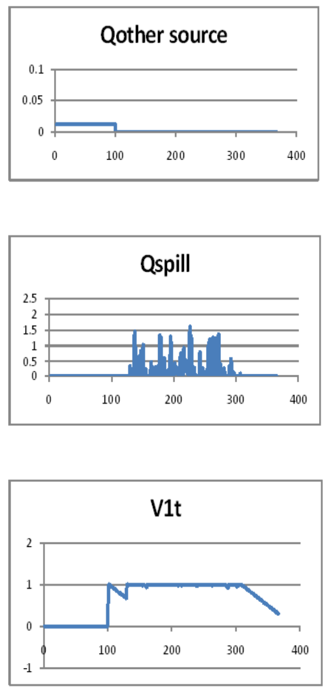

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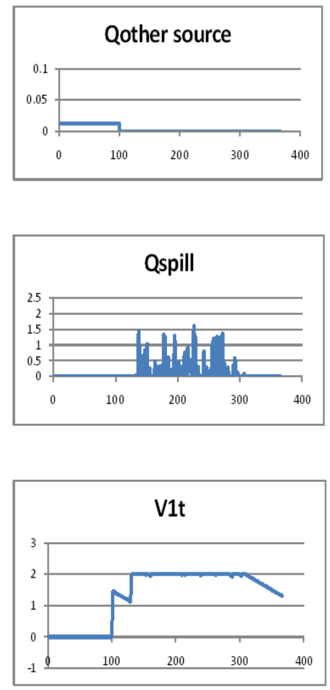

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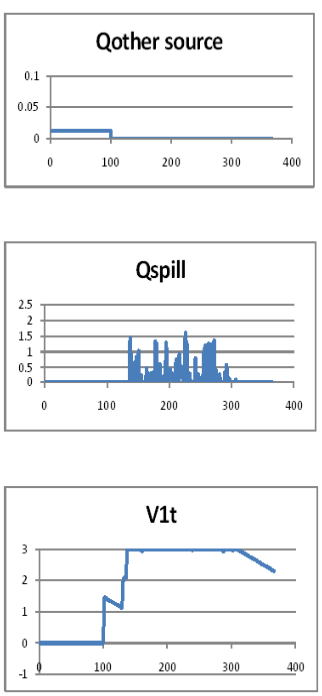

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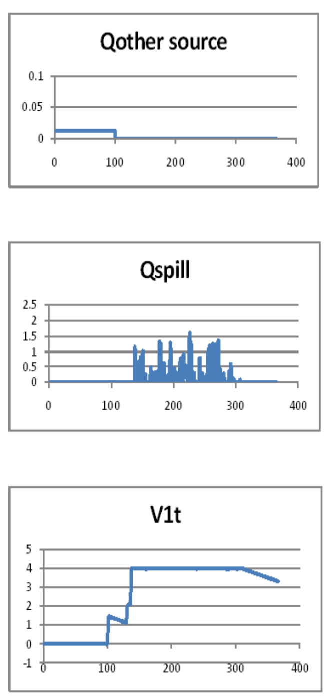

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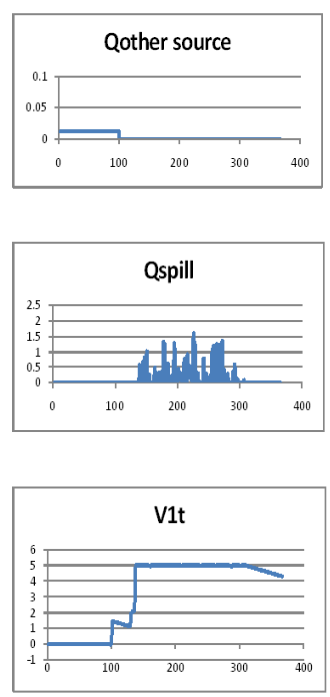
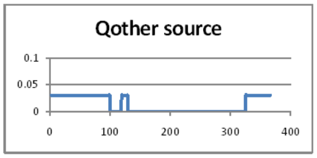
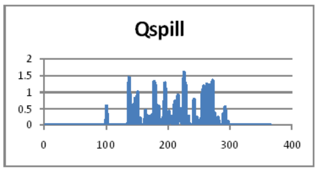
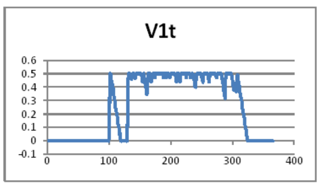


30 m² 5 lpcd

500 L







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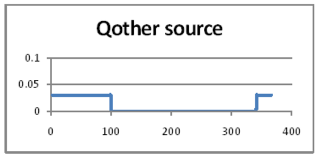

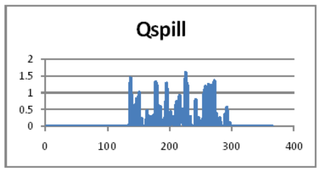

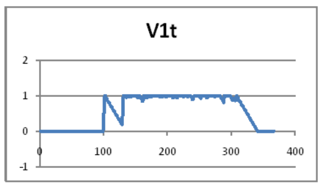

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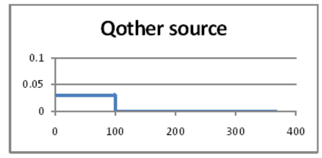

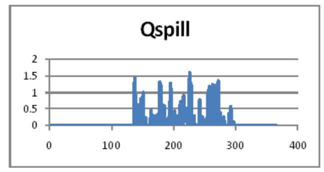

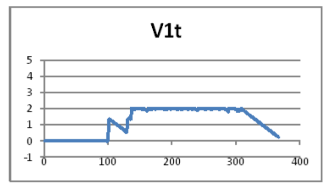

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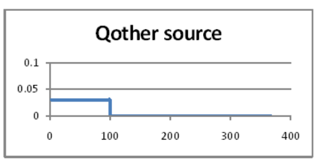

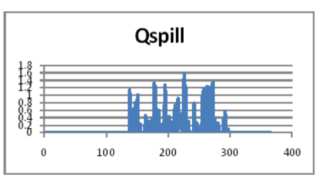

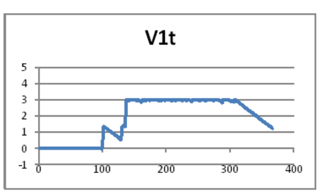

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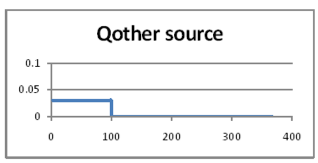

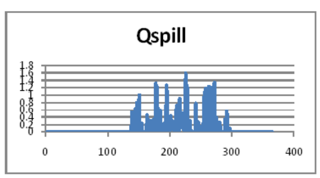

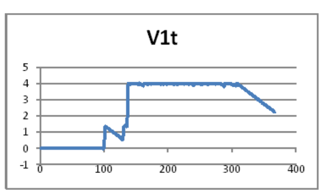

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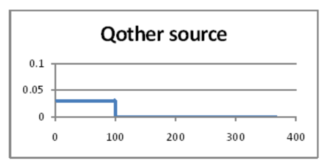
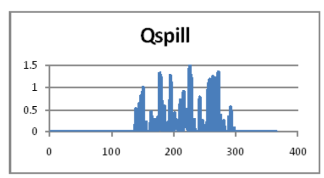
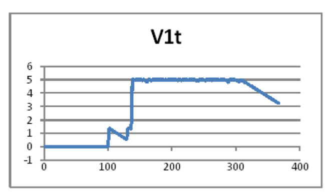
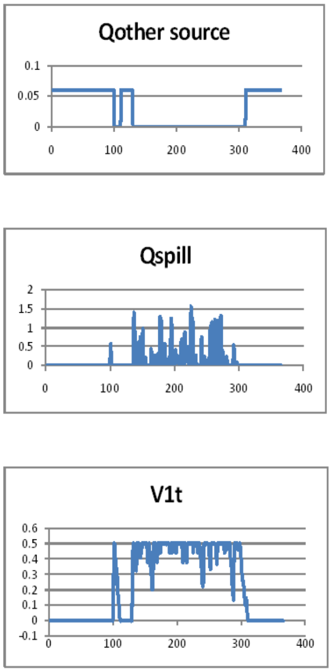






30 m² 10 lpcd

500 L



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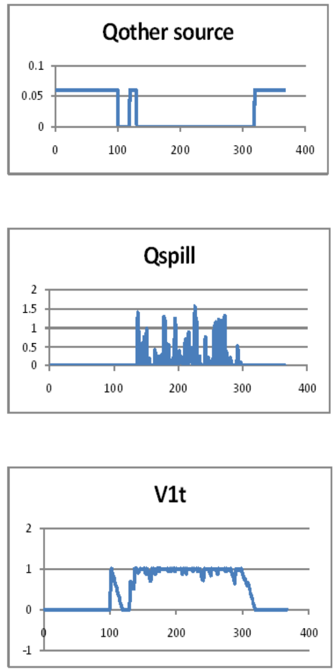

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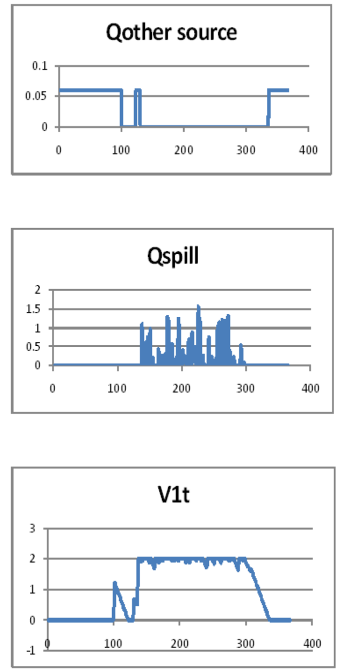

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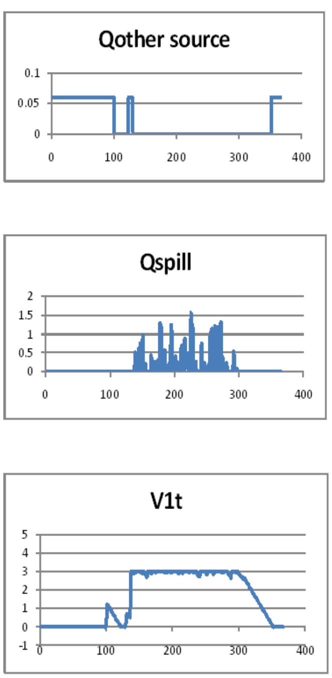

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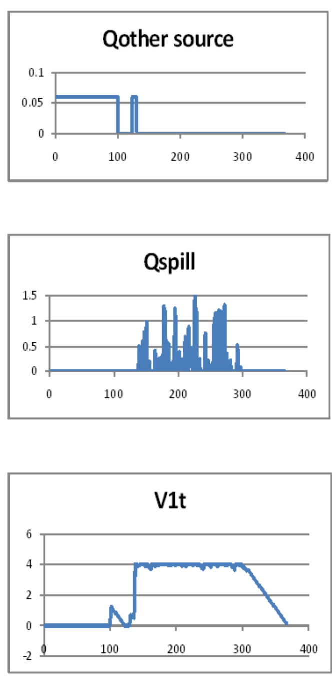

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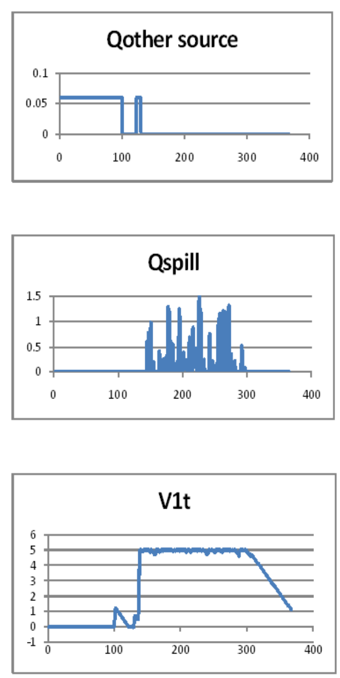
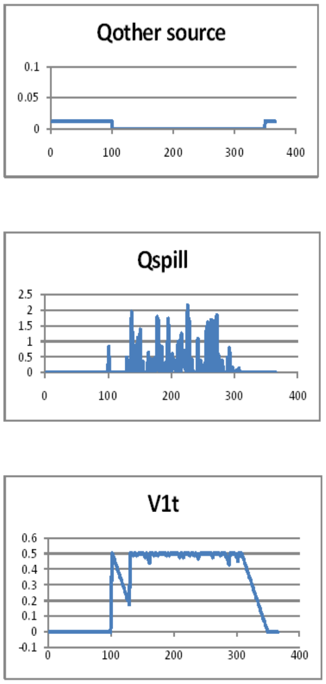


