Probabilistic Analysis of Monthly Peak Factors in a Regional Water Distribution System

by
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DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the authorship owner thereof (unless to the extent explitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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SYNOPSIS

The design of a water supply system relies on the knowledge of the water demands of its specific end-users. It is also important to understand the end-users' temporal variation in water demand. Failure of the system to provide the required volume of water at the required flow-rate is deemed a system failure. The system therefore needs to be designed with sufficient capacity to ensure that it is able to supply the required volume of water during the highest demand periods. In practice, bulk water supply systems do not have to cater for the high frequency, short duration high peak demand scenarios of the end-user, such as the peak hour or peak day events, as the impact of events is reduced by the provision of water storage capacity at the off-take from the bulk supply system. However, for peak demand scenarios with durations longer than an hour or a day, depending on the situation, the provision of sufficient storage capacity to reduce the impact on the bulk water system, becomes impractical and could lead to potential water quality issues during low demand periods. It is, therefore, a requirement that bulk water systems be designed to be able to meet the peak weekly or peak month end-user demands. These peak demand scenarios usually occur only during a certain portion of the year, generally concentrated in a two to three month period during the drier months. Existing design guidelines usually follow a deterministic design approach, whereby a suitable DPF is applied to the average annual daily system demand in order to determine the expected peak demand on the system. This DPF does not account for the potential variability in end-user demand profiles, or the impact that end-storage has on the required peak design factor of the bulk system.

This study investigated the temporal variations of end-user demand on two bulk water supply systems. These systems are located in the winter rainfall region of the Western Cape province of South Africa. The data analysed was the monthly measured consumption figures of different end-users supplied from the two systems. The data-sets extended over 14 years of data. Actual monthly peak factors were extracted from this data and used in deterministic and probabilistic methods to determine the expected monthly peak factor for both the end-user and the system design. The probabilistic method made use of a Monte Carlo analysis, whereby the actual recorded monthly peak factor for each end-user per bulk system was used as an input into discrete probability functions. The Monte Carlo analysis executed 1 500 000 iterations in order to produce probability distributions of the monthly peak factors for each system. The deterministic and probabilistic results were compared to the actual monthly peak factors as calculated from the existing water use data, as well as against current DPFs as published in guidelines used in the industry. The study demonstrated that the deterministic method would overstate the expected peak system demand and result in an oversized system. The probabilistic method yielded good results and compared well with the actual monthly peak factors. It is thus deemed an appropriate tool to use to determine the required DPF of a bulk water system for a chosen reliability of supply. The study also indicated the DPFs proposed by current guidelines to be too low. The study identified a potential relationship between the average demand of an end-user and the expected maximum monthly peak factor, whereas in current guidelines peak factors are not indicated as being influenced by the end-user average demand.

SAMEVATTING

Die ontwerp van ‘n watervoorsiening stelsel berus op die kennis van die water aanvraag van sy spesifieke eindverbruikers. Dit is ook belangrik om ‘n begrip te hê van die tydelike variasie van die eindverbruiker se water-aanvraag. Indien die voorsieningstelsel nie in staat is om die benodigde volume water teen die verlangde vloeitempo te kan lewer nie, word dit beskou as ‘n faling. Die stelsel word dus ontwerp met voldoende kapasiteit wat dit sal in staat stel om die benodigde volume gedurende die hoogste aanvraag periodes te kan voorsien. In die praktyk hoef grootmaat water-voorsiening stelsels nie te voldoen aan spits watergebeurtenisse met hoë frekwensie en kort duurtes, soos piek-dag of piek-uur aanvraag nie, aangesien hierdie gebeurtenisse se impak op die grootmaat stelsel verminder word deur die voorsiening van water-opgaring fasiliteite by die aftap-punte vanaf die grootmaatstelsels. Nieteenstaande, vir piek-aanvraag gebeurtenisse met langer duurtes as ‘n uur of dag, raak die voorsiening van voldoende wateropgaring kapasiteit by die aftap-punt onprakties en kan dit selfs lei tot waterkwaliteits probleme. Dit is dus ‘n vereiste dat grootmaat watervoorsienings stelsels ontwerp moet word om die piek-week of piek-maand eind-verbruiker aanvrae te kan voorsien. Hierdie piek-aanvraag gebeurtenisse vind algemeen in gekonsentreerde twee- of drie maand periodes tydens die droeër maande plaas. Bestaande ontwerpsriglyne volg gewoonlik ‘n deterministiese ontwerp benadering, deurdat ‘n voldoende ontwerp spits faktor toegepas word op die gemiddelde jaarlikse daaglikse stelsel aanvraag om sodoende te bepaal wat die verwagte spits aanvraag van die stelsel sal wees. Hierdie ontwerp spits faktor maak nie voorsiening vir die potensiële variasie in die eindverbruiker se aanvraag karakter of die impak van die beskikbare water-opgaring fasiliteit op die benodigde ontwerp spits faktor van die grootmaat-stelsel nie.

Hierdie studie ondersoek die tydelike variasie van die eindverbruiker se aanvraag op twee grootmaat water-voorsiening stelsels. Die twee stelsels is geleë in die winter reënval streek van die Wes-Kaap provinsie van Suid-Afrika. Die data wat geanaliseer is was die maandelikse gemeterde verbruiksyfers van verskillende eindverbruikers voorsien deur die twee stelsels. Die datastelle het oor 14 jaar gestrek. Die ware maand piek-faktore is bereken vanaf die data en is in deterministiese en probabilistiese metodes gebruik om die verwagte eindverbruiker en stelsel ontwerp se maand spits-faktore te bereken. Die probabilistiese metode het gebruik gemaak van ‘n Monte Carlo analise metode, waardeur die ware gemeette maand spits-faktor vir elke eindverbruiker vir elke grootmaatstelsel gebruik is as invoer tot diskrete waarskynlikheids funksies. Die Monte Carlo analise het 1 500 000 iterasies voltooi om waarskynlikheids-verdelings van elke maand spits-faktor vir elke stelsel te bereken. Die deterministiese en probabilistiese resultate is vergelyk met die ware maand spits faktore soos bereken vanuit die bestaande waterverbruik data, asook teen huidige gepubliseerde ontwerp spits-faktore, wat in die bedryf gebruik word.

Die studie het aangetoon dat die deterministiese metode te konserwatief is en dat dit die verwagte piek-aanvraag van die stelsel sal oorskat en dus sal lei tot ‘n oorgrootte stelsel. Die probabilistiese metode het goeie resultate opgelewer wat goed vergelyk met die ware maand piek-faktore. Dit word gereken as ‘n toepaslike metode om die benodigde ontwerp spits-faktor van ‘n grootmaat-watervoorsiening stelsel te bepaal vir ‘n gekose voorsieningsbetroubaarheid. Die studie het ook aangedui dat die ontwerps piek-faktore voorgestel deur die huidige riglyne te laag is en dat dit tot die falings van ‘n stelsel sal lei. Die studie het ‘n moontlike verwantskap tussen die gemiddelde daaglikse wateraanvraag van die eindverbruiker en die verwagte maksimum maand spits faktor geïdentifiseer, nademaal die piek-faktore soos voorgestel deur die huidige riglyne nie beïnvloed word deur die eindverbruiker se gemiddelde verbruik nie.

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LIST OF ABBREVIATIONS AND ACRONYMS

AADD	: Annual Average Daily Demand
AC	: Annual Consumption
AMC	: Average Monthly Consumption
Ave	: Average
CSIR	: Council for Scientific and Industrial Research
DPF	: Design Peak Factor
DWA	: Department of Water Affairs
ee	: Equivalent erven
ERRSC	: East Rand Regional Services Council
FSR	: Floor Space Ratio
GAADD	: Gross Annual Average Daily Demand
IWA	: International Water Association
LOFLO	: Low Flow
Max	: Maximum
MC	: Monthly Consumption
Min	: Minimum
MPF	: Monthly peak factor
PMF	: Probability Mass Function
SANS	: South African National Standards
SDD	: Summer Daily Demand
SPF	: Summer Peak Factor
Std Dev	: Standard Deviation
Swift	: Sewsan and Wadiso Interface to Treasury
WCDM	: West Coast District Municipality
WISA	: Water Institute of South Africa
WRC	: Water Research Commission
WSA	: Water Supply Authority

GLOSSARY

End-user	:	The person or customer, who is the ultimate user of a product. In this study the end-user. In this study the definition for an end-user corresponds to the metered abstraction point from the bulk supply system.
Greenfield	:	A site, in terms of its potential development, having no previous building development on it.
Erf	:	A residential plot.
Floor Space Ratio	:	The ratio of a multi-storey building's total floor area to the size of the piece of land upon which it is built.

CHAPTER 1 : INTRODUCTION

1.1 Background

South Africa is a water-stressed country (Republic of South Africa: Ministry of Finance, 2012). Not only does it have a limited supply of potable water resources available, it also lacks the required infrastructure to be able to capture and distribute this water to all households and industries. Water is deemed a basic service and a clean water supply is deemed a necessity for the health of a nation. Each year the national government allocates a significant portion of the national budget towards the maintenance and development of the country's water infrastructure in order to provide this basic service to as many of its population as is possible.

Before the government ministries, and the parastatal agencies responsible for the implementation of large water supply schemes, allocate funds towards their implementation (construction), the feasibility of such a project needs to be proved. In order to be a feasible solution, such a supply scheme needs to be able to supply the required volume, or part of the required volume, at a sustainable cost to the end-user. During these feasibility studies, different supply scheme options are identified, evaluated and compared, until eventually a preferred option is selected.

During this evaluation period it is possible that existing water supply schemes, which will require upgrading to supply the additional demand, are compared to greenfield schemes to determine the preferred supply scheme option. In the case of evaluating an existing supply scheme, two elements of the scheme are of importance in making an informed decision. One is the existing capacity of the scheme; the other is the available surplus capacity of the scheme, after the demands of existing end-users have been supplied. These two factors are as important to quantify when evaluating a new supply scheme, as they are when a decision needs to be made on whether to increase the capacity of an existing supply scheme to meet the increasing water demands of its end-users. The capacity of a supply scheme needs to be adequately sized to ensure that it does not impact on the normal operation of its end-users over a pre-set design horizon. The designer of the supply scheme therefore needs to take into account the temporal variation in demand of its end-users, as well as the anticipated growth in its end-users' operations over time. The temporal variation in demand on a system can vary from end-user to end-user due to a number of factors, some of which are:

- Variation in demand due to certain processes, only happening during specific periods
- Internal attenuation of the demand variation within the end-users' network, due to demand diversification and/or;
- Internal water storage facilities.

The definition of an end-user varies from one study to the next. This depends on the scale of the study area being investigated. In this study the definition for an end-user corresponds to the metered abstraction from the bulk supply system. Therefore, it relates to the actual metering point where the water is supplied from the bulk water supply system to the user. The term end-user may therefore include a whole town, or possibly one large consumer who may be connected directly to the bulk system. In this study the end-users include municipalities with storage reservoirs and subsequent reticulation, some of whom may have more than one point of supply on the bulk system.

1.2 Reason for study

Historically, the design of a bulk water supply system would involve the determination of end-user storage requirements, so as to ensure that:

- The bulk supply system did not have to be designed for the high frequency peak demands (daily or hourly peak demands) of the end-user;
- There was sufficient storage capacity to allow redundancy in supply in the event of scheduled or un-scheduled maintenance being required on the bulk supply system.

It can be deduced that if the end-user storage volume is significantly large, it reduces the temporal variation in demand that is required to be met by the bulk supply system. The optimum required storage volume is, in the end, a financial and practical decision. A compromise needs to be found between the cost of increasing the end-storage volume and the cost increasing the bulk supply system capacity to be able to meet the temporal water demands of the end-user.

Numerous studies have been undertaken to determine the temporal water demand variation for different types of end-user. The designed capacity of the bulk water supply system therefore needs to take into account the water demand characteristics of each of its end-users. The end-user water demand characteristics generally used in these calculations are the following:

- Annual Average Daily Demand (AADD): The end-user's annual water demand expressed as a daily average water demand, thus not taking any temporal variations into account
- Design Peak Factor (DPF): The peak factor by which the end-user's AADD value is multiplied to provide the water demand value that the bulk supply system design is required to be able to supply to the end user

The DPF is a function of the variation in the end user's temporal water demand and the available storage volume available within the end user's supply network that will attenuate the peak water demands of the end user. The design capacity of the bulk water system therefore needs to be able to supply the annual average daily demand value of each of its end users at the specific end user's determined DPF. Thus, for a series of end users, the formula for determining the bulk water system's design capacity can be expressed as follows:

$$Bulk\ Water\ System\ Design\ Capacity = \sum_{i=1}^{n} AADD_i \times DPF_i \qquad (1\text{-}1)$$

where:

n = Number of end users supplied by the bulk water system

$AADD_i$ = Annual Average Daily Demand of the i-th end user

DPF_i = DPF of the i-th end user

The formula expressed above would seem capable of accurately determining the designed capacity of the bulk water system. However, depending how the designed peak factor for each end user has been determined, this formula could be over-estimating the required capacity in the design. The definition given for the DPF above can be expressed as:

$$DPF = \frac{End\ User\ Design\ Water\ Demand}{End\ User\ AADD} \tag{1-2}$$

Thus the peak factor used in the design does not take into account when the end user's peak water demand period is, but only the magnitude of it. Therefore, although the DPF does take the temporal variation of an end user's water demand into account, it does not provide the designer of the bulk water supply system with any indication of when the end user's peak water demand period occurs. Thus, if the peak water demands of end users supplied via a single bulk water supply system occur at the same time, then the formula above would correctly calculate the required design capacity. However, if the peak water demands of the different end users do not occur at the same time, then the formula would be over-estimating the required capacity of the bulk supply system design.

It is therefore clear that even if the designer does consider the different peak water demands of each end user, but does not take into account the potential temporal variation of these end user's water demand patterns, it is possible that the design capacity required will be overestimated. Such an error can have the following consequences:

- An existing bulk water supply system is upgraded earlier than required if the planning do not take into account this potential temporal variation; and/or
- A new bulk water supply system is over-designed

Both these consequences will have an impact on the financial viability of such a project. In the first instance, the end users will be required to start financing the upgrade before they actually need to do so. In the second instance, the end users will be required to finance a larger scheme than they really require.

1.3 Objectives

From the discussions above it is clear that it is as important to understand the differences in the demand patterns of end users as it is to understand the actual peak water demand of each end user. The objectives of this research project are to:

- Investigate the temporal water demand variations of different end users supplied from a bulk water supply system;

- Select an appropriate study site;
- Investigate the differences between the demand variations of the various end users in the study area; and
- Investigate the impact of peaks not coinciding on the design capacity of the selected bulk water supply systems. This will be done making use of the Monte Carlo statistical method.

1.4 Contributions

This study has been made possible through the contributions of the West Coast District Municipality (WCDM) in providing the water demand data used in the study and GLS Consulting Engineers in providing the suburb data of the towns supplied by the WCDM supply systems.

1.5 Scope

This study focuses on the variation in monthly water demand for a bulk municipal supply system. Two separate bulk systems are analysed in this study.

The bulk system comprises a bulk water pipeline from a regional water treatment works with supply points to end users, where the monthly draw-offs are metered and recorded. All the supply points have a storage reservoir, from which the water is then further reticulated to the end-user. This study does not review the impact that the available storage volume or the operational rules of these storage facilities have on the demand from the bulk supply.

This study will not address design factors or design aspects (pipeline design, air-valve design, etc.) of a bulk supply system; however, the literature review will include a review of peak design factors currently in use in the design of water supply systems.

The focus of this study is on a potable water supply system and does not include raw-water or wastewater systems.

The area for this study is the Western Cape, which is a winter rainfall region. The variation in water demand may be different to that of other areas. The literature review will cover the spatial temporal variation on a water supply system.

The investigation will not focus on system losses or the impact of these; however, a section of the literature review does discuss this.

1.6 Layout

This thesis is organised into the following main topics:

A literature review, contained in Chapter 2, investigates previous research and publications related to the topic of this thesis. It also includes the review of current design principles used in the capacity determination of bulk water supply systems, as well as investigations into the temporal variations in water demand of different water users. Chapter 3 describes the methodology followed in analysing the data and the setting up of the Monte Carlo model which was used in calculating the actual DPF of the system. The data used in the analysis are described in Chapter 4. The analysis and results of the deterministic and probabilistic analysis of the peak factors are summarised in Chapters 5 and 6 respectively. A discussion of the results of the two analysis methods, and of actual peak factors as determined from the data and their comparison with existing design guidelines are discussed in Chapter 7, with final conclusions presented in Chapter 8.

CHAPTER 2 : LITERATURE REVIEW

2.1 Water demand descriptions

2.1.1 Categories of water demand

The United States Department of the Interior Bureau of Reclamation (2009) defines water demand as water requirements for a particular purpose, as for irrigation, power, municipal supply, plant transpiration or storage. In order to be able to quantify and evaluate the water demand of a region, town or development, the different types or categories of water user need to be defined, as each type or category of use would have its own requirements in terms of the quality and quantity of water demanded. Water demand can be categorised on whether it is supplied from a water supply authority (WSA), in which case it is deemed public water supply, or by a private water supply system established and maintained by the user itself, in which case it is categorised as a self-supply (Great Lakes Commission, 2005). Water demand can also be defined according to the eventual use of the water, such as drinking-water, irrigation, livestock watering, fisheries, leisure activities, amenities, maintenance of aquatic life and protection of the integrity of aquatic ecosystems (Enderlain, Enderlain & Williams, 2013). Sometimes it is deemed necessary to amend or diversify the categories of water demand to allow better understanding of the change in water demand per end user, as indicated in Table 2-1 (United States Geological Survey, 2013a). According to the United States Geological Survey water use terminology (2013b), their definition of public supply water is water supplied by a public supplier and used for such purposes as firefighting, street washing, flushing of water lines, and maintaining municipal parks and swimming pools. Their definition of rural water use is water used in suburban or farm areas for domestic and livestock needs. The water generally is self-supplied, and includes domestic use, drinking water for livestock, and other uses such as dairy sanitation, cleaning, and waste disposal. They then later subdivided the rural water use into three sub-categories of domestic, livestock and aquaculture. Their definition of domestic water use is water used for indoor household purposes such as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, and outdoor purposes such as watering lawns and gardens and includes water provided to households by a public water supply (domestic deliveries) and self-supplied water. The Council for Scientific and Industrial Research (CSIR) (CSIR, 2003) categorises water use into domestic and non-domestic water use, with domestic water use defined as water used for direct consumption by a person or through activities at home (washing, cooking and garden irrigation). Non-domestic water use is thus all other water use requirements and may include water fed to livestock, industrial water use and irrigation.

Table 2-1: Changes in water-use categories (United States Geological Survey, 2013a)

<table>
<tr><th>Year/Period</th><th colspan="15">Water use category</th></tr>
<tr><td>1950</td><td>Municipal</td><td>Irrigation</td><td colspan="3">Rural</td><td colspan="9">Self-supplied industrial</td><td>Water power</td></tr>
<tr><td rowspan="2">1955</td><td rowspan="2">Public supply</td><td rowspan="2">Irrigation</td><td colspan="3" rowspan="2">Rural</td><td colspan="3" rowspan="2">Other industrial</td><td colspan="6">Fuel-electric power</td><td rowspan="2">Water power</td></tr>
<tr><td colspan="3">Condensor cooling</td><td colspan="3">Other</td></tr>
<tr><td rowspan="2">1960</td><td rowspan="2">Public supply</td><td rowspan="2">Irrigation</td><td rowspan="2">Rural domestic</td><td colspan="2" rowspan="2">Livestock</td><td colspan="3" rowspan="2">Other industrial</td><td colspan="6">Fuel-electric power</td><td rowspan="2">Water power</td></tr>
<tr><td colspan="3">Condensor cooling</td><td colspan="3">Other</td></tr>
<tr><td rowspan="2">1965-1980</td><td rowspan="2">Public supply</td><td rowspan="2">Irrigation</td><td rowspan="2">Rural domestic</td><td colspan="2" rowspan="2">Livestock</td><td colspan="3" rowspan="2">Other industrial</td><td colspan="6">Fuel-electric power</td><td rowspan="2">Water power</td></tr>
<tr><td colspan="3">Condensor cooling</td><td colspan="3">Other</td></tr>
<tr><td rowspan="2">1985</td><td rowspan="2">Public supply</td><td rowspan="2">Irrigation</td><td rowspan="2">domestic</td><td colspan="2" rowspan="2">Livestock</td><td rowspan="2">Commercial</td><td rowspan="2">Industrial</td><td rowspan="2">Mining</td><td colspan="6">Thermoelectric power</td><td rowspan="2">Hydroelectric power</td></tr>
<tr><td colspan="2">Fossil fuel</td><td colspan="2">Geothermal</td><td colspan="2">Nuclear</td></tr>
<tr><td rowspan="2">1990-1995</td><td rowspan="2">Public supply</td><td rowspan="2">Irrigation</td><td rowspan="2">Domestic</td><td rowspan="2">Livestock</td><td rowspan="2">Animal specialties (incl. fish farming</td><td rowspan="2">Commercial (incl. offstream fish hatcheries</td><td rowspan="2">Industrial</td><td rowspan="2">Mining</td><td colspan="6">Thermoelectric power</td><td rowspan="2">Hydroelectric power</td></tr>
<tr><td colspan="2">Fossil fuel</td><td colspan="2">Geothermal</td><td colspan="2">Nuclear</td></tr>
<tr><td rowspan="2">2000-2010</td><td rowspan="2">Public supply</td><td rowspan="2">Irrigation</td><td rowspan="2">Domestic</td><td rowspan="2">Livestock</td><td rowspan="2">Aquaculture (incl. fish farming & hatcheries)</td><td rowspan="2">Commercial</td><td rowspan="2">Industrial</td><td rowspan="2">Mining</td><td colspan="6">Thermoelectric power</td><td rowspan="2">Hydroelectric power</td></tr>
<tr><td colspan="3">Once-through cooling</td><td colspan="3">Closed-loop cooling</td></tr>
</table>

2.1.2 Temporal variations

Temporal variations in water demand are generally influenced by spatial and time parameters. The spatial influences can be attributed to differences in climatic conditions. Water demand and specifically residential water demand is influenced to a large extent by the weather, with water demand usually higher during relatively dry months. A study by Jacobs, Geustyn, Loubser and Van der Merwe (2004) reported a difference in the AADD between a residential stand in the coastal, winter rainfall, region (Figure 2-1) and that of a similar stand in the inland, summer rainfall, region (Figure 2-2) of South Africa. The upper envelope values for a stand of a 1000 m^2 are approximately 1700 kℓ/day and 1350 kℓ/day for a winter rainfall and summer rainfall area respectively. From the data it is clear that water demand is generally higher in a winter rainfall region, as the net summer evaporation is higher, thus more water is required for outdoor use.

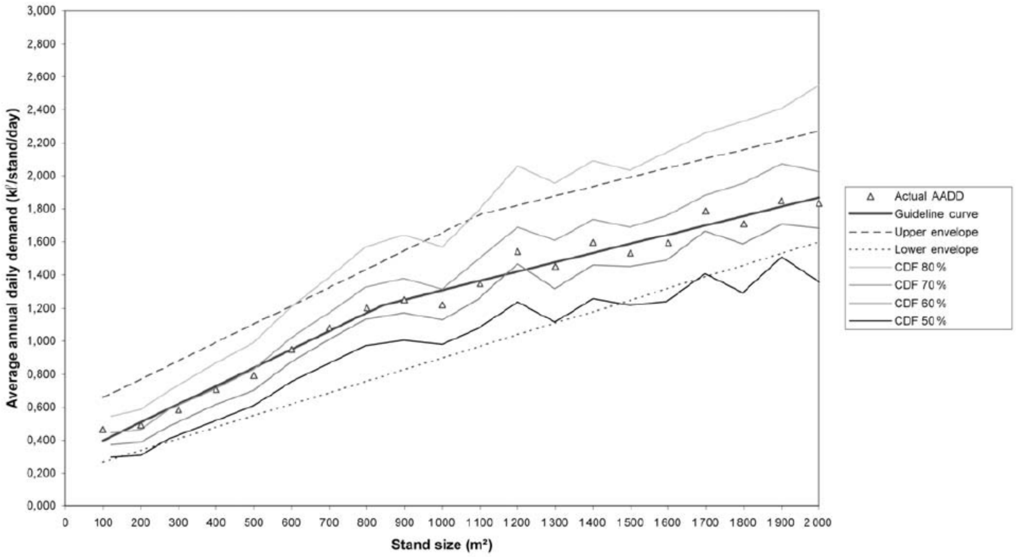

Figure 2-1: AADD for single residential stand in coastal winter rainfall region (Jacobs *et al.* 2004: Figure 9)

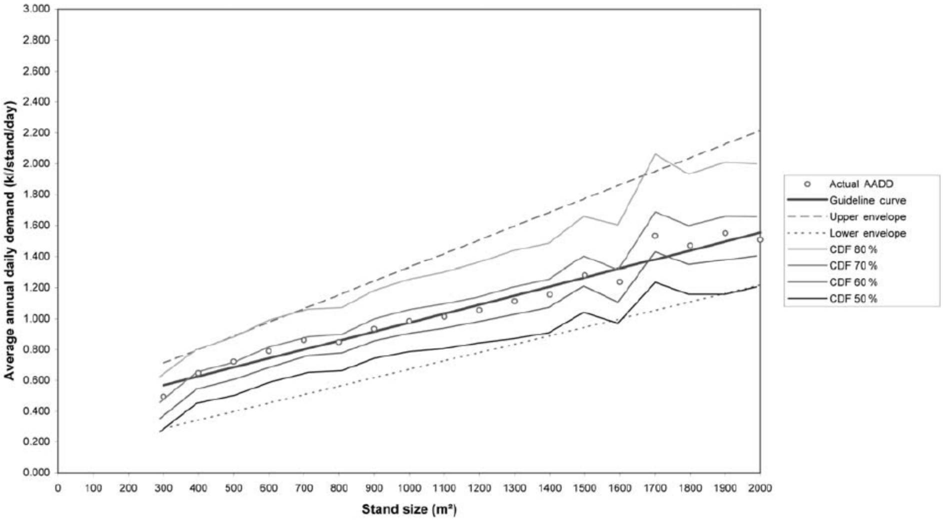

Figure 2-2: AADD for single residential stand in a suburb of an inland - summer rainfall region (Jacobs *et al*. 2004: Figure 10)

A study by Parker and Wilby (2012) indicated that water use is more heavily weighted to the relatively drier months and thus results in an increase in garden irrigation. Their study also investigated the sensitivity to the weather and day of the week in water use of three household components' (dishwasher, shower and toilet). They found that dishwasher demand is not sensitive to the weather or day of the week, whereas the shower and toilet were. Their study found that shower water consumption increased with increase in temperature and has a midweek low. The toilet water consumption showed a strong weekday/weekend variation with higher usage during weekends and also appeared to decrease with the increase in temperature. Their study found that the toilet water consumption to be the largest fraction of the daily internal household water use. It can therefore be concluded that indoor domestic demand is not that sensitive to seasonal variation, on the other hand outdoor domestic demand is sensitive to the seasonal variation throughout the year. However, without split metering of the indoor- and outdoor water consumption, it is difficult to quantify in what proportion the demand of a stand is made up from these two water use groups.

A study by Mayer, DeOreo, Hayden and Davis (2009) they separated the indoor and outdoor demand by using the minimum month or average winter consumption technique to estimate the annual indoor use. This method works reasonably well in areas with low to no winter irrigation and is therefore less accurate in area where irrigation occurs throughout the year. Another study, measured the water demand in two-week intervals spaced in time to capture the peak summer demand and low winter demand, which was assumed to include only the indoor consumption of the household (Mayer & DeOreo, 1999). The results from this study indicated that 42% of the annual water demand can be attributed to indoor use. In recent years there has been a shift to design houses and developments to be more water-wise, i.e. to ensure that less water is used in the daily domestic functions of such a household, compared to the water used in older developments. Features of the water-wise developments would be the use of high-efficiency domestic fixtures (low-flow showers and low volume toilets) and reduced external irrigation areas. A study by Mayer, William and DeOreo (2000) compared the indoor and outdoor usage of houses built before 1977, between 1984 and 1993, standard new homes built after 1997 and new water-wise homes within the city of Westminster, Colorado.

