University of Southern Queensland
Faculty of Engineering and Surveying

# Stormwater Harvest and Reuse for a Wholesale Nursery

A dissertation submitted by

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**ABSTRACT**

The recent advent of water sensitive urban design has heralded a change in attitude for many toward environmental sustainability. In particular, the reduction of potable water demand has become a topic of focus. The scope of this study is to assess the feasibility for undertaking a rainwater harvest site retrofit at a wholesale nursery site in the city of Toowoomba in Queensland’s south-east.

The process undertaken to construct and calibrate a water balance model is discussed. Several augmentation strategies are assessed using the constructed model. Each scenario is assessed based on reduction to potable water demand, rainwater harvest reliability and overflow frequencies.

It was found that the potable water demand can be reduced by as much as 70% following the installation of water sensitive design devices.

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I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

**Anthony Morris**

**Student Number:**

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Date

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An ultimate thank you must be granted to my parents for maintaining a loving family. The unconditional support you have shown has provided us with every possible opportunity to prosper.

Thanks to Richard, Ernest and Vasantha for taking the time to care.

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# 1.0 INTRODUCTION

## 1.1 PROBLEM STATEMENT

The burden to supply potable water for an increasing population is becoming greater. Following community education regarding the societal and environmental impacts associated with increasing supply, the general public has gained an appreciation for the needs to act responsibly with potable water. Attributed partly to this responsibility, contemporary water sensitive design practices are becoming more common. In some locales it is legislated that water sensitive design practices be adopted in new developments. People often take the stance that such practice is favourable and choose to retrofit existing developments.

## 1.2 WATER SENSITIVE URBAN DESIGN

Water sensitive design is increasingly becoming an integral part of the overall urban design approach. Whereby conventional stormwater drainage design has viewed stormwater discharge as waste to be routed to the nearest water body as efficiently as possible, the water sensitive approach sees the runoff as a potential resource.

The concept of water sensitive design is very broad. The scope of design decisions vary accordingly. In terms of scale of use, each project is likely to vary to suit the environment and the available budget. Simple diversion methods have the potential to provide extra runoff to vegetated areas, thus reducing the burden on potable water supplies. More complex devices such as holding ponds have the potential to impress a naturally occurring ecosystem.

Regardless of the complexity of the features, there are some common advantages and disadvantages associated with the use of water sensitive design. The premise of water sensitive design is to harvest rainfall, creating a supply from a resource which was previously considered waste. The major advantage of such an undertaking is that there is a supply of ‘free’ water to be used as and when users desire, without the burden of imposed water restrictions. This has a two-fold effect. Firstly, the reliance on reticulated supply is reduced, thus potentially easing the burden on water supply reticulation infrastructure. Secondly, and particularly with respect to water thirsty industrial developments, water supply is less likely to be the limiting factor preventing expansion. When offset against the potential advantages, the disadvantage associated with the inclusion of water sensitive design approaches appears minor. The increase in capital cost is potentially offset by the ‘free’ supply of water. The land surface area that such infrastructure occupies would often be underutilised and thus the retention devices are generally not considered to be too imposing on aesthetics or functionality. These factors must be assessed when determining the feasibility for urban design retrofit.

## 1.3 AIMS AND OBJECTIVES

It has been identified that a large wholesale nursery in Toowoomba, QLD, is a potential site for a water sensitive design retrofit. Large roof spaces expose a high surface area over which rainfall can be harvested and daily irrigation requirements ensure that the site has a high potable water demand. Thus a water sensitive design retrofit has definite potential to reduce potable water consumption.

The aim of this study is to determine the impact of a proposed on-site rainwater retention facility, and to determine the feasibility of such infrastructure with particular regard to providing a source of water for irrigation and to ease the burden on reticulated supply.

## 1.4 DISSERTATION LAYOUT

The dissertation is presented in the following structure:

### 1.4.1 Chapter 1 – Introduction

Chapter 1 introduces the concepts of rainwater harvest and water sensitive design, and provides an outline of the project objectives and the dissertation structure.

### 1.4.2 Chapter 2 – Literature Review

Chapter 2 continues the discussion of rainwater harvest for water supply, relating to previous relevant studies and pertinent literature.

### 1.4.3 Chapter 3 – Hydrology

Chapter 3 outlines the methodology used to analyse the hydrologic processes. The chapter is further disaggregated to reflect the detailed methodology involved in constructing the water balance model.

### 1.4.4 Chapter 4 – Augmentation and System Modelling

Chapter 4 introduces options for augmentation and documents major model outputs. The modelling results will be used to evaluate the impact of the proposed design retrofit with regard to water supply reliability and potable water demand reduction.

### 1.4.5 Chapter 5 – Conclusions and Recommendations

Chapter 5 seeks to review the dissertation objectives and provide further recommendations and studies.

# 2.0 LITERATURE REVIEW

## 2.1 INTRODUCTION

The issue of non-renewable resource consumption has become more and more prominent as the world's supply becomes depleted. Non-renewable resources have traditionally been among the most readily exploitable and often little care has been given to the consequences of their exploitation. Whilst fresh water appears to have a regenerative capacity brought about through the water cycle, due to the environmental and political issues associated with new dams and catchment areas, it should be thought of as a finite resource. The constant tapped supply of potable water is not something that should be taken for granted.

There are many measures that may be taken to ensure a reliable supply of water is available. Standard techniques such as increasing dam storage capacity and sourcing alternative supplies are often successful. Nevertheless, hydrologists are constantly vying to develop additional harvest methods.

Urban catchments are ideal areas for water optimisation. The reason for this is two-fold. Firstly, impervious areas such as roof tops are adept to converting rainfall into runoff with little opportunity for infiltration. This provides maximum opportunity for harvest. Perhaps more importantly, the water is then retained for subsequent reuse nearby, and in a convenient fashion. Water sensitive urban design has recently become a popular topic of study, reflecting the advancement in water harvesting and flow control procedures, the associated costs, and the changing attitudes towards the topic.

## 2.2 EVOLUTION OF WATER SENSITIVE DESIGN

In 1990's Australia, as water supply reticulation and infrastructure developed, a greater populace tended away from self-sufficiency. Given this tendency and an increasing population, the increase in potable water demand was marked. Water sensitive design approaches began gaining momentum and were afforded a greater attention. Innovative techniques such as those presented in a publication by the Unit of Sustainable Development and Environment (1997) included the use of crop furrows, fog mesh, and runoff from roads to harvest water from a previously untapped resource. As these innovative solutions provide capacity for retention, so too do they come with significant disadvantages. Fog Harvesting is largely season specific, and runoff from roads have *in* *situ* use requirements. For the purpose of this study, which involves stormwater retention on an industrial scale, these innovative techniques are not considered feasible.

Traditional water retention methods were examined by G. Vaes and J. Berlamont (1999). It was suggested that there are three main parameters in the sizing of a rainwater tank:

- The contributing catchment;
- Total demand; and
- Rainfall depths.

It was reported that the runoff volume is a product of the rainfall, the contributing catchment, and the runoff coefficient, which is a function of roof topography and splash losses. Given the relatively large nursery roof catchment area, the losses due to splashing are considered negligible. However, the shallow pitch of the roof may provide depression storage which can potentially reduce the effective runoff area.

## 2.3 INDICATIVE COSTS

The Roofwater Research Harvesting Group (2001) carried out extensive studies on stormwater harvest, particularly with respect to costing and value of water. Two major costing trends were observed, and are presented on Figure 2.1.

**Figure 2.1 – Costing Trends for Stormwater Harvest**

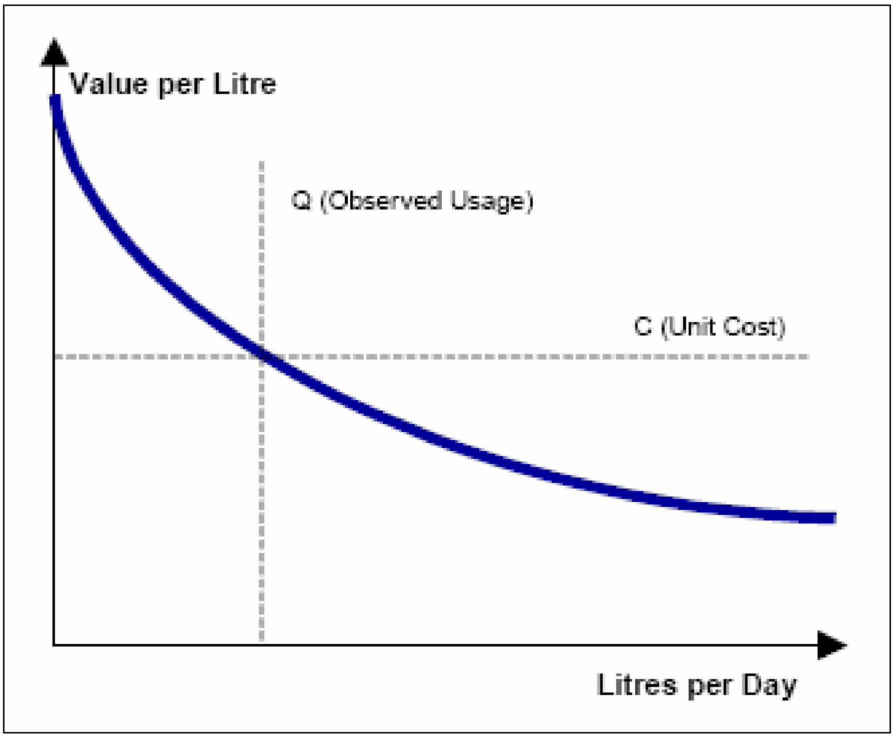


**Figure 2.1a – Value vs Quantity**

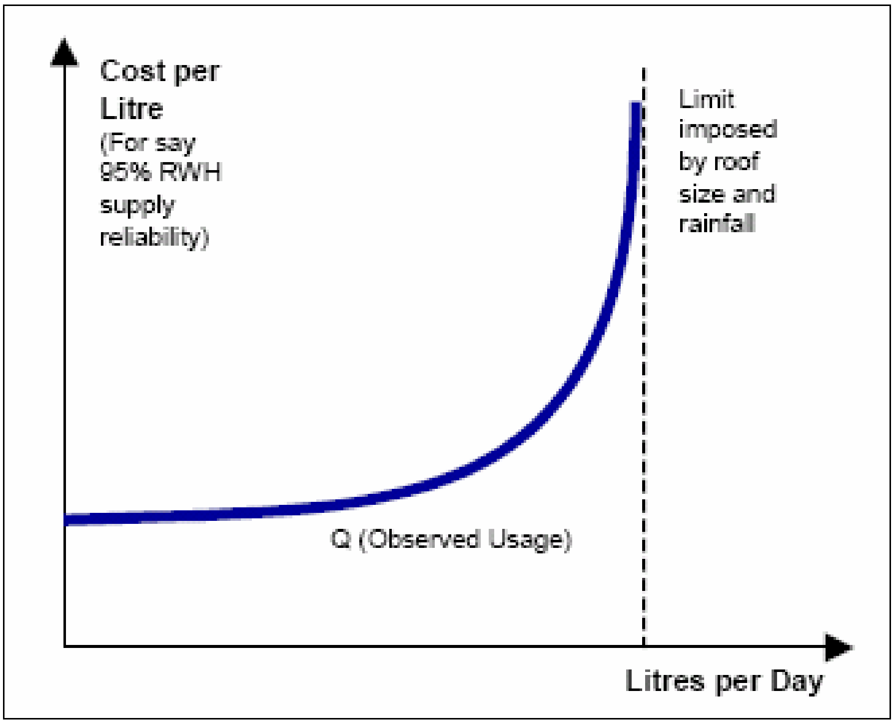


**Figure 2.1b – Cost vs Volume**

Figure 2.1a suggests that with increasing demand, the value per litre decreases. Preliminary indications suggest that the annual water consumption at the nursery is between 25 000 kL and 35 000 kL. As evident on Figure 2.1b, taking a rainwater harvest (RWH) supply reliability of 95%, there must at some stage be a trade off between storage capacity and acceptable costs. Ideally, the findings of a feasibility study will be considered when justifying such design decisions.

## 2.4 ATTITUDE TOWARDS WATER HARVEST

The advancement in technology and the reduction in costs has led to a shift in attitudes towards water harvesting. The shift was initially attributed to domestic users, whose usage was relatively low, and therefore value per litre was high. In more recent times, commercial and industrial entities have been adopting water sensitive design practices. According to the findings of the Development Technology Unit (1999), a number of non-government organisations are beginning to realise the potential of rainwater harvesting. In cases where organisations have specific water policies and strategies, rainwater harvesting is either specifically mentioned as an 'alternative water source' or implied under 'appropriate technology'.

Most recent attitudes towards water sensitive design are evident in State Government guidelines. The Draft Sustainable Water Strategy for Victoria infers indicates that recycled water and stormwater are key alternatives to river or aquifer sources. It is anticipated that the initiatives “will need to be used in the medium to long term” in order to meet recycling and reduction targets. Complementary to this, the Water Sensitive Urban Design Guidelines for Sustainable Development in Canberra (2006) document key performance targets. The target for mains water use reduction is 40% in all new developments and redevelopments, including commercial, institutional and industrial developments. It is intended that this target will be met by the effective installation and management of:

- Stormwater and wastewater re-use systems, providing the opportunity to reduce potable water demand;
- Landscaping of public open space to minimise irrigation requirements; and,
- Water efficient fixtures in such developments.

It is difficult to quantify reduction targets for regions under severe water restrictions. However, the 40% reduction outlined in the sustainable development guidelines serve as a benchmark of sorts. The percentage reduction set to be gained from the options set out in this feasibility study is a major output that can be compared with other Australian regions.

## 2.5 SUMMARY: CHAPTER 2

Recent technological advances in water sensitive design practices have resulted in more efficient harvest methods. Innovative devices such as subterranean retention tanks mean that water sensitive design can be achieved often without hindrance to development. With the shift towards mass production overall costs have decreased to a degree that rainwater harvest is often a very feasible water supply option, particularly in commercial or industrial precincts with relatively high impervious harvest areas.

# 3.0 HYDROLOGY

## 3.1 INTRODUCTION

It was identified that rainwater harvesting infrastructure may be a feasible solution to supplement the irrigation requirements of the wholesale nursery. A plan view of the nursery site can be seen on Figure 3.1.


**Figure 3.1 – Plan View of Nursery Site.**

The potential harvest areas on Figure 3.1 identify the existing roof top infrastructure. The major harvest area covers 600 $m^2$ while the minor harvest area covers 150 $m^2$. The total surface area of irrigation is 6350 $m^2$. The 80m spoon drain running along the northern boundary has a longitudinal slope of 1 %, and flows into a wet retention pond with a nominal storage volume of 1.2 ML. The natural stormwater flow direction is to the general north-east. A contour catchment plan is shown on Figure 3.2.