40 m² 2 lpcd

500 L



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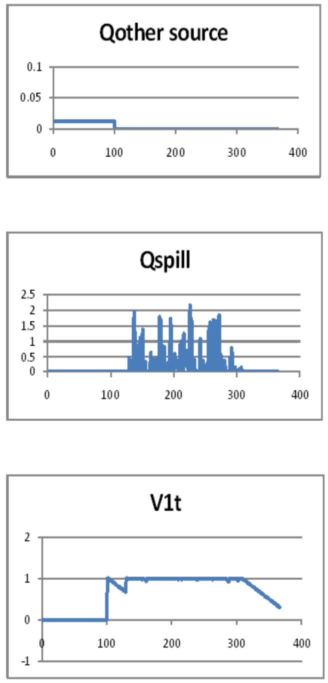

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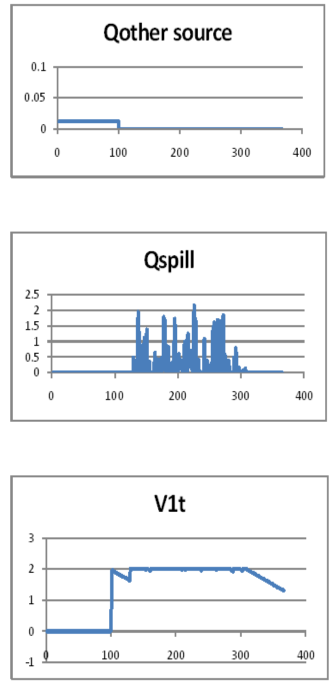

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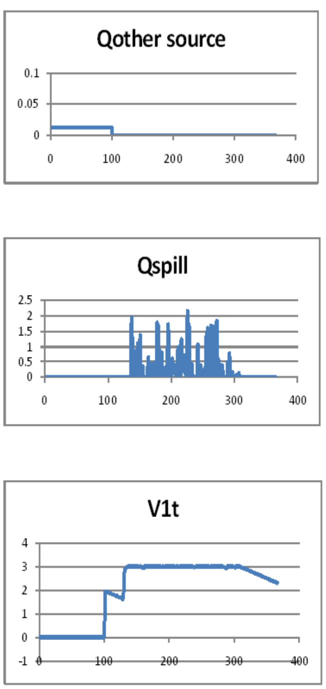

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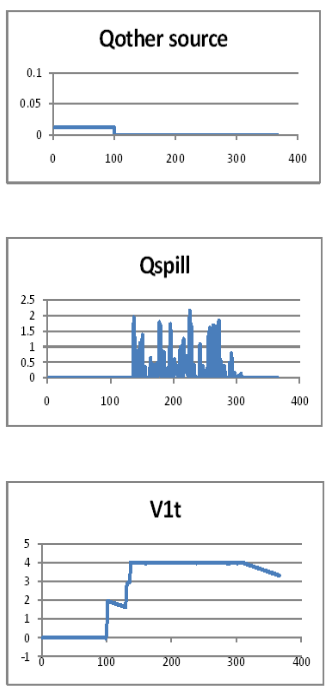

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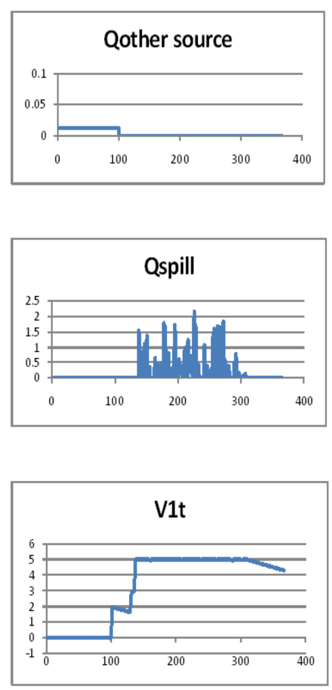
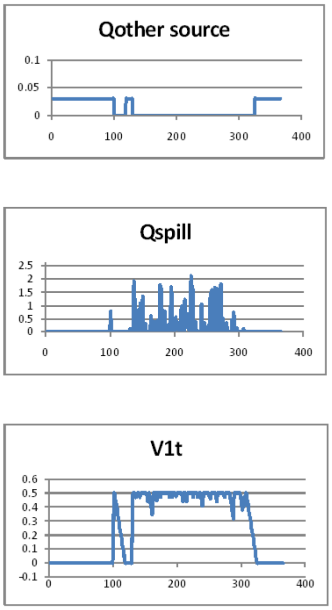


40 m² 5 lpcd

500 L



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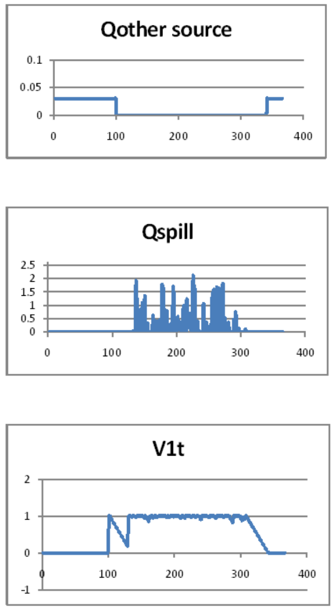

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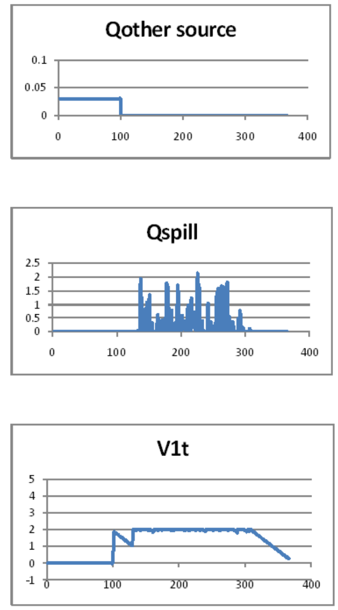

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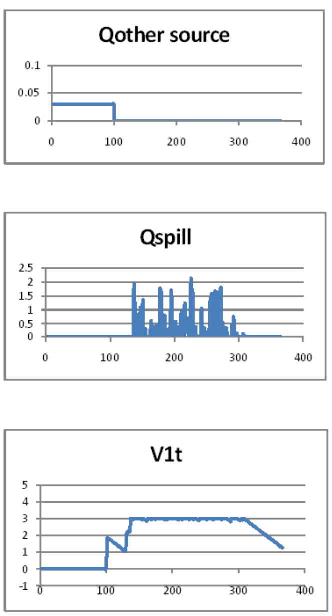

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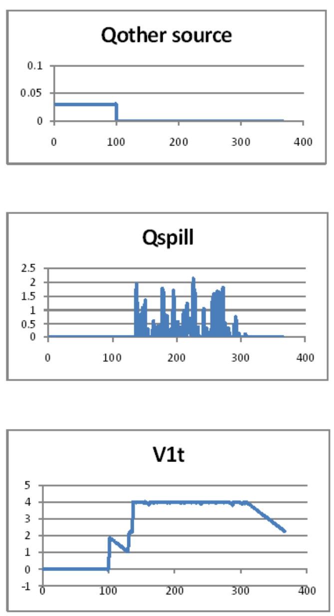

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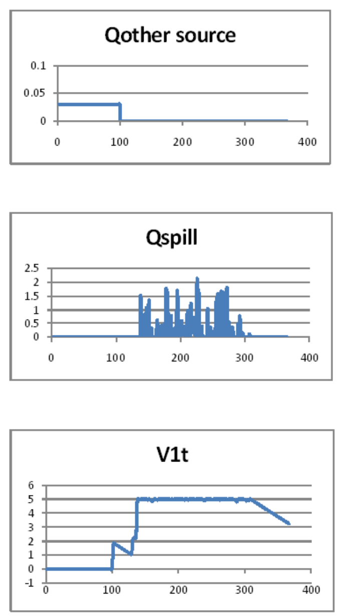
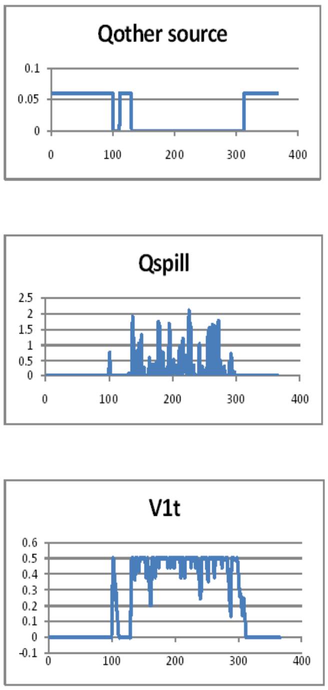


40 m² 10 lpcd

500 L



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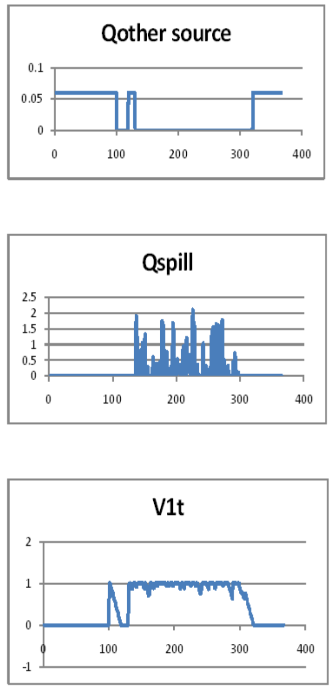

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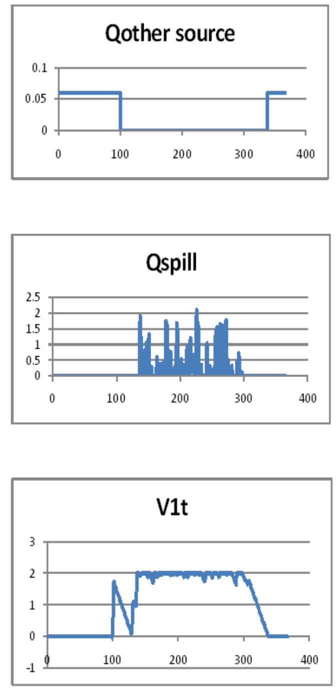

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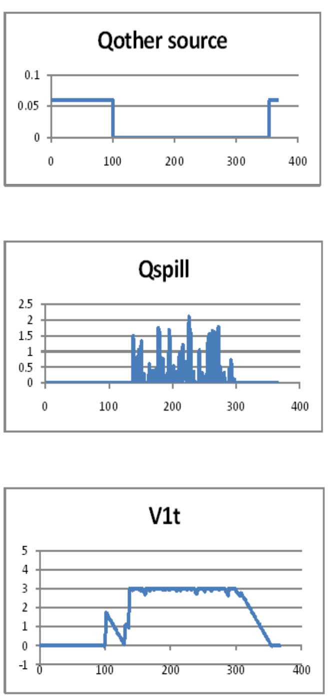

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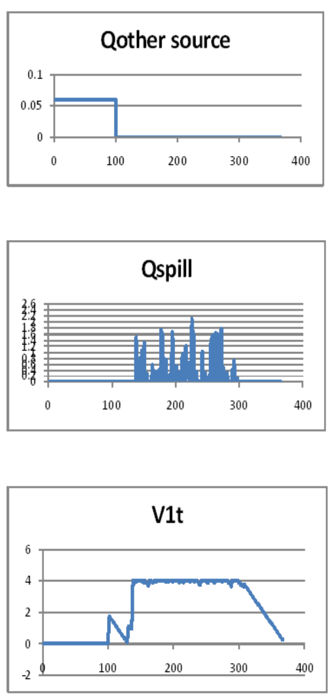