Table 2-2: Water demands for different type of houses (Table 4: Mayer *et al.*, 2000)

Type of homes	Average annual water use,1998 (kgal)	Average daily use, 1998 (gal)	Average daily per capita use, 1998 (gal)	Estimated annual indoor use (kgal)	Estimated annual outdoor use (kgal)
Water wise homes	151.9	416	151	50.0 (32.9%)	101.9 (67.1)
Standard new homes	143.7	394	140	55.1 (38.3%)	88.6 (61.7%)
Pre-77 homes	106.9	293	115	66.3 (62.0%)	40.6 (38.0%)
Post-84 homes	147.3	403	110	76.6 (52.0%)	70.6 (48.0%)

Table 2-2 shows the results of the study. The annual indoor use was estimated using the average winter consumption over the months of December, January and February (northern hemisphere study) and multiplying it by twelve. The results indicate that the water wise homes potentially use the least amount of water indoors, but the outdoor use for these homes was the highest. The study indicated that this could be due to the larger irrigation areas of these homes and that the gardens are still not yet established. The standard new and water wise homes used less water indoors than outdoors, with the indoor consumption making up between 35.7 and 40.8% of the total consumption. The outdoor water consumption is largely influenced by user behaviour and changes in land use, such as the tendency with newer developments to construct larger houses on smaller plots, thus reducing the outdoor area available for gardening (White, Milne & Riedy, 2004). Thus the temporal variation in water demand due to spatial or climatic factors has a far larger impact on bulk water systems than the time dependent temporal variation of water demand. The reason for this is that these spatial or climatic influences occurs at a lower frequency than the time influences and therefore the storage facilities available in a network are unable to act as a buffer to these variations. The time-based temporal influence on water demand occurs at a far higher frequency, as it is more dependent on end user behaviour than the climatic conditions and therefore the storage facilities at the end point of bulk supply systems make allowance for this.

2.2 Types of water supply system

A water supply system is defined as the infrastructure required for the collection, transmission, treatment, storage, and distribution of water for use in homes, commercial establishments, industry and irrigation, as well as for such public needs as fire fighting and street flushing. The CSIR (2003) says that a water supply system can be defined as distribution and storage system and these two components can be broken down into further separate elements, which may or may not all be present in a water supply system. The elements that make up a water distribution and storage system, according to the CSIR (2003) are a bulk water transmission system, bulk storage reservoirs, intermediate storage reservoirs, distribution networks and terminal consumer installations.

The American Water Works Association (2003) divides the types of water system into four categories based on the source of water the system is supplied from. The four types of system are surface water systems, groundwater systems, purchased water systems and rural water systems. The surface and groundwater systems, as their names indicate, obtain supplies from surface and groundwater sources, respectively. In the purchased water system a water utility purchases water from another water utility, such as is the case with many metropolitan municipalities and local municipalities in Gauteng province, which purchase water from Rand Water. The rural water system is a water district established to serve widely spread rural homes and communities, where there is no suitable groundwater available for these homes and communities to use. That portion of the water supply system responsible for transporting the water from the source to the end-user defines the transmission and distribution.

A transmission system is defined as a pipeline or conduit that carries water from one point to another without intermediate service connections, while distribution mains are defined as all pipelines, except for the small services pipes connecting the building or house to the water system (United States Department of the Army, 1986). The United States Fire Administration (2008) classifies the distribution system into primary feeders, secondary feeders and distribution mains. Republic of South Africa: Department of Water Affairs (2004) categorises the water conveyance system into a main distribution and a reticulation system. The United States Fire Administration (2008) also defines a distribution system according to the method by which it supplies the water to the end-user. The three methods by which a distribution system can supply water are a gravity distribution, a pumped system with elevated storage and a pump system without storage.

In most cases the transmission and distribution systems are pipelines, thus the water is conveyed in a pressurised system, however canals are sometimes used, both as transmission and distribution systems. The use of canals as conveyance systems is not always feasible, due to the topography of the area to be supplied. Pipe systems can be defined as being either a gravity or a pumped system. In a gravity system the source of water is located above the end-user, which ensures that there is sufficient pressure as a result of gravity to maintain a sufficient water pressure for an adequate supply of water to the end-user (United States Fire Administration, 2008). In a pumped system the source of water is either not located above the end-user, or is not high enough to ensure that a gravity system will be able to supply water at an acceptable pressure and flow-rate, and which therefore requires the introduction of sufficient system pressure by means of a pump as a more cost effective option of providing a storage facility at an acceptable elevation to ensure sufficient system pressure.

2.3 Annual average daily demand

In order for a water supply system to be able to supply the end-users with sufficient water at an adequate rate of supply, it needs to have adequate supply capacity. In order to determine the capacity required, the designer needs to ensure that all current potential end-users and all future end-users that would require water from the system until the design horizon of the system have been included in the calculation. The designer also has to make an informed decision when choosing the appropriate water demand values for each end-user in order to quantify the current and future water demand of the area to the be supplied.

Almost all demand calculations have as their base demand value the AADD. AADD is defined as the amount of water consumed in a community or city for all purposes (Civil Engineering Terms, 2012). It is generally expressed as the volume of water consumed per person per day, which is normally defined as litres per capita per day (ℓ/c/d). It may also be expressed in other units, as is the case when the demand for livestock is determined, when it is expressed as litres per head per day. The AADD of an end-user can only be determined once that user has consumed water for a full calendar year, hence the description of it as annual demand. Thus the AADD of an end-user does not indicate the temporal variation in water demand, but expresses the annual demand only as an equivalent daily demand. In general, water demand is divided into two main groupings, namely domestic and non-domestic water demand.

2.3.1 Domestic AADD

The water demand of a development is usually determined through the review of historic water consumption data; however, for a new development with no historic consumption data available, the water demand can be estimated by reviewing water demand data from nearby or similar developments, or by making use of design guidelines. For the estimation of the future water demand of an end-user, the use of guidelines is invaluable. There are numerous published guidelines that may be used, but some judgement is required to determine which guideline would be most appropriate for the estimation of an end-user’s AADD. Some aspects that may impact on the AADD of an end-user are the standard of the water supply service available to the end-user and the development level of the end user. The standard of service of the water supply to an end-user can be defined as the volume of water available to the end-user, the proximity of the water source and the reliability of the supply.

The minimum standard for a basic water supply service in South Africa is a minimum daily volume of 25 litres per person per day of potable water, at a minimum flow rate of 10 litres per minute. The supply point should be located within 200 metres of the end-user and reliability of supply should be such that the end-user will not be without this supply for more than seven full days in any year. (Republic of South Africa: Ministry of Water Affairs and Forestry, 2001). The CSIR Guidelines for Human Settlement Planning and Design is a useful tool in terms of providing guidelines for the design of water infrastructure (CSIR, 2003)

Table 2-3: Extracts of typical AADD for communal water points (CSIR 2003: Table 9.10)

Type of water supply	Typical consumption (ℓ/c/d)	Range (ℓ/c/d)
Communal water point		
Well or standpipe at considerable distance (>1000 m)	7	5-10
Well or standpipe at medium distance (250-1000 m)	12	10-15
Well nearby (<250 m)	20	15-25

In Table 2-3 it can clearly be seen what effect the proximity of the water source can have on the AADD for the supply point.

Table 2-4: Extracts of typical AADD in areas equipped with standpipes, yard connections or house connections (CSIR 2003: Table 9.11)

Domestic water consumption			
Type of water supply		Typical consumption (ℓ/c/d)	Range (ℓ/c/d)
Standpipe (200 m walking distance)		25	10-50
Yard connection		55	50-100
With dry sanitation			30-60
With LOFLOs			45-75
With full-flush sanitation			60-100
House connection (developed areas)			60-475
Development level:	Moderate	80	48-98
	Moderate to high	130	80-145
	High	250	130-280
	Very high	450	260-480

Table 2-4 shows AADD guidelines from the minimum required standard of water supply service (standpipe) through increasing standards of water supply systems. The impact of the standard of the water supply system on water demand is clear from the table. From Table 2-4 the impact of the level of development of the end-user is also clear, with the AADD guidelines increasing depending on the type of on-site sanitation that is provided (yard connection) or development level (house connection) of the stand. The development level as defined by the CSIR ranges from moderate, which relates to medium-sized formal housing with limited finishing and moderate gardens, to very high, which relates to formal suburban housing on large stands with extensive gardens (CSIR, 2003).

In order to use the guidelines above, it is important that the population is known. In many development planning exercises it is not easy to determine an accurate population for the development. In many cases it is easier to obtain the erf size distribution of the development and to then calculate the AADD of each erf and the development from that. The CSIR (2003) provides a guideline to use in the estimation of the AADD of an erf, given that the erf or stand size is known. As the water demand of an erf is highly dependent on the climate, the income level of the end-user and the cost of water, the CSIR (2003) guidelines give an upper and lower limit, as indicated in Figure 2-3, for a given erf size.

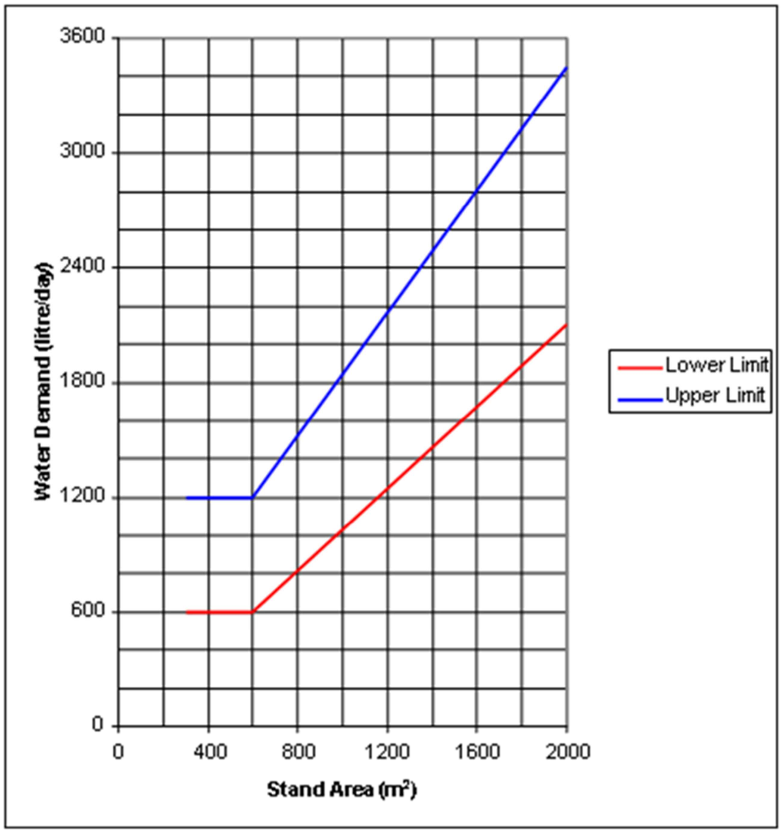

Figure 2-3: AADD for erven (CSIR 2003: Figure 9.9)

In some developments, where the floor space ratio (FSR) is larger than 1.0, as it is in apartment blocks, the size of the erf cannot be used to determine the AADD of the erf. In this instance the guidelines do not use either the population or the erf size, but instead assign a per-unit AADD value for the different units, as indicated in Table 2-5. In this instance there could also be a difference in AADD based on the development level of the properties, thus an upper and lower limit are proposed.

Table 2-5 Extracts of typical AADD based on number of units (CSIR 2003: Table 9.14)

Type of development	Unit	AADD (ℓ/day) unless otherwise stated
Low-rise multiple-dwelling unit buildings (*Residential Zone 2 and 3*)	Dwelling	Upper limit 1000$^{(a)}$ Lower limit 600$^{(a)}$
High-rise multiple-dwelling unit buildings (*Residential Zone 4*)	Dwelling	Upper limit 700$^{(a)}$ Lower limit 450$^{(a)}$
(a) Water demand includes garden watering of all common areas outside the limits of buildings.		

In some large metropolitan areas, the local water supply authority may require the planners of new developments to make use of their own internally developed water demand and infrastructure design guidelines for the planning and design of new developments to be established within the municipal area. One such guideline in use is that developed for the City of Tshwane Metropolitan Municipality, which provides planning standards for the AADD of proposed erven within its municipal boundary (City of Tshwane Metropolitan Municipality, 2004).

Table 2-6: Extracts from summary of design domestic AADD (City of Tshwane Metropolitan Municipality 2004: Table 2)

Item	Zoning	Unit	Design value
1	Residential		
1.1	Low-cost housing – erf up to 250 m²	kℓ/erf	0.7
1.2	Conventional small-sized erf up to 500 m²	kℓ/erf	1.2
1.3	Medium-sized erf up to 1 000 m²	kℓ/erf	1.6
1.4	Large-sized erf up to 1 500 m²	kℓ/erf	2.0
1.5	Extra-large erf in excess of 1 500 m²	kℓ/erf	2.4
1.6	Cluster housing up to 20 units per hectare	kℓ/erf	1.2
1.7	Cluster housing up to 40 units per hectare	kℓ/erf	0.8
1.8	Cluster housing up to 60 units per hectare	kℓ/erf	0.7
1.9	High-rise flats (± 50 m² per unit)	kℓ/unit or every 50 m²	0.6
1.10	Guest house, boarding house, hostel, hotel, retirement centre or village, orphanage, etc (with a FSR)	kℓ/unit or every 100 m² of development	0.9
1.11	Agricultural holding (house plus servants' quarters)	kℓ/holding	4.0
1.12	Guard/security office	kℓ/unit	0.7

2.3.2 Non-domestic AADD

There are also water demand guidelines for non-domestic AADD, such as those for schools, hospitals and businesses. It is difficult to quantify non-domestic water demand based on population, as this demand is not always directly related to the number of people, but is usually affected by the activities that take place at the premises of the end-users.

Table 2-7: Extract of typical non-domestic AADD based on persons (CSIR 2003: Table 9.12)

Non-domestic users		Daily water demand
Schools:	Day school Boarding school	15-20 ℓ/pupil/day 90-140 ℓ/pupil/day
Hospitals		220-300 ℓ/bed/day
Clinics:	Outpatients Inpatients	5 ℓ/bed/day 40-60 ℓ/bed/day
Bus stations		15 ℓ/passenger/day
Community halls/restaurants		65-90 ℓ/seat/day

In certain cases the of non-domestic use guidelines may measure AADD in relation to something other than per capita, as can be seen from Table 2-7 and Table 2-8. Although the AADD guidelines in Table 2-7 do seem to relate to persons (pupils, passengers, etc.), it should be noted that these persons do not make up the full population of the establishment, as there are other people at these establishments who are responsible for the functioning of the establishment (teachers, doctors, nurses, cleaners, waiters, etc.)

Table 2-8: Extracts of typical non-domestic AADD based on area (CSIR 2003: Table 9.14)

Type of development	Unit	AADD
Offices and shops	100 m^2 of gross floor area[a]	400 ℓ/day
Government and municipal offices	100 m^2 of gross floor area[a]	400 ℓ/day
Clinic	100 m^2 of gross floor area[a]	500 ℓ/day
Church	Erf	2000 ℓ/day
Developed parks	Hectare of erf area	≤2 ha: 15 kℓ >2 ha ≤10ha: 12.5 kℓ >10 ha: 10 kℓ
[a] Gross floor area obtained using applicable floor space ratio from the town planning scheme		

Most AADD data published are given as guidelines, thus the person using the guideline to determine the demand for an end-user still needs to use their judgement in selecting a demand design value from the guideline. There are some cases where the AADD is prescribed as the basis for the design and should be used as published for each specific end-user. This is generally the case where a design code is published, to which the engineer needs to adhere in terms of the design. Table 2-9 indicates the daily water demand design values to be used in the design of water reticulation systems for buildings (South African National Standard, 2012).

Table 2-9: Extract of typical water design values (SANS, 2012)

Premises	Water demand (including hot water)
Boarding schools[a], children's homes and residential nurseries	135 to 200 ℓ/c/d
Educational institutions	40 to 50 ℓ/c/d
Kitchens (full meal preparation)	8 to 12 ℓ/day per meal prepared
Multiple dwelling units, such as flats	300 to 400 ℓ/dwelling/day
Hotels, boarding houses, motels and nurses' homes:	
With resident staff	200 to 300 ℓ/bed/day
Without resident staff	200 to 250 ℓ/bed/day
Commercial premises:	
Shops (staff only)	14 to 18 ℓ/10m^2 gross floor area/day
Superstores, such as hypermarkets and warehouses	125 ℓ/day per water closet pan, or 600mm width of slab urinal
Offices with canteens	10 to 15 ℓ/10m^2 gross floor area/day
Offices without canteens	7 to 10 ℓ/10m^2 gross floor area/day
Clinics, hospitals, nursing homes and old-age homes	450 to 550 ℓ/bed/day
Factory ablutions	100 to 200 ℓ/c/day
[a] Excluding kitchen but including laundry	

As discussed in the domestic water demand section, the City of Tshwane Metropolitan Municipality (2004) also has its own guidelines for the estimation of the non-domestic water demand of developments located within its municipal area, as depicted in Table 2-10.

Table 2-10: Extracts of summary of design non-domestic AADD (City of Tshwane Metropolitan Municipality 2004: Table 2)

Item no	General type of development	Unit	Design value
3.1a	Club building	kℓ per 100m²/day	0.3
3.1b	Club grounds	kℓ/ha/day	15.0
3.2a	Stadium	per 1 000 people/day	1.5
3.2b	Stadium grounds	kℓ/ha/day	15.0
3.3a	Park building	kℓ per 100m²/day	0.4
3.3b	Park grounds	kℓ/ha/day	15.0
3.4a	Nursery (sales area)	kℓ per 100m²/day	0.8
3.4b	Nursery (planting and production area)	kℓ/ha/day	15.0
3.5a	Hospital building	kℓ per 100m²/day	1.2
3.5b	Hospital grounds	kℓ/ha/day	15.0
3.6a	Church building	kℓ per 100m²/day	0.3
3.6b	Church grounds	kℓ/ha/day	15.0
3.7a	School, crèche, educational building	kℓ per 100m²/day	0.6
3.7b	School, crèche, educational grounds	kℓ/ha/day	15.0
3.8	Municipal, governmental development	kℓ per 100m²/day	0.6
3.9	Private open space	kℓ/ha/day	15.0
3.10	Parking grounds	kℓ/ha/day	3.0

2.3.3 Updating of design guidelines

Most of the guidelines referenced in the section above have been in use for a number of years without significant amendments having been made to them. They have been useful in assisting designers and development planners in determining the demand of proposed developments or comparing the demand of an existing development against a baseline demand calculation based on the per capita or unit demand from the guidelines. In recent years, however, new research has been undertaken to determine whether these existing guidelines are still relevant and suitable for use. Most notable recent publications in this regard include the work by Van Zyl, Illemobade and Van Zyl (2008) and Van Zyl and Geustyn (2007). These studies used the actual municipal water meter readings used in the preparation of an end-user's municipal account based on data extracted from SWIFT. The commercial software package, Swift (Sewsan and Wadiso Interface to Treasury), was developed by GLS Consulting Engineers (GLS Software, 2013) and its application in research is discussed by Jacobs and Fair (2012). Swift would capture each end-user's properties from the treasury data of the specific municipality the end-user resides in. These properties are then used to categorise the end-users within a municipal area in order to determine whether a specific trend could be established between any particular end-user property and the end-user's water usage. The most notable end-user properties used the research by Van Zyl and Geustyn (2007) analyses were the land-use, stand size and total stand value of a particular end-user.

A study by Husselmann and Van Zyl (2005) investigated the effects of stand size and stand value on the AADD of the stand. The study was based on approximately 195 000 domestic stands in the Tshwane and Ekurhuleni metropolitan areas in the Gauteng province of South Africa. The study found that there is a trend of increasing water demand with the increase of the stand size and stand value. The study compared the results with guidelines published by the CSIR (2003) and found that the latter guideline can underestimate the AADD for small stand sizes and overestimate the AADD of stand sizes larger than 700 m^2. Husselmann and Van Zyl (2005) proposed a new envelope curve for estimating AADD as depicted in Figure 2-4.

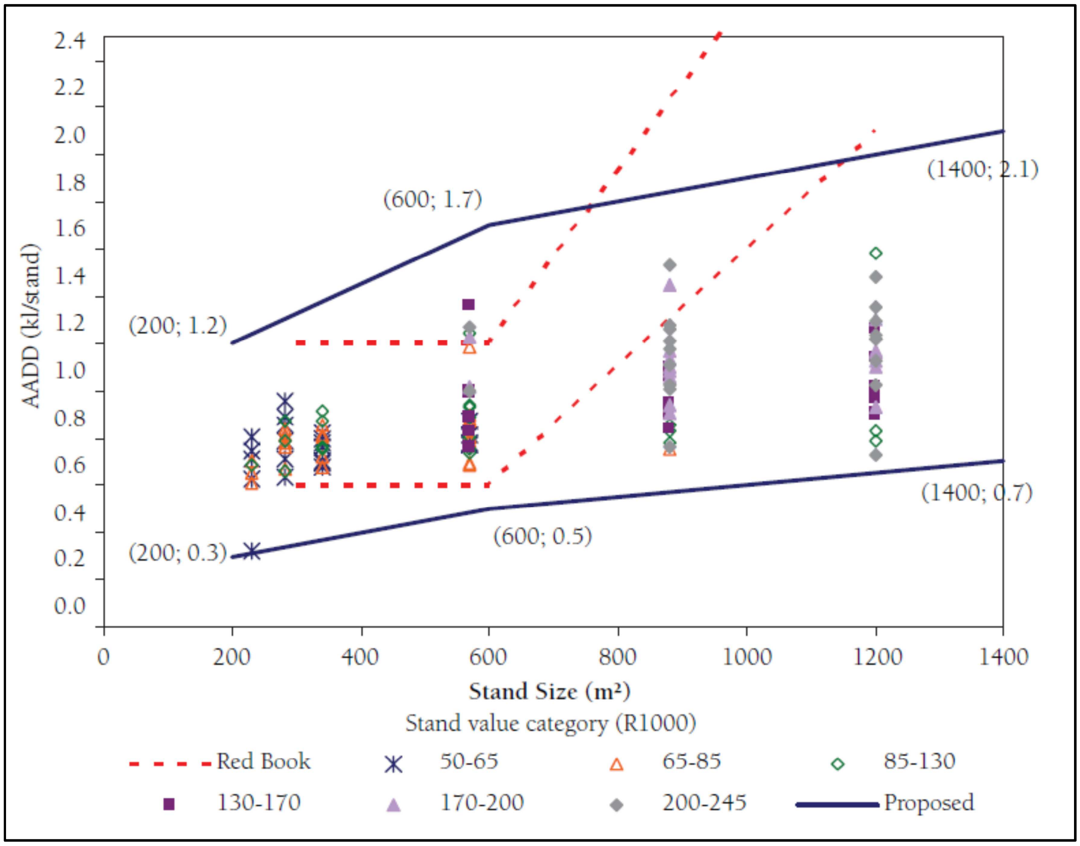

Figure 2-4: Proposed new design envelope for AADD (Husselmann and Van Zyl, 2005: Figure 3)

In another study, 2 792 053 records from 151 cities and towns throughout South Africa were analysed. (Van Zyl and Geustyn, 2007). One of the purposes of this study was to determine whether the CSIR (2003) guidelines for domestic demands were still applicable, thus whether current actual domestic water demands, as determined from the actual water consumption, fell within the guidelines. They specifically compared their results obtained from the AADD based on erf size, as depicted in Figure 2-3, with the actual water consumption. Their results, depicted in Figure 2-5, showed that the actual water demand for the majority of erven in South Africa is below the Upper Limit CSIR (2003) guideline, with a significant number of erven having an AADD below the lower limit guideline of the CSIR (2003).

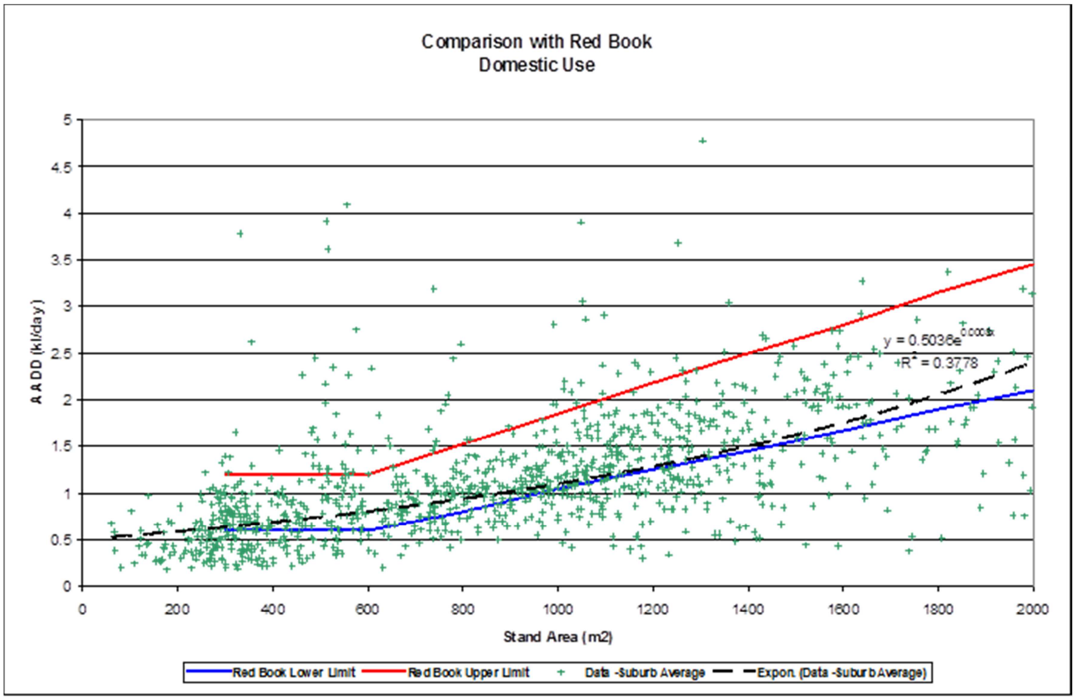

Figure 2-5: Actual AADD per erf size compared with CSIR (2003) guideline (Van Zyl *et al.*, 2007: Figure 5.1)

The WRC also investigated the water demand for erven larger than 2000 m^2, against an extrapolated upper and lower limit from the *CSIR* (2003) AADD guidelines and also included the impact on water demand of the erf being either an inland or a coastal property (Figure 2-6) and the impact of income level of the end-user on the water demand (Figure 2-7).

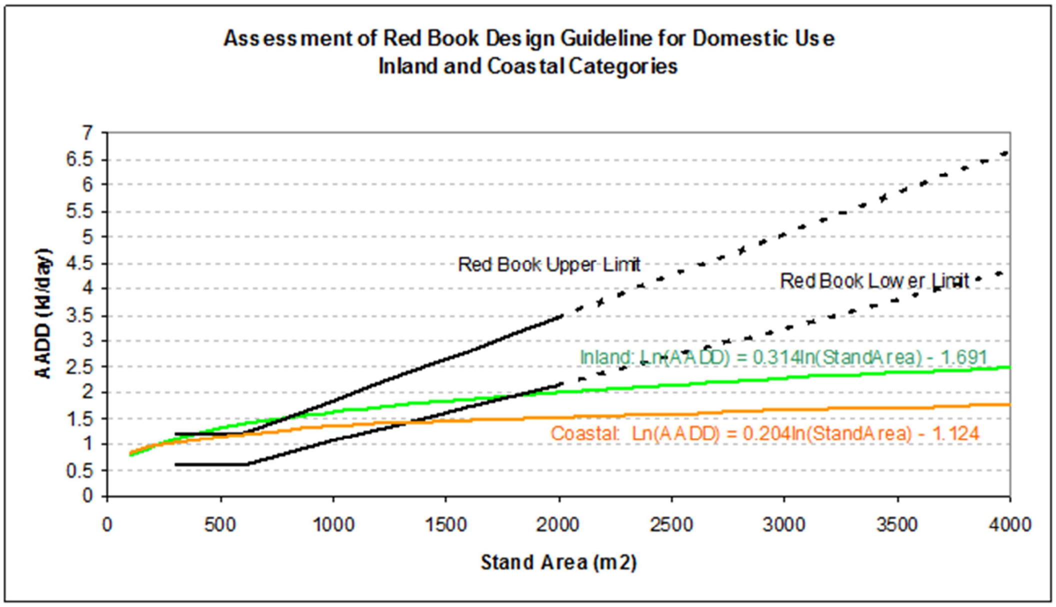

Figure 2-6: Actual AADD per erf size for coastal and inland erven compared with CSIR (2003) guideline (Van Zyl *et al.*, 2007: Figure 5.4)

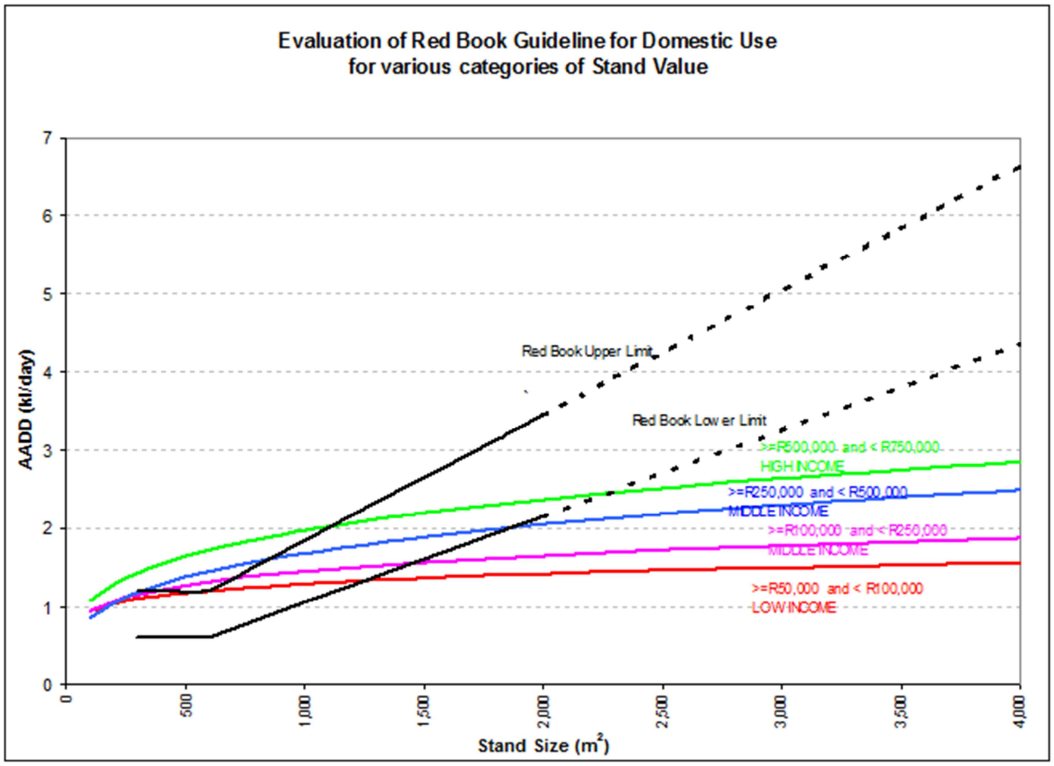

Figure 2-7: Actual AADD per erf size based on income level compared with CSIR (2003) guideline (Van Zyl *et al.*, 2007: Figure 5.5)

The outcome of these comparisons was that for erf sizes smaller than 2000 m^2, the actual water demand compared well with the CSIR (2003) guidelines, but for erf sizes larger than 2000 m^2, the extrapolated CSIR (2003) guidelines would overestimate the actual water demand quite significantly, irrespective of the locality (inland or coastal) or income level. The research also showed, for erf sizes larger than 250 m^2, the inland water demand to be higher than that of an erf located at the coast. The results also confirm that with the increase in income level of the end-user, water demand will also increase.