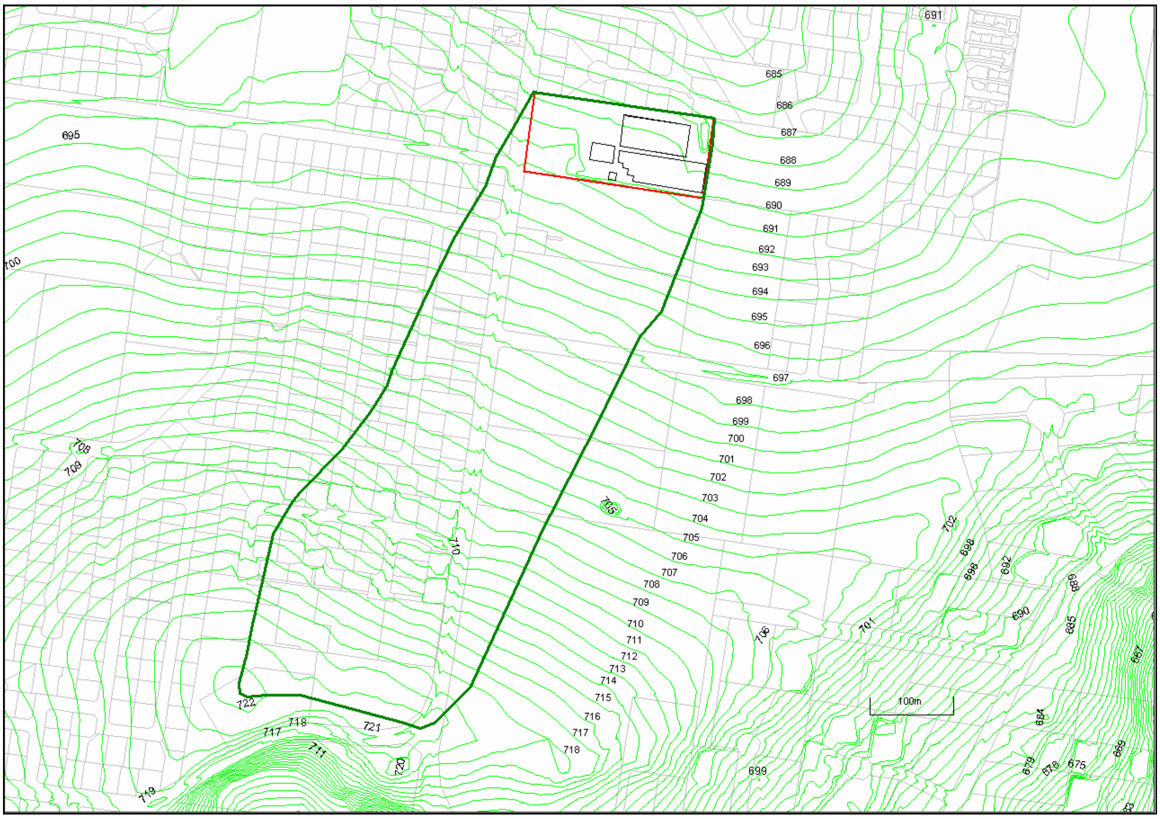


**Figure 3.2 – Contour Catchment Plan**

The total upstream stormwater catchment is shown on Figure 3.2 and covers an area of 20.5 hectares, including the nursery site. It is seen from the contour plot that the land exhibits a relatively constant slope. A slope of 4% was adopted for this study.

The purpose of this thesis is to determine the feasibility for a rainwater harvest site retrofit. In order to determine the feasibility of such works, it was considered necessary to conduct a water balance. The hydrologic processes involved on the site are outlined on the site schematic, Figure 3.3.

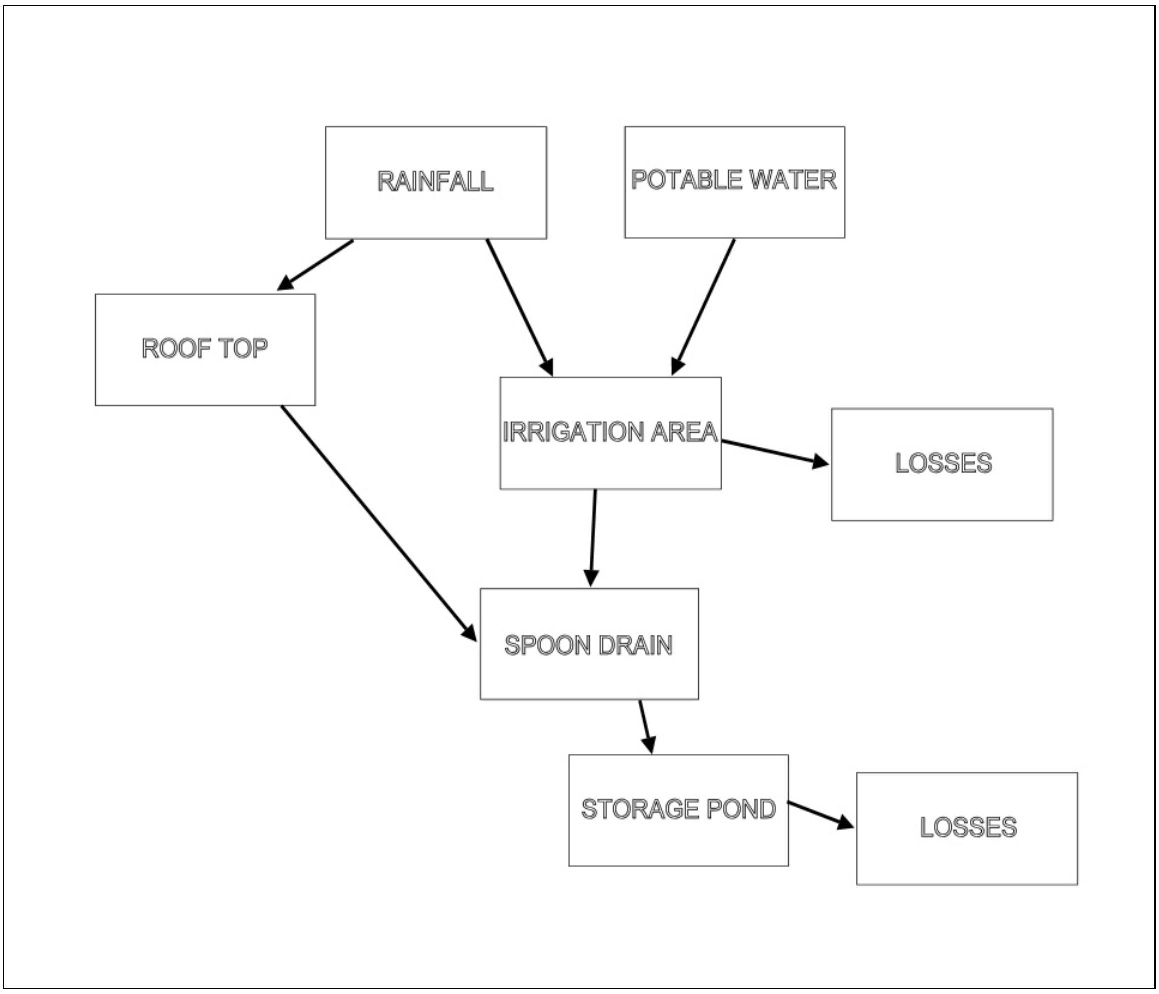


**Figure 3.3 – Schematic of Existing Site**

Current operation involves irrigation using potable water, except during rainfall events when irrigation is not required. Runoff from the roof tops and the irrigation area discharges indirectly to a wet retention pond through a longitudinal spoon drain. For the purpose of this study, losses are taken to be those flows that do not discharge in the short term to the spoon drain. These losses include evapotranspiration, deep seepage and leakage, and plant use.

Several methodologies were considered in order to conduct the water balance and determine the feasibility for on-site retention. Whilst purely analytical methods are well documented and widely accepted as solid hydrological practice, the requirement to analyse several retrofit scenarios resulted in extensive derivation times. As such, computer modelling methods were deemed to be more appropriate. The following sections document the process undertaken to construct the hydrologic model.

## 3.2 DATA ASSESSMENT

As part of its ongoing water usage monitoring program, the nursery observes rainfall and potable water usage on a daily basis. Approximately two years of historical data is available, which is sufficient for the purpose of constructing an extended period simulation model. The observations are illustrated on Figures 3.4 and 3.5.

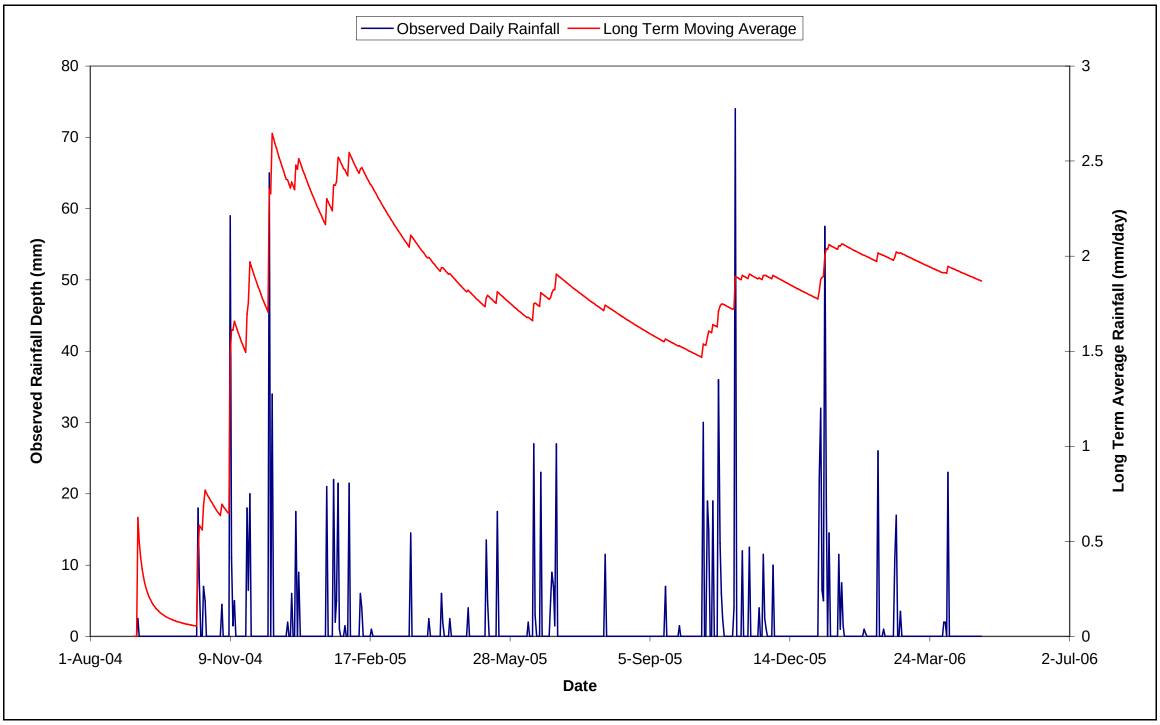


**Figure 3.4 – Daily and Long Term Average Rainfall.**

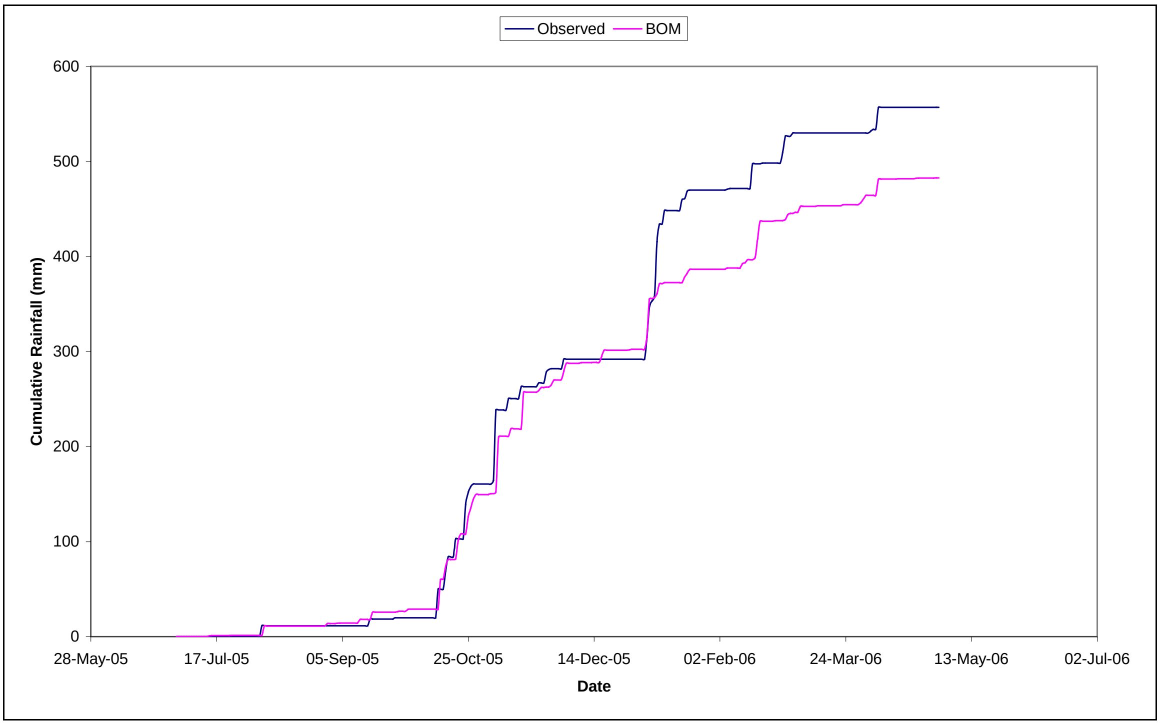


**Figure 3.5 – Cumulative Rainfall, Observed vs Bureau of Meteorology data**

It is shown on Figure 3.4 that the long term daily average rainfall is 2 mm/day, derived from daily rainfall observations. The validity of this data is verified against official Bureau of Meteorology data for Toowoomba during the corresponding period. Rainfall patterns can be highly site specific. It is noted that a significant discrepancy exists during January 2006 where the observed data overbids BOM data. The remainder of the data is in close correlation with BOM data. As such, it is assumed that the observed rainfall depths are accurate, and have been adopted for this study.

The long term daily water demand is illustrated on Figure 3.6.

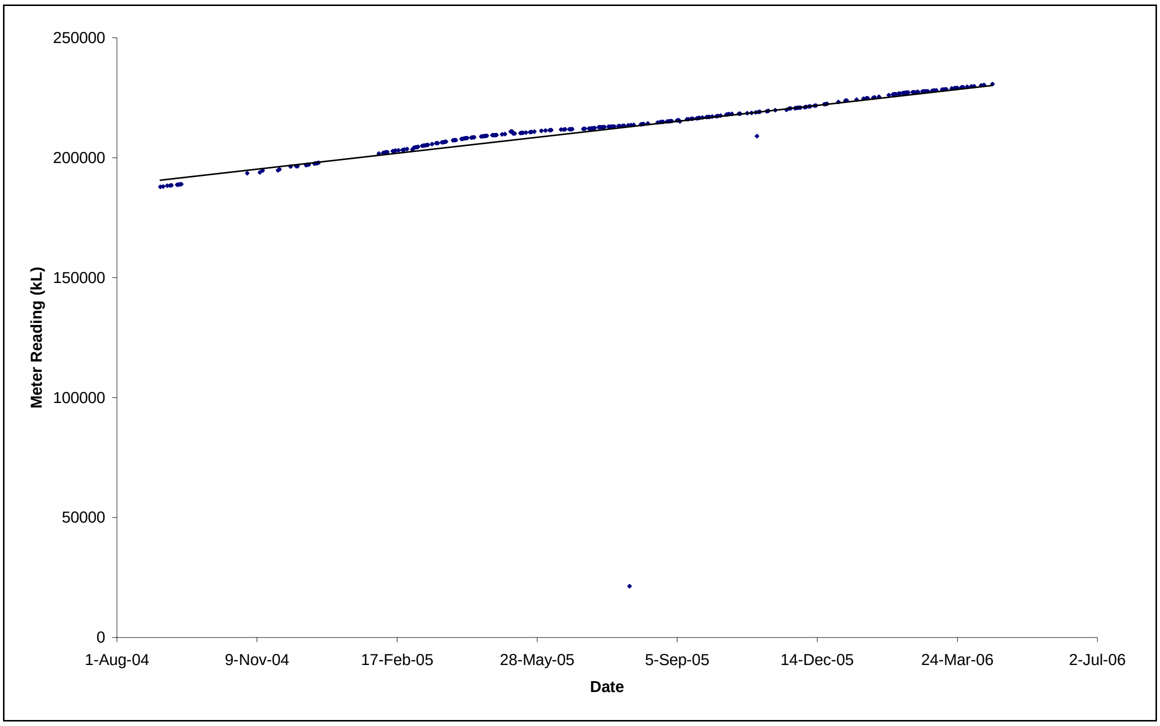


**Figure 3.6 – Cumulative Potable Water Consumption**

The linear trend line shows that the nursery water consumption follows a constant daily pattern. Long term metered consumption records indicate that the average daily consumption is 70 kL/day.

## 3.3 INTENSITY-FREQUENCY-DURATION ANALYSIS

In order to determine water supply confidence levels and overflow frequencies, an intensity-frequency-duration (IFD) analysis was undertaken for Toowoomba, QLD. The analysis is used to determine the intensity and duration of an array of average recurrence interval (ARI) events.