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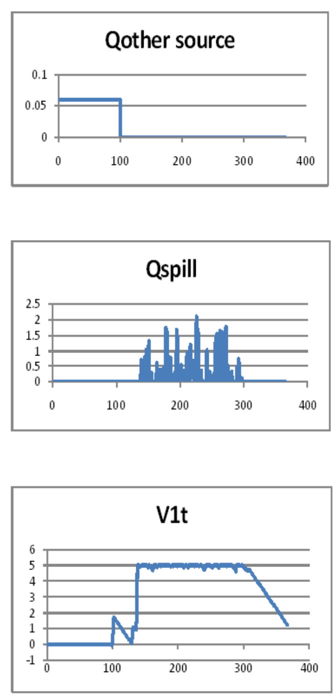
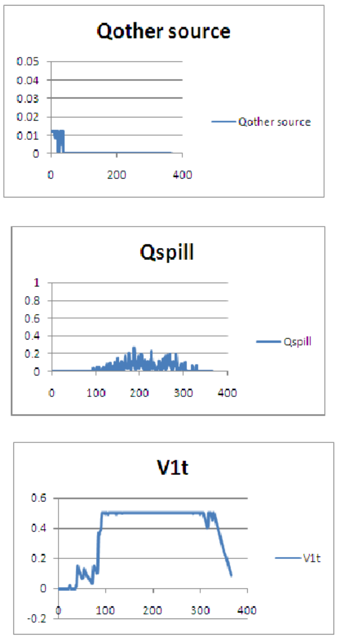


GRAPH
(AVERAGE YEAR)

10 m² 2lpcd

500 L



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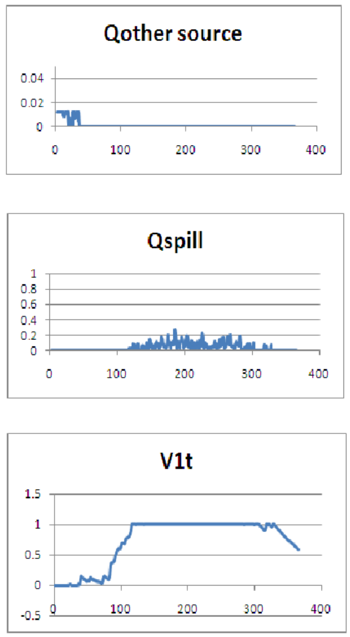

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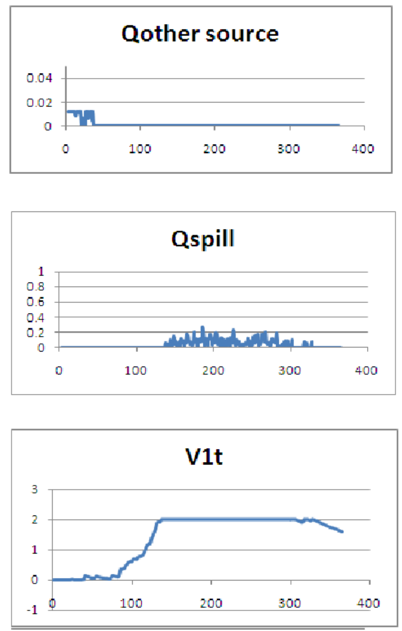

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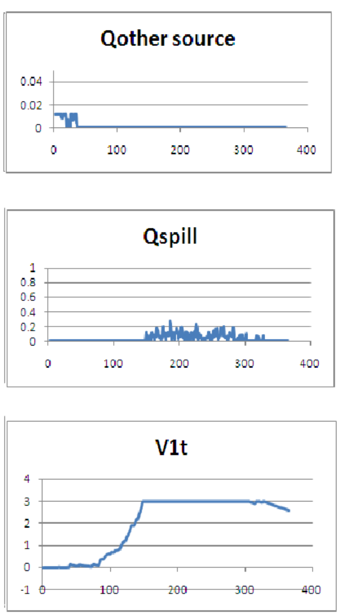

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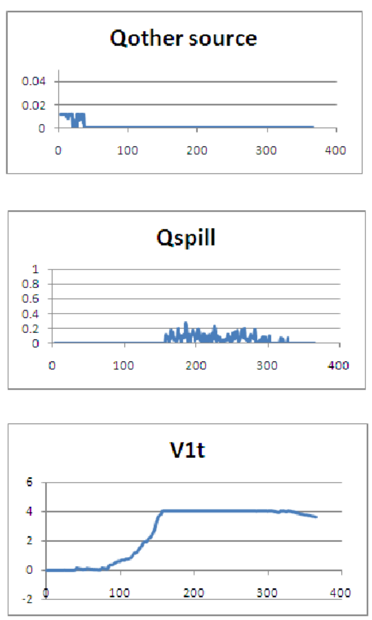

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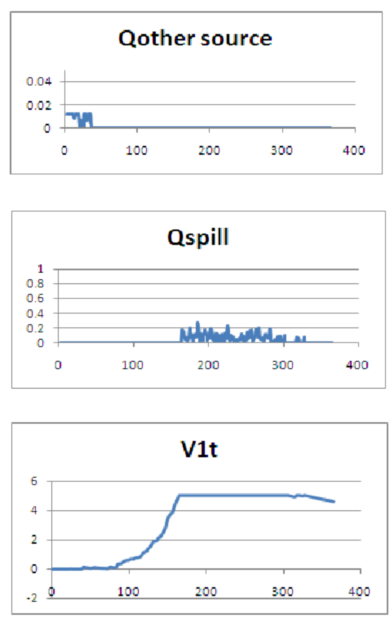

10 m² 5 lpcd

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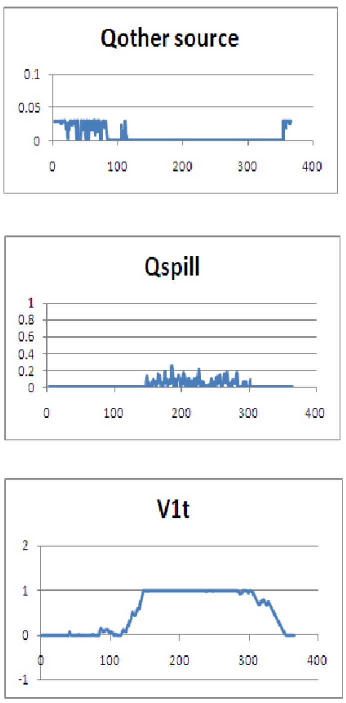

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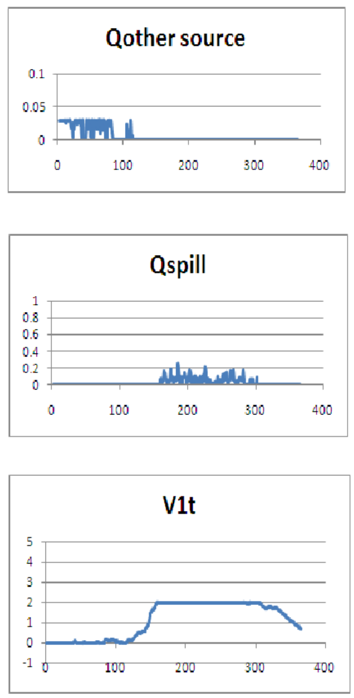

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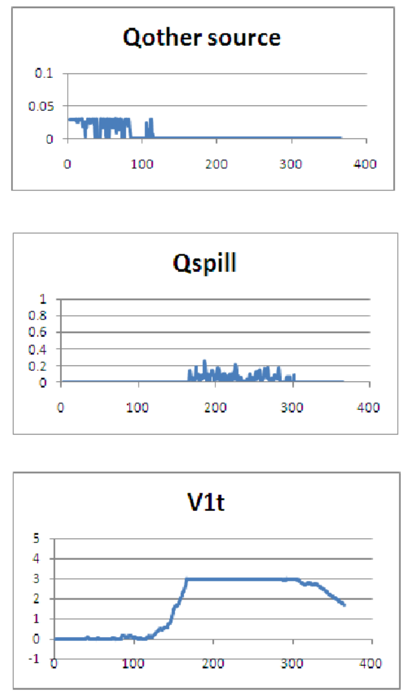

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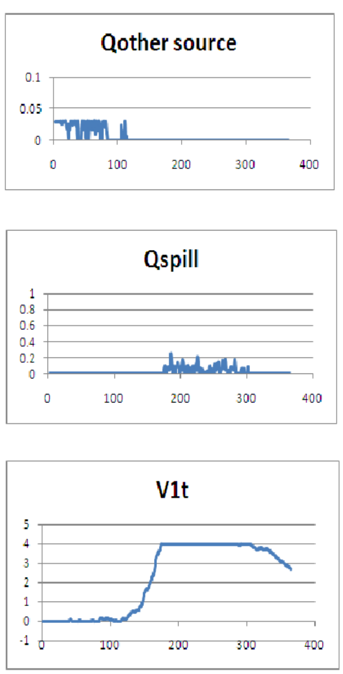

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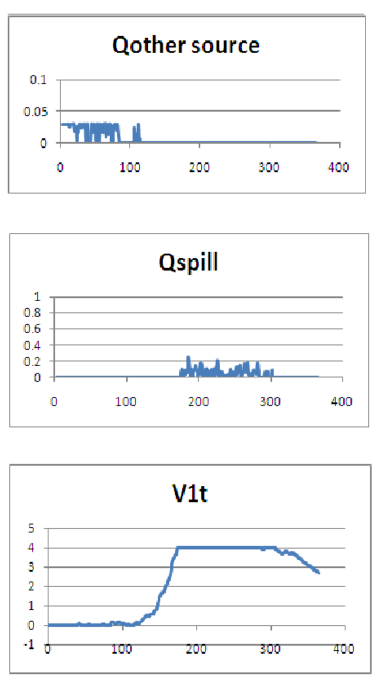

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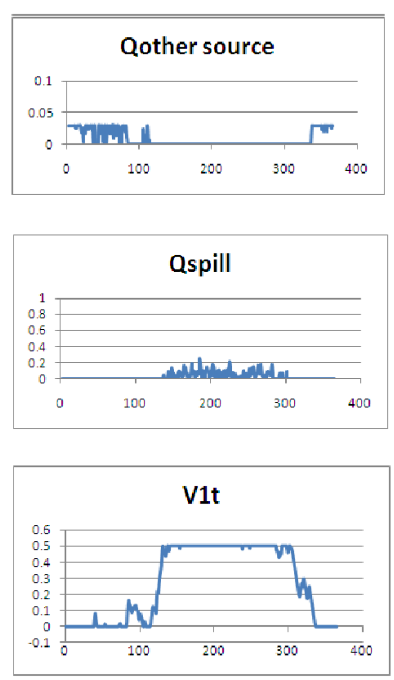

10 m² 10 lpcd

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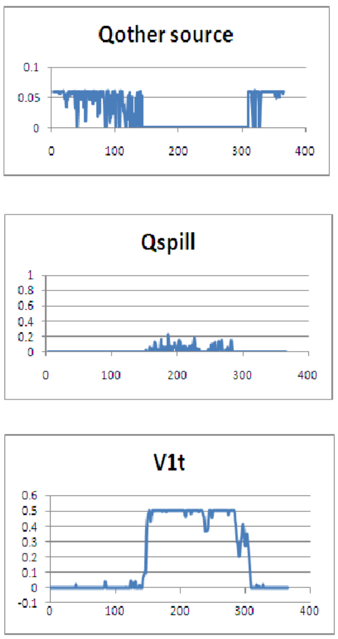