In the same study (Van Zyl and Geustyn, 2007) the end-users deemed non-domestic were grouped into the categories as defined by the treasury land-use codes (Business Commercial, Farms, Education, Government and Institutional, Industrial, Parks and Sports) and it was determined that both stand size and stand value were the two most significant variables to use in determining the water demand of an erf.

A separate study undertook to determine whether the CSIR (2003) guideline for non-domestic water demand was still a suitable tool to use for estimation (Kriegler and Jacobs, 2008). The study reviewed data collected from Large User Reports, produced by GLS Consulting Engineers, from a number of municipalities in the Western Cape. A large user report reviews the water demand of only those erven with an AADD above a specific value, usually ranging from 3 k*ℓ/day* in smaller municipalities, with limited or no large industries, to 20 k*ℓ/day* in large municipalities. These large user reports also categorised the erven by using the treasury land-use codes, similar to the categories used by Van Zyl and Geustyn (2007).

The study by Kriegler and Jacobs (2008) sub-divided these end-users further into sub-categories of each treasury land-use code. The treasury land-use codes are quite broad and do not make any distinction between various different types of end-user in some of the categories, as in the case of the Government and Institutional land-use code, within which churches, municipal offices and hospitals are categorised. The study by Kriegler and Jacobs (2008) sub-divided the end-users into different sub-categories to determine whether a definite trend could be determined in the correlation between the erf size and the water demand. The different categories proposed and the number of points analysed per category are summarised in

Table 2-11: Proposed end-use sub-categories and number of data points analysed (Kriegler and Jacobs, 2008: Table 4)

Treasury land-use category	Study sub-category	Number of users analysed per category
Commercial	Businesses	257
	Hotels	32
Education	Schools	123
Government/institutional	Churches	10
	Hospitals	45
Industrial	Abattoirs	12
	Manufacturers	140
	Wine Cellars	16

The outcome of the study was that no clear correlation could be determined between the water demand and the erf size for the proposed sub-categories. Some interesting outcomes from the study were that for churches the CSIR (2003) guideline of an AADD of 2 kℓ/day was exceeded in all cases reviewed (Figure 2-8) and for schools with an erf size larger than 100 000 m^2 a conservative AADD of 100 k*ℓ/day* may be used (Figure 2-9).

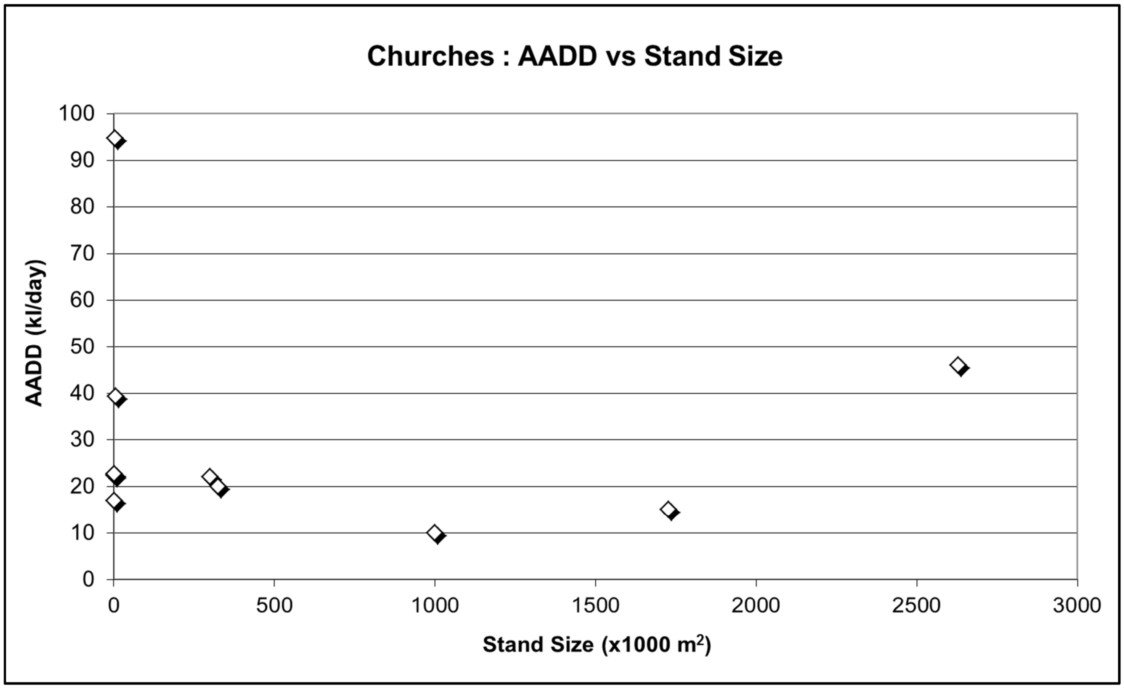

Figure 2-8: AADD of churches vs erf size (Kriegler and Jacobs, 2008: Figure 3)

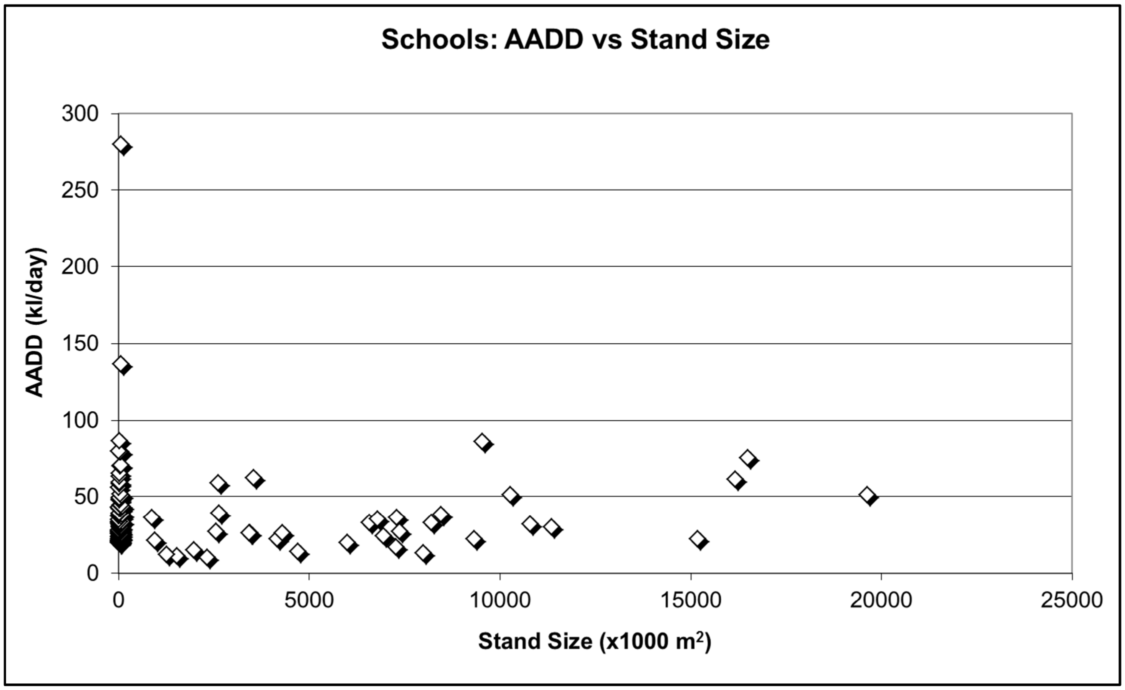

Figure 2-9: AADD of schools vs erf size (Kriegler and Jacobs, 2008: Figure 7)

2.4 Design peak factors

As stated previously, the AADD of an end-user expresses the annual amount of water consumed in the form of a daily value. This is important in determining the required volume of water that needs to be sourced for the end-user, and thus plays an important role in water resource planning for a municipality or development. The AADD is therefore a value used in long term water planning in order to ensure that a municipality or development has adequate water sources to ensure a sufficient supply of water for the foreseeable future, thus it is used in providing a longer term view of the planning process. However what is important for the designer of the water supply system, whether it be for the design of the water treatment works required for treating the water to be supplied to the end-user, or for the conveyance system, required for the transporting of the water from the source to the end-user, or for the storage facility in which the water will be stored until required, is the temporal variation of the end-users' water consumption. The fact is that a person only consumes or uses water at certain periods throughout a day; it stands to reason, therefore, that the rate of consumption is at those times higher than the average rate. Thus the supply system that will treat, supply and store the water needs to be designed to be able to provide the person with water at the required higher rate whenever it is required.

Although the water supply system is required to convey a certain volume of water from the source to the end-user daily, the required rate of supply may at certain times be significantly higher than the average rate of supply. In engineering terms this is deemed the design supply factor, also known as the DPF. The DPF can be defined as the relation between the AADD of a development and the specific peak demand in which the designer is interested. The most commonly used design supply factors used in the industry are the summer peak, daily peak and instantaneous peak (also sometimes called the hourly peak factor). As with the estimation of AADD, the determination of the design supply factor can be achieved by measuring the actual demands on a supply system. Design guidelines are also available that may be used if the actual demands and temporal demand variations are not known. The CSIR (2003) provides a number of guidelines for DPFs (Table 2-12).

Table 2-12: Extract of peak factors for developing areas (CSIR 2003: Table 9.15)

Peak factors: Developing areas: Unrestricted flow systems[1]				
Type of domestic supply	Summer peak factor	Daily peak factor	Instantaneous peak factor[1]	
			Low density[2]	High density[2]
House connection	1.5	2.4	3.6-4.0	4.0 min[3]
Yard connection	1.35	2.6	3.5-4.0	4.0 min[3]
Standpipe	1.2	3	3.0-3.6	2.0 min[3]

[1] Unrestricted systems are where no specific arrangement have been made to restrict the flow at all.

[2] Low density are generally found in rural areas and high density in urban areas

[3] Increases with diminishing number of consumers

As with the AADD of a development, there are also factors that could influence the actual peak factors of a development, such as the employment trends within the community, garden activities, economic status and number of dwellings within the development (CSIR, 2003). The number of dwellings does have a significant impact on the supply peak factors of the development, as indicated in Figure 2-10 and Figure 2-11 (note: the number of equivalent erven (ee) is determined by dividing the AADD of the development by 1000 ℓ/day).

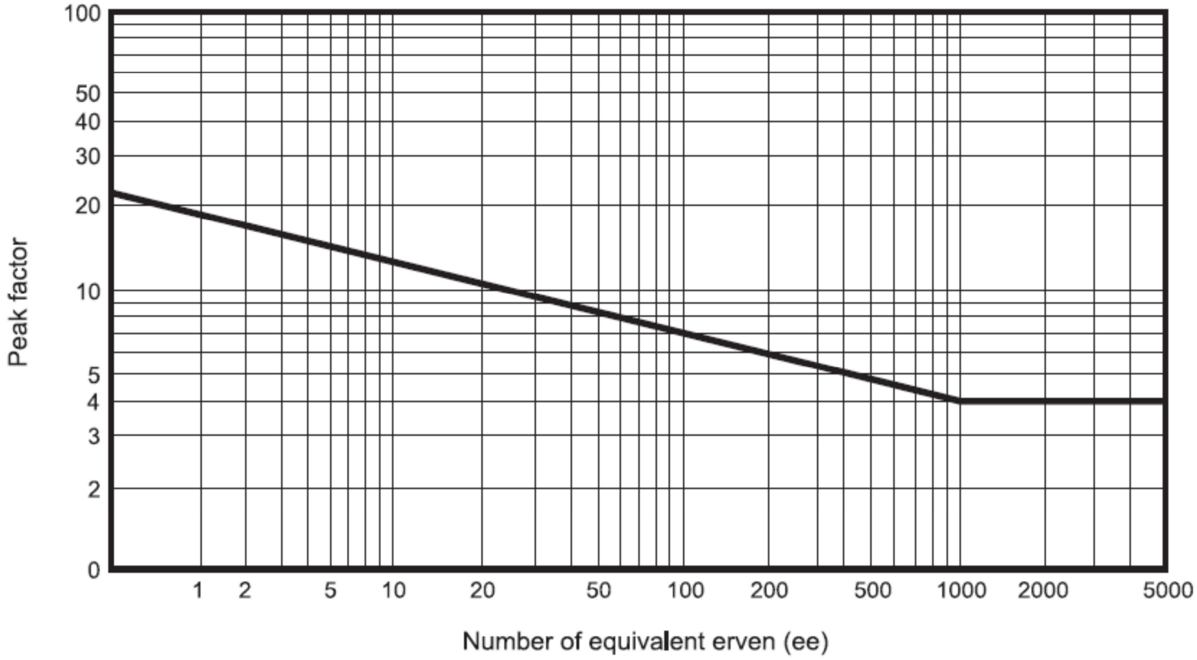

Figure 2-10: Peak factor in mains supplying low cost housing units with on-site storage (CSIR 2003: Figure 9.10)

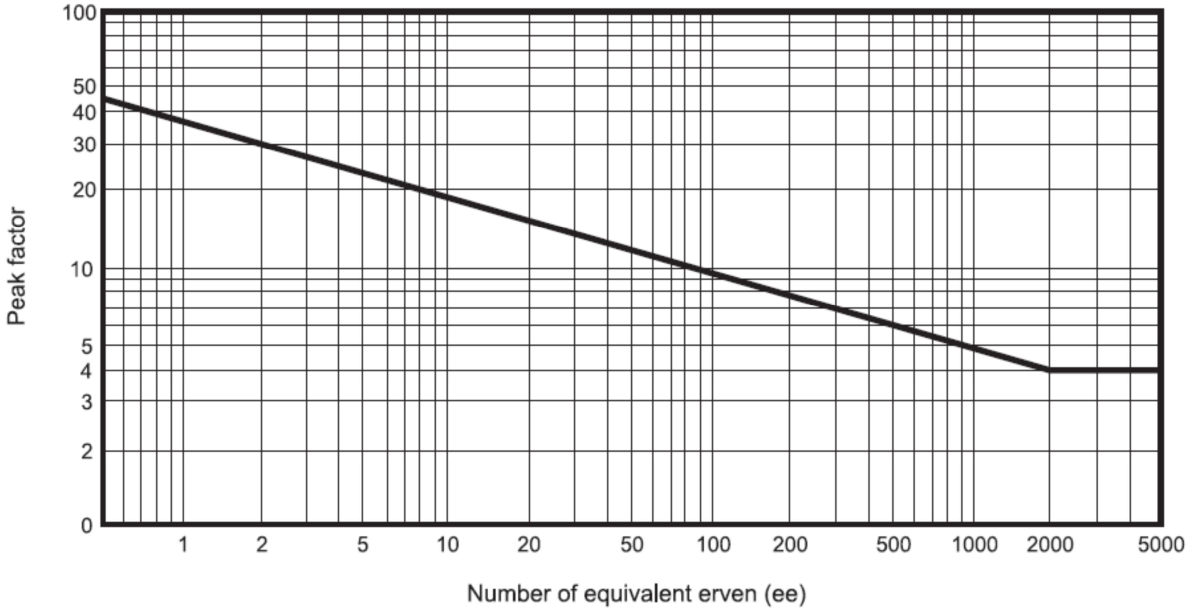

Figure 2-11: Peak factor in mains supplying developed areas (CSIR 2003: Figure 9.11)

This impact on the supply peak factor of the increase in number of dwellings or the population of the development can be defined as the impact of diversification of demand. Peak factors tend to increase with a decrease in the number of consumers (Johnson, 1999).

A number of formulas have been developed to approximate the peak factor given for specific population served, of which the Mutschmann Stimmelmayr formula (Mutschmann and Stimmelmayr, 2003) is one example, illustrated below:

$$\boldsymbol{SF = -0.1591\ \ln P + 3.5488} \tag{2-1}$$

where:

SF = design supply peak factor

P = population served

The German Technical and Scientific Association for Gas and Water (DVGW) (Deutscher Verein des Gas- und Wasserfaches, 2008) makes use of the Mutschmann Stimmelmayr formula for determining the peak day demand and has an alternative formula for determining the peak hour demand (Q_h) depending on the population served, which is expressed in the formula below:

$$\boldsymbol{Q_h = -0.75\ \ln E + 11.679} \tag{2-2}$$

where:

Q_h = the hour peak factor

E = the population served

Whereas the Mutschmann-Stimmelmayr and DVGW formulas calculate the design supply peak factor based on the population served, the Goodrich formula calculates what percentage the peak flow-rate would be of the average flow-rate for a given period (Brière, 2007).

$$\boldsymbol{p = 180 \times t^{-0.10}} \tag{2-3}$$

where:

p = the peak flow-rate as a percentage of the average flow-rate for a given period

t = the period studied in days (d)

The formula is applicable for values of t between 2/24 (2 hours) and 365 (1 year). The formula would therefore calculate that the peak day (t = 1) flow-rate would be 1.8 times higher than the average daily flow-rate and that the peak week flow-rate (t = 7) would be 1.48 times higher than the average weekly flow-rate. The peak flow-rate over a full year (t = 365) would be equal to the average annual flow-rate, as p = 100%. As the peak flow-rates are related to the average flow-rate for the specific period of duration and not related to the AADD flow-rate, it is not possible to compare the values as calculated by the Goodrich-formula with the other peak supply factors.

The above-mentioned are general guideline that may be used throughout South Africa. With the availability of consumption data, the supply peak factors may be adjusted for use in a specific metropolitan area. One such study used actual information from consumers within the East Rand Regional Services Council (ERRSC) to predict future water demand and to assist the ERRSC with infrastructure planning (Vorster, Geustyn, Loubser, Tanner and Wall, 1995). The peak factors applied in this study are summarised in Table 2-13, which also shows the impact of diversification as the areas with higher AADD (i.e more consumers) have reduced peak factors.

Table 2-13: Peak factors to be applied to AADD (Vorster *et al.* 1995: Table 5)

Predominant land use in area under consideration	AADD for area (Mℓ/day)	Peak month factor (PMF)	Peak week factor (PWF)	Peak day factor (PDF)	Peak hour factor (PHF)
Low density residential	<1.0	1.35	1.70	2.30	5.50
	1.0-5.0	1.3	1.65	2.20	4.50
	5.0-20.0	1.25	1.60	2.00	3.90
	>20.0	1.2	1.50	1.80	3.30
Medium density residential	<1.0	1.3	1.60	2.30	4.60
	1.0-5.0	1.25	1.55	2.00	4.00
	5.0-20.0	1.2	1.45	1.80	3.30
	>20.0	1.15	1.40	1.70	2.90
Industrial / commercial	<1.0	1.25	1.50	2.00	3.40
	1.0-5.0	1.2	1.45	1.80	3.00
	5.0-20.0	1.15	1.40	1.75	2.80
	>20.0	1.15	1.40	1.70	2.60

The Republic of South Africa: Department of Water Affairs (2004) indicates that a design summer peak factor of between 1.2 and 1.5 should be applied on bulk water systems and a DPF of between 2.0 to 3.0 on reticulation systems.

The City of Tshwane Metropolitan Municipality (2004) proposes the DPFs as summarised in Table 2-14, based on the average daily consumption and type of land use.

Table 2-14: Summary of DPFs used in City of Tshwane Metropolitan Municipality (City of Tshwane Metropolitan Municipality 2004: Table 3)

Land use	AADD (kℓ/day)	Peak week design factor	Peak day design factor	Peak hour design factor
Low-cost housing	<1 000	1.50	1.90	3.60
	1 000 – 5 000	1.40	1.80	3.40
	5 000 – 10 000	1.35	1.70	3.30
	10 000 – 15 000	1.30	1.50	3.20
	15 000 – 20 000	1.25	1.40	3.10
	>20 000	1.25	1.40	3.00
Residential	<1 000	1.80	2.20	4.60
	1 000 – 5 000	1.65	2.00	4.00
	5 000 – 10 000	1.50	1.80	3.60
	10 000 – 15 000	1.40	1.60	3.50
	15 000 – 20 000	1.35	1.50	3.30
	>20 000	1.30	1.50	3.00
Business/commercial/industrial	<5 000	1.45	1.70	3.30
	5 000 – 10 000	1.30	1.60	3.15

2.5 Design criteria for bulk systems

As this study focused on the peak factors experienced on two bulk water supply systems, i.e. the system does not supply water directly to the end-user consumer, but intermediate storage is provided which would reduce the peak demand factors, it remains important to review the design criteria usually used in the design of such bulk conveyance systems. The CSIR (2003) indicates that the supply main to a reservoir should have a design capacity of at least 1.5 times the AADD of the area served by the reservoir. As the supply main and storage reservoir are both part of the bulk supply system, the capacity of the supply main is also greatly influenced by the storage capacity of the reservoir it is serving, and vice versa; the storage volume of a reservoir influences the required capacity of the bulk main (Smook, 1985). With regard to this, the CSIR (2003) indicates that the storage reservoir should be sized to provide between one and two days storage of the average demand, but that this storage volume can be optimised by using the critical-period technique to determine the required balancing volume required. The Republic of South Africa: Department of Water Affairs (2004) indicated that bulk supply lines should be designed to be able to convey the summer daily demand (SDD), which is calculated as follows in the formula below.

$$SDD_{pl} = SPF * GAADD \qquad (2\text{-}4)$$

where:

SDD_{pl} = Summer Daily Demand for Pipelines

SPF = Summer Peak Factor

GAADD = Gross AADD, which is the AADD plus pipeline losses (10% of AADD of system)

The Republic of Water Affairs: Department of Water Affairs (2004) also provides guidelines on the storage volume required of reservoirs. Reservoirs required to store water that is pumped from a single source, should have at least 2 days AADD storage, while if receiving water from multiple pumped sources, the storage volume can be reduced to 1.5 days AADD storage volume. For a reservoir supplied by means of a gravity supply pipeline, the reservoir storage may be reduced to 1 day of AADD.

2.6 Water losses and leaks

In the design criteria for bulk water systems, it is indicated that allowance should be made for water losses in determining the design capacities of the bulk systems. These losses can be associated with real losses. Real losses are defined as the physical water losses from a pressurised system up to the point of metering at the consumer and water can be lost through leaks, bursts or overflows (Lambert and Hirner, 2000). The total water loss from a system can be defined as total input volume into the system minus the authorised consumption (Lambert & Hirner, 2000). Real losses are a key indicator in evaluating the condition, performance and management of a water supply system. Generally they are indicated as a percentage of the system input volume and this is a good enough indication of the volume of water lost, which can then be converted into a monetary value, but according to the International Water Association (IWA) it is not a suitable method for assessing the efficiency of the management of the supply system, as it does not take into account key influences on real water losses (Lambert & Hirner, 2000). Key local influences that make the managing of real losses difficult are the number of service connections, the length of the mains, the average operating pressure of the mains, the percentage of the year that the system is pressurised, infrastructure conditions, such as materials and frequencies of bursts and the type of soil and ground conditions (Lambert & Hirner, 2000). A more appropriate method of measuring the performance of a system in terms of real losses is the Infrastructure Leakage Index (ILI). However, to determine the additional capacity that a system should be designed for to ensure that the end-user is supplied with the acceptable volume of water, the expression of system losses as a percentage is an acceptable indication of the system losses. The reduction of real water losses is seen as an important step in the provision of basic water services to the population of South Africa, with President JG Zuma stating in his 2010 State of the Nation Address, that the target is to halve the countries' water losses by 2014 (McKenzie, Siqalaba and Wegelin, 2012). In the National Water Balance of 2009/10, the real or physical water losses in South Africa accounted for 25.4% of the total system input volume (McKenzie *et al.*, 2012). This is substantially higher than the design loss factor of 10% for total conveyance losses as proposed by DWA (Republic of South Africa: Department of Water Affairs, 2004).

2.7 Statistical and reliability analysis

2.7.1 Statistical definitions

Conner and Morrell (1977) define statistics as measurements, enumerations or estimates of natural or social phenomena systematically arranged so as to exhibit their interrelations. In order to characterise the differences and interrelations between different sets of samples, there are a number of basic statistical descriptors that describe the location, variability and shape of the data contained in a sample. The location of a sample is best described by the sample mean, which gives the analyst a quantitative measure of where the data's centre is located and is given by the following formula (Walpole and Myers, 1993).

$$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n} = \frac{x_1+x_2+\cdots+x_n}{n} \qquad (2\text{-}5)$$

where:

$\bar{x}$ = sample mean

$x_1, x_2, \ldots, x_n$ = observations in a sample

n = is the total number of observation in the sample

While the sample mean provides an indication of the location of the sample and may indicate the relative location of one sample to another, it is not capable of informing the analyst of the variability or spread of the sample. Variability in a population value is a fact of life and a large variability in a sample can prevent the analyst from drawing any clear conclusion from the data (Walpole & Myers, 1993). One of the simplest ways of indicating the variability of a sample is the sample range, which can be defined as the mathematical difference between the largest and smallest value of a sample, as expressed in the following formula:

$$Sample\ Range = X_{max} - X_{min} \qquad (2\text{-}6)$$

where:

X_{max} = Largest observation value in sample

X_{min} = Smallest observation value in sample

The sample measure of spread or variability most used in statistical analysis is the standard deviation of a sample (Walpole & Myers, 1993) and is defined as follows:

$$s = \sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \Big/ (n-1)} \qquad (2\text{-}7)$$

where:

s = Sample standard deviation

x_i = i-th observation value in sample

$\bar{x}$ = sample mean

N = number of observations in sample

The standard deviation is a value indicating the average difference between the observations in a sample and the sample mean, thus the larger the standard deviation of a sample of observations, the larger the spread or variability of the observation values.

Another statistical descriptor is the skewness of a data set. The skewness of a distribution denotes the extent of the asymmetry in the data (Das, 2009) and is calculated for sample of n value, using the following formula:

$$g_1 = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^3}{\left(\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^2\right)^{3/2}} \tag{2-8}$$

Where:

g_1 = sample skewness

x_i = i-th observation value in sample

n = number of observations in sample

$\bar{x}$ = sample mean

The skewness indicates the distance and location of the centroid (centre of weight) in relation to the sample mean. Zero skewness would indicate that the samples are symmetrically located around the sample mean, thus that the centroid of the sample is located on the sample mean. A negative skewness would indicate that the centroid is located to the right of the sample mean and a positive skewness that the centroid is located to the left of the sample mean.

2.7.2 Probability, permutations and combinations

Where the statistical descriptors for a data set would indicate the location and variation of the values within the data set, it would be unable to provide inference to the likelihood of a specific value or combinations of values occuring. This is defined by the probability (p) or the relative frequency of a certain event's occurrence in an infinite series of independent trials (Willink, 2013). In probability theory, a data set is usually defined as continuous or discrete. Peck, Olsen and Devore (2008) define a discrete data set as one in which possible values of the variable correspond to isolated points on the number line, while a continuous data set is one in which the set of possible values forms an entire interval on the number line. For a discrete random variable, the probability of a variable occurring is given by the probability mass function (pmf) (Stewart, 2009).