The theoretical used to determine the design IFD curve for Toowoomba, as shown on Figure 3.7, is presented in Appendix E. The data points are presented on Table 3.1.

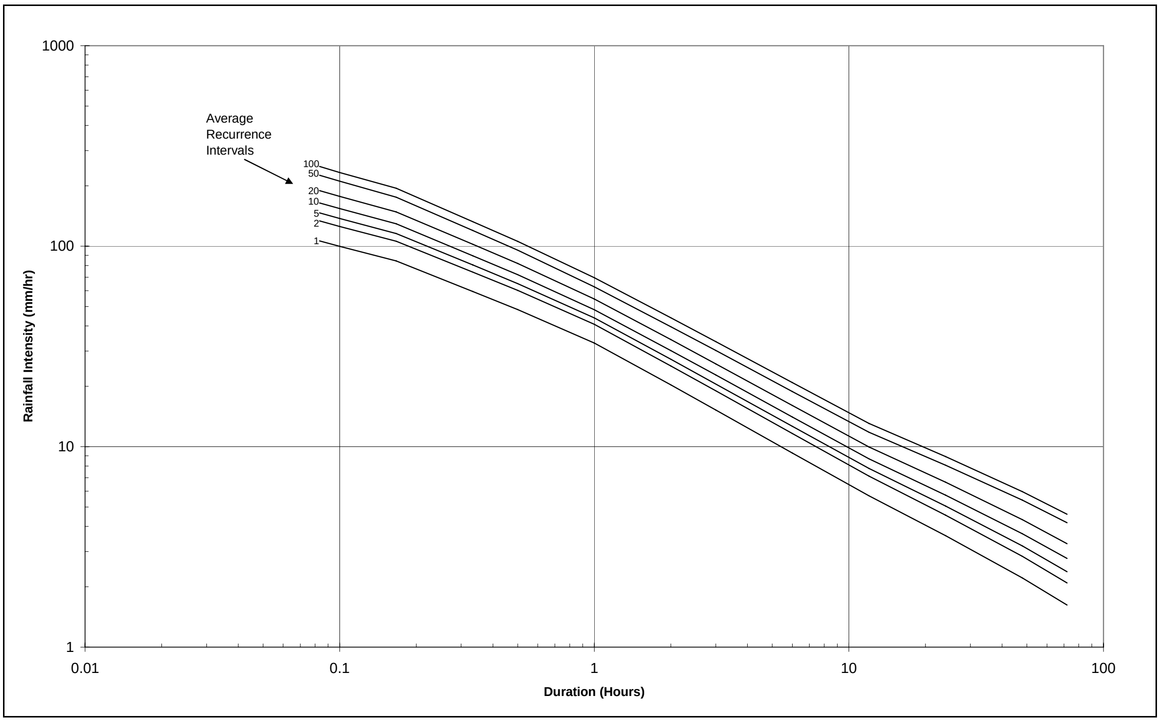


**Figure 3.7 – IFD Curve for Toowoomba, QLD**

**Table 3.1 – IFD Data for Toowoomba, QLD**

| ***Duration*** | ***Average Recurrence Interval (ARI)*** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1 Year (mm/hr)** | **2 Year (mm/hr)** | **5 Year (mm/hr)** | **10 Year (mm/hr)** | **20 Year (mm/hr)** | **50 Year (mm/hr)** | **100 Year (mm/hr)** |
| **5 min** | 106.2 | 133.6 | 146.6 | 164.4 | 189.2 | 225.7 | 249.6 |
| **6 min** | 99.8 | 125.4 | 137.5 | 154.1 | 177.1 | 210.9 | 233.3 |
| **10 min** | 84.4 | 105.9 | 115.7 | 129.3 | 148.3 | 175.6 | 194.3 |
| **20 min** | 59.4 | 74.2 | 80.6 | 89.5 | 102.2 | 119.7 | 132.5 |
| **30 min** | 48.3 | 60.1 | 65.1 | 72.0 | 81.9 | 95.4 | 105.7 |
| **1 hour** | 32.9 | 40.8 | 43.8 | 48.2 | 54.5 | 62.7 | 69.5 |
| **2 hour** | 20.3 | 25.3 | 27.3 | 30.1 | 34.2 | 39.7 | 44.0 |
| **3 hour** | 15.2 | 19.0 | 20.6 | 22.8 | 25.9 | 30.2 | 33.4 |
| **6 hour** | 9.3 | 11.6 | 12.6 | 14.0 | 16.0 | 18.8 | 20.9 |
| **12 hour** | 5.7 | 7.1 | 7.8 | 8.7 | 10.0 | 11.8 | 13.1 |
| **24 hour** | 3.6 | 4.6 | 5.1 | 5.7 | 6.6 | 8.1 | 8.9 |
| **48 hour** | 2.2 | 2.8 | 3.2 | 3.7 | 4.3 | 5.4 | 6.0 |
| **72 hour** | 1.6 | 2.1 | 2.4 | 2.8 | 3.3 | 4.2 | 4.6 |

Defining the time of concentration as the minimum time required for the entire catchment to be contributing, the design rainfall duration is set to equal the time of concentration, thus yielding the maximum stormwater discharge. This discharge is necessary in order to determine the frequency and magnitude of overflow events.

The catchment was analysed taking into account the partial area effect, whereby a greater peak discharge is achieved through a smaller catchment area but a larger design rainfall intensity (from a shorter time of concentration). However, it was found that a greater peak discharge was yielded when the catchment was contributing to runoff in its entirety.

The historical observed records and the IFD data form an input into the water balance model construction.

## 3.4 MODEL CONSTRUCTION

A commercially available software package for conducting a water balance is XP Software's Stormwater and Wastewater Management Model (XP-SWMM). The package features the ability to model areas ranging from a single site up to many square kilometres. An XP-SWMM water balance model was constructed in order to analyse the hydrologic processes occurring at the site. The model is based on a node-link-node principle; the ground surface elevation and channel invert level is input at each node, links can be assigned as open or closed conduits, natural channels or a range of other conduit types.

Nodes were placed at strategic points throughout the nursery. Nodal elevations were assigned based on the topographic plot given on Figure 3.2. At each node it is possible to assign up to five sub-catchments for hydrograph generation. Sub-catchments were defined based on the contour plot presented on Figure 3.2. The kinematic wave theory was selected as the hydrograph generation method.

Channel geometric parameters were input in accordance with site survey data. Manning's n values were adopted in accordance with tabulated data to reflect the channel roughness.

The rainfall data presented in Figure 3.4 was input to create an extended period simulation model. Such models are useful for assessing the long term water supply patterns.

Catchment parameters such as area and slope were input in accordance with the contour catchment plan on Figure 3.2 and 'As Constructed' site plans. The fraction impervious and co-efficient of runoff were adopted after methods prescribed in the *Queensland Urban Drainage Manual*.

## 3.5 MODEL CALIBRATION

In order to verify the validity of the model it was considered necessary to make comparisons between observed measurements and model outputs. The northern spoon drain provided a perfect opportunity to make this comparison. Model calibration was undertaken using a single, dry weather irrigation event. The runoff hydrograph was observed by taking regular measurements of flow depth and velocity in the spoon drain. Manning's formula was used to verify the flows.

The model was run using the initial estimates for infiltration and other losses. It was noted that the model flows were much higher than the observed flows. The infiltration and initial loss rates were tweaked until an acceptable discrepancy was reached. The comparison between observed and modeled flow rate in the spoon drain is shown on Figure 3.8.

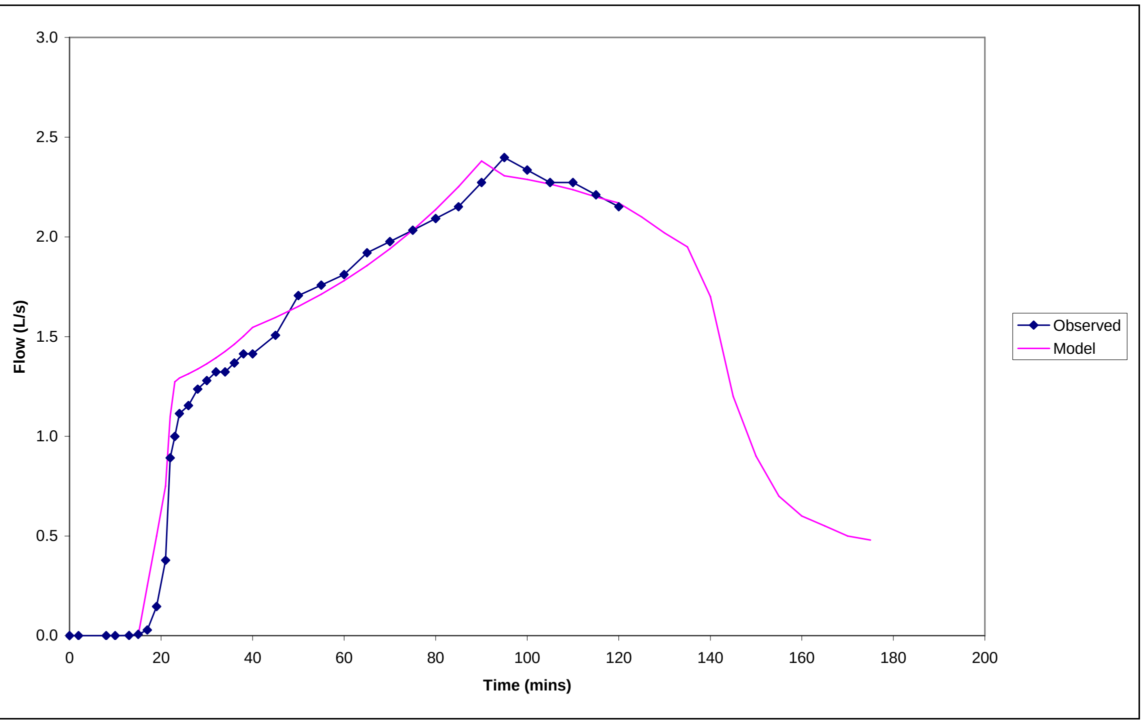


**Figure 3.8 – Observed versus Modelled Results.**

It can be seen that the modelled results closely follow the observed results. The largest noted discrepancy is in the initial stages of the hydrograph generation. The discrepancy is due to variation in the initial soil moisture and infiltration rates. The peak observed discharge is 2.40 L/s and the peak modelled discharge is 2.38 L/s, which is an error less than 1%. The maximum discrepancy is 7.3% and the total average error is 4.6%. For the purpose of this study the model was considered to be calibrated.

## 3.6 SUMMARY: CHAPTER 3

The total possible roof harvest area on the nursery site was found to be 750 $m^2$. The nursery has an irrigation area of 6350 $m^2$. The site is contained with a catchment with a total surface area of 20.5 hectares. Excess stormwater and irrigation flow discharges into a 1.2 ML wet retention pond in the north-eastern corner of the site. It was deemed that computer modelling techniques were the most effective means for conducting a water balance for this site.

An XP-SWMM model was constructed to conduct the water balance. The model inputs included the historical rainfall data and metered consumption, and the IFD data for Toowoomba. The model was calibrated to produce discharges within 5% of observed values. Provisions were made to allow the creation of model scenarios to reflect the augmentation strategies presented in the following chapter.

# 4.0 AUGMENTATIONS AND SYSTEM MODELLING

## 4.1 INTRODUCTION

As eluded to in Section 1.2, it is not uncommon to see many options available for a water sensitive design retrofit. Many options for augmentation were considered for this study. The inclusion of diversion devices were not considered feasible as they are unlikely to provide a regulated supply for irrigation. The installation of a subterranean holding tank was discounted. The increased capital cost of excavation and installation was not considered to be feasible, particularly given that external ground space does not pose a limitation. As such, it was considered that above ground retention infrastructure was the most feasible option for augmentation.

This chapter serves to outline the augmentation options available, to document the major model outputs for such options, and to critically analyse the results with particular respect to water supply confidence levels and potable water demand reduction.

## 4.2 EXISTING SITE CONDITIONS

The calibration scenario was used to model the site in its existing state to allow a comparison to the ‘Do Nothing’ approach. It is determined in Section 3.2 that the average daily demand is 70 kL. Currently, this is drawn solely from potable water supplies. The volume of runoff from an average irrigation event is equal to the integral of the calibration curve presented on Figure 3.8, which equals 16.8 kL. According to nursery staff, a maximum of three irrigation events are undertaken in an average day. It follows that from each irrigation event, 6.5 kL is lost through evaporation, seepage or leakage, or is uptaken by plants and used through internal use or transpiration.

## 4.3 AUGMENTATION STRATEGY

The XP-SWMM model was updated by creating four additional scenarios to reflect the following options for water sensitive design retrofit. All calibration parameters such as infiltration and initial loss rates were inherited to the child scenarios and used throughout the model simulations.

### 4.3.1 Option 1 – Retention Device Harvesting Major Roof Area

The first option for water sensitive design retrofit involves the installation of a retention device such as a rainwater tank to harvest the rainfall runoff from the larger roof harvest area. The tank would be the primary source for irrigation requirements, and supplemented with potable water supply when necessary.

The site was modelled with such infrastructure installed. The reliability levels and proportion of harvested water used is shown on Figure 4.1.

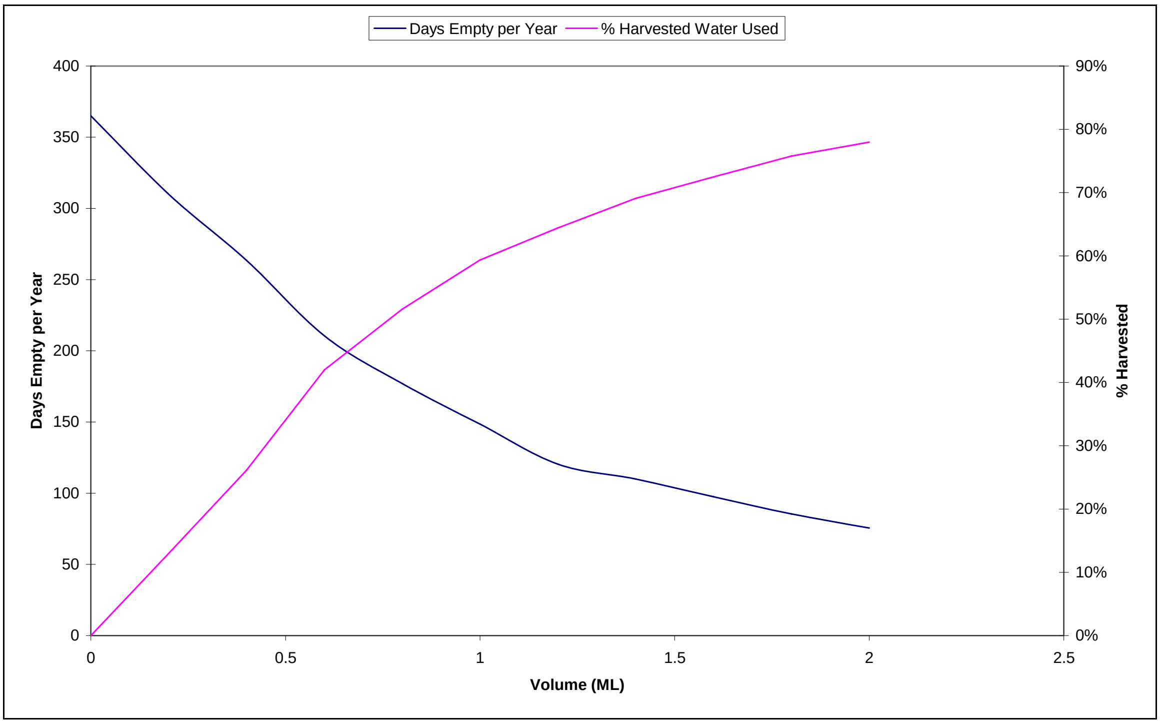


**Figure 4.1 – Harvest Details for Option 1**

It is seen that as trends occur as the volume of available retention is increased. For a volume of zero there is, of course, no water harvested, and the 'fictitious' tank is empty for 365 days per year. As the size is increased, however, it is seen that the reliability levels decrease and the proportion of harvested water used for irrigation purposes increases. With consideration given to the general trends given in Section 2.3, there must be at some point a trade off between harvest reliability and volume harvested, and the size of the infrastructure imposed by mostly by the capital cost of construction. Observing the data presented on Figure 4.1, the optimal rainwater retention capacity is 1.4 ML. This will provide a reliable source of harvested water for irrigation 250 days per year and yield 17.7 ML per year, reducing potable water consumption by 70%.