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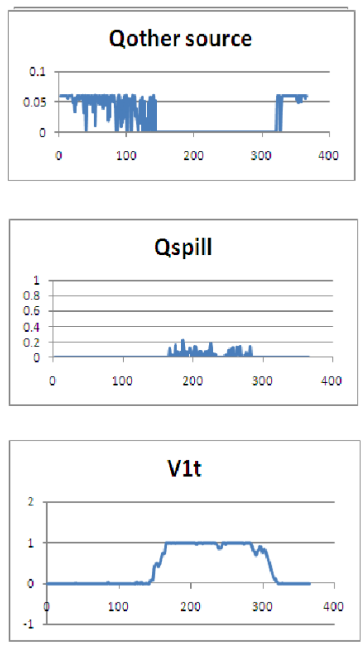

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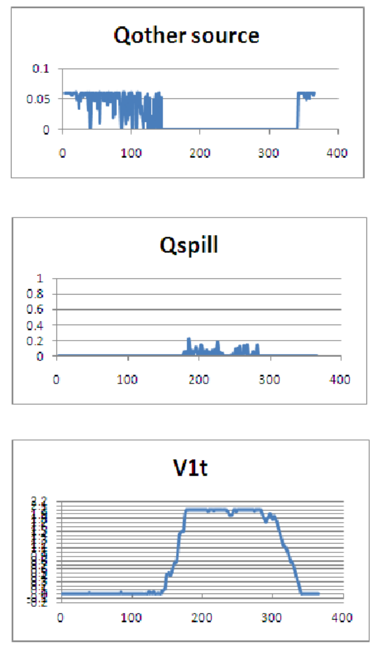

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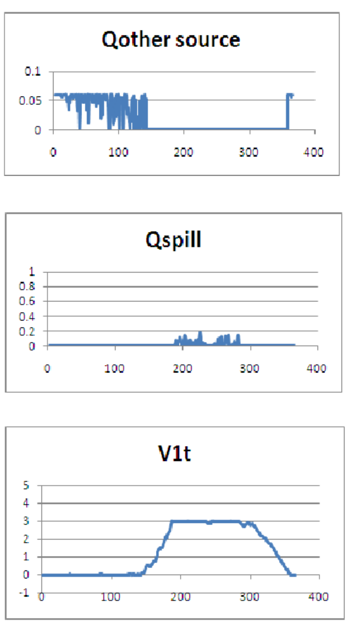

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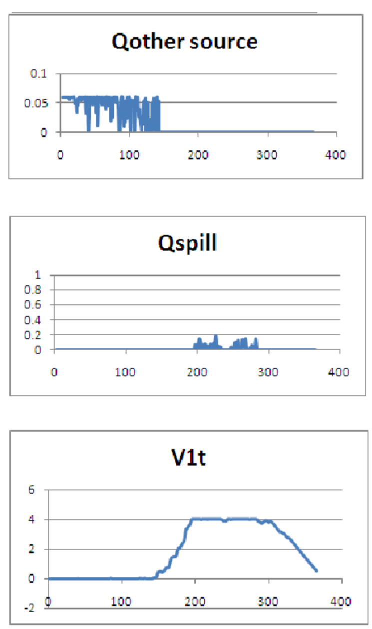

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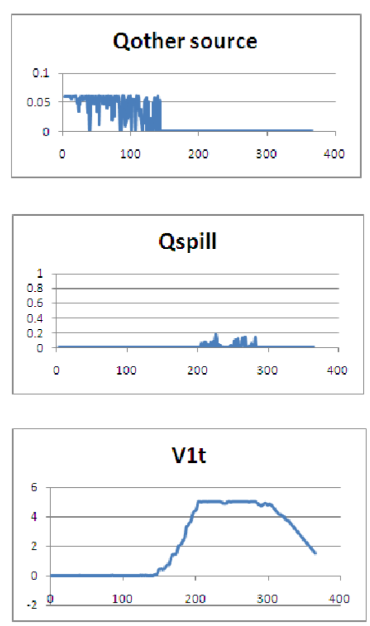
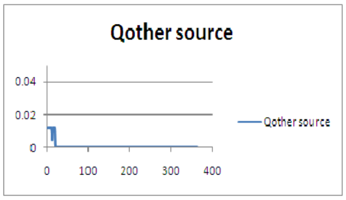
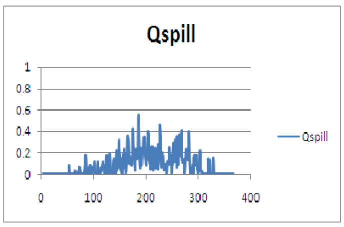
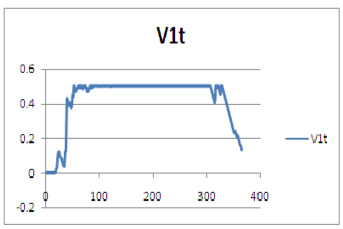


20 m² 2 lpcd

500 L







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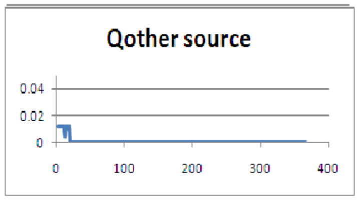

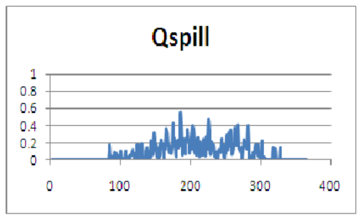

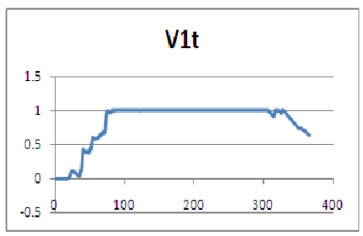

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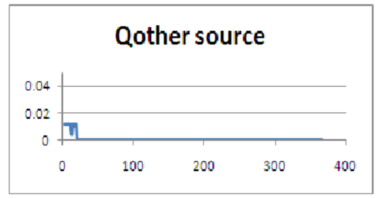

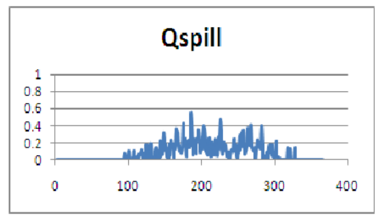

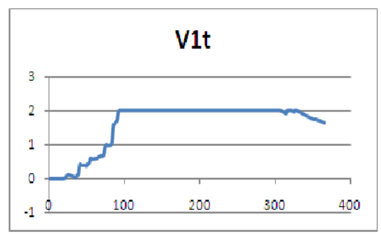

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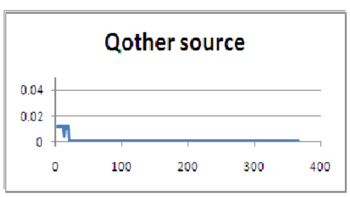

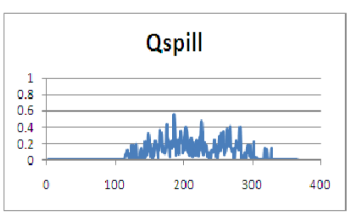

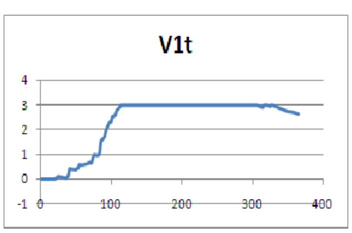

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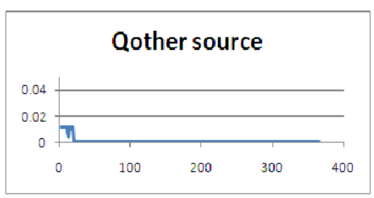

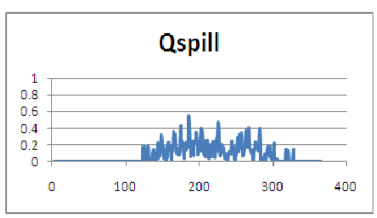

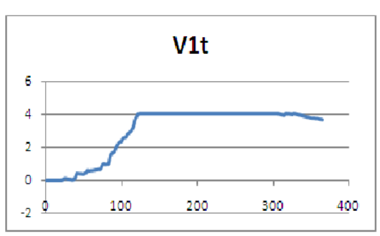

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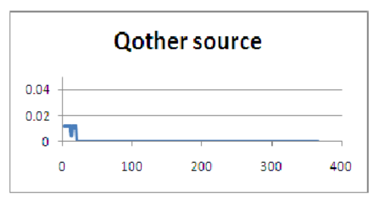
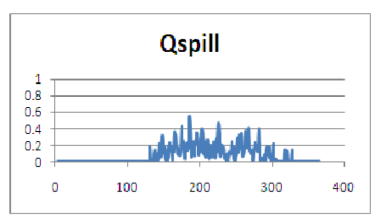
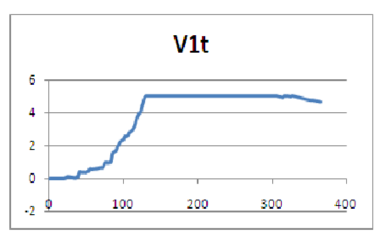
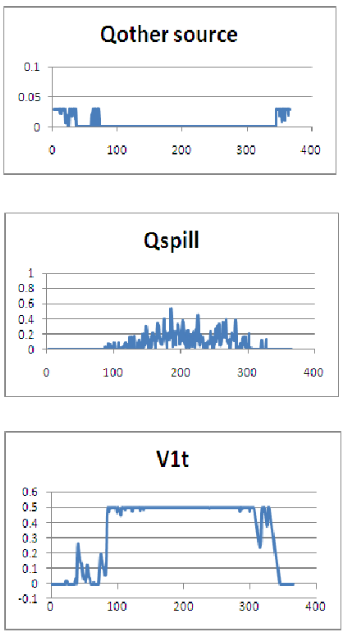






20 m² 5 lpcd

500 L



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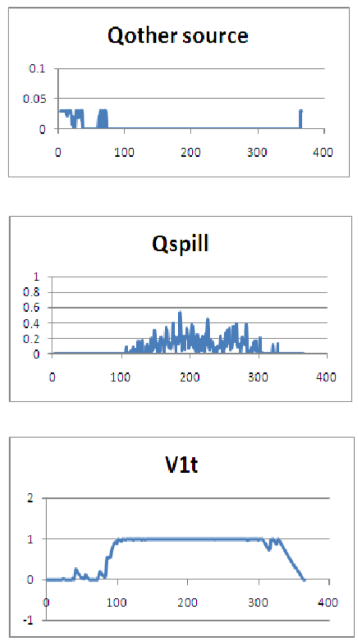

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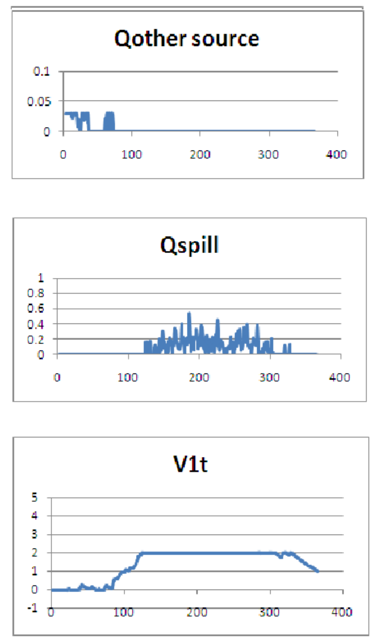

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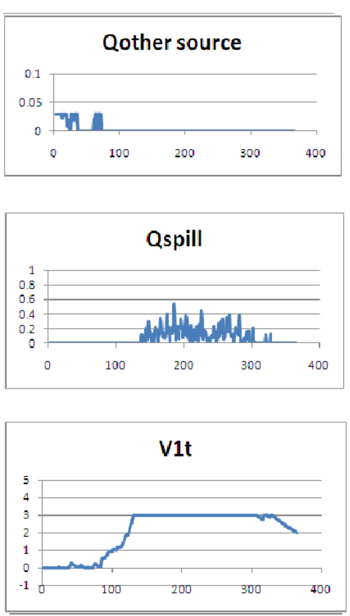