The probability of each discrete variable occurring could be different but, if the probability of each variable occurring is identical, each variable would have the same frequency of occurrence over a number of events, in which case the probability mass function can be defined as follows:

$$P_x\ (x) = \frac{1}{n} \tag{2-9}$$

where:

$P_x(x)$ = Probability mass function

n = Number of discrete variables

Walpole and Myers (1993) defines the probability of an event as the sum of the weights of all the sample points in the sample set of the event and if this is a discrete data set, with *n* number of discrete values, each with the same probability mass function, then this can be expressed as follows.

$$\boldsymbol{P(A) = \frac{1}{n} + \frac{1}{n} + \cdots + \frac{1}{n} \leq 1} \tag{2-10}$$

where:

P(A) = Probability of event A

n = Number of discrete variables

Where the outcome of one event has had no influence on the outcome of another event, the two events are deemed independent events (Walpole & Myers, 1993). However, where we are interested in the probability of specific outcomes from independent events, the multiplicative probability rule applies (Walpole & Myers, 1993), which states that the probability that two specific outcomes from two independent events would occur at the same time, is the product of the probability mass functions of the two events. This is expressed in the formula below.

$$\boldsymbol{P\ (A \cap B\ ) = P(A)\ \times P(B)} \tag{2-11}$$

where:

P (A ∩ B) = Probability of union of events A and B

P (A) = Probability of event A

P (B) = Probability of event B

For two discrete events with a number of possible outcomes and with each outcome having the same probability mass function in the sample, the probability that two specific discrete values from each independent discrete sample would occur at the same time can be defined as follows:

$$\boldsymbol{P\ (A \cap B\ ) = \frac{1}{n}\ \times \frac{1}{m}} \tag{2-12}$$

where:

P (A ∩ B) = Probability of union of event A and B

n = Number of discrete values in sample A

m = Number of discrete values in sample B

2.7.3 Application of the Monte Carlo method

As stated by Wagner, Shamir and Marks (1988), traditionally, water systems have been designed to be completely reliable, thus failure is not allowed. However, with increased costs and scarcity of public funds to undertake required maintenance on water systems, it has become important to the designers and operators of such systems to know how reliable such a system is. It is possible to simulate the reliability of a network, but this would require a substantial amount of time to generate the network model, input all the variables and then to execute the simulation. The other approach is to determine the reliability of a network through analytical methods, by means of using algorithms created for this function. These analytical methods do have limitations, as they are based on fairly stringent assumptions, which makes it difficult to use them in analysing real-life systems. Wagner *et al.* (1988) deem stochastic simulation, such as the Monte Carlo method, to be a useful augmentation to an analytical analysis in determining the reliability of a network system. Stochastic simulation methods are able of incorporating the more complicated features of a system and therefore providing more realistic analysis results. The other advantage of the stochastic network analysis method is that it yields bulk information on the system performance; duration of shortage or failure, as well as many other reliability indices can be calculated from this (Yang, Hsu, Louie and Yeh, 1996).

2.8 Monte Carlo analysis software

2.8.1 Overview

As the Monte Carlo stochastic method is the technique by which large quantities of randomly generated values are studied using a probabilistic model, it lends itself to making use of the computational power of a computer program. Currently there are a number of software applications making use of the Monte Carlo method. Most of these applications are used in the risk analysis field, for which the Monte Carlo method is well suited.

2.8.2 Crystal Ball

Crystal Ball is a Monte Carlo software packaged developed by Oracle (Oracle Products and Services, 2013). It is a spreadsheet-based application for predictive modelling, forecasting, simulation and optimization. It uses the spreadsheet program Microsoft Excel to generate a deterministic model for the analysis. The base spreadsheet model is a deterministic model, which means the inputs are fixed, thus the user can find the result of only one solution at a time. Crystal Ball allows the user to automatically generate different values for different inputs into the deterministic model. It has 21 predefined continuous and discrete distributions, which the user can use to define the parameters and variability of the deterministic model's inputs. The continuous distributions available in Crystal Ball are the following:

- Beta
- BetaPERT
- Exponential
- Gamma
- Logistic
- Lognormal
- Maximum Extreme
- Minimum Extreme
- Normal
- Pareto
- Student's *t*
- Triangular
- Uniform
- Weibull

The discrete distributions available in Crystal Ball are the following:

- Binomial
- Discrete Uniform
- Geometric
- Hypergeometric
- Negative Binomial
- Poisson
- Yes-No
- Triangular
- Uniform
- Weibull

Crystal Ball also has the capability of determining the best distribution to fit a data-set of values provided. It does this through the use of goodness-of-fit statistical tests, such as the Anderson-Darling, Kolmogorov-Smirnov and Chi-Squared tests.

Crystal Ball is available as corporate and academic licenced software. The corporate package is available as a stand-alone Crystal Ball package, or grouped together with other Oracle software such as the Decision Optimizer, in the Crystal Ball Suite, and Oracle Hyperion Smart View for Office, in the Oracle Crystal Ball Enterprise Performance Management package. The academic licensed software package, Crystal Ball Classroom Edition, is available in student and faculty editions. The student edition is a full-functioning, self-expiring, limited-term edition of Crystal Ball which has a one or two year license term option. A minimum purchase of 25 packages is required and no technical support is available for this license option. The Faculty edition is a full-functioning, non-expiring edition of the Crystal Ball software, designed specifically for university or college faculty members and technical support is available for this license option.

2.8.3 GoldSim

GoldSim is a Monte Carlo analysis package developed by GoldSim Technology Group (GoldSim Technology Group, 2013). It is a flexible probabilistic simulation platform that allows the visualisation and dynamic simulation of any kind of physical, financial or engineered system. The software is a stand-alone package that does not require any other software platform (such as Microsoft Excel) to operate. The user builds the simulation model by adding visual elements, which are interlinked and interact with other model elements as part of an influence diagram. The collective components, which comprise the system, all provide input into the final outcome or result of the simulation model. The user is responsible for providing all the required operational and statistical variables for each component in the system. Most applications where GoldSim is used fall into three main categories, which are environmental systems, business and economic systems and engineered systems modelling. Examples of GoldSim applications include water resource planning, modelling of water and waste management at mines and long-term strategic planning of complex engineered systems.

To assist the user in customizing the GoldSim package for their specific requirements, GoldSim was designed using a modular framework, with extension modules that can be added the base platform to provide additional features for each particular application. The modules available are:

- Financial Module
- Reliability Module
- Contaminant Transport Module
- Distributed Processing Module
- Dashboard Authoring Module

GoldSim differs from probabilistic spreadsheet software (such as @Risk and Crystal Ball) in that it is better at simulating dynamic systems that evolve over time, the graphical user interface of GoldSim makes it easier to understand, demonstrate and document the model's logic and structure. It is more suited to evaluating highly complex systems, without the user losing the ability to understand the model, due to its hierarchical submodel approach. Each element within the GoldSim model can be assigned deterministic and probabilistic operational properties. The probabilistic properties are expressed as a probability distribution within the element properties and during the Monte Carlo simulation, random outputs are generated based on the element's assigned properties. The following probability distributions are available within GoldSim.

- Uniform
- Beta
- Binomial
- Boolean
- Cumulative
- Discrete
- Exponential
- Extreme Maximum Value
- Extreme Minimum Value
- Gamma
- Log-Normal
- Negative Binomial
- Normal
- Pareto
- Pearson Type III
- Poisson
- Simple Result
- Student's t
- Triangular
- Uniform
- Weibull

The GoldSim product line consists of the following three products:

- GoldSim Pro – The commercial version of GoldSim, which provides all the basic functionality to build the simulation models. It includes the additional add-on modules for specific type of analysis.
- GoldSim Academic – This has the same capabilities as the GoldSim Pro package, but the model size is limited to 500 elements. It includes all the GoldSim modules, except for the Dashboard Authoring Module. It includes technical support during the download and installation stages. The academic license is valid for a certain limited duration, usually 1 year, but can be renewed. The version does have restrictions in terms of what it may be used for.

- GoldSim Research - This provides the same features as GoldSim Pro and it also includes technical support. GoldSim Research licenses do not expire. This version is intended for use by faculty or academic institutions for the purpose of research.
- GoldSim Player – This package allows the user to view, navigate and run an existing GoldSim model. It cannot be used to build a new model, or modify an existing model.

2.8.4 @Risk

@Risk is, such as Crystal Ball, spreadsheet-based Monte-Carlo analysis software (Palisade Corporation, 2013). It is developed and marketed by the Palisade Corporation. The software, as does Oracle Crystal Ball, also uses Microsoft Excel as the platform within which to build the reliability model the user wants analysed. It makes use of Microsoft Excel's built in spreadsheet functions, but additionally allows the user to quantify the variability of specific model inputs through the built-in probability distribution functions of @Risk. The @Risk software allows the user to execute a Monte Carlo simulation in order to determine the impact of the variability on some of the input parameters. @Risk also integrates Microsoft Excel with Microsoft Powerpoint, allowing the importation of project schedules and thus allowing the user to simulate the risks of the variable duration of certain activities. It also has the capability to simulate time series processes, or values that change over time.

@Risk has a built-in library of probabilistic distributions, that includes the following distribution types:

- Beta
- Beta (Generalised)
- Beta (Subjective)
- Binomial
- Chi-Squared
- Cumulative (Ascending)
- Cumulative (Descending)
- Discrete
- Discrete Uniform
- "Error Function"
- Erlang
- Exponential
- Extreme Value
- Gamma
- General
- Geometric
- Histogram
- Hypergeometric
- Integer Uniform
- Inverse Gaussian
- Logistic
- Log-Logistic
- Lognormal
- Negative Binomial
- Normal
- Pareto (First Kind)
- Pareto (Second Kind)
- Pearson Type V
- Pearson Type VI
- Pert (Beta)
- Poisson
- Rayleigh
- Student's "t"
- Triangular
- Uniform
- Weibull

@Risk is available through different license types, such as:

- Stand-alone – Intended for use by one person on one computer and this license may not be run from a server.

- Concurrent Network License – Intended to serve multiple users from a network server. The software may be installed on a server or on an unlimited number of computers. The restriction of use of the software is placed on the number of users who are allowed to use the software simultaneously which is determined by the number of licenses purchased.
- Enterprise Activation Server – This allows a client server to issue stand-alone licenses to client computers, without having to contact the Palisade licence server every time. Stand-alone computers are issued with an activation key and are then allowed to run the software directly off the stand-alone computer, not requiring access to the server all the time. Once a user has completed the required work, he/she may de-activate the license on the computer. The license is then returned to the server and may then be used by other users. The number of users is limited by how many user licenses are purchased from Palisade.
- Corporate Licenses – Under this license agreement, the user purchases a set number of concurrent network licenses or enterprise activation licenses, but at a reduced unit cost per licence. This is more suitable to large corporations requiring a substantial number of users to be able to use the software concurrently.
- Palisade Academic Software - For use by academic institutions and students, the following three academic license options are available:
  - Student Version – 95% discount on retail price. The software is fully functional software, but the licence expires 1 year after installation and may not be upgraded.
  - Course Version – Discount on the retail price depending on the number of licenses purchased. The software is fully functional and the license expires 1 year after installation, but is renewable.
  - Full Academic Version – 50% discount on retail price. The software is fully functional software and the licence does not expire.

CHAPTER 3 : METHODOLOGY

3.1 Research methodology

The research methodology followed in this thesis encompassed the completion of the following tasks, namely a literature review, selection of the study site, obtaining of data, analysis of data, determination of peak month factors for the supply systems based on deterministic and probabilistic peak factor calculations, a discussion of the results and conclusions.

3.2 Literature review

The literature review included a review of similar studies in the determination of peak factors on distribution systems. The review investigated the methods used in calculating different peak factors, as well as the DPFs proposed in guidelines that may be used in the design of reticulation systems. The results of the reviews are contained in Chapter 2, but in Chapters 7 and 8 these peak factors are compared with the peak factors obtained through the analysis of the data.

3.3 Selection of study area

In the selection of an appropriate study area, the following eligibility criteria were set:

- The data set had to contain more than 10 years of continuous consumption data to allow the identification of demand patterns could be decerned;
- The data set had to contain monthly or higher frequency consumption data (daily or weekly figures) to allow the calculation of monthly consumption values;
- The data had to be the consumption data for a bulk water supply system, thus one with each supply point having a storage facility which was fed by the bulk system;
- The bulk system had to contain at least 10 supply points, in order to allow the researcher to investigate the temporal demand variation of the different supply points;
- Permission to use the data for the analysis of consumption data; and
- The system had to be part of an active water conservation and demand management study, thus reducing the possibility of significant system losses, which would have had an impact on the demand and peak factor calculations.

3.4 Obtaining of data

The data used in this thesis was obtained from the WCDM, provided the raw monthly water consumption data for two of their bulk supply systems. Permission was obtained to review and use the data in the determination of supply peak factors and to compare these against published factors. The data was obtained via e-mail from the WCDM in a Microsoft Excel file format. The data is discussed in more detail in Chapter 4, and complied with all the eligibility criteria as set out.

3.5 Analysis of data

The data received was analysed to confirm that it complied with the eligibility criteria set out. Where end-user data did not comply with the criteria, that specific end-user was not used further in the analysis; however the complete data-set was not discarded. The data was further evaluated and, where required, the data was patched to ensure that a full data-set was available for the analysis. The annual water consumption for each end user point and for each year of the record was determined, by the summation of the monthly consumption figures, as per the following equation.

$$\boldsymbol{AC = \sum_{i=1}^{12} MC_i} \tag{3-1}$$

where:

AC = Annual Consumption per end-user (kℓ)

MC_i = Monthly Consumption per end-user for *i*-th month of the year (kℓ)

From the annual consumption of the end-user for the specific year, the average monthly consumption was then determined. The average monthly consumption was based on the number of calendar days of each month.

$$\boldsymbol{AMC_i = \frac{AC}{365} \times n_i} \tag{3-2}$$

where:

AMC_i = Average Monthly Consumption per end-user for month *i* (kℓ)

AC = Annual Consumption per end-user (kℓ)

n_i = Number of calendar days in month *i*

A dimensionless monthly peak factor (MPF) for each end-user for the each month and year was then determined as follows.

$$\boldsymbol{MPF_i = \frac{MC_i}{AMC_i}} \tag{3-3}$$

where:

MPF_i = MPF per end-user for month *i*

MC_i = Monthly Consumption per end-user for *i*-th month of the year (kℓ)

AMC_i = Average Monthly Consumption per end-user for month *i* (kℓ)

The above calculations were done for each end-user of each system for each month of the data-record.

3.6 Deterministic peak factor calculations

The approach followed to determine the peak factors by means of the deterministic method, determined the maximum monthly peak factor for each end-user for each month of the data-set. The calculation is expressed by the following equation.

$$\boldsymbol{MPF_i^j} = \mathbf{max}(\boldsymbol{MPF_{i-1}^j};\ \boldsymbol{MPF_{i-2}^j};\ \ldots;\ \boldsymbol{MPF_{i-a}^j}) \tag{3-4}$$

Where:

MPF^j_i = Monthly peak factor (MPF) of *j*-th end-user for month i of the hydrological year

$\mathrm{MPF}^j_{i\text{-}1}$ = MPF of *j*-th end-user in first data point of the month *i*-th of the hydrological year in the first year of the data-set

$\mathrm{MPF}^j_{i\text{-a}}$ = MPF of *j*-th end-user in *i*-th month of the hydrological year in the last year of the data-set

From this calculation, the maximum peak month factor to occur in a specific month throughout the data-set for a specific end-user is determined. These calculated user-defined maximum month peak factors are then used to determine the peak month factor for the entire system, as per the following equation.

$$\mathbf{MPF}_i^a = \frac{\sum_{\mathrm{i=1}}^{\mathrm{b}}\left(\mathbf{AMC}_i^j \times \mathbf{MPF}_i^j\right)}{\sum_{\mathrm{i=1}}^{\mathrm{b}} \mathbf{AMC}_i^j} \tag{3-5}$$

where:

MPF^a_i = MPF of *a*-th system for *i*-th month of the hydrological year

AMC^j_i = Average Monthly Consumption per *j*-th end-user for month *i* (kℓ)

MPF^j_i = MPF of *j*-th end-user for month *i* of the hydrological year

From the above calculations, the MPF of the specific system can be determined for each month of the hydrological year based on the maximum recorded peak month factor for each user.

3.7 Probabilistic peak factor calculations

For calculating the month peak factor of the systems by means of probabilistic analysis, the same approach as that described in described in section 3.5 was followed. The MPF for each end-user in the system and for each month was calculated. This is then repeated for each hydrological year of the data available. Whereas the deterministic method only used the maximum MPF calculated for each end-user for each month from the total data-set of hydrological years, the probabilistic method used every MPF calculated for each end-user.

The probabilistic method made use of the @Risk-software's Monte Carlo functionality to create a probability distribution for each end-user's peak month factor for each month of the hydrological year. In the analysis a discrete probability distribution was used. Each of the calculated PMFs, for each end-user, through all the hydrological years was included as a discrete variable for each month of the year in the distribution.

The probability distribution was analysed as a uniform discrete distribution, thus each of the discrete variables had a probability of the inverse of the number of discrete variables used, as defined in the following equation.

$$\boldsymbol{PMF = \frac{1}{n}} \tag{3-6}$$

where:

PMF =Probability Mass Function

n = Number of values

The Peak Month Factor for a system was therefore calculated in much the same way as the deterministic calculation method (Equation 3-5), the only difference is that instead of using the maximum recorded Peak Month Factor for the specific user and specific month, the Peak Month Factor was described using the discrete uniform probability distribution as defined in the following equation:

$$\mathbf{MPF}_{\boldsymbol{i}}^{\boldsymbol{a}} = \frac{\sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{b}}\left(\mathbf{AMC}_{\boldsymbol{i}}^{\boldsymbol{j}} \times \mathbf{f}\left(\boldsymbol{MPF}_{\boldsymbol{i}-\mathbf{1}}^{\boldsymbol{j}}; \boldsymbol{MPF}_{\boldsymbol{i}-\mathbf{2}}^{\boldsymbol{j}}; \ldots; \boldsymbol{MPF}_{\boldsymbol{i}-\boldsymbol{a}}^{\boldsymbol{j}} \middle| \boldsymbol{n}\right)\right)}{\sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{b}} \mathbf{AMC}_{\boldsymbol{i}}^{\boldsymbol{j}}} \tag{3-7}$$

where:

$\mathrm{MPF}^{a}{}_{i}$ = MPF of *a*-th system for *i*-th month of the hydrological year

$\mathrm{AMC}^{j}{}_{i}$ = Average Monthly Consumption per *j*-th end-user for month *i* (kℓ)

$\mathrm{MPF}^{j}{}_{i\text{-}1}$ = MPF of *j*-th end-user in first data point of the month *i*-th of the hydrological year in the first year of the data-set

$\mathrm{MPF}^{j}{}_{i\text{-}\mathrm{a}}$ = MPF of *j*-th end-user in *i*-th month of the hydrological year in the last year of the data-set

n = Number of values in data-set

3.8 @Risk simulation configuration

As discussed earlier, the @Risk software executes a Monte Carlo analysis by substituting the multiple discrete variables available for all the MPF inputs for all the end-user points and for each month of the hydrological year. During every iteration of the Monte Carlo analysis, the software selects a value from each discrete sample set and inputs that into the analysis. The result of this single iteration is then stored as a specific outcome value. This process is repeated until the total number of iterations specified has been executed. The software then assigns a probability mass function value to each outcome value calculated. The assigning of a probability mass function to each outcome indicates the relative frequency that the specific value occurred during the analysis of the data. All the outcomes are then plotted as a probability distribution, with the outcome values on the horizontal- and the probability mass function values on the vertical axis. The

@Risk software is capable of executing a vast number of iterations, the maximum number being restricted only by the amount of time available to execute the iterations, or by the computational capacity of the personal computer being used. It can be deduced that the more iterations that are executed, the higher the probability that all possible combinations of sample-values will be analysed. The maximum number of iterations possible with the available computational capacity was determined through a trial and error method to be 1 500 000 iterations. The Latin-Hypercube sampling method was used in the Monte Carlo analysis.

CHAPTER 4 : WATER DEMAND DATA

4.1 Overview

The data contained water consumption information for two bulk distribution systems of the WCDM, namely Swartland and Withoogte. These two systems are fed by separate supply nodes to different off-takes.

The data is arranged in hydrological years, from July to June. This is in line with the WCDM financial year. For the purpose of this research the hydrological year was used as well to organise the data. The reasons for selecting a hydrological year for analysis in this research are:

- The study area is in a winter rainfall zone, thus the highest consumption would generally occur in the driest months, which in this case is the summer months. Thus selecting the hydrological year to span the driest months, ensured that the peak consumption months of a season would be captured within the centre of the hydrological year concerned;
- Periods of interest would plot in the middle of the graphs' x-axis, which would be aesthetically pleasing;
- Normally water meter readings are taken at regular intervals, once a month and usually on the same day of each month, to ensure accuracy of monthly consumption calculations and subsequent invoicing of the consumer. During the end-of-year break, the meters are not always read at the same interval as the rest of the year, thus December consumption is usually measured only in the following month of January. Selection of the hydrological year to span the months of December and January, therefore eliminates any risk that the consumption of December will be measured as part of consumption of the following hydrological year.

The data from Swartland and Withoogte contains monthly water consumption readings for 21 supply points each. The first data point in both data-sets is consumption for July 1995 while the last data point is for consumption during February 2010, thus a total duration of 14 years and 8 months. Each of the Withoogte and Swartland systems supplies water to a range of different end users, ranging from municipalities to farmers and factories. Such a mix of consumer types is typical of bulk supply systems and complicates the theoretical estimation of peaks.

4.2 Withoogte system data

The Withoogte data contains monthly water consumption figures for 21 supply points. A summary of the number and type of water user supplied by this system is contained the Table 4-1.

Table 4-1: Withoogte water users

Category of water supply points	Number of supply points in category
Municipal	17
Industrial	1
Agricultural	1
Other	2

The two supply points classified as municipal were supply points to towns (Hopefield, Saldanha, Langebaan, etc.). These points therefore supplied numerous individual consumers, with a number of different water uses (residential, commercial, industrial, etc.) combined into each supply point.

Of the 21 supply points, 6 were not in use from the start of the data-set. These 6 supply points had less than 10 years of consumption data, thus they did not satisfy the eligibility criteria of this thesis and were therefore not included in the analysis.

A summary of the data used in the analysis is given, as well as the calculated number of different outcomes possible, based on the number of end-users and number of years of data used in the calculations, for the data set of the entire Withoogte system is given in Table 4-2. The number of outcomes relate to total number of statistically possible outcomes, based on the number of end-users and the number of years of data available to use as input to the simulation.

Table 4-2: Withoogte probabilistic analysis data input

End-user	Number of years of data used
Hopefield	14
Langebaanweg	14
Saldanha 1	14
Saldanha 2	14
Club Mykonos	14
Long Acres	14
Koringberg	14
Vredenburg 1	13
Vredenburg 2	12
St Helenabaai	14
Dwarskersbos	14
Moorreesburg	14
Spoornet (Ore Harbour)	14
Louwville	14
Vredenburg	13
Total system outcomes	114.9×10^{15}

4.3 Swartland system data

The Swartland data contains monthly water consumption figures for 21 supply points. A summary of the number and type of water user supplied by this system is contained in Table 4-3.

Table 4-3: Swartland water users

Category of water supply points	Number of supply points in category
Municipal	9
Industrial	4
Agricultural	5
Other	3

The municipal supply points were supply points to towns (Gouda, Riebeeck Wes, Riebeeck Kasteel, etc.). These points therefore supplied numerous individual consumers, with a number of different water uses (residential, commercial, industrial, etc.) combined into each supply point. Among the supply points that could not be categorised into the three main categories, were the PPC-factory housing complex, the Riebeeck West Prison and the Cheesemouse Farm Stall.

Of the 21 supply points, 7 were not in use from the start of the data-set. These 7 supply points have less than 10 years of consumption data, thus they do not satisfy the eligibility criteria of this thesis and were therefore not included in the analysis.

A summary of the data used in the analysis is given, as well as the calculated number of different outcomes possible, based on the number of end-users and number of years of data used in the calculations, for the data set of the entire Swartland system is given in Table 4-4. The number of outcomes relate to total number of statistically possible outcomes, based on the number of end-users and the number of years of data available to use as input to the simulation.

Table 4-4: Swartland probabilistic analysis data input

End-user	Number of years of data used
Gouda	14
PPC Housing	14
Riebeek Wes	14
Riebeek Prison	14
Riebeek Kasteel	14
Langewens Experimental Farm	14
Malm-Prison Main	11
Malm-Old Golf Course	14
Malm-Panorama	14
Malm-Wesbank	14
Mamreweg Cellars	14
FW Duckitt	14
Darling	14
Yzerfontein	14
Total system outcomes	8.730×10^{15}

CHAPTER 5 : RESULTS: DETERMINISTIC PEAK FACTORS

5.1 Procedure for analysis

The procedure in determining the deterministic month peak factors (MPF) for the two systems is described below.

The first step was to calculate the annual consumption of each end-user within a hydrological year, as described in equation 3-1. From the annual consumption, the monthly consumption for each end-user was calculated for each specific hydrological year, in accordance with equation 3-2. A dimensionless MPF was then calculated per end-user for each month and every hydrological year, as defined in equation 3-3. For the deterministic MPF calculation, the maximum MPF for each end-user and each month was determined by selecting the maximum MPF obtained from all the hydrological years, as per equation 3-4. The result of this calculation was the maximum MPF for each end-user for a specific month. The peak month demand per end-user for a specific month was then calculated, by multiplying the AADD of the end-user by the selected maximum MPF. The peak month demand was expressed as a daily demand (kℓ/d). The AADD used in this calculation was the AADD of the last hydrological year for which data was available, which was the 2008/09 hydrological year. This was done for each end-user and for each month. The peak month demand for the entire system was then calculated for a specific month, by adding all the end-user’s peak month demands for the specific month together. The system MPF for the specific month was then calculated by dividing this system peak month demand by the sum of all the end-user’s AADD. The calculation as described above is as per equation 3-5.

This procedure was followed for both systems.

5.2 Withoogte system deterministic results

The Withoogte system end-user monthly consumption was analysed using the deterministic method. The results of this analysis are summarised in Table 5-1. The AADD value indicated in the table was for the last hydrological year of data (July 2008 to June 2009).

Table 5-1: Withoogte deterministic results

End-user	AADD (kℓ/d)	Month											
		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	**Max**
Hopefield	968	0.85	1.01	1.06	1.18	**2.09**	1.35	2.05	2.00	1.65	1.38	1.07	0.94	**2.09**
Langebaanweg	2401	0.88	0.76	0.92	1.04	1.48	1.28	1.78	**1.89**	1.42	1.46	1.10	1.14	**1.89**
Saldanha 1	1174	1.22	1.18	1.31	**1.83**	1.24	1.04	1.54	1.41	1.23	1.37	1.31	1.32	**1.83**
Saldanha 2	8532	1.07	1.04	1.07	1.11	1.22	1.57	**2.05**	1.70	1.77	1.50	1.33	1.21	**2.05**
Club Mykonos	525	1.53	1.16	1.39	1.10	1.26	1.22	1.68	1.87	1.28	**2.03**	1.34	1.20	**2.03**
Long Acres	969	0.86	0.78	0.87	1.02	1.46	1.34	**3.05**	1.69	1.36	2.02	1.33	1.19	**3.05**
Koringberg	172	1.24	0.94	0.88	1.01	**3.31**	3.14	2.25	2.23	2.31	1.91	1.56	1.89	**3.31**
Vredenburg 1	152	0.85	0.74	0.76	1.37	1.21	**2.38**	2.10	1.93	1.44	1.79	1.03	1.34	**2.38**
Vredenburg 2	263	2.58	**4.56**	3.05	2.44	3.54	1.29	3.29	3.02	1.27	2.11	1.80	3.68	**4.56**
St Helenabaai	4289	1.05	1.09	1.02	1.11	1.18	1.40	1.28	1.61	1.34	1.40	**1.76**	1.24	**1.76**
Dwarskersbos	248	0.76	0.72	0.90	1.13	1.35	1.25	**2.63**	1.80	1.74	1.48	1.29	0.81	**2.63**
Moorreesburg	2181	1.20	0.99	0.94	1.09	1.39	1.49	1.80	**1.93**	1.46	1.40	1.08	1.02	**1.93**
Spoornet (Ore Harbour)	898	1.40	1.13	1.20	1.76	1.76	1.46	1.90	**3.48**	1.63	2.09	2.04	1.47	**3.48**
Louwville	3158	1.02	1.05	1.07	1.17	1.39	1.33	1.72	1.48	1.28	1.59	1.52	**2.11**	**2.11**
Vredenburg	5423	1.37	1.38	1.37	1.34	1.68	1.29	1.57	**2.06**	1.34	1.47	1.32	1.34	**2.06**
MPF for system		**1.13**	**1.11**	**1.12**	**1.20**	**1.43**	**1.41**	**1.81**	**1.83**	**1.49**	**1.52**	**1.39**	**1.33**	

5.3 Swartland system deterministic results

The Swartland system end-user monthly consumption was analysed using the deterministic method. The results of this analysis are summarised in Table 5-2. The AADD value indicated in the table was for the last hydrological year of data (July 2008 to June 2009).