### 4.3.2 Option 2 – Retention Device Harvesting Major Area; Rerouting from Wet Retention Pond

A variation of Option 1 is to provide an additional source to the retention device by daily pumping from the wet retention pond in the north-eastern corner of the site. It is proposed to reroute 16.8 kL per day from the wet retention pond to the proposed rainwater tank, which is a volume equal to the discharge of a single irrigation event. This is in addition to the proposed augmentation given in Option 1. That is, a rainwater tank is proposed to harvest the rainfall runoff from the major harvest area. Again, the tank would be the primary source for irrigation requirements, and supplemented with potable water supply when necessary.

The site was modelled with such infrastructure installed. The reliability levels and proportion of harvested water used is shown on Figure 4.2.

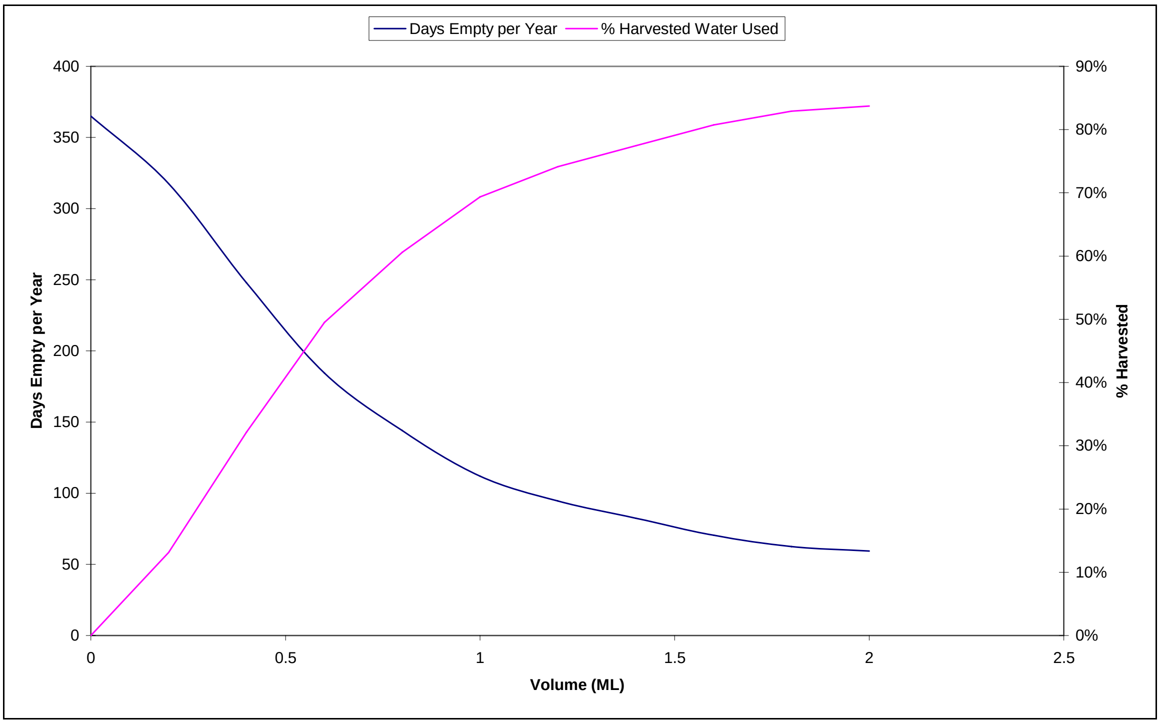


**Figure 4.2 – Harvest Details for Option 2**

Similar trends are seen for this option in that increasing the retention capacity produces a greater supply reliability and proportion harvest. With the additional source of pumping runoff from the wet retention pond, it is seen that it is possible to maintain the 70% potable water demand reduction whilst maintaining supply for 250 days of the year. However, it is possible to reduce the retention capacity to 1 ML. The decreased size of the retention infrastructure is a definite advantage, however, the question remains whether this advantage is offset by the increased cost and complexity associated with the pumping of runoff effluent. For example, hidden costs such as ongoing maintenance and energy costs for pumping should not be forgotten when considering this option.

### 4.3.3 Option 3 – Retention Device Harvesting Major and Minor Roof Areas

The third option for water sensitive design retrofit involves the installation of a rainwater tank or similar device to harvest the rainfall runoff from the all available roof areas. The tank would be the primary source for irrigation requirements, and supplemented with potable water supply when necessary.

The site was modelled with such infrastructure installed. The reliability levels and proportion of harvested water used is shown on Figure 4.3.

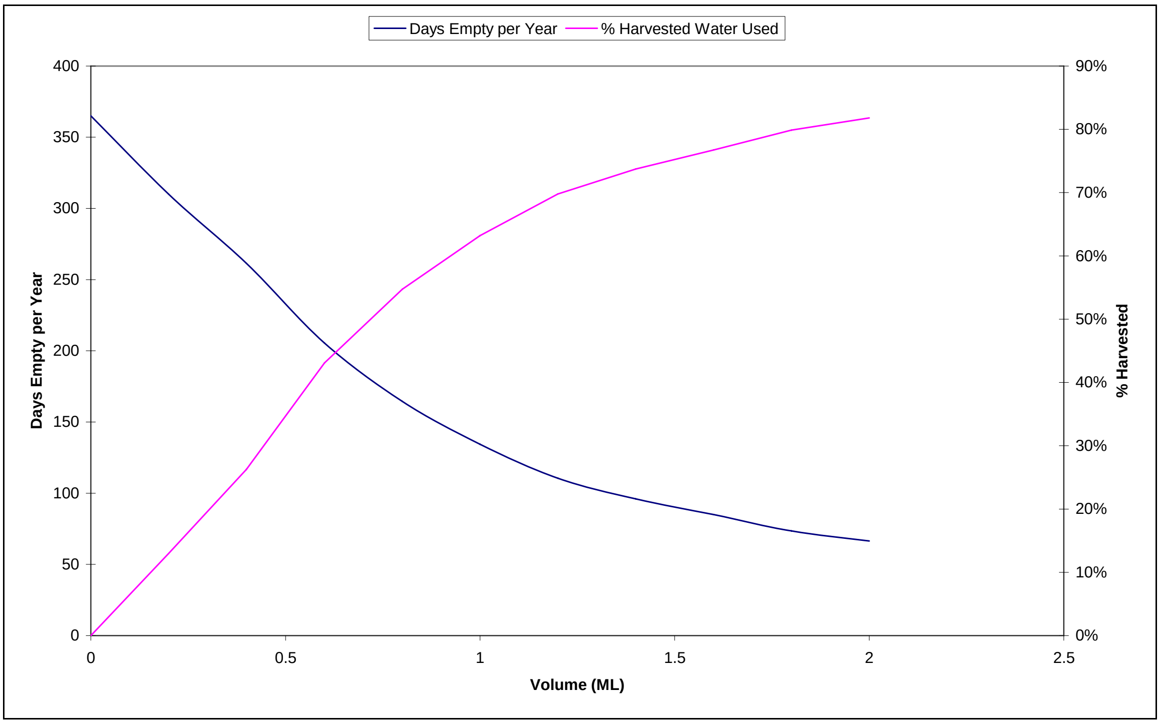


**Figure 4.3 – Harvest Details for Option 3**

Once again it is seen that the harvest becomes more fruitful as the available retention capacity is increased. Given that the roof area of 750 $m^2$ is being used as a catchment area, and considering the theoretical limit imposed by roof size and rainfall on Figure 2.1b, it is deduced that the optimal size for the retention tank is 1.2 ML. This is a slight reduction on the 1.4 ML tank that is optimal for Option 1, however, a reliable source is maintained throughout 250 days per year, and potable water consumption is still expected to drop by 70%. Should a 1.4 ML tank be installed in this option, the annual yield will increase slightly to 18.8 ML per year, reducing potable water consumption by 74%.

### 4.3.4 Option 4 – Retention Device Harvesting Major and Minor Areas; Rerouting from Wet Retention Pond

The daily pumping of irrigation discharge from the wet retention pond to a proposed rainwater tank provides a variant of Option 3. The rainwater tank is proposed to harvest the rainfall runoff from all available roof areas, and have sufficient capacity to accommodate 16.8 kL per day rerouted from the wet pond, which is equivalent to the volume of discharge from a single irrigation event. It is proposed that the tank be drawn upon for primary irrigation requirements, but supplemented with potable supplies when necessary.

The site was modelled with such infrastructure installed. The reliability levels and proportion of harvested water used is shown on Figure 4.2.

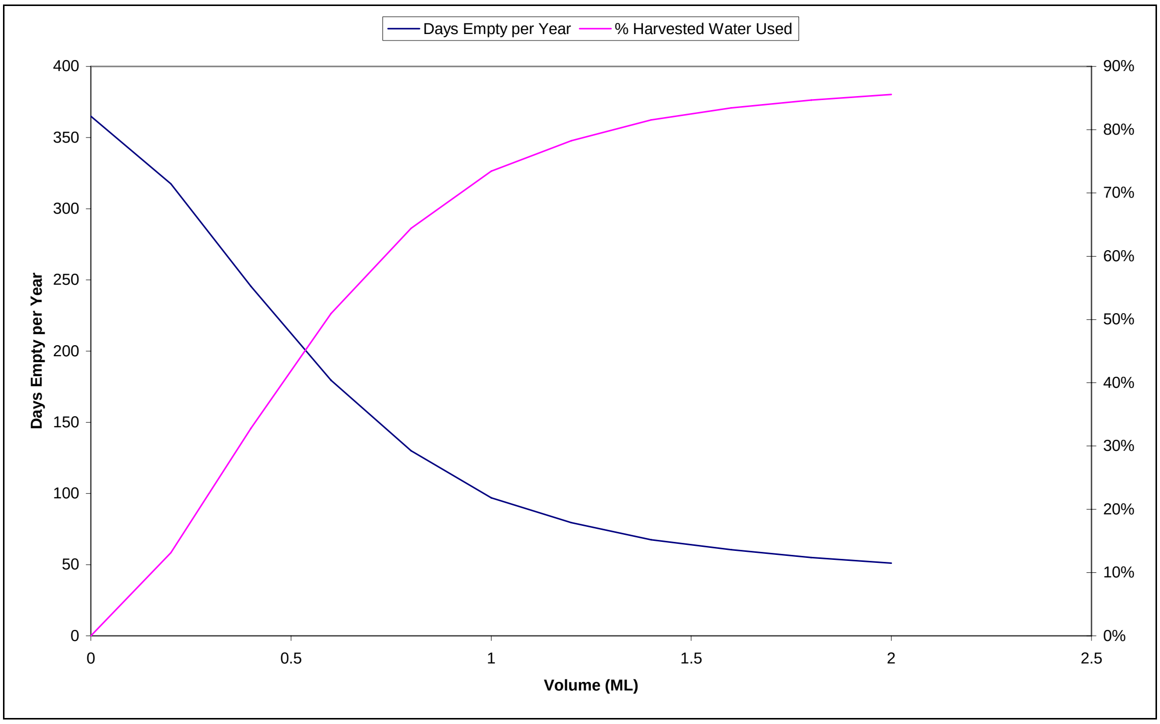


**Figure 4.4 – Harvest Details for Option 4**

It is seen that this option provides the highest yield of rainwater harvest. A nominal retention capacity of 1 ML is sufficient to provide a reliable source of harvested water for 270 days per year, yielding 18.8 ML of rainwater harvest per annum. This equates to a reduction in potable water consumption of 73%. It should not be a given that this is the most feasible solution for rainwater harvest, however. As with Option 2, above, the possibility of ongoing hidden pumping costs should not be forgotten.

## 4.4 CRITICAL ANALYSIS OF OPTIONS

System modelling has indicated that all four of the proposed augmentation strategies were quite effective in reducing potable water consumption. The major model outputs for each augmentation strategy are summarised in Table 4.1.

**Table 4.1 – Summary of Proposed Augmentation Strategies and Major Model Outputs**

| Description | Nominal Tank Size (ML) | Total Harvest (ML) | Potable Water Consumption (ML) | Percentage Reduction | Days Empty | Overflow Events |
|---|---|---|---|---|---|---|
| *Do Nothing* - No changes | N/A | 0.0 | 25.6 | 0% | N/A | N/A |
| *Option 1* - Retention tank harvesting major roof area | 1.4 | 17.7 | 7.8 | 69% | 110 | 42 |
| *Option 2* - Retention tank harvesting major roof area; rerouting of flow from wet retention pond | 1.0 | 17.7 | 7.8 | 69% | 112 | 59 |
| *Option 3* - Retention tank harvesting all available roof areas | 1.2 | 17.8 | 7.7 | 70% | 111 | 57 |
| *Option 4* - Retention tank harvesting all available roof areas; rerouting of flow from wet retention pond | 1.0 | 18.8 | 6.8 | 74% | 97 | 61 |

It can be seen that the four options for harvest vary in the retention capacity required to yield comparable volumes, and the number of overflow events. Both Options 2 and 4 involving the pumping of irrigation effluent back into the system require lesser retention sizes to provide similar benefits to Options 1 and 3. However, the smaller retention volumes also cause an increase in the number of overflow events. This increase in overflow frequency is considered less optimal. While irrigation effluent is being returned to the system through pumping, fresh rainwater harvest opportunities are being neglected. In addition to this, the pumping of irrigation effluent can be costly and adds complexity to the harvest infrastructure. Therefore, the most effective means for providing rainwater harvest supply to the nursery does not involve rerouting flow from the wet retention pond. Thus, Options 2 and 4 are discounted.

Both Options 1 and 3 yield comparable harvest volumes. Differentiating between the two options, Option 3 involves the harvesting of all potential catchment areas, and thus requires a smaller retention volume. As such, the most feasible means for creating a supply of rainwater for nursery irrigation involves a nominal retention capacity of 1.2 ML set to harvest the major and minor roof areas in the central region of the site.

## 4.5 SUMMARY: CHAPTER 5

In order to service the nursery with a rainwater harvest supply, four augmentation strategies were proposed. The calibrated water balance model was used to assess each scenario based on reliability of supply and reduction in potable water consumption.

Critical findings were made based on total harvest volume, reliability of supply, and overflow frequencies. It was found that whilst all four proposed augmentation strategies were effective in reducing the potable water demand, Option 3 that involved the harvesting of all available roof space for single irrigation use provided the most feasible means for rainwater harvest.

# 5.0 CONCLUSIONS AND RECOMMENDATIONS

## 5.1 ACHIEVEMENT OF AIMS

The aim of this thesis was to determine the impact of a proposed on-site rainwater retention facility, and to determine the feasibility of such infrastructure with particular regard to providing a source of water for nursery irrigation and to ease the burden on reticulated supply. Detailed objectives are outlined in the following sections.

### 5.1.1 Review of Previous Studies

A detailed literature review was undertaken in Chapter 2 to gain an understanding of previous studies and literature. It was found that the water sensitive urban design was becoming more prominent in an evolving society due to the advancement in water harvesting and flow control procedures, the associated costs, and the changing attitudes of the general public.

### 5.1.2 Data Assessment

As part of its ongoing water usage monitoring program, the nursery observes rainfall and potable water usage on a daily basis. This data was assessed to determine the long term average daily rainfall intensity and the average daily consumption. From this it was determined that some additional data was required to complete the study. The irrigation effluent was observed as part of the ongoing data acquisition and was integral in the study.

### 5.1.3 Statistical IFD Analysis

A statistical intensity-frequency-duration analysis was undertaken for Toowoomba to determine the rainfall intensity for various event durations and average recurrence intervals. Together with the observed rainfall readings, this data formed a major input to the water balance.

### 5.1.4 Water Balance

An XP-SWMM stormwater management water balance model was constructed in order to analyse the hydrologic processes occurring at the site. The model was calibrated to produce flows within 5% of observed flows.