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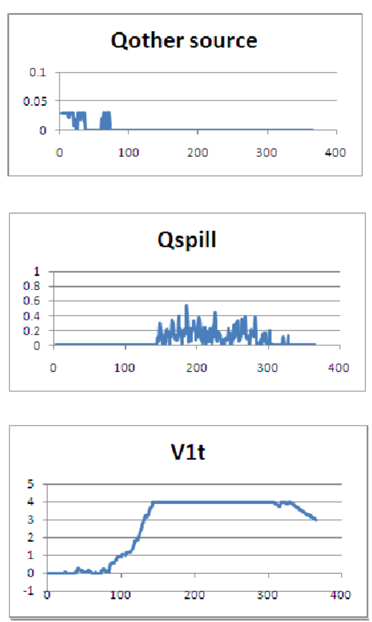

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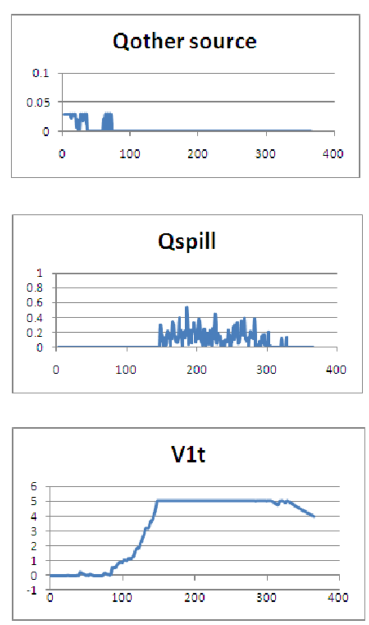
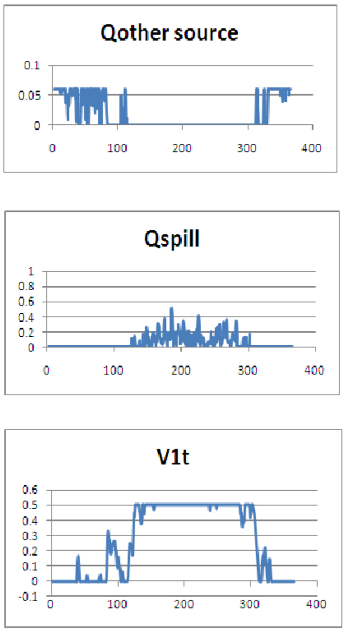


20 m² 10 lpcd

500 L



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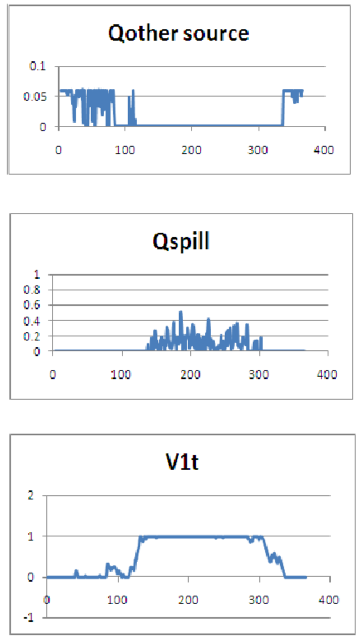

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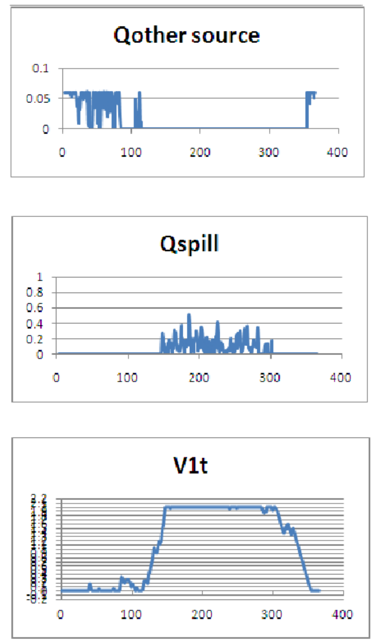

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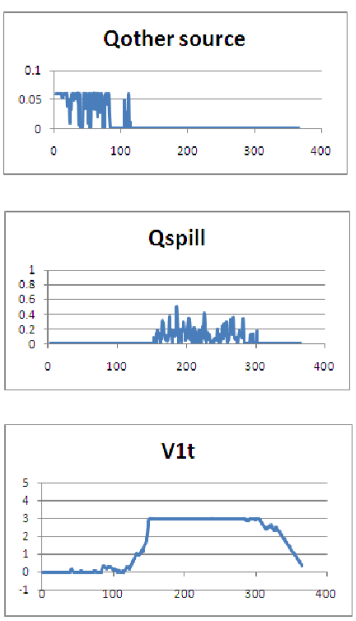

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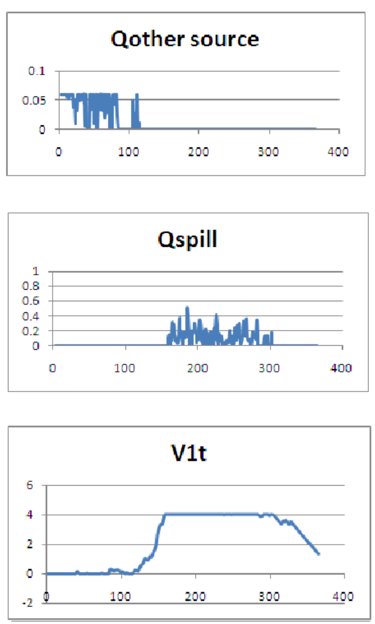

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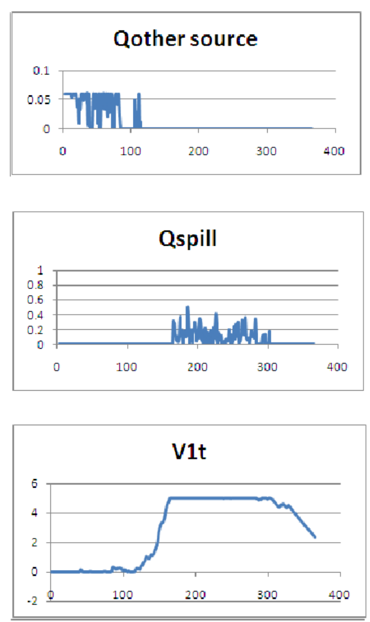
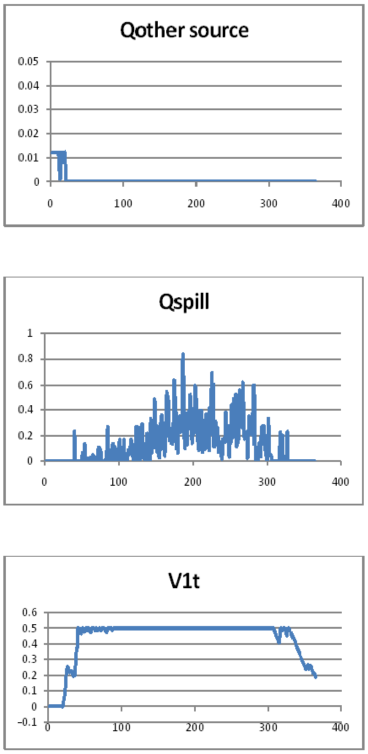


30 m² 2 lpcd

500 L



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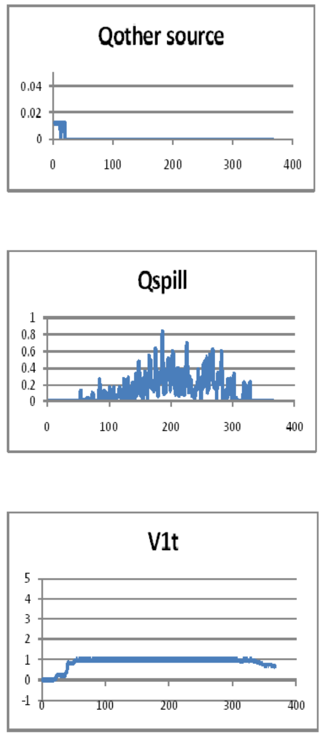

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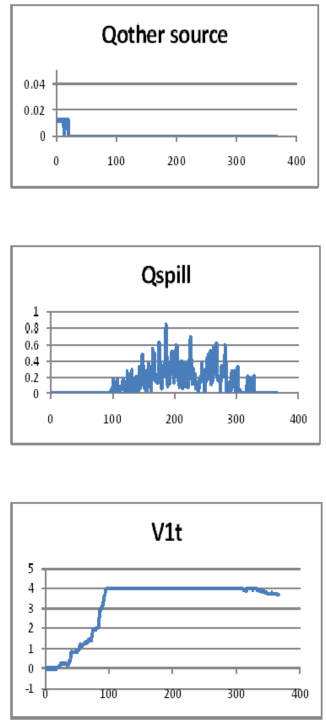

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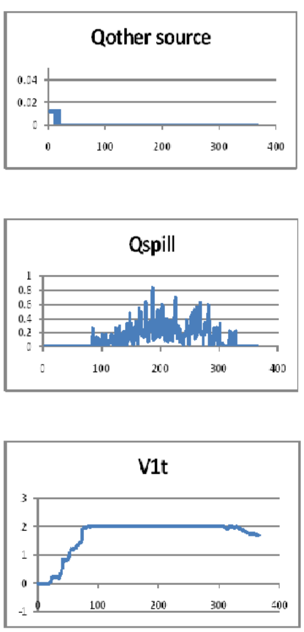

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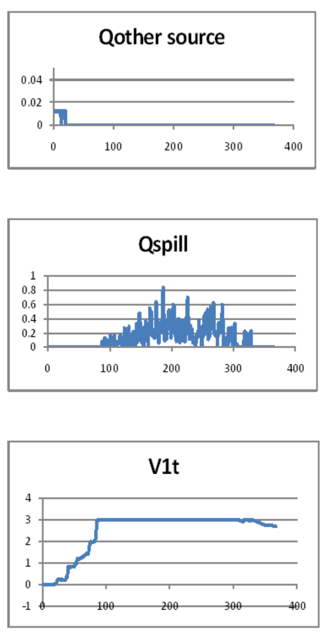

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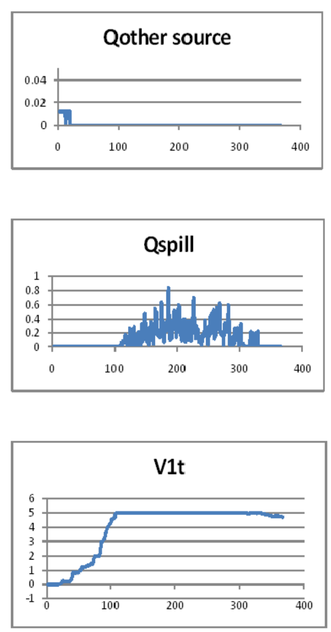
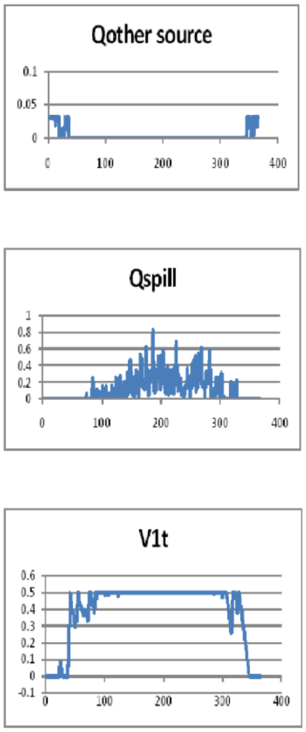


30 m² 5 lpcd

500 L



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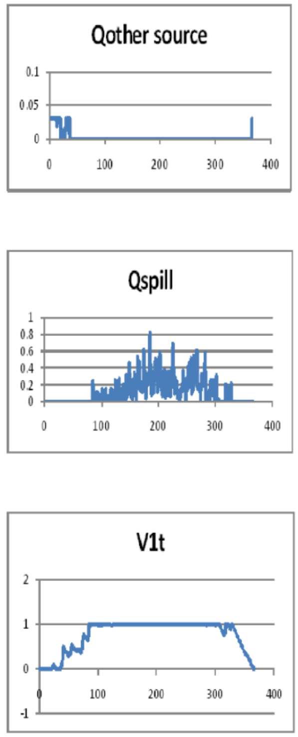