Table 5-2: Swartland deterministic results

End-user	AADD (kℓ/d)	Month												
		Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	**Max**
Gouda	405	1.32	0.96	1.26	1.14	1.06	1.29	1.70	**2.09**	1.85	1.88	1.30	1.11	**2.09**
PPC-Housing	158	4.02	0.96	0.80	**4.81**	1.57	1.50	2.00	2.35	1.97	1.78	1.45	0.88	**4.81**
Riebeek Wes	457	1.35	1.12	1.03	1.96	1.59	**1.99**	1.60	1.65	1.35	1.76	1.43	1.26	**1.99**
Riebeek Prison	113	0.91	1.29	0.94	1.44	1.40	**3.15**	2.01	1.61	1.65	1.87	1.38	1.55	**3.15**
Riebeek Kasteel	706	0.85	1.10	1.23	1.15	1.89	1.91	1.55	**2.31**	1.61	1.57	1.25	1.47	**2.31**
Langewens Experimental Farm	45	1.35	1.61	0.95	1.56	1.94	1.69	**3.39**	2.32	2.08	1.86	1.35	1.45	**3.39**
Malm-Prison Main	809	1.13	1.18	1.20	1.41	1.87	1.25	1.55	**3.03**	1.31	2.06	1.19	1.15	**3.03**
Malm-Ou Gholfbaan	2548	1.43	1.21	1.44	1.43	1.57	1.30	2.00	**2.38**	1.69	1.50	0.99	1.30	**2.38**
Malm-Panorama	2729	0.95	1.12	0.95	1.12	1.57	1.42	1.74	**2.18**	1.56	1.46	1.20	1.14	**2.18**
Malm-Wesbank	2258	1.04	1.22	1.07	1.43	1.30	**1.49**	1.46	1.45	1.21	1.22	1.17	1.16	**1.49**
Mamreweg Cellars	57	0.79	1.00	0.76	0.83	1.01	1.25	1.67	**2.85**	2.42	1.94	1.12	0.95	**2.85**
FW Duckitt	115	0.87	0.37	0.95	1.51	1.91	1.75	3.66	2.98	3.14	**3.75**	1.68	0.66	**3.75**
Darling	1462	0.96	1.01	1.05	1.14	1.27	1.26	1.55	**1.92**	1.42	1.59	1.66	1.75	**1.92**
Yzerfontein	815	0.83	0.85	0.88	1.22	1.36	1.61	**2.54**	2.20	1.37	2.19	1.15	0.86	**2.54**
MPF for system		**1.13**	**1.12**	**1.12**	**1.35**	**1.49**	**1.45**	**1.77**	**2.11**	**1.51**	**1.59**	**1.23**	**1.25**	

CHAPTER 6 : RESULTS: PROBABILISTIC PEAK FACTORS

6.1 Procedure for analysis

The procedure in determining the probabilistic month peak factors (MPF) for the two systems is described below.

The first step was to calculate the annual consumption of each end-user within a hydrological year, as described in equation 3-1. From the annual consumption, the monthly consumption for each end-user was calculated for each specific hydrological year, in accordance with equation 3-2. The MPF was then calculated per end-user for each month and every hydrological year, as defined in equation 3-3. For the probabilistic MPF calculation, each of the calculated MPF for each end-user and each month was used as a variable in a uniform discrete probabilistic function. The probability mass function for each user's discrete probabilistic function was dependent on the number of years data available for that user. The probability mass function (PMF) for each variable was calculated in accordance with equation 3-6. The probabilistic system MPF for each month was calculated in accordance with equation 3-7. The method is similar to the calculation used in determining the deterministic MPF, but where the deterministic method only used the maximum MPF of each end-user for each month, the probabilistic method used all the calculated MPFs as variables in the probabilistic function. By making use of the Monte Carlo analysis capabilities of the @Risk software, multiple MPFs were calculated, by substituting a new MPF from the range of available MPFs into the formula to calculate a new system MPF. The results from the Monte Carlo analysis were then ranked in terms of probability of occurrence. This calculation method was done for both systems.

6.2 Withoogte system Monte Carlo analysis inputs

For the probabilistic calculation of the system's MPF, the complete range of MPFs for each end-user and for each month as calculated throughout the entire data-set was used as input to the model. In Table 6-1 to Table 6-15, the statistical properties and probability mass function value used in the Monte Carlo analysis of the range of MPFs for the Withoogte system are summarised.

Table 6-1: Hopefield MPFs statistical properties (Withoogte system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	0.85	1.01	1.06	1.18	**2.09**	1.35	2.05	2.00	1.65	1.38	1.07	0.94
Min	0.04	0.07	**0.02**	0.28	0.96	0.76	1.24	1.29	0.96	0.84	0.32	0.18
Ave	0.50	0.56	0.55	0.80	1.24	1.16	1.61	1.62	1.31	1.18	0.81	0.71
Std dev	0.26	0.30	0.32	0.21	0.30	0.20	0.30	0.24	0.19	0.15	0.19	0.20
Skewness	-0.64	-0.48	-0.49	-0.55	1.87	-0.07	0.43	0.21	0.00	-0.88	-1.51	-1.44
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-2: Langebaanweg MPFs statistical properties (Withoogte system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	0.88	0.76	0.92	1.04	1.48	1.28	1.78	**1.89**	1.42	1.46	1.10	1.14
Min	**0.37**	0.47	0.45	0.61	0.98	0.87	1.27	1.35	0.85	1.01	0.59	0.50
Ave	0.60	0.62	0.70	0.81	1.18	1.10	1.52	1.51	1.20	1.22	0.85	0.74
Std dev	0.16	0.10	0.12	0.13	0.14	0.13	0.16	0.14	0.15	0.13	0.17	0.17
Skewness	0.49	0.01	-0.09	0.14	0.33	-0.35	-0.01	1.55	-0.69	0.02	-0.14	0.74
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-3: Saldanha 1 MPFs statistical properties (Withoogte system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.22	1.18	1.31	**1.83**	1.24	1.04	1.54	1.41	1.23	1.37	1.31	1.32
Min	0.65	0.73	0.62	0.68	0.45	**0.35**	0.43	0.80	0.75	0.91	0.84	0.74
Ave	0.91	0.91	0.99	0.97	0.96	0.83	1.13	1.13	1.01	1.12	1.02	1.03
Std dev	0.18	0.15	0.19	0.28	0.21	0.18	0.24	0.15	0.16	0.16	0.15	0.17
Skewness	0.08	-0.14	-0.47	1.96	-1.07	-1.19	-1.46	-0.28	-0.24	-0.15	0.79	0.16
N	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-4: Saldanha 2 MPFs statistical properties (Withoogte system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.07	1.04	1.07	1.11	1.22	1.57	**2.05**	1.70	1.77	1.50	1.33	1.21
Min	0.33	0.29	0.31	0.39	0.57	0.75	1.07	0.99	0.94	**0.28**	0.65	0.55
Ave	0.81	0.78	0.81	0.81	1.04	1.02	1.36	1.40	1.16	1.06	0.89	0.88
Std dev	0.18	0.20	0.22	0.20	0.24	0.20	0.30	0.22	0.22	0.33	0.23	0.24
Skewness	-1.47	-1.24	-1.18	-0.76	-0.77	1.59	1.17	-0.14	1.59	-1.63	-1.24	-1.32
N	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-5: Club Mykonos MPFs statistical properties (Withoogte system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.53	1.16	1.39	1.10	1.26	1.22	1.68	1.87	1.28	**2.03**	1.34	1.20
Min	0.33	0.44	**0.13**	0.23	0.88	0.21	0.24	0.19	0.16	0.80	0.71	0.75
Ave	0.85	0.79	0.81	0.81	1.04	0.96	1.45	1.28	1.01	1.22	0.94	0.85
Std dev	0.27	0.16	0.26	0.25	0.11	0.24	0.40	0.35	0.28	0.27	0.19	0.25
Skewness	0.82	0.09	-0.58	-1.54	0.24	-2.21	-1.84	-1.95	-1.94	1.80	-0.09	-2.06
N	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-6: Long Acres MPFs statistical properties (Withoogte system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	0.86	0.78	0.87	1.02	1.46	1.34	**3.05**	1.69	1.36	2.02	1.33	1.19
Min	0.40	0.53	**0.37**	0.52	0.94	0.63	1.20	1.10	0.89	0.84	0.65	0.54
Ave	0.57	0.61	0.67	0.84	1.06	1.03	1.62	1.40	1.21	1.31	0.93	0.79
Std dev	0.13	0.09	0.13	0.16	0.14	0.20	0.46	0.20	0.36	0.26	0.17	0.18
Skewness	0.89	-0.31	-0.74	-0.88	1.39	-1.25	2.28	-0.01	2.59	1.03	0.85	0.58
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-7: Koringberg MPFs statistical properties (Withoogte system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.24	0.94	0.88	1.01	3.31	**3.14**	2.25	2.23	2.31	1.91	1.56	1.89
Min	0.11	0.14	0.12	0.21	0.14	0.77	**0.00**	0.72	0.80	0.20	0.33	0.33
Ave	0.69	0.58	0.47	0.84	1.13	1.41	1.23	1.46	1.30	1.22	0.90	0.80
Std dev	0.31	0.28	0.22	0.19	0.69	0.63	0.50	0.38	0.43	0.48	0.30	0.39
Skewness	-0.24	-0.41	0.35	-2.45	2.19	1.86	-0.57	0.00	1.59	-0.62	0.32	1.58
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-8: Vredenburg 1 MPFs statistical properties (Withoogte system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	0.85	0.74	0.76	1.37	1.21	**2.38**	2.10	1.93	1.44	1.79	1.03	1.34
Min	0.46	0.21	**0.07**	0.52	0.95	0.75	1.18	1.26	0.39	0.96	0.66	0.50
Ave	0.63	0.53	0.60	0.79	1.06	1.21	1.62	1.57	1.15	1.19	0.84	0.85
Std dev	0.10	0.14	0.17	0.21	0.09	0.36	0.25	0.21	0.26	0.23	0.10	0.25
Skewness	0.54	-0.53	-2.52	1.65	0.74	2.72	0.39	0.28	-1.92	1.40	0.04	0.60
n	13	13	13	13	13	13	13	13	13	13	13	13
PMF	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077

Table 6-9: Vredenburg 2 MPFs statistical properties (Withoogte system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	2.58	4.56	3.05	2.44	3.54	1.29	**3.29**	3.02	1.27	2.11	1.80	3.68
Min	**0.00**	0.19	0.08	0.06	0.01	0.10	0.05	0.01	0.06	0.03	**0.00**	0.01
Ave	0.88	1.39	0.98	0.97	1.26	0.67	1.64	1.16	0.83	0.84	0.63	0.76
Std dev	0.75	1.16	0.81	0.61	1.03	0.39	0.83	0.86	0.45	0.67	0.54	0.94
Skewness	0.99	1.81	1.59	1.32	1.05	-0.21	0.05	0.72	-0.51	0.22	0.52	2.72
n	12	12	12	12	12	12	12	12	12	12	12	12
PMF	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083

Table 6-10: St Helenabaai MPFs statistical properties (Withoogte system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.05	1.09	1.02	1.11	1.18	1.40	1.28	1.61	1.34	1.40	**1.76**	1.24
Min	0.73	0.68	0.65	0.68	0.64	0.73	0.61	0.89	0.88	0.95	0.90	**0.40**
Ave	0.86	0.85	0.87	0.91	1.03	1.00	0.95	1.16	1.13	1.18	1.12	0.96
Std dev	0.10	0.14	0.11	0.12	0.14	0.17	0.17	0.18	0.13	0.14	0.20	0.21
Skewness	0.54	0.31	-0.32	-0.14	-1.50	0.92	0.04	0.75	-0.04	-0.08	2.29	-1.12
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-11: Dwarskersbos MPFs statistical properties (Withoogte system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.37	1.38	1.37	1.34	1.68	1.29	1.57	**2.06**	1.34	1.47	1.32	1.34
Min	0.37	0.53	0.71	0.91	0.91	0.74	0.67	0.93	0.46	0.55	0.15	**0.02**
Ave	0.86	0.94	1.00	1.09	1.22	1.00	1.18	1.25	0.96	1.00	0.78	0.75
Std dev	0.24	0.21	0.18	0.12	0.21	0.16	0.22	0.28	0.21	0.23	0.33	0.35
Skewness	0.21	0.50	0.66	0.99	0.64	0.42	-0.38	1.87	-0.66	-0.15	-0.05	-0.36
n	13	13	13	13	13	13	13	13	13	13	13	13
PMF	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077

Table 6-12: Moorreesburg MPFs statistical properties (Withoogte system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.20	0.99	0.94	1.09	1.39	1.49	1.80	**1.93**	1.46	1.40	1.08	1.02
Min	**0.47**	0.50	0.64	0.62	0.89	0.83	1.10	1.17	0.87	0.97	0.53	0.59
Ave	0.68	0.69	0.75	0.83	1.08	1.10	1.42	1.43	1.21	1.16	0.87	0.80
Std dev	0.18	0.13	0.09	0.14	0.12	0.17	0.18	0.21	0.16	0.12	0.13	0.14
Skewness	1.54	1.20	0.88	0.17	0.87	0.43	0.31	0.90	-0.44	0.45	-0.98	-0.23
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-13: Saldanha (Ore Harbour) MPFs statistical properties (Withoogte system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.40	1.13	1.20	1.76	1.76	1.46	1.90	3.48	1.63	**2.09**	2.04	1.47
Min	0.14	0.36	0.42	0.65	1.03	0.44	**0.13**	0.16	0.14	**0.13**	0.53	0.35
Ave	0.71	0.71	0.80	1.05	1.26	0.90	1.24	1.43	1.02	1.23	0.97	0.72
Std dev	0.33	0.22	0.24	0.34	0.19	0.28	0.47	0.76	0.43	0.51	0.41	0.31
Skewness	0.31	0.25	0.05	0.91	1.28	0.24	-0.88	1.09	-0.32	-0.46	1.51	1.12
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-14: Louwville MPFs statistical properties (Withoogte system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.02	1.05	1.07	1.17	1.39	1.33	1.72	1.48	1.28	1.59	1.52	**2.11**
Min	0.31	0.62	0.44	0.08	**0.23**	0.81	0.98	1.04	0.93	0.39	0.71	0.55
Ave	0.77	0.84	0.86	0.84	1.05	0.98	1.30	1.24	1.07	1.07	0.99	1.00
Std dev	0.23	0.13	0.15	0.25	0.27	0.13	0.20	0.14	0.11	0.25	0.18	0.33
Skewness	-1.01	-0.58	-1.67	-2.15	-2.00	1.10	0.66	-0.11	0.45	-0.86	1.46	2.79
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-15: Vredenburg MPFs statistical properties (Withoogte system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.37	1.38	1.37	1.34	**1.68**	1.29	1.57	2.06	1.34	1.47	1.32	1.34
Min	0.37	0.53	0.71	0.91	0.91	0.74	0.67	0.93	0.46	0.55	0.15	**0.02**
Ave	0.86	0.94	1.00	1.09	1.22	1.00	1.18	1.25	0.96	1.00	0.78	0.75
Std dev	0.24	0.21	0.18	0.12	0.21	0.16	0.22	0.28	0.21	0.23	0.33	0.35
Skewness	0.21	0.50	0.66	0.99	0.64	0.42	-0.38	1.87	-0.66	-0.15	-0.05	-0.36
n	13	13	13	13	13	13	13	13	13	13	13	13
PMF	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077

6.3 Swartland system Monte Carlo analysis inputs

For the probabilistic calculation of the system's MPF, the complete range of MPFs for each end-user and for each month as calculated throughout the entire data-set was used as input into the Monte Carlo analysis. In Table 6-16 to Table 6-29, the statistical properties and probability mass function value used in the Monte Carlo analysis of the range of MPFs for the Swartland system are summarised.

Table 6-16: Gouda MPFs statistical properties (Swartland system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.32	0.96	1.26	1.14	1.06	1.29	1.70	**2.09**	1.85	1.88	1.30	1.11
Min	0.22	0.51	**0.15**	0.21	0.61	0.36	0.71	1.23	0.70	1.04	0.77	0.42
Ave	0.75	0.72	0.73	0.80	0.90	0.91	1.41	1.49	1.13	1.30	1.02	0.87
Std dev	0.22	0.17	0.23	0.20	0.19	0.24	0.32	0.28	0.35	0.28	0.23	0.24
Skewness	0.26	-0.65	-0.36	-1.40	1.10	-0.84	0.21	0.09	0.30	0.28	1.85	0.41
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-17: PPC Housing MPFs statistical properties (Swartland system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	**4.02**	0.96	0.80	4.81	1.57	1.50	2.00	2.35	1.97	1.78	1.45	0.88
Min	0.21	0.22	**0.18**	0.41	0.45	0.71	0.47	0.53	0.50	0.84	0.35	0.40
Ave	0.84	0.51	0.55	1.07	1.01	1.06	1.45	1.59	1.30	1.32	0.81	0.52
Std dev	0.93	0.19	0.18	1.08	0.27	0.25	0.46	0.45	0.37	0.25	0.30	0.17
Skewness	3.20	0.82	-0.44	3.23	-0.07	0.21	-0.55	-0.66	-0.39	-0.13	0.69	-0.50
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-18: Riebeek Wes MPFs statistical properties (Swartland system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.35	1.12	1.03	1.96	1.59	**1.99**	1.60	1.65	1.35	1.76	1.43	1.26
Min	**0.00**	0.58	**0.00**	0.72	0.91	0.77	0.49	0.01	0.36	0.26	0.17	0.01
Ave	0.77	0.80	0.79	1.07	1.12	1.14	1.21	1.15	1.06	1.17	0.92	0.81
Std dev	0.32	0.17	0.25	0.34	0.19	0.31	0.27	0.39	0.26	0.33	0.33	0.35
Skewness	-0.41	0.46	-2.50	1.27	1.11	1.44	-1.23	-1.61	-1.51	-1.16	-1.16	-1.30
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-19: Riebeek Prison MPFs statistical properties (Swartland system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	0.91	1.29	0.94	1.44	1.40	**3.15**	2.01	1.61	1.65	1.87	1.38	1.55
Min	0.34	**0.17**	0.21	0.45	0.73	0.59	0.37	0.35	0.31	0.33	0.77	0.49
Ave	0.68	0.70	0.70	0.92	1.09	1.29	1.37	1.24	1.05	1.15	0.98	0.84
Std dev	0.15	0.24	0.18	0.27	0.21	0.63	0.41	0.34	0.35	0.34	0.18	0.26
Skewness	-0.76	0.33	-1.21	0.29	-0.10	1.86	-0.83	-1.66	-0.59	-0.49	1.01	1.46
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-20: Riebeek Kasteel MPFs statistical properties (Swartland system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	0.85	1.10	1.23	1.15	1.89	1.91	1.55	**2.31**	1.61	1.57	1.25	1.47
Min	**0.15**	0.25	0.50	0.58	0.22	0.67	0.50	0.82	1.00	0.85	0.74	0.16
Ave	0.60	0.64	0.70	0.82	1.06	1.24	1.24	1.60	1.23	1.21	0.94	0.76
Std dev	0.17	0.21	0.18	0.18	0.37	0.83	0.26	0.39	0.19	0.22	0.19	0.31
Skewness	-1.12	0.21	1.61	0.14	-0.06	2.99	-1.55	0.08	0.59	-0.30	0.19	0.42
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-21: Langewens Experimental Farm MPFs statistical properties (Swartland system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.35	1.61	0.95	1.56	1.94	1.69	**3.39**	2.32	2.08	1.86	1.35	1.45
Min	0.20	0.11	0.22	**0.06**	0.12	0.09	0.54	0.49	0.88	0.62	0.16	0.10
Ave	0.67	0.71	0.65	0.74	1.06	1.01	1.61	1.39	1.35	1.29	0.81	0.73
Std dev	0.27	0.37	0.19	0.38	0.45	0.39	0.67	0.51	0.36	0.38	0.35	0.40
Skewness	0.61	0.73	-0.71	0.01	0.13	-0.75	1.14	-0.07	0.43	0.00	-0.23	0.05
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-22: Malm-Prison Main MPFs statistical properties (Swartland system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.13	1.18	1.20	1.41	1.87	1.25	1.55	**3.03**	1.31	2.06	1.19	1.15
Min	0.60	0.57	**0.08**	0.22	0.75	0.81	0.95	0.44	0.56	0.94	0.39	0.27
Ave	0.78	0.84	0.79	0.93	1.09	1.00	1.29	1.32	1.03	1.21	0.90	0.84
Std dev	0.15	0.19	0.26	0.31	0.30	0.12	0.18	0.62	0.20	0.29	0.21	0.25
Skewness	0.95	0.31	-1.61	-0.75	1.59	0.79	-0.27	1.78	-1.12	2.64	-1.34	-1.41
n	11	11	11	11	11	11	11	11	11	11	11	11
PMF	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091

Table 6-23: Malm-Old Golf Course MPFs statistical properties (Swartland system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.43	1.21	1.44	1.43	1.57	1.30	2.00	2.38	1.69	1.50	0.99	1.30
Min	0.43	0.20	0.48	0.55	0.31	0.64	0.75	0.68	0.57	0.57	0.43	0.47
Ave	0.87	0.92	0.98	0.90	1.01	1.02	1.28	1.33	1.08	1.01	0.81	0.82
Std dev	0.31	0.29	0.29	0.32	0.31	0.26	0.33	0.40	0.30	0.26	0.15	0.22
Skewness	1.56	-0.74	0.82	-0.51	-0.44	0.69	0.18	0.82	0.67	0.10	-1.27	0.50
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-24: Malm-Panorama MPFs statistical properties (Swartland system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	0.95	1.12	0.95	1.12	1.57	1.42	1.74	2.18	1.56	1.46	1.20	1.14
Min	0.44	0.45	0.55	0.41	0.60	0.86	1.17	0.19	0.89	0.72	0.42	0.62
Ave	0.65	0.72	0.72	0.82	1.00	1.14	1.47	1.43	1.24	1.15	0.85	0.83
Std dev	0.12	0.16	0.11	0.19	0.23	0.23	0.17	0.44	0.18	0.22	0.18	0.15
Skewness	0.52	0.93	0.56	-0.64	0.67	1.31	-0.01	-1.46	0.06	-0.60	-0.61	0.80
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-25: Malm-Wesbank MPFs statistical properties (Swartland system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.04	1.22	1.07	1.43	1.30	1.49	1.46	1.45	1.21	1.22	1.17	1.16
Min	0.66	0.72	0.80	0.76	0.64	0.69	0.93	0.84	0.85	0.68	0.80	0.73
Ave	0.84	0.86	0.89	0.97	1.02	0.97	1.24	1.22	1.02	1.04	1.01	0.95
Std dev	0.11	0.13	0.09	0.17	0.16	0.22	0.18	0.16	0.14	0.14	0.13	0.12
Skewness	0.38	1.20	0.28	1.63	-0.48	0.54	0.11	-0.74	1.07	-1.34	-0.21	0.18
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-26: Mamreweg Cellars MPFs statistical properties (Swartland system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	0.79	1.00	0.76	0.83	1.01	1.25	1.67	2.85	2.42	1.94	1.12	0.95
Min	0.45	0.33	0.41	0.40	0.49	0.56	0.82	1.47	1.59	0.85	0.40	0.49
Ave	0.62	0.60	0.55	0.60	0.72	0.82	1.13	2.32	1.95	1.33	0.76	0.69
Std dev	0.11	0.17	0.08	0.11	0.16	0.19	0.21	0.37	0.28	0.25	0.18	0.14
Skewness	-0.03	0.87	1.05	0.31	0.51	0.80	1.01	-0.70	0.74	0.65	0.44	0.41
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-27: FW Duckitt MPFs statistical properties (Swartland system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	0.87	0.37	0.95	1.51	1.91	1.75	3.66	2.98	3.14	3.75	1.68	0.66
Min	0.04	0.03	0.02	0.10	0.08	0.09	0.03	0.50	0.01	0.52	0.25	0.00
Ave	0.22	0.16	0.35	0.81	1.24	1.12	1.72	2.00	1.62	1.72	0.79	0.31
Std dev	0.22	0.12	0.27	0.45	0.49	0.52	0.87	0.64	0.86	0.94	0.41	0.23
Skewness	2.18	0.54	0.85	-0.22	-1.19	-0.95	-0.03	-0.27	-0.03	1.06	0.36	0.24
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-28: Darling MPFs statistical properties (Swartland system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	0.96	1.01	1.05	1.14	1.27	1.26	1.55	1.92	1.42	1.59	1.66	1.75
Min	0.57	0.63	0.68	0.57	0.37	0.57	0.83	1.04	0.76	0.85	0.58	0.42
Ave	0.73	0.73	0.79	0.88	0.99	1.01	1.22	1.45	1.15	1.19	0.95	0.92
Std dev	0.11	0.12	0.12	0.16	0.22	0.22	0.19	0.21	0.19	0.16	0.24	0.28
Skewness	0.44	0.46	0.91	-0.53	-1.64	-0.43	-0.46	0.08	-0.66	0.43	1.60	1.53
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

Table 6-29: Yzerfontein MPFs statistical properties (Swartland system)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	0.83	0.85	0.88	1.22	1.36	1.61	2.54	2.20	1.37	2.19	1.15	0.86
Min	0.48	0.07	0.50	0.29	0.50	0.68	0.14	1.02	0.71	1.11	0.14	0.22
Ave	0.65	0.56	0.67	0.76	1.02	1.14	1.69	1.61	1.09	1.39	0.76	0.69
Std dev	0.10	0.20	0.11	0.24	0.24	0.29	0.59	0.33	0.18	0.28	0.24	0.16
Skewness	-0.13	-0.84	0.32	-0.18	-1.30	-0.08	-1.55	-0.11	-0.65	1.83	-0.99	-1.78
n	14	14	14	14	14	14	14	14	14	14	14	14
PMF	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071

6.4 Withoogte system probabilistic analysis results

The probabilistic Peak Month Factor results for the Withoogte system as calculated by means of the Monte Carlo simulation for each month of the hydrological year are depicted in Figure A-1to Figure A-12, attached in Appendix A, and the statistical properties of each month’s result are summarised in Table 6-30.

Table 6-30: Withoogte system probabilistic MPF results statistics

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.06	1.06	1.07	1.15	1.40	1.35	1.75	1.74	1.46	1.46	1.31	1.26
Min	0.45	0.50	0.52	0.59	0.73	0.78	0.96	1.04	0.84	0.66	0.52	0.39
Ave	0.78	0.80	0.83	0.89	1.10	1.02	1.30	1.33	1.11	1.11	0.91	0.85
Std dev	0.07	0.07	0.07	0.07	0.08	0.07	0.1	0.09	0.08	0.11	0.09	0.10
Skewness	-0.35	-0.42	0.55	-0.37	-0.34	0.71	0.54	0.28	0.60	-0.90	-0.27	-0.31

6.5 Swartland system probabilistic analysis results

The probabilistic Peak Month Factor results for the Swartland system as calculated by means of the Monte Carlo simulation for each month of the hydrological year are depicted in Figure A-13 to Figure A-24, attached in Appendix A, and the statistical properties of each month’s result are summarised in Table 6-31.

Table 6-31: Swartland system probabilistic MPF results statistics

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.10	1.12	1.10	1.27	1.44	1.62	1.73	2.01	1.49	1.51	1.18	1.21
Min	0.51	0.46	0.55	0.47	0.56	0.73	0.90	0.79	0.79	0.78	0.57	0.54
Ave	0.75	0.77	0.81	0.88	1.02	1.06	1.34	1.39	1.13	1.14	0.89	0.84
Std dev	0.07	0.08	0.07	0.09	0.09	0.10	0.10	0.14	0.08	0.08	0.07	0.07
Skewness	0.82	-0.18	0.41	-0.16	-0.06	0.51	-0.04	-0.23	0.24	-0.07	-0.14	0.25

CHAPTER 7 : DISCUSSION

7.1 Comparison of actual MPFs with probabilistic and deterministic results

7.1.1 Withoogte system

The actual MPFs based on the data, for the entire Withoogte system was also calculated and is reflected in Table 7-1.