### 5.1.5 Analysis and Recommendations

The constructed model was used to assess four proposed water sensitive design retrofit options. The feasibility of each option was assessed based on various factors such as reduction to potable water consumption and rainwater harvest reliability.

The third proposed augmentation strategy was recommended as the most feasible means for on-site stormwater retention and subsequent reuse.

## 5.2 FURTHER RECOMMENDATIONS AND STUDIES

The reduction of potable water consumption is integral in the growth of the greater Toowoomba region. The findings of this report detail the possibility to assist in meeting demand reduction targets for the city and surrounds.

It is recommended that an ongoing monitoring scheme be documented to determine the actual impact of the proposed water sensitive design retrofit on potable water consumption. The possibility remains to expand the nursery operation given a harvested supply of irrigation water.

# 6.0 REFERENCES


Canberra City Council, 2006, Water Sensitive Urban Design Guidelines for Sustainable Development in Canberra.

Department of Natural Resources, The Queensland Urban Drainage Manual, 1993.

Engineers Australia, 2003, Australian Rainfall and Runoff, Australia.

Masters, Gilbert 1997, Introduction to Environmental Engineering and Science, Prentice-Hall, Sydney.

Unit of Sustainable Development and Environment,1997, Guidelines to Sustainable Development.

Vaes G and Berlamont J, 1999, Rainwater Tank Sizing Guidelines.

XP Software, 2006, XP-SWMM User Manual.

# APPENDIX A

# Project Specification

The University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

## ENG4111/2 Research Project

## PROJECT SPECIFICATION

FOR: Anthony Morris

TOPIC: Stormwater Harvest and Reuse for a Wholesale Nursery

SUPERVISORS: Dr. Ernest Yoong

Mr. Richard Colclough

PROJECT AIM: The aim of this project is to undertake a site specific water balance and to determine the feasibility for installing on-site stormwater detention capacity for the purpose of irrigation reuse.

PROGRAMME: *Issue A, 16 March, 2006*

1. Review of Previous Studies

A review of previous studies and literature will be undertaken to provide a theoretical benchmark on which the study can be based. The theoretical aspect will be included to assist in the understanding of the technical content of the report, and to ensure the engineering concepts can be applied to alternative sites, should the need arise.

2. Assessment of Supplied Data

In the early stages of project commencement, supplied historical data will be assessed to determine it's suitability for use in the project. Following this assessment, any additional information required will be identified and the necessary data acquisition measures will be taken.

3. Perform Statistical IFD Analysis

A site-specific intensity-frequency-duration analysis will be undertaken to determine the rainfall intensity for a number of event durations and average recurrence intervals. The analysis will be compared with historical site rainfall recordings to provide a calibrated set of rainfall data.

The statistical rainfall data will form an input to the water balance, and allow the determination of water supply confidence levels and overflow frequencies.

4. Conduct Water Balance

Based on the input data and by determining catchment and flow parameters as necessary, a volumetric water balance will be performed. As part of the analysis the key hydrologic components of the nursery will be identified, and flow pattern relationships will be assigned.

With known water usage and quantified flow relationships, it is possible to balance the system and predict the destination of irrigation discharge and stormwater runoff.

5. Analysis and Recommendations

The water balance conceptualisation will form the topic for a detailed critical analysis. A number of options will be presented outlining effective means for on-site stormwater detention. The feasibility of each option will be assessed based on predicted reduction of potable water demand, lifecycle costs, infrastructure logistics and water quality treatment necessity.

Ultimately, a recommendation will be made which represents the most effective means for on-site stormwater detention and subsequent reuse.

AGREED:

__________ (Student) __________, __________ (Supervisors)

Dated: 27 / 3 / 2006

# APPENDIX B

## Raw Data

**Table B1 – Observed Daily Rainfall and Metered Consumption**

| DAY | DATE | OBSERVED DAILY RAINFALL | METER READING |
|---|---|---|---|
| Saturday | 1-May-04 | 0 | |
| Sunday | 2-May-04 | 0 | |
| Monday | 3-May-04 | 0 | |
| Tuesday | 4-May-04 | 0 | |
| Wednesday | 5-May-04 | 0 | |
| Thursday | 6-May-04 | 0 | |
| Friday | 7-May-04 | 0 | |
| Saturday | 8-May-04 | 0 | |
| Sunday | 9-May-04 | 0 | |
| Monday | 10-May-04 | 0 | |
| Tuesday | 11-May-04 | 0 | |
| Wednesday | 12-May-04 | 0 | |
| Thursday | 13-May-04 | 0 | |
| Friday | 14-May-04 | 0 | |
| Saturday | 15-May-04 | 0 | |
| Sunday | 16-May-04 | 0 | |
| Monday | 17-May-04 | 0 | |
| Tuesday | 18-May-04 | 0 | |
| Wednesday | 19-May-04 | 0 | |
| Thursday | 20-May-04 | 0 | |
| Friday | 21-May-04 | 0 | |
| Saturday | 22-May-04 | 0 | |
| Sunday | 23-May-04 | 0 | |
| Monday | 24-May-04 | 0 | |
| Tuesday | 25-May-04 | 0 | |
| Wednesday | 26-May-04 | 0 | |
| Thursday | 27-May-04 | 12 | |
| Friday | 28-May-04 | 0 | |
| Saturday | 29-May-04 | 0 | |
| Sunday | 30-May-04 | 0 | |
| Monday | 31-May-04 | 0 | |
| Tuesday | 1-Jun-04 | 0 | |
| Wednesday | 2-Jun-04 | 0 | |
| Thursday | 3-Jun-04 | 0 | |
| Friday | 4-Jun-04 | 0 | |
| Saturday | 5-Jun-04 | 0 | |
| Sunday | 6-Jun-04 | 0 | |
| Monday | 7-Jun-04 | 0 | |
| Tuesday | 8-Jun-04 | 0 | |
| Wednesday | 9-Jun-04 | 0 | |
| Thursday | 10-Jun-04 | 0 | |
| Friday | 11-Jun-04 | 3 | |
| Saturday | 12-Jun-04 | 0 | |
| Sunday | 13-Jun-04 | 0 | |
| Monday | 14-Jun-04 | 0 | |
| Tuesday | 15-Jun-04 | 0 | |
| Wednesday | 16-Jun-04 | 0 | |
| Thursday | 17-Jun-04 | 0 | |
| Friday | 18-Jun-04 | 0 | |

| | | | |
|---|---|---|---|
| Saturday | 19-Jun-04 | 0 | |
| Sunday | 20-Jun-04 | 0 | |
| Monday | 21-Jun-04 | 0 | |
| Tuesday | 22-Jun-04 | 0 | |
| Wednesday | 23-Jun-04 | 0 | |
| Thursday | 24-Jun-04 | 0 | |
| Friday | 25-Jun-04 | 0 | |
| Saturday | 26-Jun-04 | 0 | |
| Sunday | 27-Jun-04 | 0 | |
| Monday | 28-Jun-04 | 0 | |
| Tuesday | 29-Jun-04 | 0 | |
| Wednesday | 30-Jun-04 | 0 | |
| Thursday | 1-Jul-04 | 0 | |
| Friday | 2-Jul-04 | 0 | |
| Saturday | 3-Jul-04 | 0 | |
| Sunday | 4-Jul-04 | 0 | |
| Monday | 5-Jul-04 | 0 | |
| Tuesday | 6-Jul-04 | 0 | |
| Wednesday | 7-Jul-04 | 0 | |
| Thursday | 8-Jul-04 | 0 | |
| Friday | 9-Jul-04 | 0 | |
| Saturday | 10-Jul-04 | 0 | |
| Sunday | 11-Jul-04 | 3.5 | |
| Monday | 12-Jul-04 | 0 | |
| Tuesday | 13-Jul-04 | 0 | |
| Wednesday | 14-Jul-04 | 0 | |
| Thursday | 15-Jul-04 | 0 | |
| Friday | 16-Jul-04 | 0 | |
| Saturday | 17-Jul-04 | 0 | |
| Sunday | 18-Jul-04 | 0 | |
| Monday | 19-Jul-04 | 0 | |
| Tuesday | 20-Jul-04 | 0 | |
| Wednesday | 21-Jul-04 | 0 | |
| Thursday | 22-Jul-04 | 0 | |
| Friday | 23-Jul-04 | 0 | |
| Saturday | 24-Jul-04 | 0 | |
| Sunday | 25-Jul-04 | 0 | |
| Monday | 26-Jul-04 | 0 | |
| Tuesday | 27-Jul-04 | 8.5 | |
| Wednesday | 28-Jul-04 | 0 | |
| Thursday | 29-Jul-04 | 0 | |
| Friday | 30-Jul-04 | 0 | |
| Saturday | 31-Jul-04 | 0 | |
| Sunday | 1-Aug-04 | 0 | |
| Monday | 2-Aug-04 | 0 | |
| Tuesday | 3-Aug-04 | 0 | |
| Wednesday | 4-Aug-04 | 0 | |
| Thursday | 5-Aug-04 | 0 | |
| Friday | 6-Aug-04 | 0 | |
| Saturday | 7-Aug-04 | 0 | |
| Sunday | 8-Aug-04 | 0 | |
| Monday | 9-Aug-04 | 0 | |
| Tuesday | 10-Aug-04 | 0 | |

| | | | |
|---|---|---|---|
| Wednesday | 11-Aug-04 | 0 | |
| Thursday | 12-Aug-04 | 0 | |
| Friday | 13-Aug-04 | 0 | |
| Saturday | 14-Aug-04 | 0 | |
| Sunday | 15-Aug-04 | 0 | |
| Monday | 16-Aug-04 | 0 | |
| Tuesday | 17-Aug-04 | 0 | |
| Wednesday | 18-Aug-04 | 0 | |
| Thursday | 19-Aug-04 | 0 | |
| Friday | 20-Aug-04 | 10 | |
| Saturday | 21-Aug-04 | 0 | |
| Sunday | 22-Aug-04 | 0 | |
| Monday | 23-Aug-04 | 0 | 187194.0 |
| Tuesday | 24-Aug-04 | 0 | 187290.4 |
| Wednesday | 25-Aug-04 | 0 | |
| Thursday | 26-Aug-04 | 0 | |
| Friday | 27-Aug-04 | 0 | |
| Saturday | 28-Aug-04 | 0 | |
| Sunday | 29-Aug-04 | 0 | |
| Monday | 30-Aug-04 | 5 | |
| Tuesday | 31-Aug-04 | 5.5 | |
| Wednesday | 1-Sep-04 | 0 | 187835.5 |
| Thursday | 2-Sep-04 | 0 | |
| Friday | 3-Sep-04 | 0 | 188020.6 |
| Saturday | 4-Sep-04 | 2.5 | |
| Sunday | 5-Sep-04 | 0 | |
| Monday | 6-Sep-04 | 0 | 188310.7 |
| Tuesday | 7-Sep-04 | 0 | |
| Wednesday | 8-Sep-04 | 0 | 188436.5 |
| Thursday | 9-Sep-04 | 0 | 188457.7 |
| Friday | 10-Sep-04 | 0 | |
| Saturday | 11-Sep-04 | 0 | |
| Sunday | 12-Sep-04 | 0 | |
| Monday | 13-Sep-04 | 0 | 188754.8 |
| Tuesday | 14-Sep-04 | 0 | 188836.3 |
| Wednesday | 15-Sep-04 | 0 | 188910.7 |
| Thursday | 16-Sep-04 | 0 | 189001.0 |
| Friday | 17-Sep-04 | 0 | |
| Saturday | 18-Sep-04 | 0 | |
| Sunday | 19-Sep-04 | 0 | |
| Monday | 20-Sep-04 | 0 | |
| Tuesday | 21-Sep-04 | 0 | |
| Wednesday | 22-Sep-04 | 0 | |
| Thursday | 23-Sep-04 | 0 | |
| Friday | 24-Sep-04 | 0 | |
| Saturday | 25-Sep-04 | 0 | |
| Sunday | 26-Sep-04 | 0 | |
| Monday | 27-Sep-04 | 0 | |
| Tuesday | 28-Sep-04 | 0 | |
| Wednesday | 29-Sep-04 | 0 | |
| Thursday | 30-Sep-04 | 0 | |
| Friday | 1-Oct-04 | 0 | |
| Saturday | 2-Oct-04 | 0 | |

| | | | |
|---|---|---|---|
| Sunday | 3-Oct-04 | 0 | |
| Monday | 4-Oct-04 | 0 | |
| Tuesday | 5-Oct-04 | 0 | |
| Wednesday | 6-Oct-04 | 0 | |
| Thursday | 7-Oct-04 | 0 | |
| Friday | 8-Oct-04 | 0 | |
| Saturday | 9-Oct-04 | 0 | |
| Sunday | 10-Oct-04 | 0 | |
| Monday | 11-Oct-04 | 0 | |
| Tuesday | 12-Oct-04 | 0 | |
| Wednesday | 13-Oct-04 | 0 | |
| Thursday | 14-Oct-04 | 0 | |
| Friday | 15-Oct-04 | 0 | |
| Saturday | 16-Oct-04 | 0 | |
| Sunday | 17-Oct-04 | 18 | |
| Monday | 18-Oct-04 | 7.5 | |
| Tuesday | 19-Oct-04 | 0 | |
| Wednesday | 20-Oct-04 | 0 | |
| Thursday | 21-Oct-04 | 7 | |
| Friday | 22-Oct-04 | 5 | |
| Saturday | 23-Oct-04 | 0 | |
| Sunday | 24-Oct-04 | 0 | |
| Monday | 25-Oct-04 | 0 | |
| Tuesday | 26-Oct-04 | 0 | |
| Wednesday | 27-Oct-04 | 0 | |
| Thursday | 28-Oct-04 | 0 | |
| Friday | 29-Oct-04 | 0 | |
| Saturday | 30-Oct-04 | 0 | |
| Sunday | 31-Oct-04 | 0 | |
| Monday | 1-Nov-04 | 0 | |
| Tuesday | 2-Nov-04 | 0 | 193532.4 |
| Wednesday | 3-Nov-04 | 4.5 | |
| Thursday | 4-Nov-04 | 0 | |
| Friday | 5-Nov-04 | 0 | |
| Saturday | 6-Nov-04 | 0 | |
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| Monday | 8-Nov-04 | 0 | |
| Tuesday | 9-Nov-04 | 59 | |
| Wednesday | 10-Nov-04 | 11 | |
| Thursday | 11-Nov-04 | 1.5 | 193867.0 |
| Friday | 12-Nov-04 | 5 | |
| Saturday | 13-Nov-04 | 0 | 194636.4 |
| Sunday | 14-Nov-04 | 0 | |
| Monday | 15-Nov-04 | 0 | |
| Tuesday | 16-Nov-04 | 0 | |
| Wednesday | 17-Nov-04 | 0 | |
| Thursday | 18-Nov-04 | 0 | |
| Friday | 19-Nov-04 | 0 | |
| Saturday | 20-Nov-04 | 0 | |
| Sunday | 21-Nov-04 | 18 | |
| Monday | 22-Nov-04 | 6.5 | |
| Tuesday | 23-Nov-04 | 20 | |
| Wednesday | 24-Nov-04 | 0 | 194733.3 |