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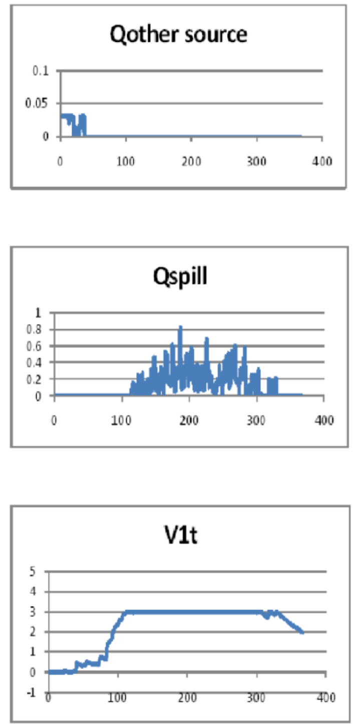

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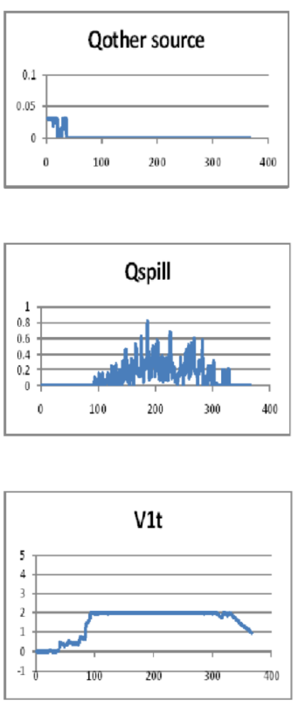

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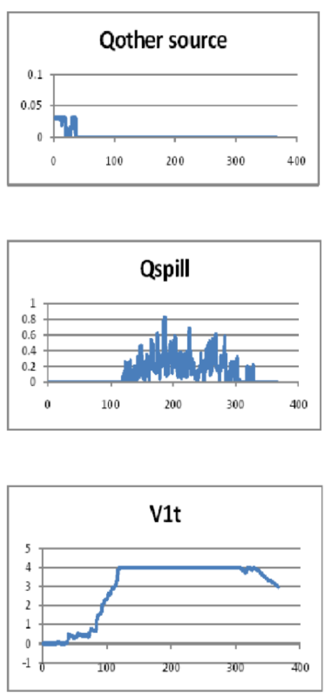

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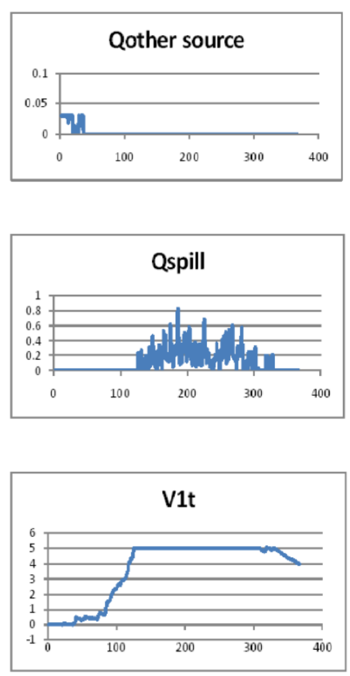
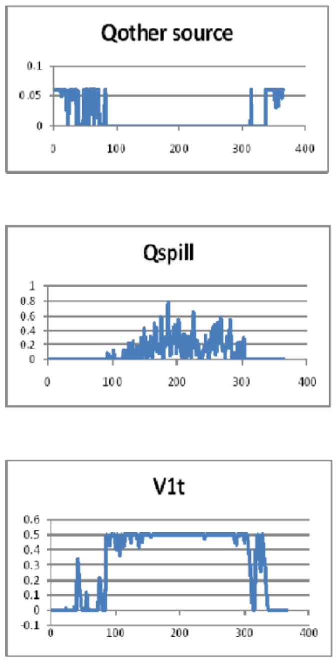


30 m² 10lpcd

500 L



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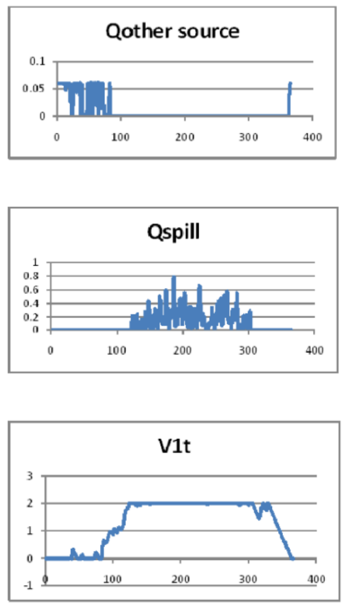

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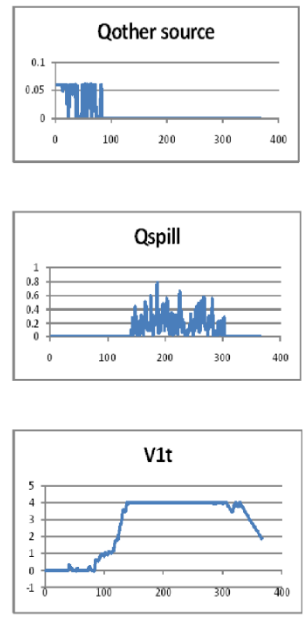

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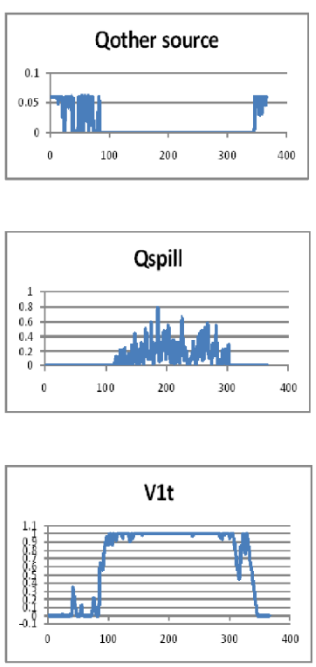

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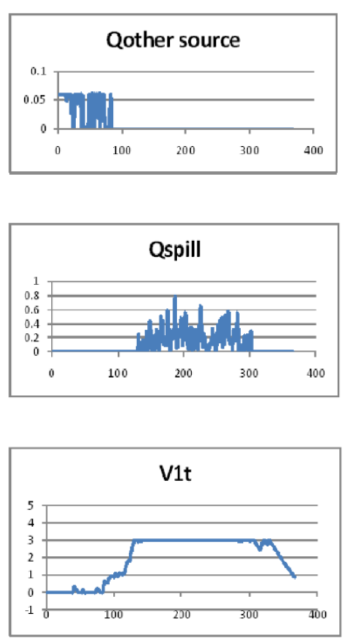

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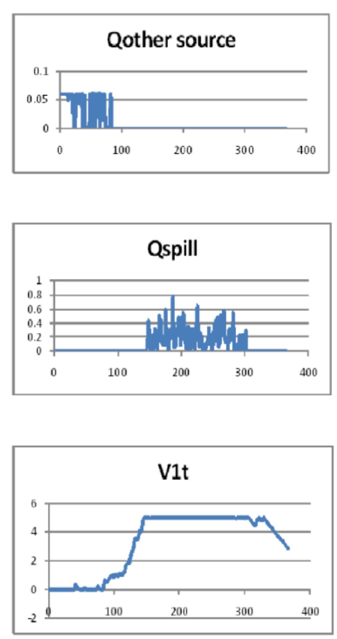

40 m² 2 lpcd

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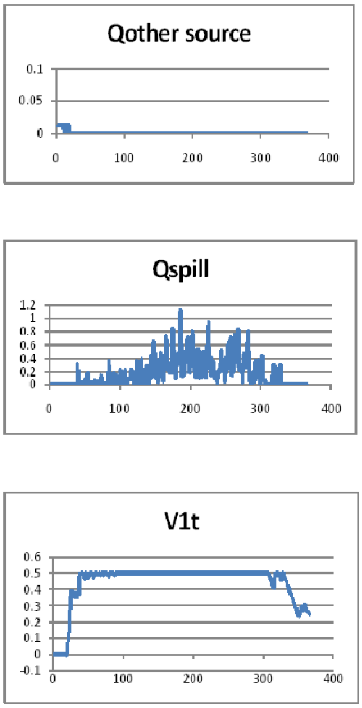

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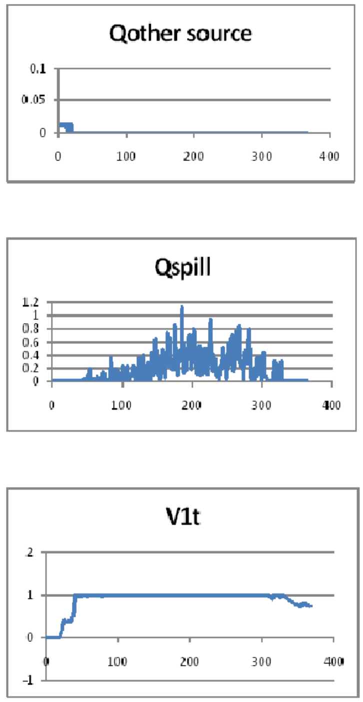

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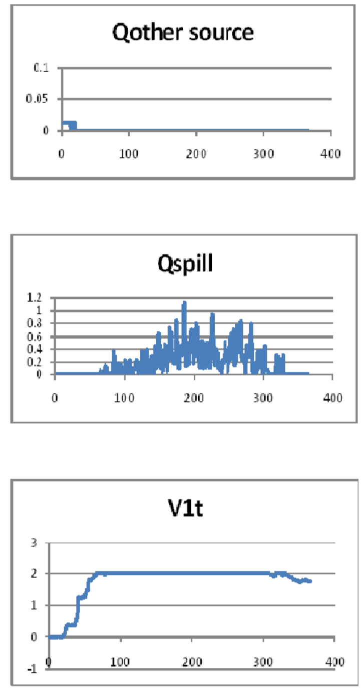

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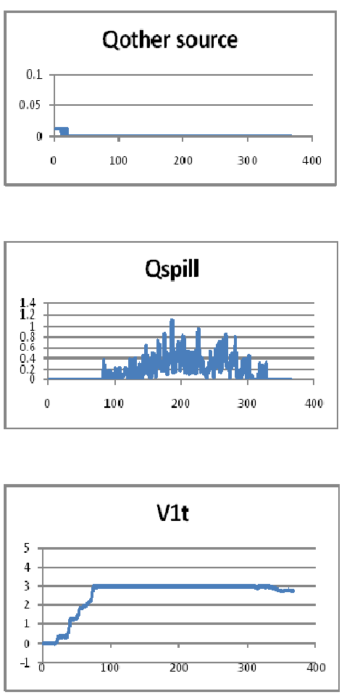

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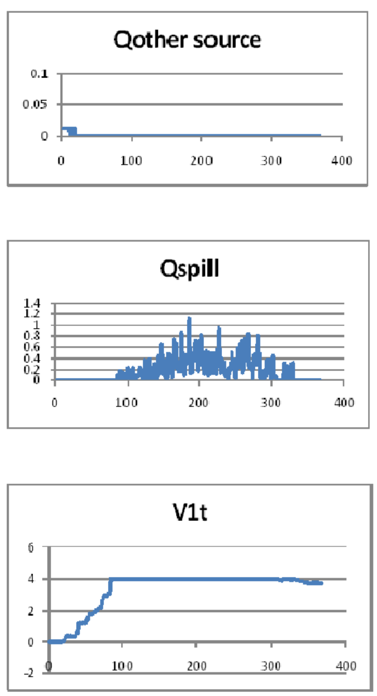

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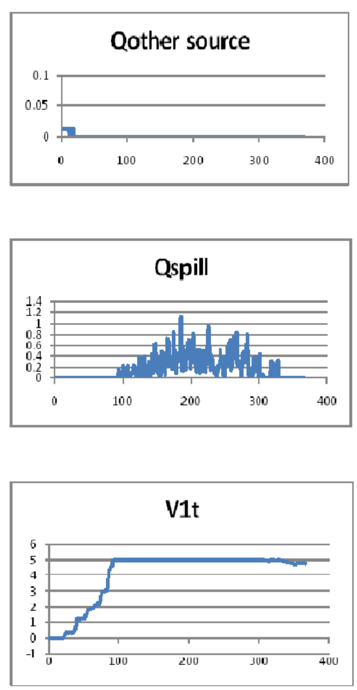