Table 7-1: Withoogte system: Actual MPFs

Year	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
95/96	0.67	0.61	0.87	0.89	1.21	1.16	1.56	1.47	1.46	1.09	0.98	0.94
96/97	0.74	0.79	0.78	0.81	1.16	1.04	1.14	**1.72**	0.98	1.04	0.91	0.97
97/98	0.60	0.81	0.75	1.00	1.27	0.88	1.39	1.45	1.13	1.04	0.89	0.83
98/99	**0.53**	0.75	0.78	0.92	1.17	1.10	1.22	1.33	1.19	1.27	0.98	0.83
99/00	0.68	0.77	0.85	0.93	1.11	0.84	1.47	1.25	1.06	1.18	1.05	0.81
00/01	0.93	0.86	0.94	1.13	1.12	0.86	1.20	1.11	1.07	1.11	0.91	0.77
01/02	0.80	0.87	0.97	0.96	1.14	1.06	1.42	1.14	1.23	0.98	0.73	0.70
02/03	0.81	0.76	0.82	0.83	1.13	1.17	1.30	1.37	0.97	1.32	0.85	1.12
03/04	1.02	0.80	0.91	0.86	1.14	1.11	1.27	1.33	1.14	1.10	0.86	0.85
04/05	0.87	0.89	0.94	1.01	1.10	0.90	1.31	1.24	1.02	1.09	0.77	0.88
05/06	0.75	0.79	0.94	0.94	1.17	1.10	1.14	1.31	0.98	1.11	1.22	0.59
06/07	0.75	0.89	0.88	0.93	1.14	1.00	1.28	1.30	1.06	1.09	0.85	0.86
07/08	0.84	0.81	0.83	0.91	0.98	1.03	1.10	1.28	1.07	1.19	1.02	0.95
08/09	0.95	0.94	0.92	0.85	0.94	1.03	1.14	1.21	1.15	1.16	0.88	0.83
Max	1.02	0.94	0.97	1.13	1.27	1.17	1.56	1.72	1.46	1.32	1.22	1.12
Min	0.53	0.61	0.75	0.81	0.94	0.84	1.10	1.11	0.97	0.98	0.73	0.59
Ave	0.78	0.81	0.87	0.93	1.13	1.02	1.28	1.32	1.11	1.13	0.92	0.85
Std dev	0.13	0.08	0.07	0.08	0.08	0.11	0.13	0.15	0.13	0.09	0.12	0.12
Skewness	-0.06	-0.88	-0.31	0.99	-0.88	-0.43	0.58	1.28	1.58	0.72	0.82	-0.04

Table 7-2: Withoogte system probabilistic MPF results statistics (from Table 6-30)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.06	1.06	1.07	1.15	1.40	1.35	1.75	1.74	1.46	1.46	1.31	1.26
Min	0.45	0.50	0.52	0.59	0.73	0.78	0.96	1.04	0.84	0.66	0.52	0.39
Ave	0.78	0.80	0.83	0.89	1.10	1.02	1.30	1.33	1.11	1.11	0.91	0.85
Std dev	0.07	0.07	0.07	0.07	0.08	0.07	0.1	0.09	0.08	0.11	0.09	0.10
Skewness	-0.35	-0.42	0.55	-0.37	-0.34	0.71	0.54	0.28	0.60	-0.90	-0.27	-0.31

The results from probabilistic analysis of the Withoogte system presented in Table 7-2 relate well with the maximum MPF values of the actual data, with the two result sets maximum MPF all within 13.3% of each other and the average difference is 7.4%. For all months, except March, the maximum MPF as determined by the probabilistic method exceeded the actual MPF. For the month of March, the actual and probabilistic maximum MPFs were equal (1.46). The maximum actual MPF of 1.72 occurred in February in the 1996/97 hydrological year, while the probabilistic analysis predicted that the maximum MPF of 1.75 would occur in January. The minimum MPF values of the actual and probabilistic results do not correlate as well as with the maximum MPF-values, with a maximum difference of 51.3% and an average difference of 27.9%. What is also of interest is that with the minimum MPF values, the actual MPF values exceeded the probabilistic results for all the months. In Table 7-3 the corresponding probabilities, as calculated for the Withoogte system in the probabilistic analysis, of the actual MPFs are summarised.

Table 7-3: Withoogte system actual MPFs and corresponding probabilities

Year	Actual MPFs and probability as per probabilistic analysis																							
	Jul	P(x)	Aug	P(x)	Sep	P(x)	Oct	P(x)	Nov	P(x)	Dec	P(x)	Jan	P(x)	Feb	P(x)	Mar	P(x)	Apr	P(x)	May	P(x)	Jun	P(x)
1995/96	0.67	0.082	0.61	0.011	0.87	0.682	0.89	0.479	1.21	0.924	1.16	0.955	1.56	0.991	1.47	0.932	1.46	1.000	1.09	0.319	0.98	0.758	0.94	0.800
1996/97	0.74	0.253	0.79	0.426	0.78	0.210	0.81	0.132	1.16	0.774	1.04	0.707	1.14	0.030	1.72	1.000	0.98	0.025	1.04	0.191	0.91	0.474	0.97	0.879
1997/98	0.60	0.017	0.81	0.527	0.75	0.151	1.00	0.951	1.27	0.987	0.88	0.010	1.39	0.812	1.45	0.907	1.13	0.654	1.04	0.187	0.89	0.417	0.83	0.364
1998/99	0.53	0.001	0.75	0.229	0.78	0.206	0.92	0.640	1.17	0.803	1.10	0.887	1.22	0.225	1.33	0.494	1.19	0.844	1.27	0.970	0.98	0.774	0.83	0.392
1999/00	0.68	0.095	0.77	0.335	0.85	0.574	0.93	0.681	1.11	0.538	0.84	0.001	1.47	0.931	1.25	0.189	1.06	0.278	1.18	0.786	1.05	0.939	0.81	0.321
2000/01	0.93	0.987	0.86	0.805	0.94	0.959	1.13	1.000	1.12	0.577	0.86	0.003	1.20	0.147	1.11	0.002	1.07	0.306	1.11	0.387	0.91	0.466	0.77	0.204
2001/02	0.80	0.591	0.87	0.859	0.97	0.987	0.96	0.841	1.14	0.689	1.06	0.785	1.42	0.866	1.14	0.008	1.23	0.917	0.98	0.134	0.73	0.037	0.70	0.082
2002/03	0.81	0.653	0.76	0.253	0.82	0.387	0.83	0.202	1.13	0.610	1.17	0.967	1.30	0.567	1.37	0.678	0.97	0.017	1.32	0.995	0.85	0.236	1.12	0.996
2003/04	1.02	1.000	0.80	0.514	0.91	0.871	0.86	0.291	1.14	0.701	1.11	0.899	1.27	0.448	1.33	0.513	1.14	0.702	1.10	0.366	0.86	0.282	0.85	0.446
2004/05	0.87	0.917	0.89	0.907	0.94	0.956	1.01	0.970	1.10	0.478	0.90	0.022	1.31	0.614	1.24	0.165	1.02	0.097	1.09	0.315	0.77	0.066	0.88	0.595
2005/06	0.75	0.311	0.79	0.419	0.94	0.950	0.94	0.732	1.17	0.804	1.10	0.886	1.14	0.032	1.31	0.421	0.98	0.028	1.11	0.395	1.22	1.000	0.59	0.010
2006/07	0.75	0.318	0.89	0.912	0.88	0.749	0.93	0.702	1.14	0.677	1.00	0.430	1.28	0.491	1.30	0.378	1.06	0.273	1.09	0.335	0.85	0.224	0.86	0.483
2007/08	0.84	0.809	0.81	0.537	0.83	0.423	0.91	0.562	0.98	0.099	1.03	0.641	1.10	0.008	1.28	0.287	1.07	0.329	1.19	0.806	1.02	0.896	0.95	0.847
2008/09	0.95	0.995	0.94	0.981	0.92	0.919	0.85	0.241	0.94	0.050	1.03	0.642	1.14	0.034	1.21	0.083	1.15	0.747	1.16	0.651	0.88	0.374	0.83	0.401
Max	1.02	1.000	0.94	0.981	0.97	0.987	1.13	1.000	1.27	0.987	1.17	0.967	1.56	0.991	1.72	1.000	1.46	1.000	1.32	0.995	1.22	1.000	1.12	0.996
Min	0.53	0.001	0.61	0.011	0.75	0.151	0.81	0.132	0.94	0.050	0.84	0.001	1.10	0.008	1.11	0.002	0.97	0.017	0.98	0.134	0.73	0.037	0.59	0.010
Ave	0.78	0.502	0.81	0.551	0.87	0.645	0.93	0.602	1.13	0.622	1.02	0.560	1.28	0.443	1.32	0.433	1.11	0.444	1.13	0.488	0.92	0.496	0.85	0.487

The MPFs calculated for this system by the deterministic method (Table 5-1) exceeded the actual values on average by 13%. A further analysis of the actual data was done to determine the occurrence of multiple end-users maximum MPF for a specific hydrological year occurring in the same month. The number of users with peak months coinciding, as reflected in Table 7-4, indicate that the maximum number of end-users to have coinciding peak months consumption was 13 out of 15 end-users, as recorded in the 1999/2000 hydrological year in the month of January. This occurred only once in the 14 years of the data-set. Interestingly, this was neither the year nor the month within which the maximum MPF of the system was recorded. The maximum MPF of 1.72 was recorded in February of the 1996/1997 hydrological year. In that month only 11 of the 15 end-user's MPFs coincided in the same month. A possible explanation for this mismatch is that in the 1996/97 hydrological year, consumption throughout the year was relatively low compared to the consumption in February, which resulted in a higher than normal MPF for the month. Figure 7-1 gives a graphical interpretation of these results.

Table 7-4: Withoogte system: End-user MPF occurrence

Month	Hydrological year													
	95/96	96/97	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08	08/09
Jul	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Sep	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Oct	0	1	0	0	0	0	1	0	0	0	1	0	0	0
Nov	0	0	1	0	1	1	2	0	0	2	1	1	0	1
Dec	0	0	1	1	0	0	0	3	1	0	0	0	1	0
Jan	9	2	8	2	**13**	10	7	3	4	5	3	9	4	7
Feb	2	11	3	7	0	1	0	6	6	6	8	5	8	2
Mar	3	0	1	0	0	1	1	0	2	0	0	0	0	2
Apr	0	1	0	3	1	2	3	1	0	1	0	0	2	1
May	0	0	1	0	0	0	0	0	1	0	1	0	0	1
Jun	0	0	0	1	0	0	0	1	0	0	1	0	0	0
Max	9	11	8	7	13	10	7	6	6	6	8	9	8	7

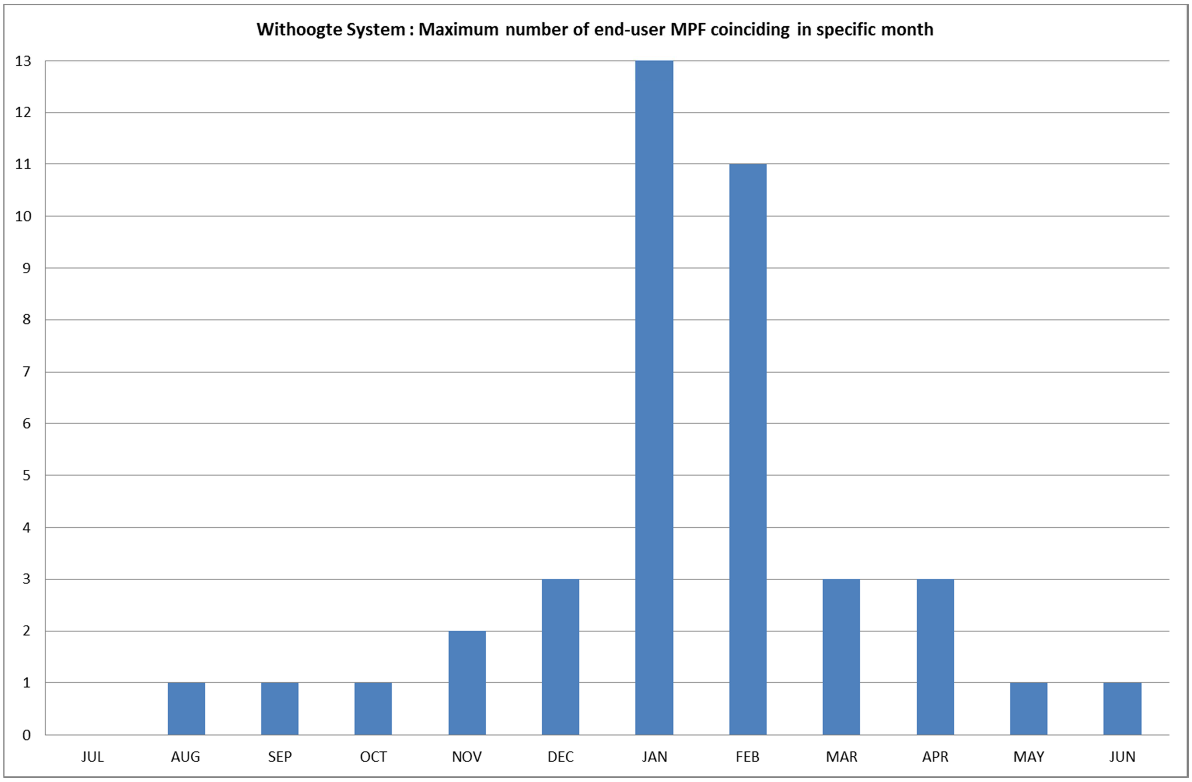

Figure 7-1: Withoogte system: Maximum number of end-user MPFs coincing in specific month

From this analysis, it is clear that the likelihood of all end-user maximum MPFs occurring within the same month is relatively small.

7.1.2 Swartland system

The actual MPFs based on the data, for the entire Swartland system was also calculated in a similar manner to those above and is reflected in Table 7-5.

Table 7-5: Swartland system: Actual MPFs

Year	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
95/96	0.74	0.64	0.78	0.98	0.99	1.44	1.32	1.35	1.26	1.04	0.92	0.74
96/97	0.70	0.63	0.72	0.82	0.90	1.14	1.25	**1.75**	1.17	1.29	0.96	0.87
97/98	0.66	0.80	0.79	0.81	1.30	0.81	1.34	1.55	1.35	1.12	1.03	0.89
98/99	0.67	0.80	0.74	0.69	0.97	1.08	1.22	1.49	1.17	1.27	0.95	0.73
99/00	0.62	0.79	0.70	0.85	1.13	1.04	1.38	1.25	1.06	1.31	0.97	0.84
00/01	0.96	0.83	0.76	0.93	1.15	0.97	1.37	1.16	1.25	1.22	0.81	0.62
01/02	0.78	0.71	0.74	0.94	0.99	0.94	1.58	1.30	1.30	1.18	0.72	0.80
02/03	0.74	**0.59**	0.93	0.93	0.93	1.30	1.32	1.45	1.11	0.98	0.94	0.95
03/04	0.80	0.67	0.84	0.97	0.98	1.23	1.34	1.32	1.00	1.00	1.04	1.05
04/05	0.73	0.99	0.91	0.80	0.83	1.08	1.44	1.23	0.90	1.01	0.87	0.85
05/06	0.67	0.89	0.77	0.75	1.05	1.07	1.22	1.52	1.07	1.16	0.79	0.93
06/07	0.72	0.77	0.80	1.15	1.11	0.81	1.59	1.42	1.05	1.17	0.85	0.86
07/08	0.75	0.75	0.79	0.91	1.02	1.03	1.24	1.43	1.18	1.19	0.88	0.77
08/09	0.80	0.79	0.84	0.89	1.04	0.93	1.26	1.45	1.21	1.14	0.89	0.85
Max	0.96	0.99	0.93	1.15	1.30	1.44	1.59	1.75	1.35	1.31	1.04	1.05
Min	0.62	0.59	0.70	0.69	0.83	0.81	1.22	1.16	0.90	0.98	0.72	0.62
Ave	0.74	0.76	0.79	0.89	1.03	1.06	1.35	1.40	1.15	1.15	0.90	0.84
Std dev	0.08	0.10	0.06	0.11	0.11	0.17	0.11	0.15	0.12	0.10	0.09	0.10
Skewness	1.34	0.34	0.80	0.47	0.67	0.58	1.05	0.51	-0.34	-0.22	-0.34	-0.17

Table 7-6: Swartland system probabilistic MPF results statistics (from Table 6-31)

Statistical properties	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Max	1.10	1.12	1.10	1.27	1.44	1.62	1.73	2.01	1.49	1.51	1.18	1.21
Min	0.51	0.46	0.55	0.47	0.56	0.73	0.90	0.79	0.79	0.78	0.57	0.54
Ave	0.75	0.77	0.81	0.88	1.02	1.06	1.34	1.39	1.13	1.14	0.89	0.84
Std dev	0.07	0.08	0.07	0.09	0.09	0.10	0.10	0.14	0.08	0.08	0.07	0.07
Skewness	0.82	-0.18	0.41	-0.16	-0.06	0.51	-0.04	-0.23	0.24	-0.07	-0.14	0.25

As with the Withoogte system, the results from probabilistic analysis of the Swartland system (Table 7-6) relate well with the maximum MPF values of the actual data, with the two result sets maximum MPF all within 15.5% of each other and the average difference is 11.6%. For all months, the maximum MPF as determined by the probabilistic method exceeded the actual MPFs. As found with the comparison of the Withoogte actual and probabilistic MPF results, the minimum MPF values of the actual results all excceded the probabilistic MPF results, with a maximum difference of 48.2% and an average difference of 28.8%. In Table 7-3 the corresponding probabilities, as calculated for the Withoogte system in the probabilistic analysis, of the actual MPFs are summarised.

Table 7-7: Swartland system actual MPFs and corresponding probabilities

Year	Actual MPFs and probability as per probabilistic analysis																						
	Jul	P(x)	Aug	P(x)	Sep	P(x)	Oct	P(x)	Nov	P(x)	Dec	P(x)	Jan	P(x)	Feb	P(x)	Mar	P(x)	Apr	P(x)	May	P(x)	Jun	P(x)
1995/96	0.74	0.50	0.64	0.05	0.78	0.35	0.98	0.86	0.99	0.37	1.44	1.00	1.32	0.42	1.35	0.34	1.26	0.93	1.04	0.10	0.92	0.63	0.74	0.07
1996/97	0.70	0.26	0.63	0.05	0.72	0.10	0.82	0.24	0.90	0.11	1.14	0.79	1.25	0.16	1.75	0.99	1.17	0.70	1.29	0.96	0.96	0.83	0.87	0.70
1997/98	0.66	0.09	0.80	0.65	0.79	0.44	0.81	0.21	1.30	1.00	0.81	0.00	1.34	0.50	1.55	0.89	1.35	0.99	1.12	0.37	1.03	0.98	0.89	0.77
1998/99	0.67	0.10	0.80	0.64	0.74	0.14	0.69	0.02	0.97	0.32	1.08	0.61	1.22	0.11	1.49	0.79	1.17	0.71	1.27	0.94	0.95	0.82	0.73	0.07
1999/00	0.62	0.02	0.79	0.56	0.70	0.04	0.85	0.34	1.13	0.88	1.04	0.44	1.38	0.67	1.25	0.13	1.06	0.22	1.31	0.98	0.97	0.87	0.84	0.53
2000/01	0.96	0.99	0.83	0.77	0.76	0.22	0.93	0.70	1.15	0.92	0.97	0.17	1.37	0.60	1.16	0.06	1.25	0.92	1.22	0.81	0.81	0.10	0.62	0.00
2001/02	0.78	0.75	0.71	0.19	0.74	0.17	0.94	0.73	0.99	0.39	0.94	0.11	1.58	0.99	1.30	0.21	1.30	0.97	1.18	0.68	0.72	0.01	0.80	0.32
2002/03	0.74	0.53	0.59	0.01	0.93	0.93	0.93	0.69	0.93	0.18	1.30	0.98	1.32	0.41	1.45	0.67	1.11	0.43	0.98	0.02	0.94	0.77	0.95	0.93
2003/04	0.80	0.80	0.67	0.09	0.84	0.73	0.97	0.83	0.98	0.32	1.23	0.94	1.34	0.49	1.32	0.28	1.00	0.05	1.00	0.04	1.04	0.99	1.05	1.00
2004/05	0.73	0.48	0.99	1.00	0.91	0.91	0.80	0.17	0.83	0.03	1.08	0.63	1.44	0.85	1.23	0.12	0.90	0.00	1.01	0.06	0.87	0.37	0.85	0.58
2005/06	0.67	0.13	0.89	0.95	0.77	0.31	0.75	0.07	1.05	0.65	1.07	0.56	1.22	0.12	1.52	0.84	1.07	0.22	1.16	0.56	0.79	0.06	0.93	0.89
2006/07	0.72	0.37	0.77	0.49	0.80	0.50	1.15	1.00	1.11	0.83	0.81	0.00	1.59	0.99	1.42	0.59	1.05	0.16	1.17	0.60	0.85	0.27	0.86	0.62
2007/08	0.75	0.60	0.75	0.37	0.79	0.44	0.91	0.60	1.02	0.49	1.03	0.42	1.24	0.15	1.43	0.63	1.18	0.72	1.19	0.72	0.88	0.40	0.77	0.19
2008/09	0.80	0.82	0.79	0.61	0.84	0.73	0.89	0.53	1.04	0.59	0.93	0.08	1.26	0.21	1.45	0.68	1.21	0.83	1.14	0.49	0.89	0.46	0.85	0.58
Max	0.96	0.99	0.99	1.00	0.93	0.93	1.15	1.00	1.30	1.00	1.44	1.00	1.59	0.99	1.75	0.99	1.35	0.99	1.31	0.98	1.04	0.99	1.05	1.00
Min	0.62	0.02	0.59	0.01	0.70	0.04	0.69	0.02	0.83	0.03	0.81	0.00	1.22	0.11	1.16	0.06	0.90	0.00	0.98	0.02	0.72	0.01	0.62	0.00
Ave	0.74	0.46	0.76	0.46	0.79	0.43	0.89	0.50	1.03	0.51	1.06	0.48	1.35	0.48	1.40	0.52	1.15	0.56	1.15	0.52	0.90	0.54	0.84	0.52

The MPFs calculated for this system by means of the deterministic method (Table 5-2) exceeded the actual values on average by 16%. As with the Withoogte system, an analysis of the actual data was done to determine how many times all the end-user's maximum annual peak month consumption occurred in the same month of a specific year. The results, as reflected in Table 7-8, indicate that in the 14 year data record for the Swartland system, the maximum number of end-users to have their maximum monthly consumption within the same month of the same year was 10 out of 14 end-users, as recorded in the 1998/1999 and 2001/2002 hydrological years in the months of February and January respectively. As found with the Withoogte analysis, the maximum actual MPF of 1.75 did not occur in either of the two years. The maximum MPF of 1.75 was recorded in February of the 1996/1997 hydrological year. In this month only 9 of the 15 end-user's MPFs coincided in the same month. Similar to the Withoogte system, this can be attributed to a lower than average consumption within the other months compared to the peak month. Figure 7-2 gives a graphical interpretation of these results.

Table 7-8: Swartland system: End-user MPF occurrence

Month	Hydrological year													
	95/96	96/97	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08	08/09
Jul	1	0	0	0	0	1	0	0	1	0	0	0	0	0
Aug	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oct	0	1	1	0	0	1	1	0	0	2	0	0	0	1
Nov	0	0	2	1	1	1	0	0	0	1	0	1	0	1
Dec	3	0	0	1	1	0	0	3	0	0	1	0	0	0
Jan	4	1	2	0	6	8	**10**	2	3	8	2	9	2	3
Feb	4	9	5	**10**	4	3	0	8	8	2	7	4	9	6
Mar	1	0	2	1	0	0	3	1	1	0	0	0	2	2
Apr	0	2	0	1	2	0	0	0	1	1	3	0	1	1
May	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Jun	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Max	4	9	5	10	6	8	10	8	8	8	7	9	9	6

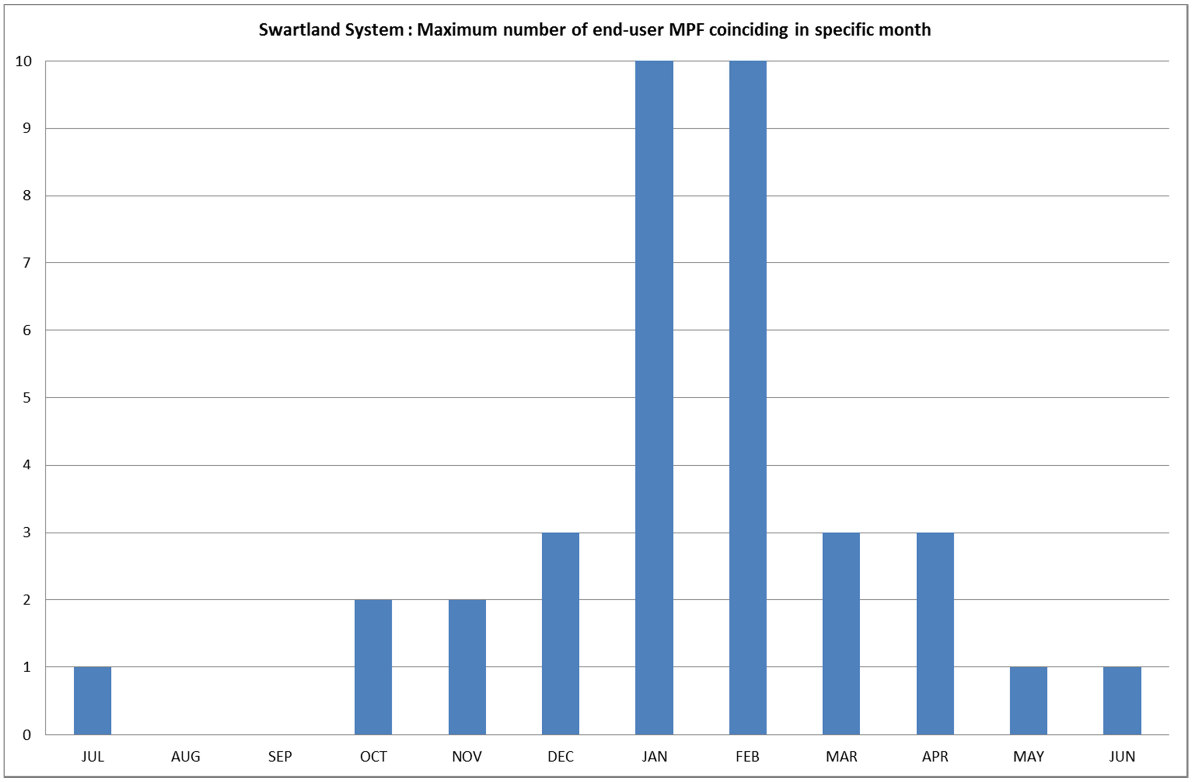

Figure 7-2: Swartland system: Maximum number of end-user MPFs coinciding in specific month

From this analysis, it is clear that the likelihood of all end-user maximum MPFs occurring within the same month is relatively small.

7.2 Temporal variation in water demand of end-users

7.2.1 Withoogte system

As discussed in section 2.1.2 of this document, the time of year has an impact on the water-use characteristics of an end-user. In general the warmer and drier season would result in an increase in water demand, as the outdoor usage increases. This is also clear from all data and results presented in Chapter 5 and Chapter 6, where most peaks occurred in the summer months. This is in line with expectations to see an increased water demand in the summer months in the Western Cape region when the temperatures are higher and rainfall is lower.

In Table 7-9 the average of the actual MPFs for the Withoogte system end-users are summarised. The Max/Min column in Table 7-9 indicated the ratio between the minimum and maximum MPF for each end user, thus indicates the relationship between the maximum month demand and lowest month demand for each end user. The last column of Table 7-9 (labelled %Outdoor) calculated the estimated percentage of water use that could be attributed to outdoor use using the following equation.

$$\%\boldsymbol{Outdoor} = \frac{\left(\mathbf{max}\left(\boldsymbol{ave}\left(\boldsymbol{MPF^{j}}\right)\right)-\mathbf{min}\left(\boldsymbol{ave}\left(\boldsymbol{MPF^{j}}\right)\right)\right)}{\mathbf{max}\left(\boldsymbol{ave}\left(\boldsymbol{MPF^{j}}\right)\right)} \qquad \textbf{(7-1)}$$

Where:

MPF^j = Monthly peak factor (MPF) of *j*-th end-user of the hydrological year

Table 7-10 summarises an analysis done to determine how many times the maximum peak month factor or minimum peak month factor for each end-user occurred in specific month. From this analysis it is clear that the highest water demand occurred most often during the months of January or February, while the lowest water demand occurred during the months of July and August. The months of January to February are generally regarded as the hottest and driest months of the summer in the Western Cape region. The average peak month factors for these latter two months for all the end-users were calculated at 0.72 and 0.76 respectively. The average peak month factors for the months of January and February for all the end-users was calculated at 1.43 and 1.36 respectively. The water demand increases considerably from the winter months to the summer months, with the maximum-to-minimum MPF ratio varying from 1.36 for Saldanha 1 to 4.03 for Dwarskersbos, with the average factor for all end-users at 1.98. This means on average the water demand during the peak demand month is almost double that of the water demand during the low water demand month for the Withoogte system.