| | | | |
|---|---|---|---|
| Thursday | 25-Nov-04 | 0 | 195113.8 |
| Friday | 26-Nov-04 | 0 | |
| Saturday | 27-Nov-04 | 0 | |
| Sunday | 28-Nov-04 | 0 | |
| Monday | 29-Nov-04 | 0 | |
| Tuesday | 30-Nov-04 | 0 | |
| Wednesday | 1-Dec-04 | 0 | |
| Thursday | 2-Dec-04 | 0 | |
| Friday | 3-Dec-04 | 0 | 196296.2 |
| Saturday | 4-Dec-04 | 0 | |
| Sunday | 5-Dec-04 | 0 | |
| Monday | 6-Dec-04 | 0 | |
| Tuesday | 7-Dec-04 | 65 | 196494.2 |
| Wednesday | 8-Dec-04 | 0 | 196498.3 |
| Thursday | 9-Dec-04 | 34 | |
| Friday | 10-Dec-04 | 0 | |
| Saturday | 11-Dec-04 | 0 | |
| Sunday | 12-Dec-04 | 0 | |
| Monday | 13-Dec-04 | 0 | |
| Tuesday | 14-Dec-04 | 0 | 196849.5 |
| Wednesday | 15-Dec-04 | 0 | 197001.7 |
| Thursday | 16-Dec-04 | 0 | 197103.4 |
| Friday | 17-Dec-04 | 0 | |
| Saturday | 18-Dec-04 | 0 | |
| Sunday | 19-Dec-04 | 0 | |
| Monday | 20-Dec-04 | 2 | 197546.8 |
| Tuesday | 21-Dec-04 | 0 | 197666.6 |
| Wednesday | 22-Dec-04 | 0 | 197782.6 |
| Thursday | 23-Dec-04 | 6 | 197905.2 |
| Friday | 24-Dec-04 | 0 | |
| Saturday | 25-Dec-04 | 0 | |
| Sunday | 26-Dec-04 | 17.5 | |
| Monday | 27-Dec-04 | 0 | |
| Tuesday | 28-Dec-04 | 9 | |
| Wednesday | 29-Dec-04 | 0 | |
| Thursday | 30-Dec-04 | 0 | |
| Friday | 31-Dec-04 | 0 | |
| Saturday | 1-Jan-05 | 0 | |
| Sunday | 2-Jan-05 | 0 | |
| Monday | 3-Jan-05 | 0 | |
| Tuesday | 4-Jan-05 | 0 | |
| Wednesday | 5-Jan-05 | 0 | |
| Thursday | 6-Jan-05 | 0 | |
| Friday | 7-Jan-05 | 0 | |
| Saturday | 8-Jan-05 | 0 | |
| Sunday | 9-Jan-05 | 0 | |
| Monday | 10-Jan-05 | 0 | |
| Tuesday | 11-Jan-05 | 0 | |
| Wednesday | 12-Jan-05 | 0 | |
| Thursday | 13-Jan-05 | 0 | |
| Friday | 14-Jan-05 | 0 | |
| Saturday | 15-Jan-05 | 0 | |
| Sunday | 16-Jan-05 | 0 | |

| | | | |
|---|---|---|---|
| Monday | 17-Jan-05 | 21 | |
| Tuesday | 18-Jan-05 | 0 | |
| Wednesday | 19-Jan-05 | 0 | |
| Thursday | 20-Jan-05 | 0 | |
| Friday | 21-Jan-05 | 0 | |
| Saturday | 22-Jan-05 | 22 | |
| Sunday | 23-Jan-05 | 2 | |
| Monday | 24-Jan-05 | 5 | |
| Tuesday | 25-Jan-05 | 21.5 | |
| Wednesday | 26-Jan-05 | 1 | |
| Thursday | 27-Jan-05 | 0 | |
| Friday | 28-Jan-05 | 0 | |
| Saturday | 29-Jan-05 | 0 | |
| Sunday | 30-Jan-05 | 1.5 | |
| Monday | 31-Jan-05 | 0 | |
| Tuesday | 1-Feb-05 | 0 | |
| Wednesday | 2-Feb-05 | 21.5 | |
| Thursday | 3-Feb-05 | 0 | |
| Friday | 4-Feb-05 | 0 | 201671.7 |
| Saturday | 5-Feb-05 | 0 | |
| Sunday | 6-Feb-05 | 0 | |
| Monday | 7-Feb-05 | 0 | 202018.7 |
| Tuesday | 8-Feb-05 | 0 | 202137.8 |
| Wednesday | 9-Feb-05 | 0 | 202245.1 |
| Thursday | 10-Feb-05 | 6 | 202306.1 |
| Friday | 11-Feb-05 | 4 | |
| Saturday | 12-Feb-05 | 0 | |
| Sunday | 13-Feb-05 | 0 | |
| Monday | 14-Feb-05 | 0 | 202736.8 |
| Tuesday | 15-Feb-05 | 0 | 202851.5 |
| Wednesday | 16-Feb-05 | 0 | 202990.7 |
| Thursday | 17-Feb-05 | 0 | |
| Friday | 18-Feb-05 | 1 | 203058.8 |
| Saturday | 19-Feb-05 | 0 | |
| Sunday | 20-Feb-05 | 0 | |
| Monday | 21-Feb-05 | 0 | 203229.5 |
| Tuesday | 22-Feb-05 | 0 | 203383.2 |
| Wednesday | 23-Feb-05 | 0 | |
| Thursday | 24-Feb-05 | 0 | 203620.0 |
| Friday | 25-Feb-05 | 0 | |
| Saturday | 26-Feb-05 | 0 | |
| Sunday | 27-Feb-05 | 0 | |
| Monday | 28-Feb-05 | 0 | 203408.5 |
| Tuesday | 1-Mar-05 | 0 | 204200.6 |
| Wednesday | 2-Mar-05 | 0 | 204312.6 |
| Thursday | 3-Mar-05 | 0 | 204425.4 |
| Friday | 4-Mar-05 | 0 | 204540.0 |
| Saturday | 5-Mar-05 | 0 | |
| Sunday | 6-Mar-05 | 0 | |
| Monday | 7-Mar-05 | 0 | 204916.6 |
| Tuesday | 8-Mar-05 | 0 | 205023.8 |
| Wednesday | 9-Mar-05 | 0 | 205139.5 |
| Thursday | 10-Mar-05 | 0 | 205257.7 |

| | | | |
|---|---|---|---|
| Friday | 11-Mar-05 | 0 | 205370.4 |
| Saturday | 12-Mar-05 | 0 | |
| Sunday | 13-Mar-05 | 0 | |
| Monday | 14-Mar-05 | 0 | 205673.1 |
| Tuesday | 15-Mar-05 | 0 | |
| Wednesday | 16-Mar-05 | 0 | |
| Thursday | 17-Mar-05 | 0 | 206032.4 |
| Friday | 18-Mar-05 | 14.5 | 206043.6 |
| Saturday | 19-Mar-05 | 0 | |
| Sunday | 20-Mar-05 | 0 | |
| Monday | 21-Mar-05 | 0 | 206381.1 |
| Tuesday | 22-Mar-05 | 0 | 206493.0 |
| Wednesday | 23-Mar-05 | 0 | 206603.7 |
| Thursday | 24-Mar-05 | 0 | 206718.9 |
| Friday | 25-Mar-05 | 0 | |
| Saturday | 26-Mar-05 | 0 | |
| Sunday | 27-Mar-05 | 0 | |
| Monday | 28-Mar-05 | 0 | |
| Tuesday | 29-Mar-05 | 0 | 207271.2 |
| Wednesday | 30-Mar-05 | 0 | 207347.5 |
| Thursday | 31-Mar-05 | 2.5 | 207360.3 |
| Friday | 1-Apr-05 | 0 | |
| Saturday | 2-Apr-05 | 0 | |
| Sunday | 3-Apr-05 | 0 | |
| Monday | 4-Apr-05 | 0 | 207796.3 |
| Tuesday | 5-Apr-05 | 0 | 207915.9 |
| Wednesday | 6-Apr-05 | 0 | 208021.6 |
| Thursday | 7-Apr-05 | 0 | 208124.3 |
| Friday | 8-Apr-05 | 0 | 208179.9 |
| Saturday | 9-Apr-05 | 6 | |
| Sunday | 10-Apr-05 | 2 | |
| Monday | 11-Apr-05 | 0 | 208352.1 |
| Tuesday | 12-Apr-05 | 0 | 208451.6 |
| Wednesday | 13-Apr-05 | 0 | 208542.1 |
| Thursday | 14-Apr-05 | 0 | |
| Friday | 15-Apr-05 | 2.5 | |
| Saturday | 16-Apr-05 | 0 | |
| Sunday | 17-Apr-05 | 0 | |
| Monday | 18-Apr-05 | 0 | 208834.6 |
| Tuesday | 19-Apr-05 | 0 | 208921.2 |
| Wednesday | 20-Apr-05 | 0 | 209003.2 |
| Thursday | 21-Apr-05 | 0 | 209085.7 |
| Friday | 22-Apr-05 | 0 | 209149.4 |
| Saturday | 23-Apr-05 | 0 | |
| Sunday | 24-Apr-05 | 0 | |
| Monday | 25-Apr-05 | 0 | |
| Tuesday | 26-Apr-05 | 0 | 209395.4 |
| Wednesday | 27-Apr-05 | 0 | 209424.7 |
| Thursday | 28-Apr-05 | 4 | 209426.1 |
| Friday | 29-Apr-05 | 0 | 209500.6 |
| Saturday | 30-Apr-05 | 0 | |
| Sunday | 1-May-05 | 0 | |
| Monday | 2-May-05 | 0 | |

| | | | |
|---|---|---|---|
| Tuesday | 3-May-05 | 0 | 209719.6 |
| Wednesday | 4-May-05 | 0 | |
| Thursday | 5-May-05 | 0 | 209837.7 |
| Friday | 6-May-05 | 0 | |
| Saturday | 7-May-05 | 0 | |
| Sunday | 8-May-05 | 0 | |
| Monday | 9-May-05 | 0 | 210869.5 |
| Tuesday | 10-May-05 | 0 | 210988.6 |
| Wednesday | 11-May-05 | 13.5 | 210100.2 |
| Thursday | 12-May-05 | 5 | 210102.2 |
| Friday | 13-May-05 | 0 | |
| Saturday | 14-May-05 | 0 | |
| Sunday | 15-May-05 | 0 | |
| Monday | 16-May-05 | 0 | 210297.0 |
| Tuesday | 17-May-05 | 0 | 210350.2 |
| Wednesday | 18-May-05 | 0 | 210407.8 |
| Thursday | 19-May-05 | 17.5 | |
| Friday | 20-May-05 | 0 | 210473.3 |
| Saturday | 21-May-05 | 0 | |
| Sunday | 22-May-05 | 0 | |
| Monday | 23-May-05 | 0 | 210674.1 |
| Tuesday | 24-May-05 | 0 | 210754.8 |
| Wednesday | 25-May-05 | 0 | |
| Thursday | 26-May-05 | 0 | 210895.8 |
| Friday | 27-May-05 | 0 | |
| Saturday | 28-May-05 | 0 | |
| Sunday | 29-May-05 | 0 | |
| Monday | 30-May-05 | 0 | |
| Tuesday | 31-May-05 | 0 | 211206.4 |
| Wednesday | 1-Jun-05 | 0 | |
| Thursday | 2-Jun-05 | 0 | |
| Friday | 3-Jun-05 | 0 | 211334.2 |
| Saturday | 4-Jun-05 | 0 | |
| Sunday | 5-Jun-05 | 0 | |
| Monday | 6-Jun-05 | 0 | 211407.8 |
| Tuesday | 7-Jun-05 | 0 | 211545.1 |
| Wednesday | 8-Jun-05 | 0 | |
| Thursday | 9-Jun-05 | 0 | |
| Friday | 10-Jun-05 | 2 | |
| Saturday | 11-Jun-05 | 0 | |
| Sunday | 12-Jun-05 | 0 | |
| Monday | 13-Jun-05 | 0 | |
| Tuesday | 14-Jun-05 | 27 | 211791.9 |
| Wednesday | 15-Jun-05 | 3 | |
| Thursday | 16-Jun-05 | 0 | 211792.7 |
| Friday | 17-Jun-05 | 0 | 211824.3 |
| Saturday | 18-Jun-05 | 0 | |
| Sunday | 19-Jun-05 | 23 | |
| Monday | 20-Jun-05 | 0 | 211881.0 |
| Tuesday | 21-Jun-05 | 0 | 211882.2 |
| Wednesday | 22-Jun-05 | 0 | 211909.6 |
| Thursday | 23-Jun-05 | 0 | |
| Friday | 24-Jun-05 | 0 | |

| | | | |
|---|---|---|---|
| Saturday | 25-Jun-05 | 0 | |
| Sunday | 26-Jun-05 | 5 | |
| Monday | 27-Jun-05 | 9 | |
| Tuesday | 28-Jun-05 | 7 | |
| Wednesday | 29-Jun-05 | 1.5 | |
| Thursday | 30-Jun-05 | 27 | 212002.3 |
| Friday | 1-Jul-05 | 0 | 212093.3 |
| Saturday | 2-Jul-05 | 0 | |
| Sunday | 3-Jul-05 | 0 | |
| Monday | 4-Jul-05 | 0 | 212158.2 |
| Tuesday | 5-Jul-05 | 0 | 212188.4 |
| Wednesday | 6-Jul-05 | 0 | 212229.4 |
| Thursday | 7-Jul-05 | 0 | 212270.3 |
| Friday | 8-Jul-05 | 0 | 212378.4 |
| Saturday | 9-Jul-05 | 0 | |
| Sunday | 10-Jul-05 | 0 | |
| Monday | 11-Jul-05 | 0 | 212688.5 |
| Tuesday | 12-Jul-05 | 0 | 212690.1 |
| Wednesday | 13-Jul-05 | 0 | 212724.5 |
| Thursday | 14-Jul-05 | 0 | 212726.8 |
| Friday | 15-Jul-05 | 0 | 212792.7 |
| Saturday | 16-Jul-05 | 0 | |
| Sunday | 17-Jul-05 | 0 | |
| Monday | 18-Jul-05 | 0 | 212974.2 |
| Tuesday | 19-Jul-05 | 0 | 212976.6 |
| Wednesday | 20-Jul-05 | 0 | 212985.4 |
| Thursday | 21-Jul-05 | 0 | 213044.0 |
| Friday | 22-Jul-05 | 0 | 213062.2 |
| Saturday | 23-Jul-05 | 0 | |
| Sunday | 24-Jul-05 | 0 | |
| Monday | 25-Jul-05 | 0 | 213152.0 |
| Tuesday | 26-Jul-05 | 0 | 213198.9 |
| Wednesday | 27-Jul-05 | 0 | |
| Thursday | 28-Jul-05 | 0 | 213281.4 |
| Friday | 29-Jul-05 | 0 | 213347.6 |
| Saturday | 30-Jul-05 | 0 | |
| Sunday | 31-Jul-05 | 0 | |
| Monday | 1-Aug-05 | 0 | 213495.2 |
| Tuesday | 2-Aug-05 | 0 | 21352.8 |
| Wednesday | 3-Aug-05 | 0 | 213595.0 |
| Thursday | 4-Aug-05 | 11.5 | |
| Friday | 5-Aug-05 | 0 | 213632.8 |
| Saturday | 6-Aug-05 | 0 | |
| Sunday | 7-Aug-05 | 0 | |
| Monday | 8-Aug-05 | 0 | |
| Tuesday | 9-Aug-05 | 0 | |
| Wednesday | 10-Aug-05 | 0 | 213931.7 |
| Thursday | 11-Aug-05 | 0 | 213993.6 |
| Friday | 12-Aug-05 | 0 | 214067.7 |
| Saturday | 13-Aug-05 | 0 | |
| Sunday | 14-Aug-05 | 0 | |
| Monday | 15-Aug-05 | 0 | 214275.9 |
| Tuesday | 16-Aug-05 | 0 | |