40 m² 5 lpcd

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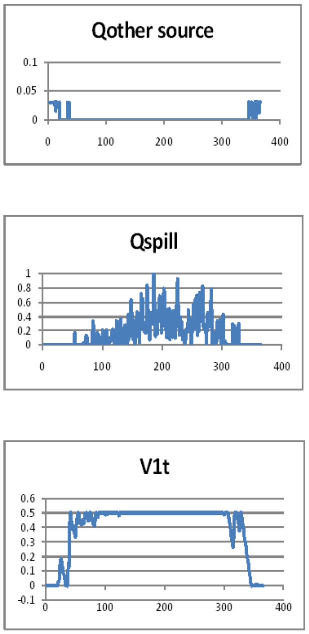

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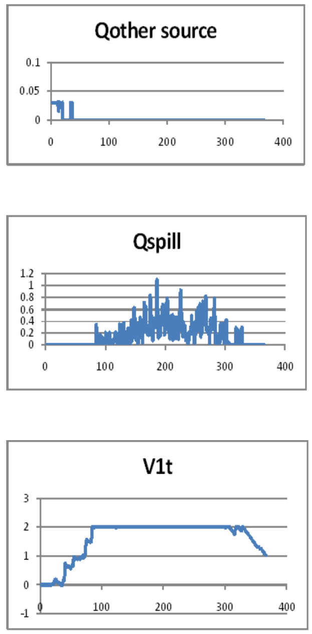

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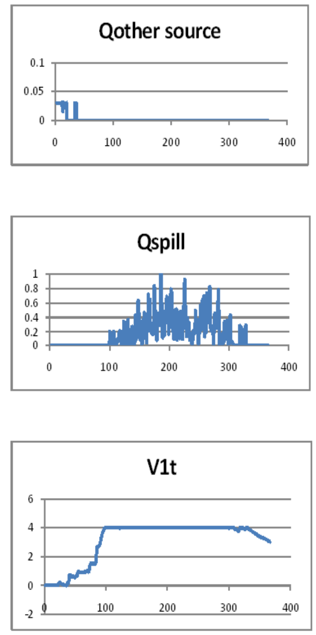

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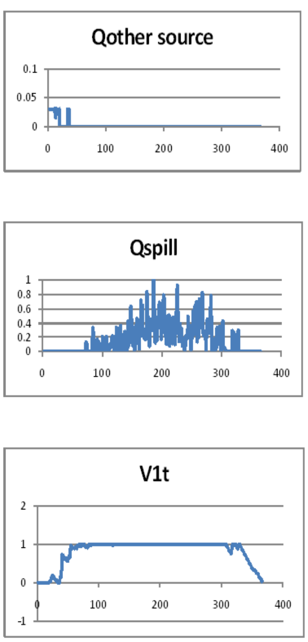

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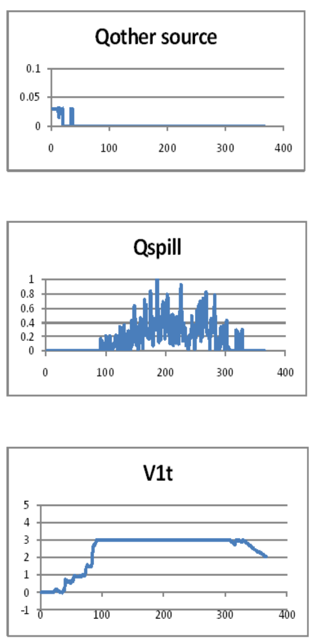
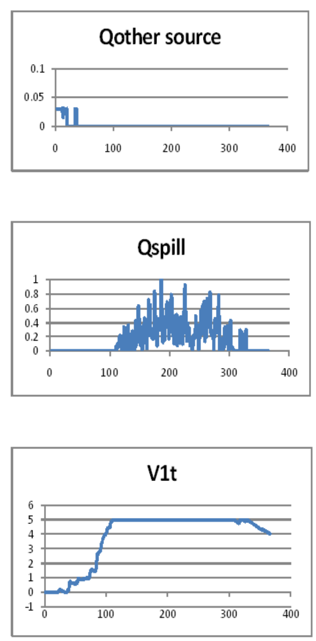
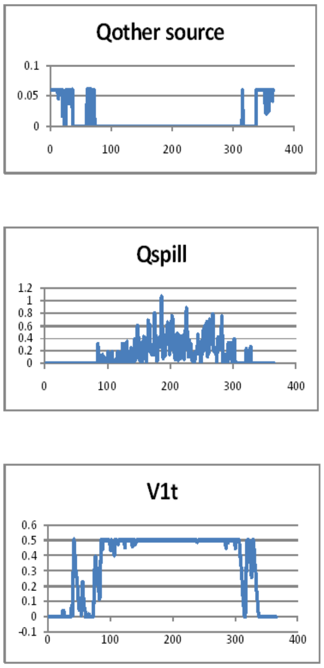


5000 L

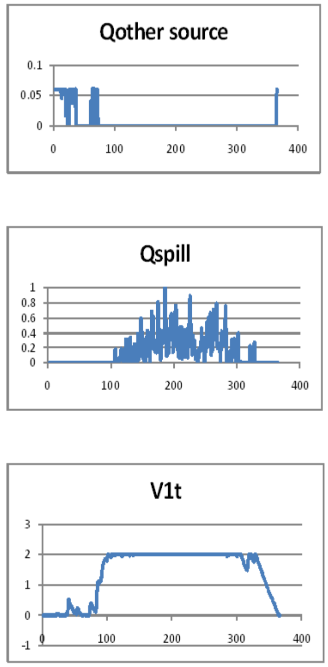


40 m² 10 lpcd

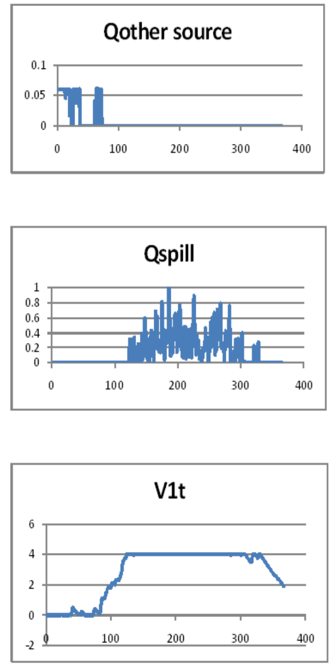
500 L



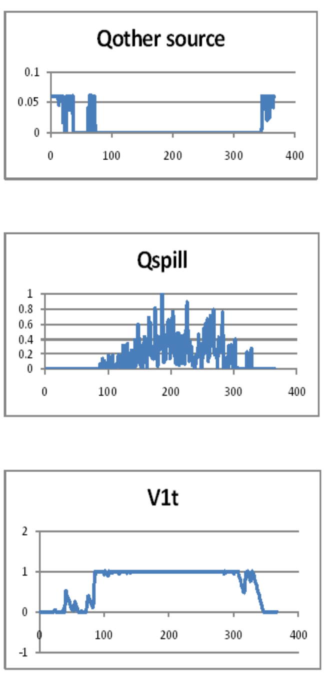
2000 L



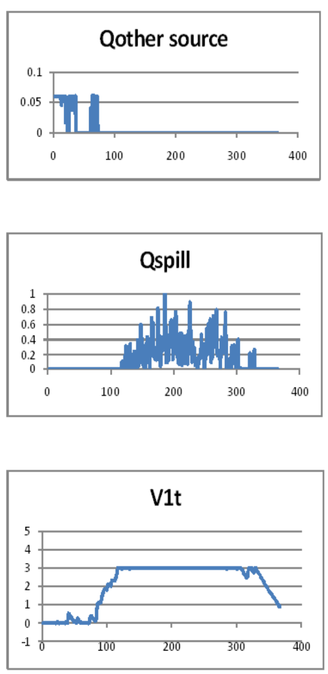
4000 L



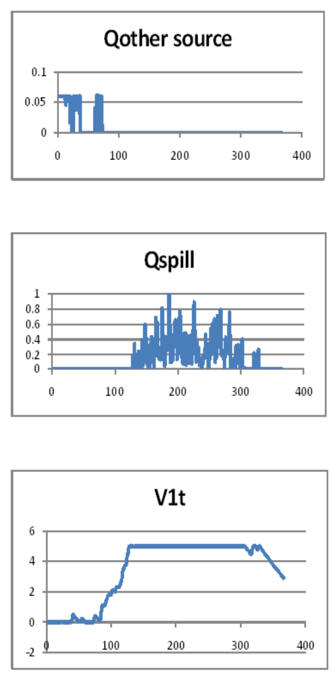
1000 L



3000 L



5000 L



Appendix
SECTION B

Catchment area 10m² average years

Demand (lpcd)	Tank volume (liter)	Reliability (%)	Tank full days (%)	Spilling volume (m³)	Supplementary water demand (m³)
2	500	91.50684932	56.71232877	13.3044	0.3234
	1000	91.50684932	52.05479452	12.9933	0.3234
	2000	91.50684932	46.84931507	12.4887	0.3234
	3000	91.50684932	44.10958904	11.9577	0.3234
	4000	91.50684932	41.64383562	11.5068	0.3234
	5000	91.50684932	39.7260274	11.0499	0.3234
5	500	70.68493151	28.49315068	9.5115	2.7993
	1000	75.34246575	26.30136986	9.2898	2.3073
	2000	78.63013699	23.28767123	8.6958	1.9608
	3000	78.63013699	21.09589041	8.2377	1.9608
	4000	78.63013699	18.63013699	7.6356	1.9608
	5000	78.63013699	16.43835616	7.1919	1.9608
10	500	50.68493151	28.49315068	5.0859	9.2583
	1000	53.69863014	26.30136986	4.7097	8.6871
	2000	58.63013699	23.28767123	4.2546	7.6578
	3000	63.28767123	21.09589041	3.6003	6.6648
	4000	65.47945205	18.63013699	3.159	6.1893
	5000	65.47945205	16.43835616	2.6592	6.1893

Catchment area 20 m² average area

Demand (lpcd)	Tank volume (liter)	Reliability (%)	Tank full days (%)	Spilling volume (m³)	Supplementary water demand (m³)
2	500	95.06849315	65.20547945	29.814	0.2034
	1000	95.06849315	61.91780822	29.4816	0.2034
	2000	95.06849315	59.45205479	28.9788	0.2034
	3000	95.06849315	54.52054795	28.4058	0.2034
	4000	95.06849315	52.05479452	27.9546	0.2034
	5000	95.06849315	50.4109589	27.3618	0.2034
5	500	82.73972603	41.36986301	25.4928	1.6368
	1000	87.94520548	39.17808219	25.1448	1.1298
	2000	88.49315068	36.43835616	24.651	1.0698
	3000	88.49315068	34.24657534	23.985	1.0698
	4000	88.49315068	32.05479452	23.4306	1.0698
	5000	88.49315068	29.8630137	23.157	1.0698
10	500	67.67123288	42.73972603	19.3626	6.1686
	1000	70.68493151	41.36986301	19.023	5.5986
	2000	75.34246575	39.7260274	18.5796	4.6146
	3000	78.63013699	38.35616438	17.9196	3.9216
	4000	78.63013699	36.43835616	17.3916	3.9216
	5000	78.63013699	34.79452055	16.9872	3.9216