Table 7-9: Withoogte system: Average actual MPFs per end-user

Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	$\frac{\text{Max}}{\text{Min}}$	%Outdoor
Hopefield	0.50	0.56	0.55	0.80	1.24	1.16	1.61	1.62	1.31	1.18	0.81	0.71	3.27	69%
Langebaanweg	0.60	0.62	0.70	0.81	1.18	1.10	1.52	1.51	1.20	1.22	0.85	0.74	2.54	61%
Saldanha 1	0.91	0.91	0.99	0.97	0.96	0.83	1.13	1.13	1.01	1.12	1.02	1.03	1.36	26%
Saldanha 2	0.81	0.78	0.81	0.81	1.04	1.02	1.36	1.40	1.16	1.06	0.89	0.88	1.79	44%
Club Mykonos	0.85	0.79	0.81	0.81	1.04	0.96	1.45	1.28	1.01	1.22	0.94	0.85	1.83	45%
Long Acres	0.57	0.61	0.67	0.84	1.06	1.03	1.62	1.40	1.21	1.31	0.93	0.79	2.86	65%
Koringberg	0.69	0.58	0.47	0.84	1.13	1.41	1.23	1.46	1.30	1.22	0.90	0.80	3.10	68%
Vredenburg 1	0.63	0.53	0.60	0.79	1.06	1.21	1.62	1.57	1.15	1.19	0.84	0.85	3.07	67%
Vredenburg 2	0.88	1.39	0.98	0.97	1.26	0.67	1.64	1.16	0.83	0.84	0.63	0.76	2.61	62%
St Helenabaai	0.86	0.85	0.87	0.91	1.03	1.00	0.95	1.16	1.13	1.18	1.12	0.96	1.40	28%
Dwarskersbos	0.55	0.56	0.59	0.86	1.06	1.02	2.21	1.30	1.16	1.24	0.84	0.64	4.03	75%
Moorrees burg	0.68	0.69	0.75	0.83	1.08	1.10	1.42	1.43	1.21	1.16	0.87	0.80	2.10	52%
Spoornet (Ore Harbour)	0.71	0.71	0.80	1.05	1.26	0.90	1.24	1.43	1.02	1.23	0.97	0.72	2.02	51%
Louwville	0.77	0.84	0.86	0.84	1.05	0.98	1.30	1.24	1.07	1.07	0.99	1.00	1.68	41%
Vredenburg	0.86	0.94	1.00	1.09	1.22	1.00	1.18	1.25	0.96	1.00	0.78	0.75	1.68	41%
Ave	0.72	0.76	0.76	0.88	1.11	1.03	1.43	1.36	1.11	1.15	0.89	0.82	1.98	49%

Table 7-10: Withoogte system: Maximum MPFs occurring in specific month

Month	Number of max MPF occurrences in month	Percentage of occurrences	Min MPF in month	Percentage of occurrences
Jul	0	0%	63	31%
Aug	2	1%	55	27%
Sep	1	0%	21	10%
Oct	3	1%	9	4%
Nov	10	5%	1	0%
Dec	7	3%	9	4%
Jan	86	42%	5	2%
Feb	65	32%	2	1%
Mar	10	5%	3	1%
Apr	15	7%	4	2%
May	4	2%	15	7%
Jun	3	1%	19	9%

7.2.2 Swartland system

The same analysis was done on the Swartland system data. Similarly to the Withoogte system, the maximum water demands occurred during the months of January and February, as indicated in Table 7-12, with the average MPFs for these two months calculated as 1.38 and 1.51 respectively, as indicated in Table 7-11. The month during which the minimum water demands generally occurred were also July and August, with the average MPFs for these months for all the users being 0.65 and 0.56 respectively. The maximum-to-minimum peak month factor for the Swartland system ranged from 1.48 for Malmesbury Wes Bank to 12.13 for FW Duckitt, with an average ratio of 2.23, which is a higher ratio than calculated for the Withoogte system.

Table 7-11: Swartland system: Average actual MPFs per end-user

Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	$\frac{\text{Max}}{\text{Min}}$	%Outdoor
Gouda	0.75	0.72	0.73	0.80	0.90	0.91	1.41	1.49	1.13	1.30	1.02	0.87	2.06	51%
PPC Housing	0.84	0.51	0.55	1.07	1.01	1.06	1.45	1.59	1.30	1.32	0.81	0.52	3.13	68%
Riebeeck Wes	0.77	0.80	0.79	1.07	1.12	1.14	1.21	1.15	1.06	1.17	0.92	0.81	1.58	37%
Riebeeck Gevangenis	0.68	0.70	0.70	0.92	1.09	1.29	1.37	1.24	1.05	1.15	0.98	0.84	2.02	50%
Riebeeck Kasteel	0.60	0.64	0.70	0.82	1.06	1.24	1.24	1.60	1.23	1.21	0.94	0.76	2.68	63%
Langewens Proefplaas	0.67	0.71	0.65	0.74	1.06	1.01	1.61	1.39	1.35	1.29	0.81	0.73	2.47	60%
Malm-Prison Main	0.78	0.84	0.79	0.93	1.09	1.00	1.29	1.32	1.03	1.21	0.90	0.84	1.71	41%
Malm-Ou Gholfbaan	0.87	0.92	0.98	0.90	1.01	1.02	1.28	1.33	1.08	1.01	0.81	0.82	1.64	39%
Malm-Panorama	0.65	0.72	0.72	0.82	1.00	1.14	1.47	1.43	1.24	1.15	0.85	0.83	2.26	56%
Malm-Wesbank	0.84	0.86	0.89	0.97	1.02	0.97	1.24	1.22	1.02	1.04	1.01	0.95	1.48	32%
Mamreweg Cellars	0.62	0.60	0.55	0.60	0.72	0.82	1.13	2.32	1.95	1.33	0.76	0.69	4.20	76%
FW Duckitt	0.22	0.16	0.35	0.81	1.24	1.12	1.72	2.00	1.62	1.72	0.79	0.31	12.13	92%
Darling	0.73	0.73	0.79	0.88	0.99	1.01	1.22	1.45	1.15	1.19	0.95	0.92	1.99	50%
Yzerfontein	0.65	0.56	0.67	0.76	1.02	1.14	1.69	1.61	1.09	1.39	0.76	0.69	3.01	67%
Ave	0.69	0.68	0.70	0.86	1.02	1.06	1.38	1.51	1.24	1.25	0.88	0.76	2.23	55%

Table 7-12: Swartland system: Maximum MPFs occurring in specific month

Month	Number of max MPF occurrences in month	Percentage of occurrences	Min MPF in month	Percentage of occurrences
Jul	3	2%	35	18%
Aug	0	0%	51	26%
Sep	0	0%	22	11%
Oct	7	4%	17	9%
Nov	8	4%	4	2%
Dec	9	5%	8	4%
Jan	60	31%	3	2%
Feb	79	41%	4	2%
Mar	13	7%	5	3%
Apr	12	6%	2	1%
May	1	1%	12	6%
Jun	1	1%	30	16%

7.3 Impact of end-user demand on maximum MPF

In the analysis of the actual MPFs of each of the end-users, it was found that the end-users with a high AADD generally had a lower maximum MPF than the end-users with lower annual average water demand. In Figure 7-3, the maximum MPF that occurred in a specific hydrological year for each end-user was plotted against the end-user's AADD (kℓ/d) for that specific hydrological year. A total of 206 and 193 points were plotted from the Withoogte and Swartland system data respectively. It is clear that there could be an upper envelope for the MPF for a specific annual average annual demand. From the plotted data it there also seems to be an approximate lower envelope for the MPF. From the chart, it is clear that for an end-user with a very small annual demand, the maximum MPF could be as high as 5. This maximum MPF reduces to approximately 2 for an end-user with an AADD of 4000 kℓ/day. For end-user with an annual average annual water demand in the region of 14 000 kℓ/day the maximum MPF reduces to 1.5. A minimum value of 1.1 seems to be valid for the entire range of water demand range.

There are a number of possible reasons to explain this relationship between the AADD and the maximum MPF. One possible reason for the higher maximum MPF for smaller end-users is that they lack sufficient storage facilities, or are supplied directly off the bulk water main. The other reason for the high MPF could be that the bulk water system is not the only water source (such as groundwater) for the end-user and that the end-user makes use of bulk water system only in high demand months, when it's own water system's capacity is inadequate. This would skew the water consumption figures from the bulk water system, indicating a very high MPF for the specific month when water is supplied from the bulk water main compared to the other months when almost no water is supplied from the bulk main. The maximum theoretical MPF achievable is 12. This is when the end-user uses the bulk water system as a water source for only one month of the year, with no further water use recorded during the other months. Reasons for the lower MPF for end-users with a higher AADD include the diversification of demand, as described by the Mutschmann Stimmelmayr and other formulas, as discussed in Section 2.4. The theoretical lowest possible value for a maximum MPF is 1. This is the scenario where there is no variation in the end-user's water consumption throughout the hydrological year.

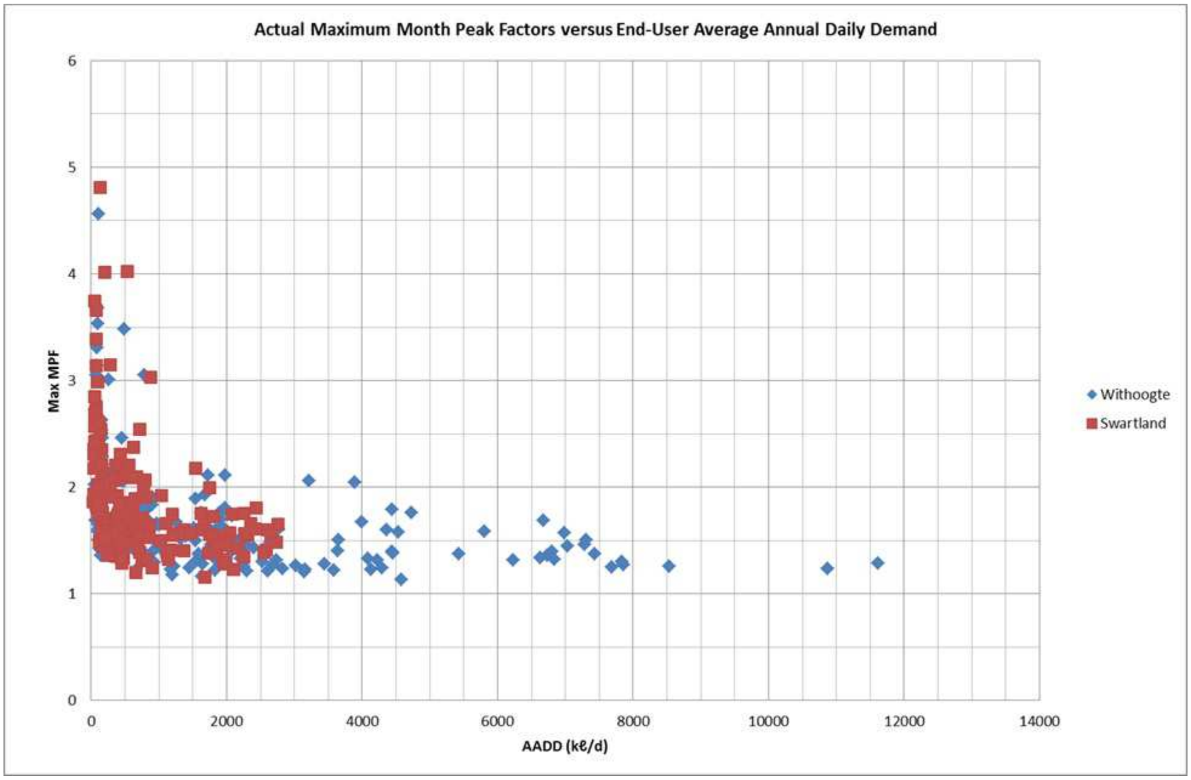

Figure 7-3: Actual end-user maximum MPF versus end-user AADD

7.4 Impact of system demand on system maximum MPF

As discussed in section 7.3, it would appear that the amount of water consumed by an end-user does have an impact on the magnitude of the end-user's MPF. This is in line with knowledge formerly published regarding instantaneous peaks (e.g. CSIR, 2003). A further analysis was therefore undertaken to see whether the same principle applies for the entire bulk system, and therefore whether there is a relationship between the volume of water supplied by a system and the system's maximum MPF. As can be seen in Figure 7-4, the Swartland system supplies a smaller amount of water than the Withoogte system; however, the actual maximum MPFs of the two systems are similar and there is no distinct difference in the maximum MPFs of the two systems. It is, however, interesting to note that the Withoogte system did experience maximum MPFs equal to or lower than 1.3 in 4 of the 14 years of data, where the lowest maximum MPF of the Swartland system was 1.34. A slight trend is visible that would indicate a lower maximum monthly peak factor for increased total bulk system AADD. This is in line with reports for demand on a smaller temporal scale.

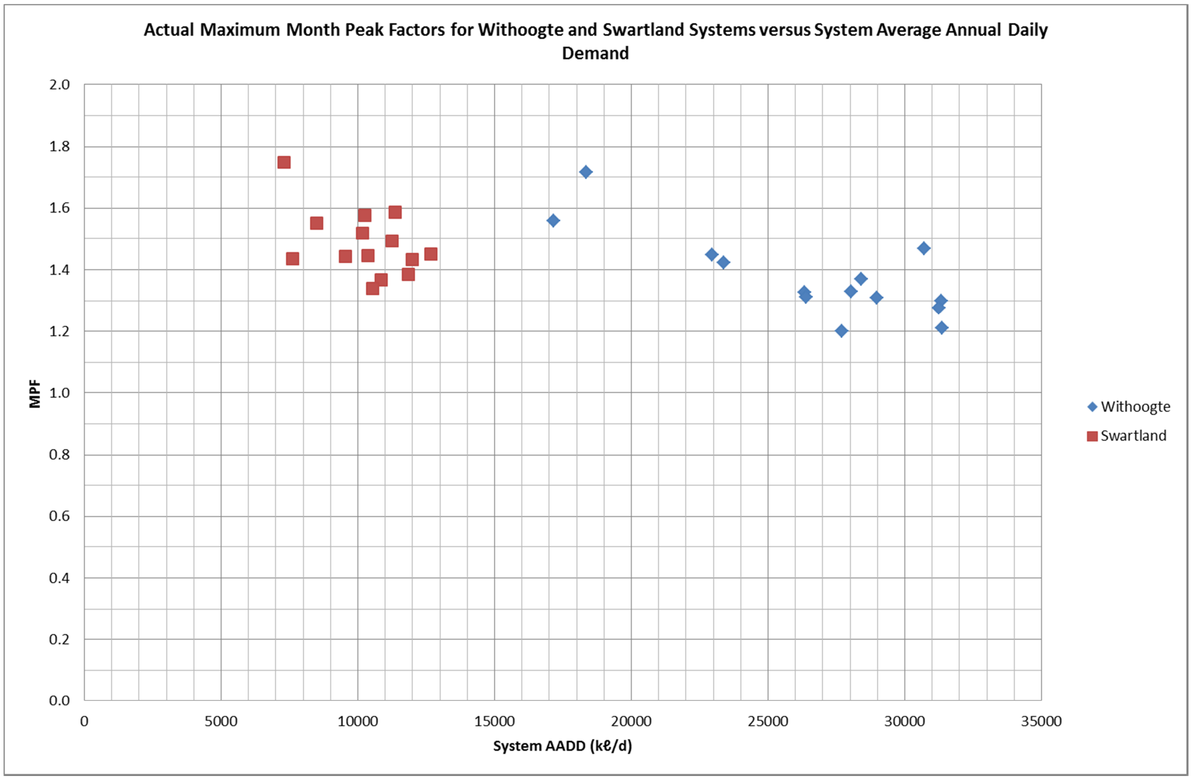

Figure 7-4: Actual system maximum MPF versus system AADD

7.5 Comparison with guideline peak factors

One of the objectives of this research project was to determine whether the demand peak factors of various published guidelines correspond to the peak factors determined from actual water consumption data of a bulk water system. These guideline peak factors were discussed in section 2.4. The CSIR (2003) suggests summer peak factors (Table 2-12) of between 1.2 for standpipes and 1.5 for house connections. Month Factors reported by Vorster *et al*. (1995) vary between 1.15 and 1.35 for different types of land-use, while the peak week factors proposed by them range from 1.4 to 1.7. The Department of Water Affairs guidelines (DWA, 2004) indicate a design summer peak factor of between 1.2 and 1.5 for bulk water systems. The Goodrich formula (Brière, 2007) for periods of 28, 30 and 31 days calculates peak flow ratios of 128.99, 128.10 and 127.68 respectively, which relate to peak design factors of 1.289, 1.281 and 1.276.

The deterministic MPFs for each end-user varied between 1.76 to 4.56, for the Withoogte system, and between 1.49 and 4.81 for the Swartland system. The deterministic MPFs for entire system each month varied between 1.11 and 1.83 for the Withoogte system and between 1.12 and 2.11 for the Swartland system. The probabilistic maximum MPFs for the Withoogte system ranged from 1.06 to 1.75 and from 1.1 to 2.01 for the Swartland system.

The actual maximum MPFs calculated ranged from 1.02 to 1.72 and from 0.93 to 1.75 for the Withoogte and Swartland systems respectively.

It would seem that the values proposed by the guidelines are generally above the minimum values of the probabilistic, deterministic and actual values. The guideline MPFs correspond well with the average MPFs of the probabilistic and actual MPFs. It is, however, clear that the maximum MPFs of the actual, probabilistic and deterministic analysis exceed the highest guideline peak month factor value of 1.5. As the guideline MPF is intended to be used in a deterministic calculation method, this value would be required to be sufficiently large not to be exceeded. In Table 7-13 and Table 7-14 an indication is given of the number of months the actual MPF of the end-user exceeded the 1.5 guideline value. It is clear that the guideline of MPF = 1.5 x AADD was often exceeded, suggesting the need for an improvement.

Table 7-13: Withoogte system: End-user MPF excedance of guideline MPF

End-user	Number of months MPF > 1.5	Percentage of total data period
Hopefield	23	14%
Langebaanweg	14	8%
Saldanha 1	2	1%
Saldanha 2	12	7%
Club Mykonos	10	6%
LongAcres	14	8%
Koringberg	27	16%
Vredenburg 1	21	13%
Vredenburg 2	28	19%
St Helenabaai	2	1%
Dwarskersbos	19	11%
Moorreesburg	7	4%
Spoornet (Ore Harbour)	20	12%
Louwville	6	4%
Vredenburg	5	3%
Total	210	8%

Table 7-14: Swartland system: End-user MPF excedance of guideline MPF

End-user	Number of months MPF > 1.5	Percentage of total data period
Gouda	19	11%
PPC Housing	29	17%
Riebeeck Wes	9	5%
Riebeeck Prison	14	8%
Riebeeck Kasteel	18	11%
Langewens Experimental Farm	28	17%
Malm-Prison Main	6	5%
Malm-Ou Gholfbaan	12	7%
Malm-Panorama	16	10%
Malm-Wesbank	1	1%
Mamreweg Cellars	31	18%
FW Duckitt	49	29%
Darling	11	7%
Yzerfontein	28	17%
Total	271	12%

CHAPTER 8 : CONCLUSION

8.1 Summary of findings

The design of a bulk water system needs to cater for the worst-case demand scenario in order to maintain an adequate level of service to the end-users. The temporal variation in the water demand of the different end-users needs to be taken into account. Generally the end-user does have water storage facilities to reduce the demand fluctuations induced on the bulk water system. As a general rule, however, the bulk system should be able to meet the peak month demand of the end-users, as it is unrealistic for the end-users to provide a storage volume sufficiently large enough to cater for these long duration high demand periods.

The literature reviewed in this study would indicate that a bulk system should be able to meet the peak summer or peak month demand of the end-users. The method of determining the maximum summer or month demand for an end-user would be to multiply the AADD of the end-user with a MPF. If a bulk system needs to supply a number of end-users, the peak design capacity of the bulk supply system is the sum of all the end-users' peak demands. This approach therefore assumes that the peak demand periods of all the end-users in a particular system may coincide. This approach therefore follows a deterministic design method.

In this study, the actual monthly water demand data of end-users, supplied from two independent bulk water systems, was analysed in order to determine whether the difference in temporal variation of the various end-users' water demand has had an impact on the overall design capacity of the bulk system, thus on the overall MPF of the system. In the study the actual MPFs calculated from the data received for each end-user were used in deterministic and probabilistic MPF calculations. These were then compared with the actual peak month factors as they occurred in the system.

As part of this research, the actual monthly consumption data of two independent bulk supply systems, the Withoogte and Swartland systems of the WCDM was analysed. Each system supplied a number of end-users, each with internal storage facilities. Land use in the study area ranged from mostly municipal to a number of industrial, agricultural and other land uses. In order to be used in the analysis, it was a requirement that the data-set contained at least 10 consecutive years of water consumption data for an end-user. In the analysis, the Withoogte and Swartland systems comprised 15 and 14 end-users, respectively. The data analysed for each end-user extended over 11 to 14 hydrological years (July to June). The actual month peak factors for each month and end-user were calculated from the data. These month peak factors were then used in both deterministic and probabilistic methods of calculation to determine the month peak factor of each end-user, as well as each system's MPF.

The probabilistic method used the actual MPF values as discrete data sets and these data sets were used in a Monte Carlo analysis, making use of the @Risk software package. The Monte Carlo analysis executed 1.5 million iterations to produce probability distributions of the MPFs of the two systems for each month in the hydrological year. The results from the probabilistic and deterministic methods were then compared with the actual MPFs as they occurred each year in the two systems. The results were also compared with MPFs from typical design guidelines used in the industry.

8.2 Deduction

The deterministic method produced relatively high MPFs, as this method calculated the ultimate MPF scenario, whereby all the end-users' maximum recorded MPFs over the 14 years of the data-set were deemed to coincide. It could be viewed as an upper limit. This yielded MPFs 12.9% (on average) higher than the actual MPFs on the Withoogte system and 15.4% (on average) higher than factors on the Swartland system. During the high demand months of January and February the MPF were over-estimated by between 11.4% and 20.6%. The highest deterministic system MPF calculated was 2.11, while the maximum actual system MPF recorded was only 1.75. The deterministic method is considered to be relatively conservative based on this research and the two bulk systems analysed.

The probabilistic method produced MPFs that aligned well with actual MPFs. The maximum probabilistic system MPFs determined on the Withoogte system exceeded the actual maximum system MPFs recorded by 8.2% on average. For the Swartland system, the maximum system MPFs determined exceeded the actual maximum factors by an average of 13.1%. This method also over-estimated the MPFs during the high demand months by between 8.8% and 15.4%. What is of interest is that all the actual maximum MPFs that occurred during the 14 years of data for both systems plotted within the 93rd percentile value of the probabilistic results.

Although the probabilistic method's MPFs still exceeded the actual maximums recorded within the 14 years, it is deemed a good method to use to determine a reliability-based design MPF for the system. A system DPF can therefore be determined in this manner for any system by selecting an acceptable level of reliability or risk of failure for the system. By using this reliability-based design MPF it would be possible to determine when the system would need to be upgraded in order to maintain the selected level of reliability of the system, given the knowledge of expected growth in demand.

The existing design guidelines in use by the industry for the design of bulk water systems recommend a summer or MPF of between 1.2 and 1.5. The actual MPFs for the entire Withoogte and Swartland systems exceeded the 1.5 guideline value for 12 months in the 14 years of data. In reviewing the actual MPFs of the different end-users within each system, the 1.5 guideline value was exceeded in 8% and 12% of the total months in the data-set for the end-users of the Withoogte and Swartland systems respectively. Thus the guideline values are deemed too low and should be used with care.

This study suggests a relationship between the maximum MPF of an end-user and the end-user's AADD. Whereas existing guidelines have indicated a fixed summer or MPF irrespective of the end-user's water demand, this study's results would indicate that an end-user with a lower AADD would have a higher maximum MPF than an end-user with a higher AADD. The upper limit MPF for very small end-users appear to be about 5, while the MPF for very large end-users reduces to a factor of 1.5, which correlates with

CSIR (2003). Although not of any importance in the design of a bulk water system, the absolute minimum MPF, irrespective of AADD of the end-user was 1.1 for the systems in this research. For the complete system, with multiple end-users, the trend is not as clear; however, the results do indicate a downward trend in MPF with an increase in the system AADD.

8.3 Suggestions for further research

This study focused on the temporal variation of water demand for individual end-users, as well as for a bulk system with a number of end-users supplied from the system. As mentioned in section 8.2, an inverse relation between the MPF of an end-user and the end-user’s AADD seems likely. Further work, involving more bulk systems is needed to investigate this matter.

Another factor that could have an impact on this relationship would be the storage capacity available at each end-user’s supply point. As defined by Smook (1985), the supply main and end storage reservoir are both part of the bulk supply system and therefore the capacity of the system is as much influenced by the storage capacity as it is influenced by the supply main’s conveyance capacity. Investigating the variation in an end-user’s MPF in relation to the end-user’s available storage capacity could improve the estimation of suitable design MPFs.