| | | | |
|---|---|---|---|
| Wednesday | 17-Aug-05 | 0 | |
| Thursday | 18-Aug-05 | 0 | |
| Friday | 19-Aug-05 | 0 | |
| Saturday | 20-Aug-05 | 0 | |
| Sunday | 21-Aug-05 | 0 | |
| Monday | 22-Aug-05 | 0 | 214698.9 |
| Tuesday | 23-Aug-05 | 0 | |
| Wednesday | 24-Aug-05 | 0 | 214830.8 |
| Thursday | 25-Aug-05 | 0 | 214893.9 |
| Friday | 26-Aug-05 | 0 | 214947.1 |
| Saturday | 27-Aug-05 | 0 | |
| Sunday | 28-Aug-05 | 0 | |
| Monday | 29-Aug-05 | 0 | 215155.3 |
| Tuesday | 30-Aug-05 | 0 | 215205.3 |
| Wednesday | 31-Aug-05 | 0 | 215208.2 |
| Thursday | 1-Sep-05 | 0 | 215262.5 |
| Friday | 2-Sep-05 | 0 | |
| Saturday | 3-Sep-05 | 0 | |
| Sunday | 4-Sep-05 | 0 | |
| Monday | 5-Sep-05 | 0 | 215558.5 |
| Tuesday | 6-Sep-05 | 0 | 215628.0 |
| Wednesday | 7-Sep-05 | 0 | 215203.9 |
| Thursday | 8-Sep-05 | 0 | |
| Friday | 9-Sep-05 | 0 | |
| Saturday | 10-Sep-05 | 0 | |
| Sunday | 11-Sep-05 | 0 | |
| Monday | 12-Sep-05 | 0 | 216037.4 |
| Tuesday | 13-Sep-05 | 0 | 216074.4 |
| Wednesday | 14-Sep-05 | 0 | |
| Thursday | 15-Sep-05 | 0 | 216196.4 |
| Friday | 16-Sep-05 | 7 | 216261.6 |
| Saturday | 17-Sep-05 | 0 | |
| Sunday | 18-Sep-05 | 0 | |
| Monday | 19-Sep-05 | 0 | 216465.4 |
| Tuesday | 20-Sep-05 | 0 | 216537.7 |
| Wednesday | 21-Sep-05 | 0 | 216606.3 |
| Thursday | 22-Sep-05 | 0 | |
| Friday | 23-Sep-05 | 0 | 216725.0 |
| Saturday | 24-Sep-05 | 0 | |
| Sunday | 25-Sep-05 | 0 | |
| Monday | 26-Sep-05 | 1.5 | 216899.1 |
| Tuesday | 27-Sep-05 | 0 | 216953.6 |
| Wednesday | 28-Sep-05 | 0 | 217007.6 |
| Thursday | 29-Sep-05 | 0 | |
| Friday | 30-Sep-05 | 0 | 217122.3 |
| Saturday | 1-Oct-05 | 0 | |
| Sunday | 2-Oct-05 | 0 | |
| Monday | 3-Oct-05 | 0 | 217304.1 |
| Tuesday | 4-Oct-05 | 0 | 217363.6 |
| Wednesday | 5-Oct-05 | 0 | |
| Thursday | 6-Oct-05 | 0 | 217519.6 |
| Friday | 7-Oct-05 | 0 | |
| Saturday | 8-Oct-05 | 0 | |

| | | | |
|---|---|---|---|
| Sunday | 9-Oct-05 | 0 | |
| Monday | 10-Oct-05 | 0 | 217945.6 |
| Tuesday | 11-Oct-05 | 0 | 218058.8 |
| Wednesday | 12-Oct-05 | 0 | 218169.0 |
| Thursday | 13-Oct-05 | 30 | |
| Friday | 14-Oct-05 | 0 | 218272.8 |
| Saturday | 15-Oct-05 | 0 | |
| Sunday | 16-Oct-05 | 19 | |
| Monday | 17-Oct-05 | 15 | |
| Tuesday | 18-Oct-05 | 0 | |
| Wednesday | 19-Oct-05 | 0 | 218337.4 |
| Thursday | 20-Oct-05 | 19 | 218338.4 |
| Friday | 21-Oct-05 | 0 | |
| Saturday | 22-Oct-05 | 0 | |
| Sunday | 23-Oct-05 | 0 | |
| Monday | 24-Oct-05 | 36 | |
| Tuesday | 25-Oct-05 | 13 | 218561.2 |
| Wednesday | 26-Oct-05 | 6 | |
| Thursday | 27-Oct-05 | 2.5 | |
| Friday | 28-Oct-05 | 0 | 218663.6 |
| Saturday | 29-Oct-05 | 0 | |
| Sunday | 30-Oct-05 | 0 | |
| Monday | 31-Oct-05 | 0 | 218908.2 |
| Tuesday | 1-Nov-05 | 0 | 208995.9 |
| Wednesday | 2-Nov-05 | 0 | 219084.4 |
| Thursday | 3-Nov-05 | 0 | 219145.4 |
| Friday | 4-Nov-05 | 4 | |
| Saturday | 5-Nov-05 | 74 | |
| Sunday | 6-Nov-05 | 0 | |
| Monday | 7-Nov-05 | 0 | |
| Tuesday | 8-Nov-05 | 0 | 219341.7 |
| Wednesday | 9-Nov-05 | 0 | 219523.3 |
| Thursday | 10-Nov-05 | 12 | |
| Friday | 11-Nov-05 | 0 | |
| Saturday | 12-Nov-05 | 0 | |
| Sunday | 13-Nov-05 | 0 | |
| Monday | 14-Nov-05 | 0 | 219824.7 |
| Tuesday | 15-Nov-05 | 12.5 | |
| Wednesday | 16-Nov-05 | 0 | |
| Thursday | 17-Nov-05 | 0 | |
| Friday | 18-Nov-05 | 0 | |
| Saturday | 19-Nov-05 | 0 | |
| Sunday | 20-Nov-05 | 0 | |
| Monday | 21-Nov-05 | 0 | |
| Tuesday | 22-Nov-05 | 4 | 219893.9 |
| Wednesday | 23-Nov-05 | 0 | |
| Thursday | 24-Nov-05 | 0 | 220517.9 |
| Friday | 25-Nov-05 | 11.5 | 220517.9 |
| Saturday | 26-Nov-05 | 2.5 | |
| Sunday | 27-Nov-05 | 1 | |
| Monday | 28-Nov-05 | 0 | 220654.9 |
| Tuesday | 29-Nov-05 | 0 | 220736.4 |
| Wednesday | 30-Nov-05 | 0 | 220818.9 |

| | | | |
|---|---|---|---|
| Thursday | 1-Dec-05 | 0 | 220848.9 |
| Friday | 2-Dec-05 | 10 | 220855.5 |
| Saturday | 3-Dec-05 | 0 | |
| Sunday | 4-Dec-05 | 0 | |
| Monday | 5-Dec-05 | 0 | 221044.5 |
| Tuesday | 6-Dec-05 | 0 | 221148.5 |
| Wednesday | 7-Dec-05 | 0 | |
| Thursday | 8-Dec-05 | 0 | 221323.5 |
| Friday | 9-Dec-05 | 0 | 221392.5 |
| Saturday | 10-Dec-05 | 0 | |
| Sunday | 11-Dec-05 | 0 | |
| Monday | 12-Dec-05 | 0 | 221671.1 |
| Tuesday | 13-Dec-05 | 0 | 221759.5 |
| Wednesday | 14-Dec-05 | 0 | |
| Thursday | 15-Dec-05 | 0 | |
| Friday | 16-Dec-05 | 0 | |
| Saturday | 17-Dec-05 | 0 | |
| Sunday | 18-Dec-05 | 0 | |
| Monday | 19-Dec-05 | 0 | 222279.0 |
| Tuesday | 20-Dec-05 | 0 | 222369.0 |
| Wednesday | 21-Dec-05 | 0 | 222470.0 |
| Thursday | 22-Dec-05 | 0 | |
| Friday | 23-Dec-05 | 0 | |
| Saturday | 24-Dec-05 | 0 | |
| Sunday | 25-Dec-05 | 0 | |
| Monday | 26-Dec-05 | 0 | |
| Tuesday | 27-Dec-05 | 0 | |
| Wednesday | 28-Dec-05 | 0 | |
| Thursday | 29-Dec-05 | 0 | 223276.0 |
| Friday | 30-Dec-05 | 0 | |
| Saturday | 31-Dec-05 | 0 | |
| Sunday | 1-Jan-06 | 0 | |
| Monday | 2-Jan-06 | 0 | |
| Tuesday | 3-Jan-06 | 0 | 223789.9 |
| Wednesday | 4-Jan-06 | 22.5 | 223898.4 |
| Thursday | 5-Jan-06 | 32 | |
| Friday | 6-Jan-06 | 6.5 | |
| Saturday | 7-Jan-06 | 5 | |
| Sunday | 8-Jan-06 | 57.5 | |
| Monday | 9-Jan-06 | 18.5 | |
| Tuesday | 10-Jan-06 | 0 | |
| Wednesday | 11-Jan-06 | 14.5 | 224170.9 |
| Thursday | 12-Jan-06 | 0 | |
| Friday | 13-Jan-06 | 0 | |
| Saturday | 14-Jan-06 | 0 | |
| Sunday | 15-Jan-06 | 0 | |
| Monday | 16-Jan-06 | 0 | 224589.1 |
| Tuesday | 17-Jan-06 | 0 | |
| Wednesday | 18-Jan-06 | 11.5 | 224789.1 |
| Thursday | 19-Jan-06 | 1 | 224847.5 |
| Friday | 20-Jan-06 | 7.5 | |
| Saturday | 21-Jan-06 | 1.5 | |
| Sunday | 22-Jan-06 | 0 | |

| | | | |
|---|---|---|---|
| Monday | 23-Jan-06 | 0 | 225023.4 |
| Tuesday | 24-Jan-06 | 0 | 225118.5 |
| Wednesday | 25-Jan-06 | 0 | |
| Thursday | 26-Jan-06 | 0 | |
| Friday | 27-Jan-06 | 0 | 225389.7 |
| Saturday | 28-Jan-06 | 0 | |
| Sunday | 29-Jan-06 | 0 | |
| Monday | 30-Jan-06 | 0 | |
| Tuesday | 31-Jan-06 | 0 | |
| Wednesday | 1-Feb-06 | 0 | |
| Thursday | 2-Feb-06 | 0 | |
| Friday | 3-Feb-06 | 0 | 226119.3 |
| Saturday | 4-Feb-06 | 0 | |
| Sunday | 5-Feb-06 | 1 | |
| Monday | 6-Feb-06 | 0.5 | 226388.0 |
| Tuesday | 7-Feb-06 | 0 | 226499.4 |
| Wednesday | 8-Feb-06 | 0 | 226521.4 |
| Thursday | 9-Feb-06 | 0 | |
| Friday | 10-Feb-06 | 0 | 226712.7 |
| Saturday | 11-Feb-06 | 0 | 226738.1 |
| Sunday | 12-Feb-06 | 0 | |
| Monday | 13-Feb-06 | 0 | 226980.4 |
| Tuesday | 14-Feb-06 | 0 | 227053.6 |
| Wednesday | 15-Feb-06 | 26 | 227108.8 |
| Thursday | 16-Feb-06 | 0 | 227142.2 |
| Friday | 17-Feb-06 | 0 | 227174.5 |
| Saturday | 18-Feb-06 | 0 | |
| Sunday | 19-Feb-06 | 1 | |
| Monday | 20-Feb-06 | 0 | 227255.9 |
| Tuesday | 21-Feb-06 | 0 | 227324.4 |
| Wednesday | 22-Feb-06 | 0 | |
| Thursday | 23-Feb-06 | 0 | 227422.3 |
| Friday | 24-Feb-06 | 0 | 227476.7 |
| Saturday | 25-Feb-06 | 0 | |
| Sunday | 26-Feb-06 | 0 | |
| Monday | 27-Feb-06 | 11 | 227588.2 |
| Tuesday | 28-Feb-06 | 17 | 227655.3 |
| Wednesday | 1-Mar-06 | 0 | 227654.6 |
| Thursday | 2-Mar-06 | 0 | 227679.8 |
| Friday | 3-Mar-06 | 3.5 | 227706.4 |
| Saturday | 4-Mar-06 | 0 | |
| Sunday | 5-Mar-06 | 0 | |
| Monday | 6-Mar-06 | 0 | 227896.1 |
| Tuesday | 7-Mar-06 | 0 | 227954.9 |
| Wednesday | 8-Mar-06 | 0 | 228015.6 |
| Thursday | 9-Mar-06 | 0 | 228067.6 |
| Friday | 10-Mar-06 | 0 | |
| Saturday | 11-Mar-06 | 0 | |
| Sunday | 12-Mar-06 | 0 | |
| Monday | 13-Mar-06 | 0 | 228360.0 |
| Tuesday | 14-Mar-06 | 0 | 228427.5 |
| Wednesday | 15-Mar-06 | 0 | 228496.2 |
| Thursday | 16-Mar-06 | 0 | 228563.8 |

| | | | |
|---|---|---|---|
| Friday | 17-Mar-06 | 0 | |
| Saturday | 18-Mar-06 | 0 | |
| Sunday | 19-Mar-06 | 0 | |
| Monday | 20-Mar-06 | 0 | 228870.1 |
| Tuesday | 21-Mar-06 | 0 | |
| Wednesday | 22-Mar-06 | 0 | 229007.4 |
| Thursday | 23-Mar-06 | 0 | 229042.4 |
| Friday | 24-Mar-06 | 0 | 229127.9 |
| Saturday | 25-Mar-06 | 0 | |
| Sunday | 26-Mar-06 | 0 | |
| Monday | 27-Mar-06 | 0 | 229364.6 |
| Tuesday | 28-Mar-06 | 0 | 229423.9 |
| Wednesday | 29-Mar-06 | 0 | |
| Thursday | 30-Mar-06 | 0 | |
| Friday | 31-Mar-06 | 0 | 229590.4 |
| Saturday | 1-Apr-06 | 0 | |
| Sunday | 2-Apr-06 | 0 | |
| Monday | 3-Apr-06 | 2 | 229769.8 |
| Tuesday | 4-Apr-06 | 2 | |
| Wednesday | 5-Apr-06 | 0 | 229850.6 |
| Thursday | 6-Apr-06 | 23 | |
| Friday | 7-Apr-06 | 0 | |
| Saturday | 8-Apr-06 | 0 | |
| Sunday | 9-Apr-06 | 0 | |
| Monday | 10-Apr-06 | 0 | 230152.2 |
| Tuesday | 11-Apr-06 | 0 | |
| Wednesday | 12-Apr-06 | 0 | 230333.8 |
| Thursday | 13-Apr-06 | 0 | |
| Friday | 14-Apr-06 | 0 | |
| Saturday | 15-Apr-06 | 0 | |
| Sunday | 16-Apr-06 | 0 | |
| Monday | 17-Apr-06 | 0 | |
| Tuesday | 18-Apr-06 | 0 | 230723.1 |
| Wednesday | 19-Apr-06 | 0 | |
| Thursday | 20-Apr-06 | 0 | |
| Friday | 21-Apr-06 | 0 | |
| Saturday | 22-Apr-06 | 0 | |
| Sunday | 23-Apr-06 | 0 | |
| Monday | 24-Apr-06 | 0 | |
| Tuesday | 25-Apr-06 | 0 | |
| Wednesday | 26-Apr-06 | 0 | |
| Thursday | 27-Apr-06 | 0 | |
| Friday | 28-Apr-06 | 0 | |
| Saturday | 29-Apr-06 | 0 | |
| Sunday | 30-Apr-06 | 0 | |

## Table B2 – Observed Spoon Drain Data

| Cumulative Time (mins) | Observed Flow (L/s) |
|---|---|
| 0 | 0.00 |
| 2 | 0.00 |
| 8 | 0.00 |
| 10 | 0.00 |
| 13 | 0.00 |
| 15 | 0.01 |
| 17 | 0.03 |
| 19 | 0.15 |
| 21 | 0.38 |
| 22 | 0.89 |
| 23 | 1.00 |
| 24 | 1.11 |
| 26 | 1.15 |
| 28 | 1.24 |
| 30 | 1.28 |
| 32 | 1.32 |
| 34 | 1.32 |
| 36 | 1.37 |
| 38 | 1.41 |
| 40 | 1.41 |
| 45 | 1.51 |
| 50 | 1.71 |
| 55 | 1.76 |
| 60 | 1.81 |
| 65 | 1.92 |
| 70 | 1.98 |
| 75 | 2.03 |
| 80 | 2.09 |
| 85 | 2.15 |
| 90 | 2.27 |
| 95 | 2.40 |
| 100 | 2.33 |
| 105 | 2.27 |
| 110 | 2.27 |
| 115 | 2.21 |
| 120 | 2.15 |

# APPENDIX C

## Site Overview

Figure C1 – Site Photography

Figure C1a – Overlooking Drainage infrastructure towards potential harvest area

Figure C1b – Looking east along spoon drain

**Figure C1c – Overlooking wet retention pond**

# APPENDIX D

## Model Schematic

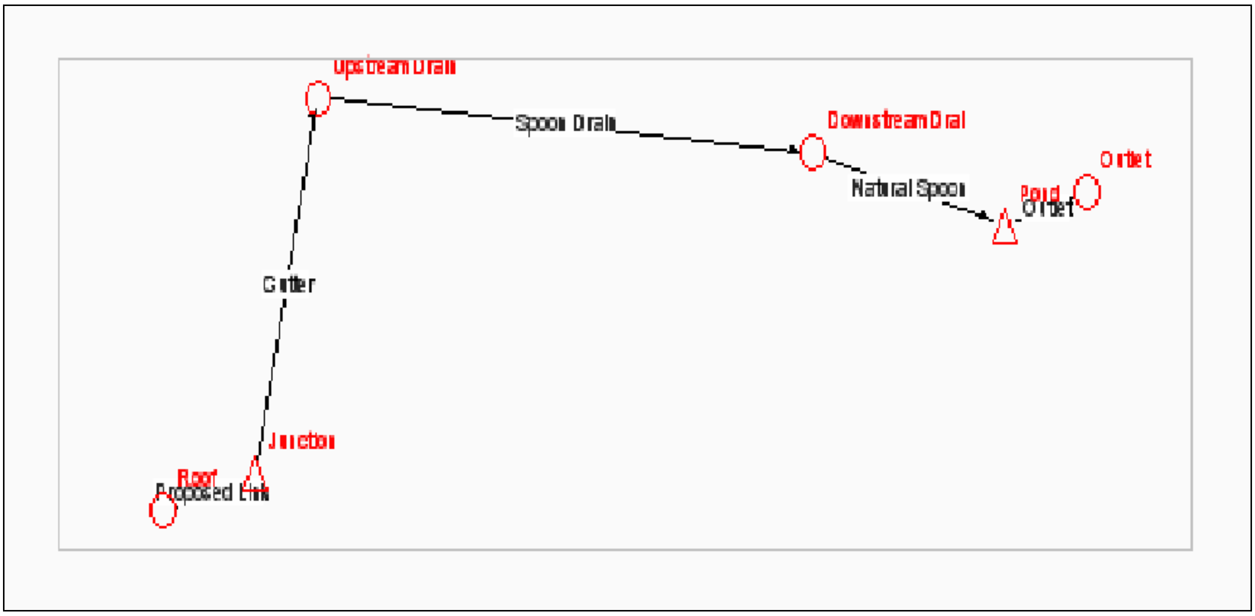


**Figure D1 – Model Schematic**

# APPENDIX E

## IFD Theoretical

This appendix outlines the procedural steps involved for the determination of a complete set of IFD information. The procedure is set out in numbered steps.