Catchment area 30 m² average year

Demand (lpcd)	Tank volume (liter)	Reliability (%)	Tank full days (%)	Spilling volume (m^3)	Supplementary water demand (m^3)
2	500	95.06849315	70.4109589	46.6059	0.197
	1000	95.06849315	68.76712329	46.2963	0.197
	2000	95.06849315	63.56164384	45.7113	0.197
	3000	95.06849315	62.46575342	45.2208	0.197
	4000	95.06849315	60.2739726	44.6337	0.197
	5000	95.06849315	56.71232877	44.1747	0.197
5	500	86.84931507	61.36986301	41.8143	1.2591
	1000	92.32876712	60	41.58	0.7536
	2000	92.60273973	57.80821918	41.0658	0.7236
	3000	92.60273973	53.69863014	40.4772	0.7236
	4000	92.60273973	52.05479452	39.9525	0.7236
	5000	92.60273973	50.4109589	39.438	0.7236
10	500	75.06849315	51.78082192	34.8654	4.6728
	1000	77.80821918	49.8630137	34.5438	4.1187
	2000	82.73972603	47.12328767	34.1262	3.1197
	3000	83.56164384	45.47945205	33.4596	2.9532
	4000	83.56164384	44.10958904	32.9328	2.9532
	5000	83.56164384	42.46575342	32.3871	2.9532

Catchment area 40 m²　　average year

Demand (lpcd)	Tank volume (liter)	Reliability (%)	Tank full days (%)	Spilling volume (m³)	Supplementary water demand (m³)
2	500	95.34246575	71.50684932	63.1404	0.1908
	1000	95.34246575	70.68493151	62.8044	0.1908
	2000	95.34246575	67.12328767	62.4024	0.1908
	3000	95.34246575	64.10958904	61.8228	0.1908
	4000	95.34246575	63.01369863	61.1568	0.1908
	5000	95.34246575	61.36986301	60.6864	0.1908
5	500	89.04109589	64.38356164	58.236	1.08
	1000	94.24657534	63.01369863	58.0308	0.576
	2000	94.24657534	61.36986301	57.4848	0.576
	3000	94.24657534	59.7260274	56.9136	0.576
	4000	94.24657534	57.80821918	56.4084	0.576
	5000	94.24657534	55.06849315	55.9008	0.576
10	500	80	57.26027397	51.2928	3.8736
	1000	82.73972603	56.71232877	50.9856	3.2736
	2000	87.94520548	53.42465753	50.2896	2.2596
	3000	88.49315068	51.23287671	49.6044	2.1396
	4000	88.49315068	49.5890411	49.302	2.1396
	5000	88.49315068	48.49315068	48.5856	2.1396

Catchment area 10 m² dry year

Demand (lpcd)	Tank volume (liter)	Reliability (%)	Tank full days (%)	Spilling volume (m³)	Supplementary water demand (m³)
2	500	67.94520548	33.15068493	12.75	1.404
	1000	73.15068493	32.87671233	12.285	1.176
	2000	73.15068493	32.60273973	11.733	1.176
	3000	73.15068493	30.95890411	11.514	1.176
	4000	73.15068493	29.8630137	10.977	1.176
	5000	73.15068493	28.21917808	10.332	1.176
5	500	54.79452055	26.02739726	10.881	4.95
	1000	59.45205479	25.75342466	10.077	4.44
	2000	68.49315068	24.93150685	9.918	3.45
	3000	68.76712329	23.56164384	9.246	3.42
	4000	68.76712329	21.91780822	8.787	3.42
	5000	68.76712329	20	8.436	3.42
10	500	47.94520548	15.34246575	6.984	11.301
	1000	50.68493151	15.34246575	6.657	10.746
	2000	55.34246575	13.97260274	6.309	9.726
	3000	59.7260274	12.87671233	5.859	8.766
	4000	64.38356164	11.78082192	5.112	7.746
	5000	65.47945205	10.95890411	4.572	7.506

Catchment area 20 m² dry year

Demand (lpcd)	Tank volume (liter)	Reliability (%)	Tank full days (%)	Spilling volume (m³)	Supplementary water demand (m³)
2	500	68.49315068	36.98630137	26.85	1.38
	1000	73.15068493	36.43835616	26.85	1.176
	2000	73.15068493	35.34246575	26.826	1.176
	3000	73.15068493	35.06849315	25.122	1.176
	4000	73.15068493	34.79452055	25.122	1.176
	5000	73.15068493	34.79452055	24.756	1.176
5	500	57.53424658	32.87671233	24.93	4.65
	1000	65.20547945	32.05479452	24.924	3.81
	2000	73.15068493	31.78082192	24	2.94
	3000	73.15068493	31.78082192	23.256	2.94
	4000	73.15068493	31.50684932	22.908	2.94
	5000	73.15068493	30.4109589	22.488	2.94
10	500	51.78082192	26.30136986	21.762	10.548
	1000	54.79452055	26.02739726	21.762	9.9
	2000	59.45205479	25.75342466	20.154	8.88
	3000	64.10958904	25.47945205	19.836	7.86
	4000	68.49315068	24.93150685	19.836	6.9
	5000	68.76712329	24.38356164	19.446	6.84

Catchment area 30 m² dry year

Demand (lpcd)	Tank volume (liter)	Reliability (%)	Tank full days (%)	Spilling volume (m³)	Supplementary water demand (m³)
2	500	68.49315068	39.17808219	42.108	1.38
	1000	73.15068493	38.90410959	41.499	1.176
	2000	73.15068493	38.08219178	41.037	1.176
	3000	73.15068493	36.98630137	40.98	1.176
	4000	73.15068493	36.71232877	39.561	1.176
	5000	73.15068493	36.71232877	38.412	1.176
5	500	58.63013699	34.52054795	39.462	4.53
	1000	66.30136986	33.97260274	38.871	3.69
	2000	73.15068493	33.15068493	38.847	2.94
	3000	73.15068493	32.87671233	37.446	2.94
	4000	73.15068493	32.87671233	36.315	2.94
	5000	73.15068493	32.87671233	36.315	2.94
10	500	52.60273973	30.1369863	36.072	10.38
	1000	56.98630137	29.5890411	35.511	9.42
	2000	62.73972603	29.04109589	34.14	8.16
	3000	67.12328767	29.04109589	33.039	7.2
	4000	71.23287671	29.04109589	33.039	6.3
	5000	71.23287671	28.76712329	32.532	6.3

Catchment area 40 m² dry year

Demand (lpcd)	Tank volume (liter)	Reliability (%)	Tank full days (%)	Spilling volume (m³)	Supplementary water demand (m³)
2	500	68.49315068	39.45205479	56.64	1.38
	1000	73.15068493	39.45205479	55.824	1.176
	2000	73.15068493	38.90410959	55.824	1.176
	3000	73.15068493	37.26027397	55.116	1.176
	4000	73.15068493	37.26027397	55.116	1.176
	5000	73.15068493	36.98630137	53.22	1.176
5	500	58.63013699	36.16438356	54.006	4.53
	1000	66.30136986	36.16438356	53.094	3.69
	2000	73.15068493	35.61643836	53.094	2.94
	3000	73.15068493	34.52054795	53.052	2.94
	4000	73.15068493	34.52054795	53.052	2.94
	5000	73.15068493	34.24657534	51.174	2.94
10	500	53.15068493	33.42465753	50.712	10.26
	1000	57.53424658	32.87671233	49.86	9.3
	2000	65.20547945	32.05479452	49.848	7.62
	3000	69.5890411	31.78082192	48	6.66
	4000	73.15068493	31.78082192	48	5.88
	5000	73.15068493	31.78082192	46.512	5.88

Catchment area 10 m² wet year

Demand (lpcd)	Tank volume (liter)	Reliability (%)	Tank full days (%)	Spilling volume (m³)	Supplementary water demand (m³)
2	500	65.47945205	31.23287671	16.842	1.503
	1000	74.79452055	30.1369863	16.497	1.095
	2000	74.79452055	28.21917808	15.825	1.095
	3000	74.79452055	26.02739726	15.3	1.095
	4000	74.79452055	24.65753425	14.964	1.095
	5000	74.79452055	24.38356164	14.229	1.095
5	500	56.43835616	24.10958904	14.676	4.734
	1000	61.09589041	23.28767123	14.49	4.224
	2000	70.1369863	21.36986301	13.791	3.234
	3000	73.97260274	20.82191781	13.524	2.814
	4000	73.97260274	20.2739726	12.807	2.814
	5000	73.97260274	19.17808219	12.078	2.814
10	500	49.04109589	16.98630137	10.971	11.043
	1000	53.42465753	15.34246575	10.281	10.155
	2000	58.08219178	14.79452055	9.594	9.135
	3000	62.73972603	13.97260274	8.883	8.115
	4000	67.12328767	13.42465753	8.283	7.155
	5000	71.23287671	12.32876712	7.944	6.255

Catchment area 20 m² wet year

Demand (lpcd)	Tank volume (liter)	Reliability (%)	Tank full days (%)	Spilling volume (m³)	Supplementary water demand (m³)
2	500	66.84931507	32.87671233	34.92	1.452
	1000	76.16438356	32.60273973	34.92	1.044
	2000	76.16438356	31.78082192	34.206	1.044
	3000	76.16438356	30.95890411	33.948	1.044
	4000	76.16438356	30.1369863	33.198	1.044
	5000	76.16438356	28.76712329	32.628	1.044
5	500	58.35616438	29.04109589	32.454	4.542
	1000	62.73972603	28.76712329	32.454	4.062
	2000	72.05479452	27.67123288	31.812	3.042
	3000	74.52054795	27.12328767	31.23	2.772
	4000	74.52054795	25.47945205	30.93	2.772
	5000	74.52054795	25.20547945	30.126	2.772
10	500	50.1369863	25.20547945	29.562	10.794
	1000	56.43835616	24.10958904	29.352	9.468
	2000	61.09589041	23.28767123	28.98	8.488
	3000	65.75342466	21.91780822	27.882	7.428
	4000	70.1369863	21.36986301	27.582	6.468
	5000	73.97260274	20.82191781	27.048	5.628

Catchment area 30 m² wet year

Demand (lpcd)	Tank volume (liter)	Reliability (%)	Tank full days (%)	Spilling volume (m³)	Supplementary water demand (m³)
2	500	67.12328767	34.24657534	53.565	1.44
	1000	76.43835616	33.97260274	52.956	1.032
	2000	76.43835616	33.42465753	52.32	1.032
	3000	76.43835616	32.87671233	51.873	1.032
	4000	76.43835616	32.32876712	51.48	1.032
	5000	76.43835616	31.78082192	50.574	1.032
5	500	58.90410959	31.78082192	51.633	4.473
	1000	63.56164384	31.50684932	51.042	3.963
	2000	72.60273973	30.95890411	50.424	2.973
	3000	75.06849315	30.1369863	49.995	2.703
	4000	75.06849315	29.5890411	49.62	2.703
	5000	75.06849315	29.31506849	48.732	2.703
10	500	51.50684932	27.39726027	48.021	10.545
	1000	57.26027397	26.84931507	46.926	9.315
	2000	61.91780822	26.30136986	46.338	8.292
	3000	66.57534247	25.20547945	45.993	7.272
	4000	70.95890411	24.93150685	45.135	6.312
	5000	74.24657534	23.56164384	44.715	5.592

Catchment area 40 m² wet year

Demand (lpcd)	Tank volume (liter)	Reliability (%)	Tank full days (%)	Spilling volume (m³)	Supplementary water demand (m³)
2	500	67.67123288	34.24657534	71.808	1.416
	1000	76.98630137	33.97260274	70.992	1.008
	2000	76.98630137	33.69863014	70.992	1.008
	3000	76.98630137	33.42465753	70.14	1.008
	4000	76.98630137	32.87671233	69.54	1.008
	5000	76.98630137	32.60273973	69.54	1.008
5	500	59.7260274	32.60273973	69.798	4.404
	1000	64.38356164	32.32876712	69	3.894
	2000	73.42465753	32.05479452	69	2.904
	3000	75.89041096	31.78082192	68.166	2.634
	4000	75.89041096	31.23287671	67.584	2.634
	5000	75.89041096	30.68493151	67.074	2.634
10	500	52.32876712	29.8630137	66.96	10.368
	1000	58.35616438	29.04109589	64.908	9.084
	2000	62.73972603	28.76712329	64.908	8.124
	3000	67.39726027	28.49315068	64.104	7.104
	4000	72.05479452	27.67123288	63.624	6.084
	5000	74.52054795	27.39726027	63.624	5.544