***STEP 1 DETERMINE INPUT DATA***

***PROCEDURE:***

Read from the maps in Australian Rainfall and Runoff Volume 2 (Volume 2) the six basic rainfall intensities (MAPs 1-6) and one skewness value (MAP 7) for the required location. In Volume 2 these maps are numbered with a second digit which simply refers to the region of Australia covered by the maps. If durations less than one hour are required then the geographical short duration factors (F2 and F50) should also be read (MAPs 8 and 9 in Volume 2). The values obtained are:

MAP 1 = ${}^{2}i_{1}$ = 1 hour duration, ARI = 2 years

MAP 2 = ${}^{2}i_{12}$ = 12 hour duration, ARI = 2 years

MAP 3 = ${}^{2}i_{72}$ = 72 hour duration, ARI = 2 years

MAP 4 = ${}^{50}i_{1}$ = 1 hour duration, ARI = 50 years

MAP 5 = ${}^{50}i_{12}$ = 12 hour duration, ARI = 50 years

MAP 6 = ${}^{50}i_{72}$ = 72 hour duration, ARI = 50 years

MAP 7 = G = skewness

* MAP 8 = F2 = geographical factor for obtaining 6 minute duration intensities, ARI = 2 years

* MAP 9 = F50 = geographical factor for obtaining 6 minute duration intensities, ARI = 50 years

Here i represents the log-normal rainfall intensity read from the maps. These basic input intensities are log-normal estimates (G = 0) for ARIs of 2 and 50 years. If G = 0, ie the location is not in an area where log-normality applies, then these basic intensities must be converted to LPIII intensities (STEP 3).

* Note: If durations less than 1 hour are not required then MAPs 8 and 9 need not be read. The relationships shown by MAPs 8 and 9 are described by complex algebraic expressions given in the Appendix. It is only recommended that these algebraic expressions be used if numerous IFD relations are required, and it is desired that the technique be automated for use on a microcomputer or programmable calculator. In these cases MAPs 8 and 9 can be used to check that the formulae have been entered correctly.

***STEP 2: REQUIRED FOR INTENSITIES FOR DURATIONS LESS THAN ONE HOUR***

***PROCEDURE:***

Calculate the 6 minute intensities for ARI 2 years, ${}^{2}i_{6m}$ and for ARI 50 years, ${}^{50}i_{6m}$ using the following formulae:

$${}^{2}i_{6m} = F2 \times ({}^{2}i_{1})^{0.9} \quad \textbf{(E.1)}$$

$^{50}i_{6m} = F50 \times (^{50}i_1)^{0.6}$ …………………………………………………………………………………… **(E.2)**

where $^{2}i_1$, $^{50}i_1$, F2 and F50 are obtained in STEP 1.

***STEP 3: DETERMINE LPIII DESIGN RAINFALLS FOR ARI 2 AND 50 YEARS FOR BASIC DURATIONS***

***PREAMBLE:***

*To determine the LPIII estimates from the basic log-normal (ARI 2 year and 50 years) input intensities, the mean and standard deviation of the logarithms of the rainfall intensities for the specific duration required must be calculated. Equations A(3.3) and A(3.4) are used to determine these means and standard deviations. The basic durations are the three from the maps (1, 12 and 72 hours) and the 6 minute duration (if STEP 2 has been followed). The log-normal rainfall intensity estimates are symbolised by i while the LPIII estimates are symbolised by I. If G = 0, the calculations of this step will produce LPIII intensities equivalent to the input log-normal intensities (STEPs 1 and 2). However it is still necessary to carry out the calculations for G = 0 in order to derive the parameters (means and standard deviations) required for STEP 5 and as a check on the correct use of the procedures.*

*The mean and standard deviation of the logarithms of the primary rainfall intensities are given by the following formulae:*

$X_D = \log_{10}(^{2}i_D / 1.13)$ ……………………………………………………………………………………. **(E.3)**

$S_D = 0.4869 \times \log_{10}(^{50}i_D \times 1.13 / {}^{2}i_D)$ ………………………………………………………………….**(E.4)**

*where* D = *6 minutes, 1 hour, 12 hours or 72 hours,*

$X_D$ = *mean of the logarithms of the primary rainfall series for duration* D *and*

$S_D$ = *standard deviation of the primary rainfall series for duration* D.

*The LPIII estimates of design rainfall are then calculated from:*

$^{Y}I_D = {}^{Y}P[\text{antilog}_{10}(X_D + {}^{Y}K \times S_D)]$ ………………………………………………………………………. **(E.5)**

*where* $^{Y}I_D$ = *the LPIII rainfall intensity estimate for an ARI of Y years and duration D*

*and where*

(i) $^{Y}$P = *conversion factor for annual to partial series estimates:*

$^{Y}P$ = *1.13 if Y = 2 years*

= *1.05 if Y = 5 years*

= *1.00 if Y = 10 years or more*

(ii) $^{Y}K$ = *The LPIII standard deviate for ARI = Y years*

*Alternatively,* $^{Y}K$ *can be obtained using the equation:*

$^{Y}K = 2 \times [\{(^{Y}K_N - G / 6) \times G / 6 + 1\}^3 - 1]/G$ for G>0

$= {}^{Y}K_N$ for G=0 ........ **(E.6)**

*Where G is the skewness (to 2 decimal places) for the location (MAP 7) and* $^{Y}K_N$ *are the standard normal deviates for an ARI of Y years:*

$^{2}K_N = 0$ $^{5}K_N = 0.8416$

$^{10}K_N = 1.2816$ $^{20}K_N = 1.6449$

$^{50}K_N = 2.0537$ $^{100}K_N = 2.326$

***PROCEDURE:***

i. Calculate, using equations (E.3), (E.4) and (E.5) the ARI 2 year and 50 year LPIII estimates for D = 1, 12 and 72 hours and 6 minutes (if durations less than 1 hour are required).

At a later step, STEP 5, the intensities for the other standard ARIs (5, 10, 20 and 100 years), as required by the user, will be determined using the same equations.

ii. The LPIII estimates determined at (i) are represented by the symbol I:

$^{2}I_{6m}$ = 6 min duration, ARI 2 years

$^{2}I_{1}$ = 1 hour duration, ARI 2 years

$^{2}I_{12}$ = 12 hour duration, ARI 2 years

$^{2}I_{72}$ = 72 hour duration, ARI 2 years

$^{50}I_{6m}$ = 6 min duration, ARI 50 years

$^{50}I_{1}$ = 1 hour duration, ARI 50 years

$^{50}I_{12}$ = 12 hour duration, ARI 50 years

$^{50}I_{72}$ = 72 hour duration, ARI 50 years

If G = 0, these intensity values will be the same as the log-normal estimates, i, obtained in STEPs 1 and 2. Otherwise, for G > 0, the ARI 50 year values will be slightly higher, depending on G, and the ARI 2 year slightly lower than the log-normal estimates. For example, for an extreme skewness of 0.8, say, these differences will be of the order of -5% and +20% for ARI 2 years and ARI 50 years respectively.

### *STEP 4: PLOT LPIII RAINFALLS FOR ARI 2 AND 50 YEARS AND FOR BASIC DURATIONS ON DIAGRAM 2.1. (VOLUME 2): OPTIONAL FOR ALGEBRAIC PROCEDURES*

***PREAMBLE:***

*This step is optional for the algebraic procedures of this Part. However it is recommended simply as a graphical confirmation of calculations and need not be repeated for many locations if the procedures are being programmed.*

***PROCEDURE:***

Plot the values ${}^{2}I_{1}$, ${}^{2}I_{12}$, ${}^{2}I_{72}$, ${}^{50}I_{1}$, ${}^{50}I_{12}$ and ${}^{50}I_{72}$ together with ${}^{2}I_{6m}$ and ${}^{50}I_{6m}$ if required, on a duration interpolation diagram. The plotted ARI 2 and 50 years data can be joined by straight lines. The intermediate duration data are calculated at a later step (STEP 7). This need not be done if the user does not require a graphical representation of the curves. However, plotting the ARI 2 and 50 year curves, and other ARIs as the user may require, is recommended as a check on calculations. These curves can be restricted to the durations of interest and to one or two locations if the procedures are being programmed.

### *STEP 5: DETERMINE LPIII DESIGN RAINFALLS FOR ARIs 5, 10, 20 AND 100 YEARS FOR BASIC DURATIONS*

***PREAMBLE:***

*The LPIII rainfall intensities for the basic durations for ARIs other than 1,2 and 50 years are calculated in this step. The mean and standard deviation of the logarithms of the rainfall intensities for the basic durations were calculated in STEP 3 using equations (E.3) and (E.4). These parameters are now used with equations (E.5) and (E.6) and the procedures of STEP 3 to calculate LPIII rainfall intensities for ARI 5, 10, 20 and 100 years. Rainfall intensities for other non-standard ARIs may also be calculated in this step (except ARI 1 year – see STEP 6).*

***PROCEDURE:***

(i) For durations 1, 12 and 72 hours and 6 min (if short durations are required) determine the LPIII estimates for other ARIs as required (ARI 2 and 50 year estimates were calculated in STEP 3). The equations for this determination are (E.5) and (E.6) described in full in STEP 3.
For a standard set of IFD curves, the ARIs to be calculated in this step are 5, 10, 20 and 100 years. However the equations allow any ARI above 2 years to be calculated.

(ii) Optional:

If the user wishes to represent the curves graphically, these LPIII estimates can be plotted on Aa duration interpolation diagram.

***STEP 6: CALCULATE ONE YEAR ARI RAINFALL INTENSITIES FOR BASIC DURATIONS***

***PREAMBLE:***

*If ARI = 1 year is not required, this step may be ignored and the user should proceed to STEP 7.*

***PROCEDURE***:

Calculate the ARI 1 year intensities for durations, D, of 6 minutes (if required), 1 hour, 12 hours and 72 hours using the formula:

$$^{1}I_D = 0.885 \times {}^{2}I_D / [1 + 0.4046 \log_{10}(1.13 \times {}^{50}I_D / {}^{2}I_D)] \quad \text{...........} \textbf{(E.7)}$$

where $^{2}I_D$ = ARI 2 year LPIII rainfall intensity for duration D

and $^{50}I_D$ = ARI 50 year LPIII rainfall intensity for duration D.

***STEP 7: INTERPOLATE FROM BASIC DURATIONS TO ALL OTHER DURATIONS FOR ALL ARIs.***

***PREAMBLE:***

***General Equations***

*The following formula forms the basis for interpolation and extrapolation between the basic durations of 6 minutes 1, 12, and 72 hours, for all ARIs:*

$$P_D = \log_{10}(D) + 0.103(\log_{10}(D))^2 - 0.0710(\log_{10}(D))^3 + 0.0108(\log_{10}(D))^5 \quad \text{...........} \textbf{(E.8)}$$

*where* $P_D$ *is the plotting position for the required duration, D (hours).*
*The interpolated LPIII rainfall intensity (for all ARIs) for the required duration, D, is then given by:*

$$I_D = I_L(I_U/I_L)^N \quad \text{...........} \textbf{(E.9)}$$

where N = $(P_D - P_L) / (P_U - P_L)$,

L (Lower) = *the basic duration below the required duration D,*

U (Upper) = *the basic duration above the required duration D,*

$P_L$ = *lower plotting position using D = L in (E.8),*

$P_U$ = *upper plotting position using D = U in (E.8),*

*and* $P_D$ = *the plotting position for the required duration, D,* *between L and U, using (E.8).* $I_D$, $I_L$ *and* $I_U$ *are the intensities corresponding to the durations D, L and U. The lower and upper durations, L and U are selected from the basic durations of 6 minutes, 1, 12 and 72 hours. For example, for a required duration, D, between 12 hours and 72 hours, L = 12 and U= 72;* $P_{12}$*,* $P_{72}$*, and* $P_D$ *are calculated from (E.8) and then used to determine N for input to equation (E.9).*

***Specific Equations For Standard Durations***

*For any ARI, the equations, (E.10), are:*

D = 5 minutes, $I_{5m} = I_{6m} (I_1 / I_{6m})^{-0.058}$

D = 6 minutes, $I_{6m}$ = *basic duration intensity calculated in STEP 3 for ARI 2 and 50 years and STEPs 5 and 6 for other ARIs.*

D = 10 minutes, $I_{10m} = I_{6m} (I_1 / I_{6m})^{0.181}$

D = 20 minutes, $I_{20m} = I_{6m} (I_1 / I_{6m})^{0.467}$

D = 30 minutes, $I_{30m} = I_{6m} (I_1 / I_{6m})^{0.654}$

D = 1 hour, $I_1$ = *basic duration intensity calculated in STEP 3 for ARI 2 and 50 years and in STEPs 5 and 6 for other ARIs.*

D = 2 hours, $I_2 = I_1 (I_{12} / I_1)^{0.274}$

D = 3 hours, $I_3 = I_1 ( I_{12} / I_1)^{0.438}$

D = 6 hours, $I_6 = I_1 (I_{12} / I_1)^{0.720}$

D = 12 hours, $I_{12}$ = *basic duration intensity calculated in STEP 3 for ARI 2 and 50 years and in STEPs 5 and 6 for other ARIs.*

D = 24 hours, $I_{24} = I_{12} (I_{72} / I_{12})^{0.365}$

D = 48 hours, $I_{48} = I_{12} (I_{72} / I_{12})^{0.751}$

D = 72 hours, $I_{72}$ = *basic duration intensity calculated in STEP 3 for ARI 2 and 50 years and in STEPs 5 and 6 for other ARIs.*

**(E.10)**

***PROCEDURE***:

(i) Calculate the standard duration LPIII estimates, for the required ARIs, using the specific equations given in the preamble (E.10).

If durations other than the standard ones are required, the general equation (E.9) can be used.

(ii) The rainfall IFD tabulated data, can now be completed for the standard durations and ARIs using (i) above.