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APPENDIX A

Withoogte and Swartland Systems Probabilistic Analysis Results

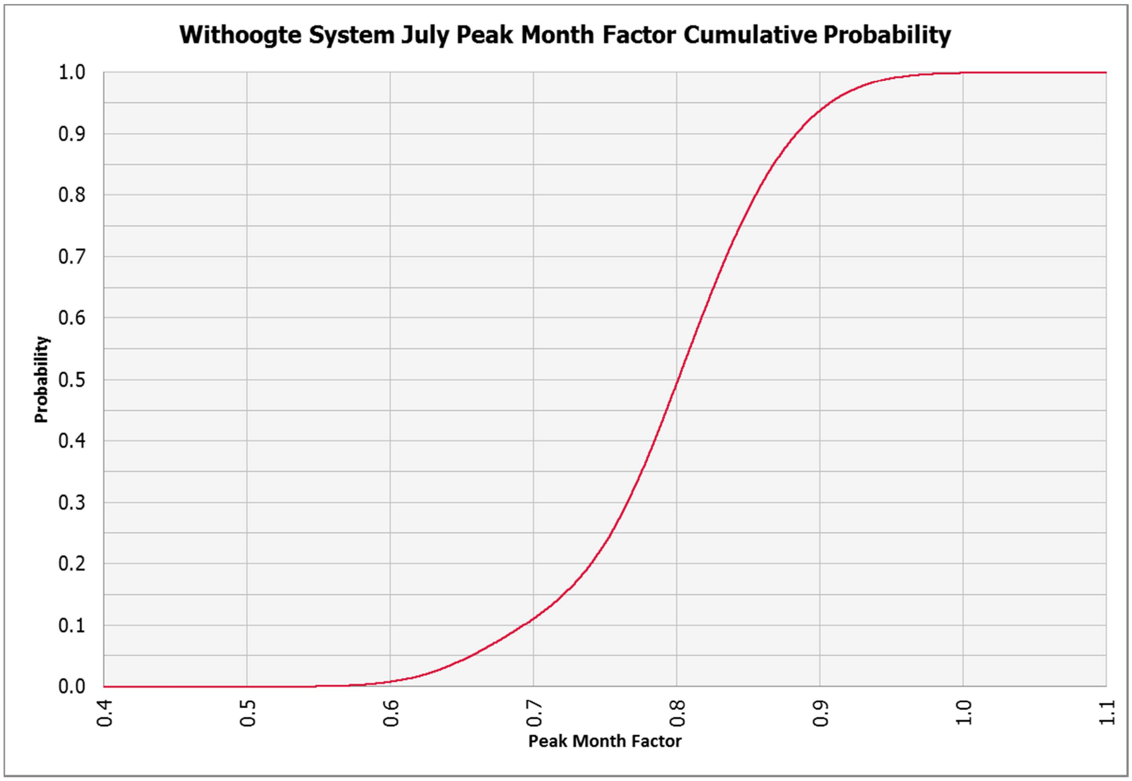

Figure A-1: Withoogte system probabilistic peak month factor for July

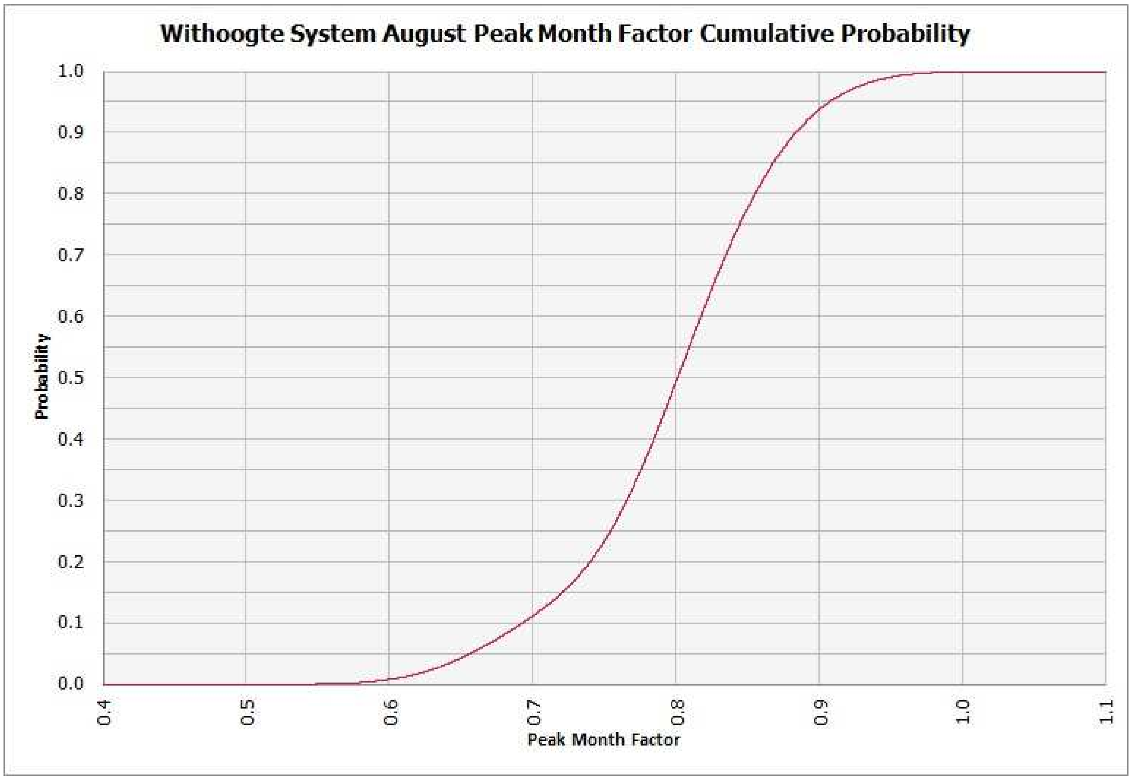

Figure A-2: Withoogte system probabilistic peak month factor for August

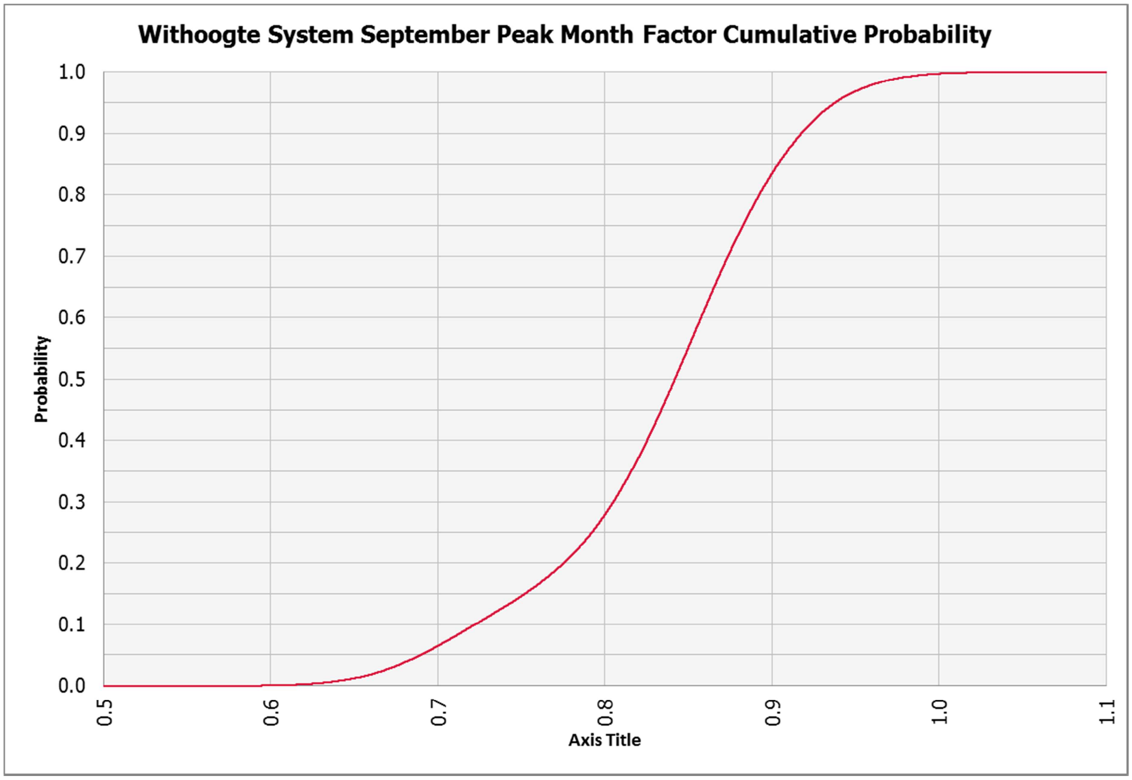

Figure A-3: Withoogte system probabilistic peak month factor for September

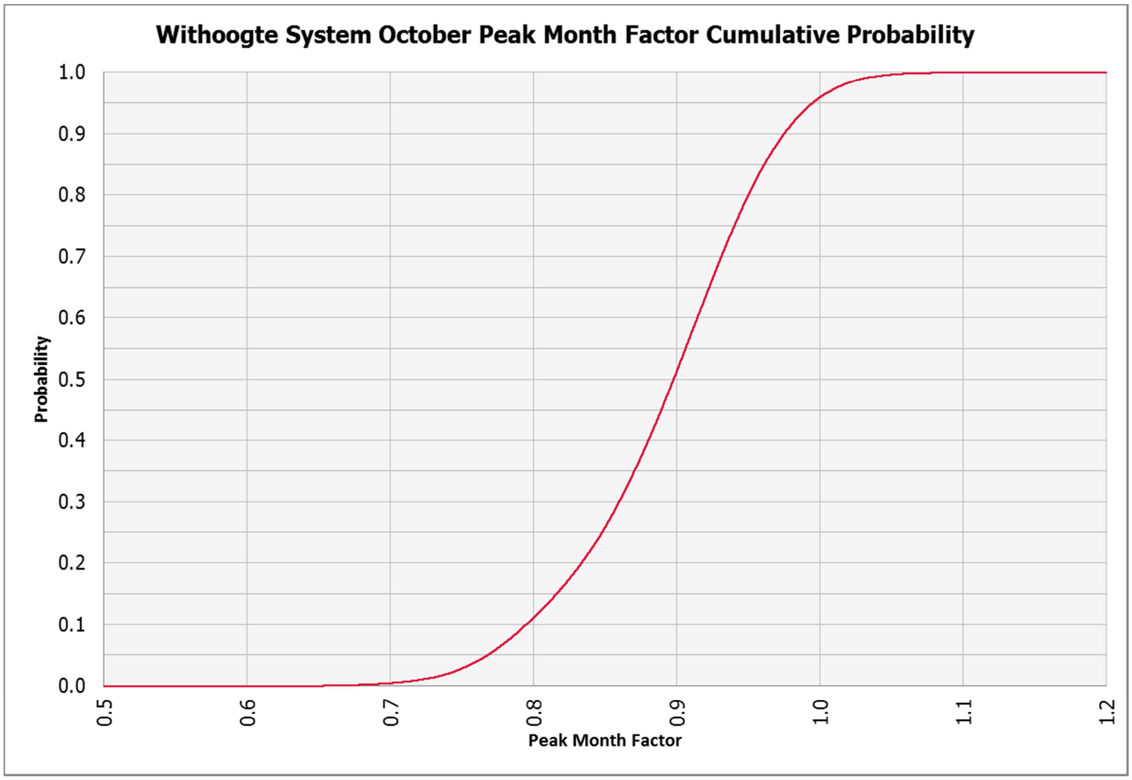

Figure A-4: Withoogte system probabilistic peak month factor for October

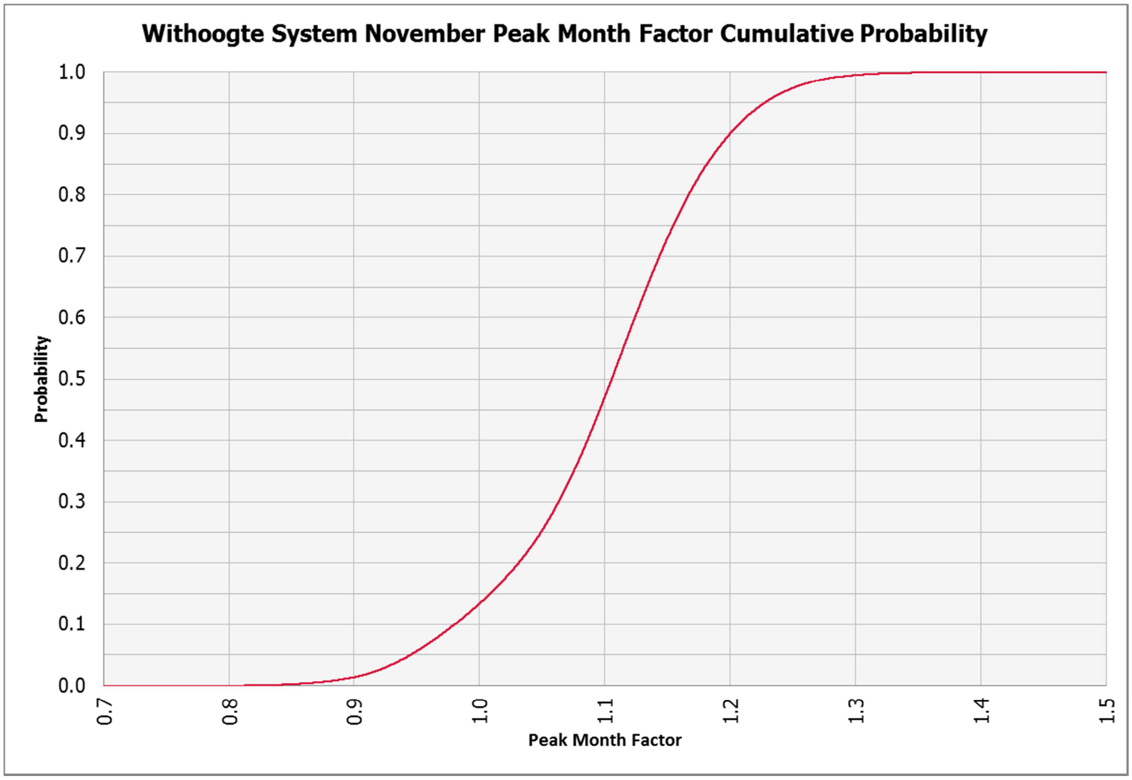

Figure A-5: Withoogte system probabilistic peak month factor for November

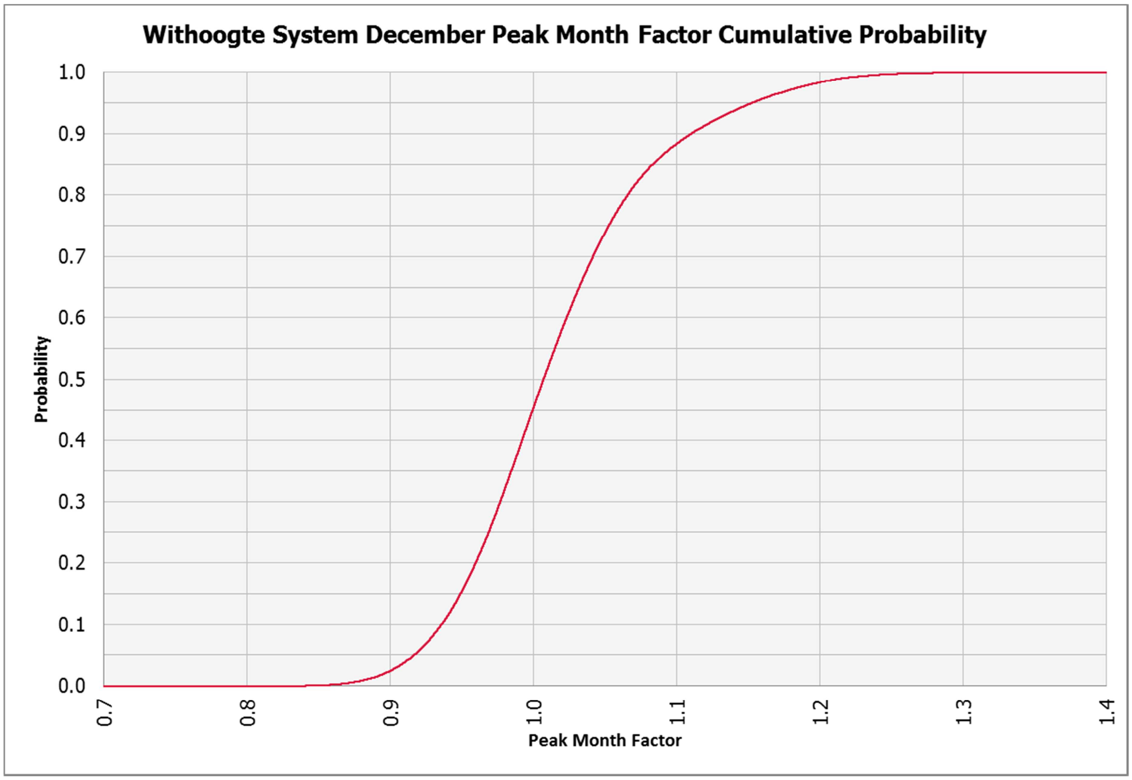

Figure A-6: Withoogte system probabilistic peak month factor for December

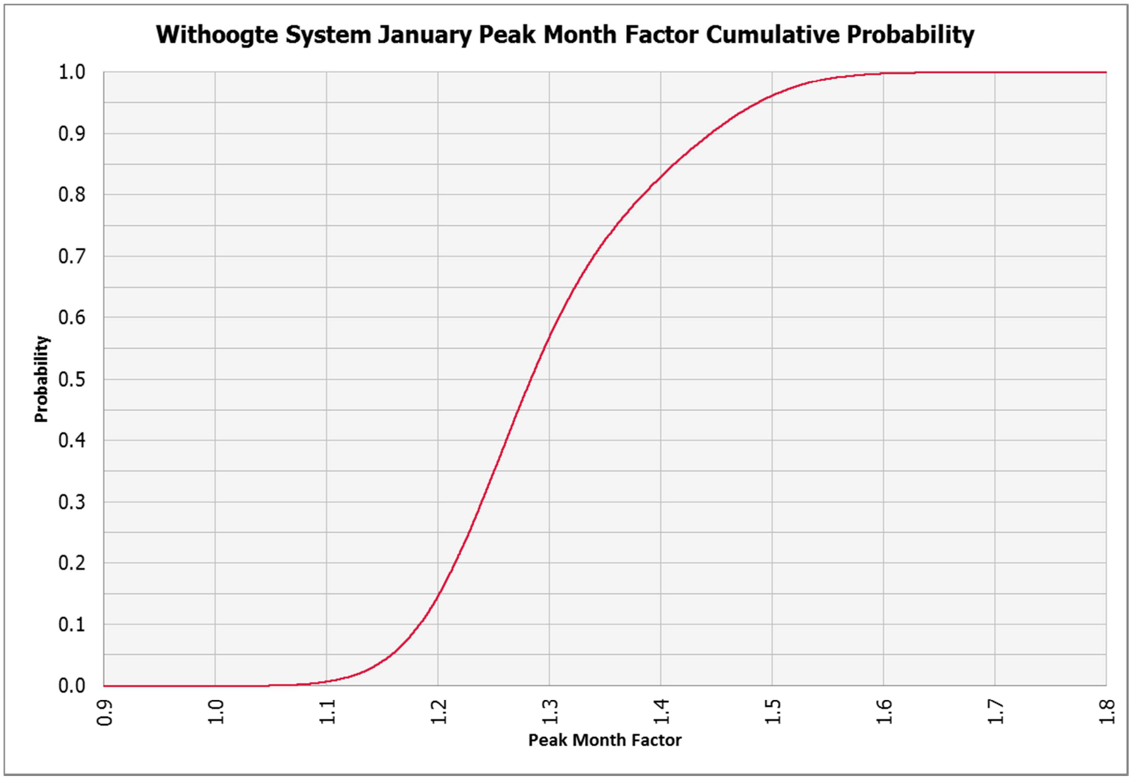

Figure A-7: Withoogte system probabilistic peak month factor for January

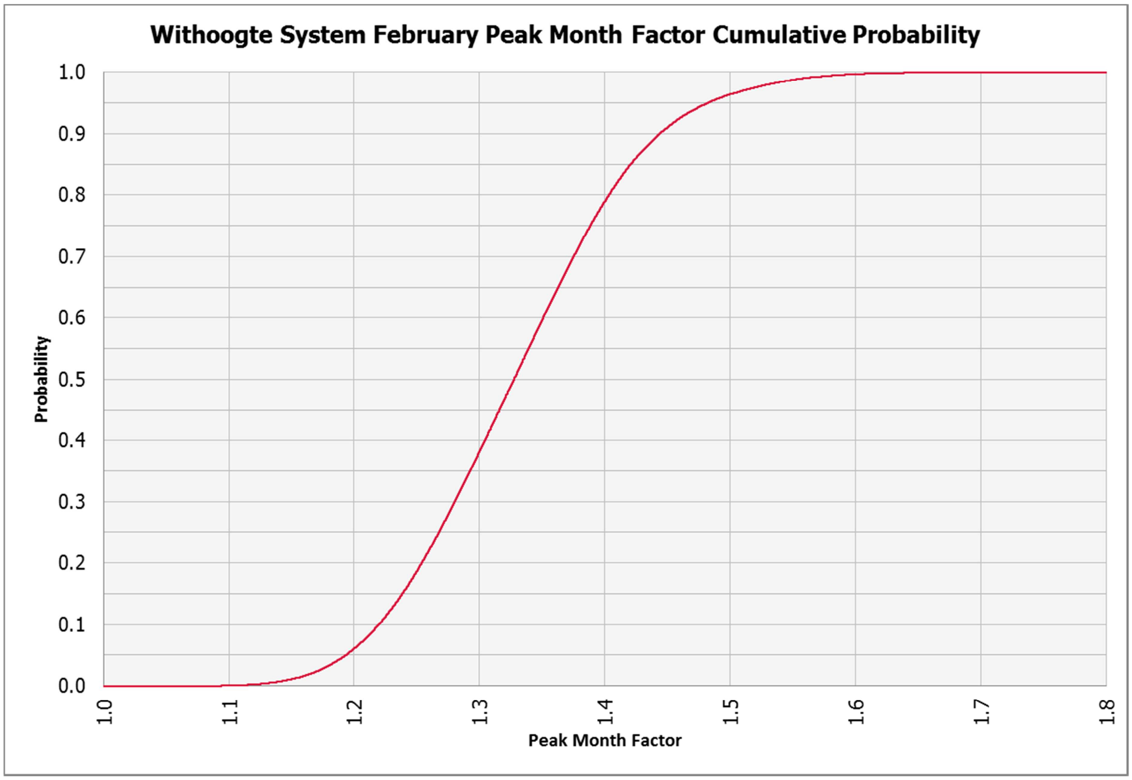

Figure A-8: Withoogte system probabilistic peak month factor for February

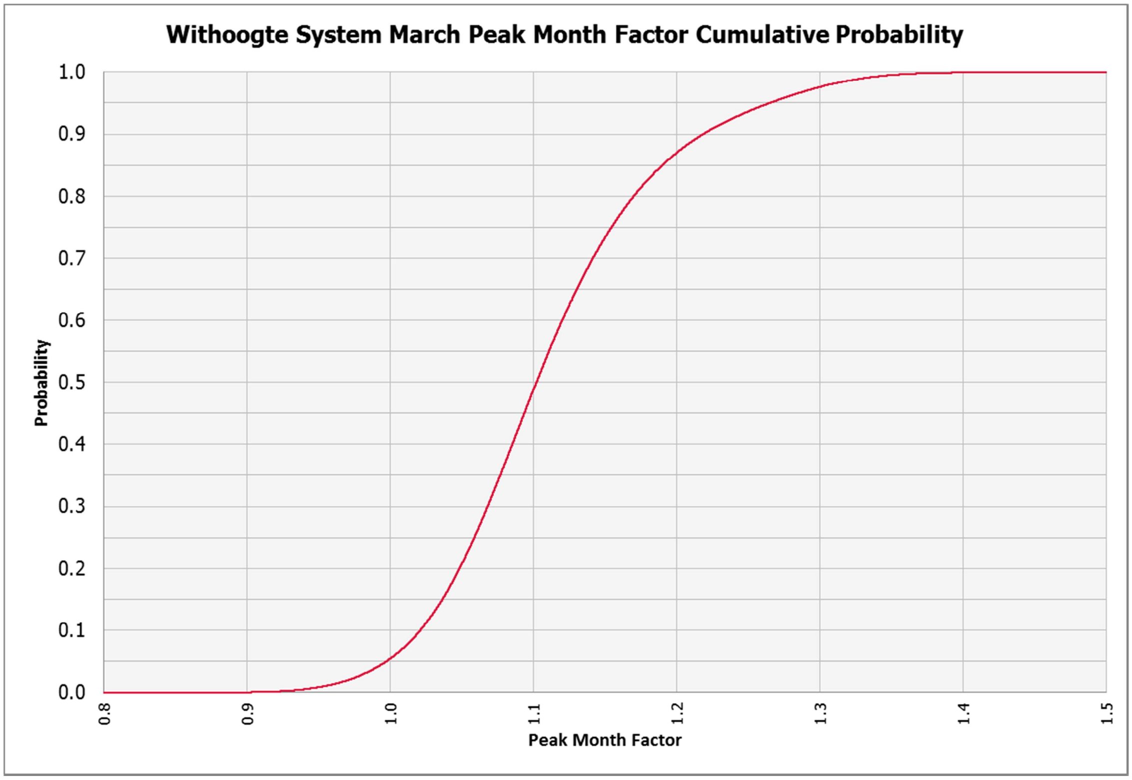

Figure A-9: Withoogte system probabilistic peak month factor for March

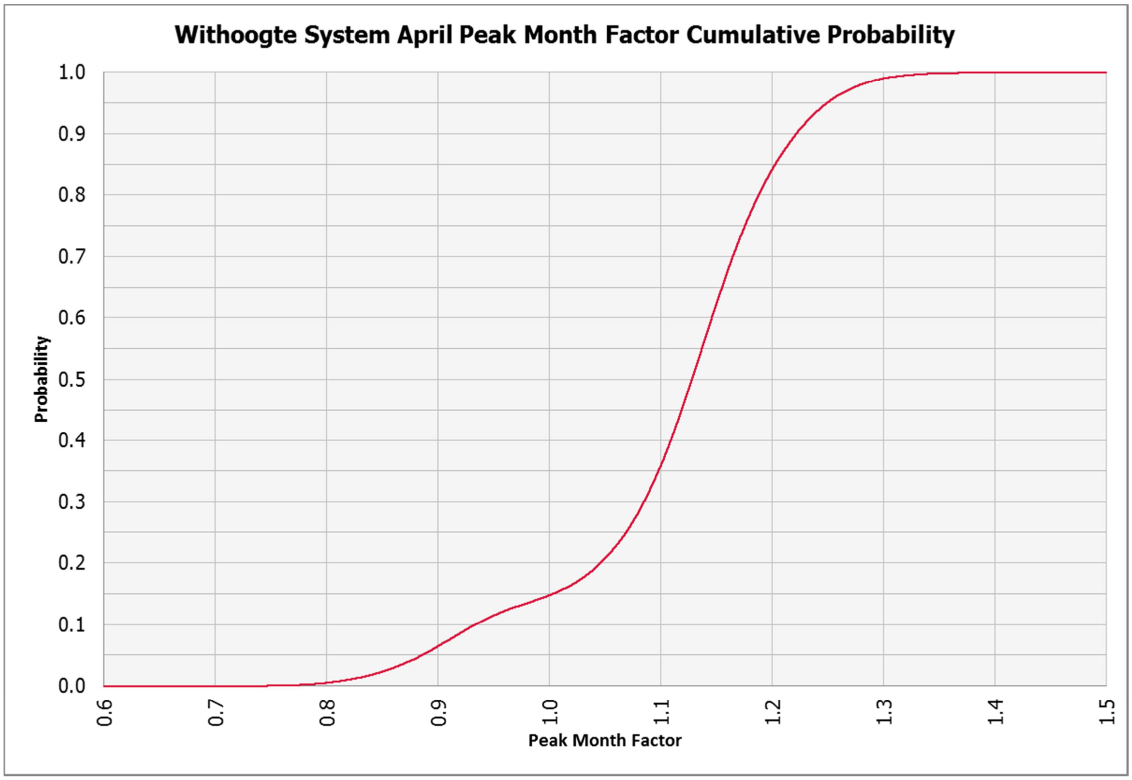

Figure A-10: Withoogte system probabilistic peak month factor for April

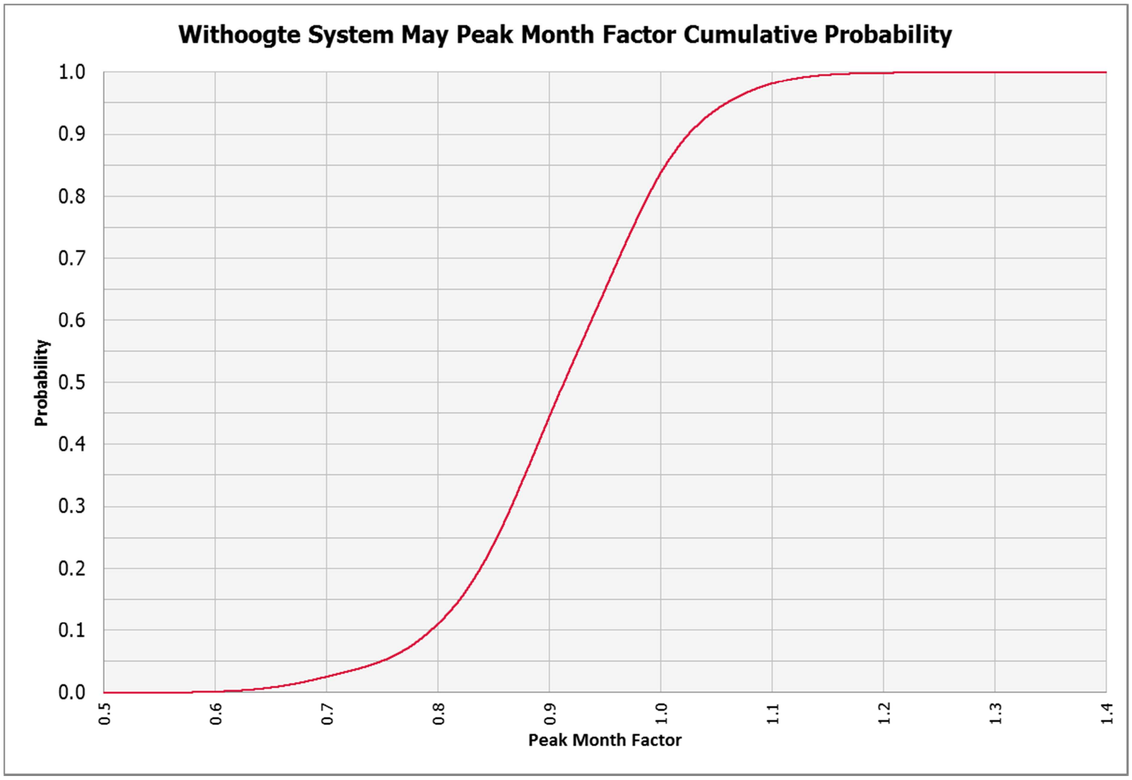

Figure A-11: Withoogte system probabilistic peak month factor for May

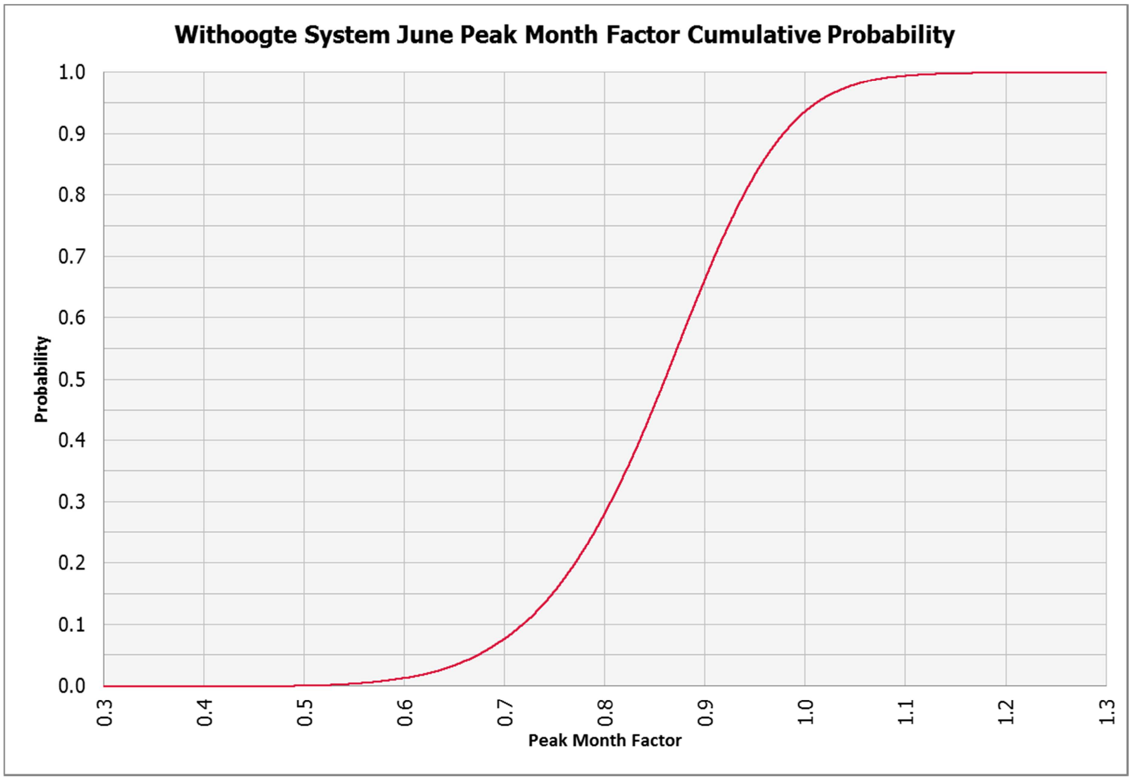

Figure A-12: Withoogte system probabilistic peak month factor for June

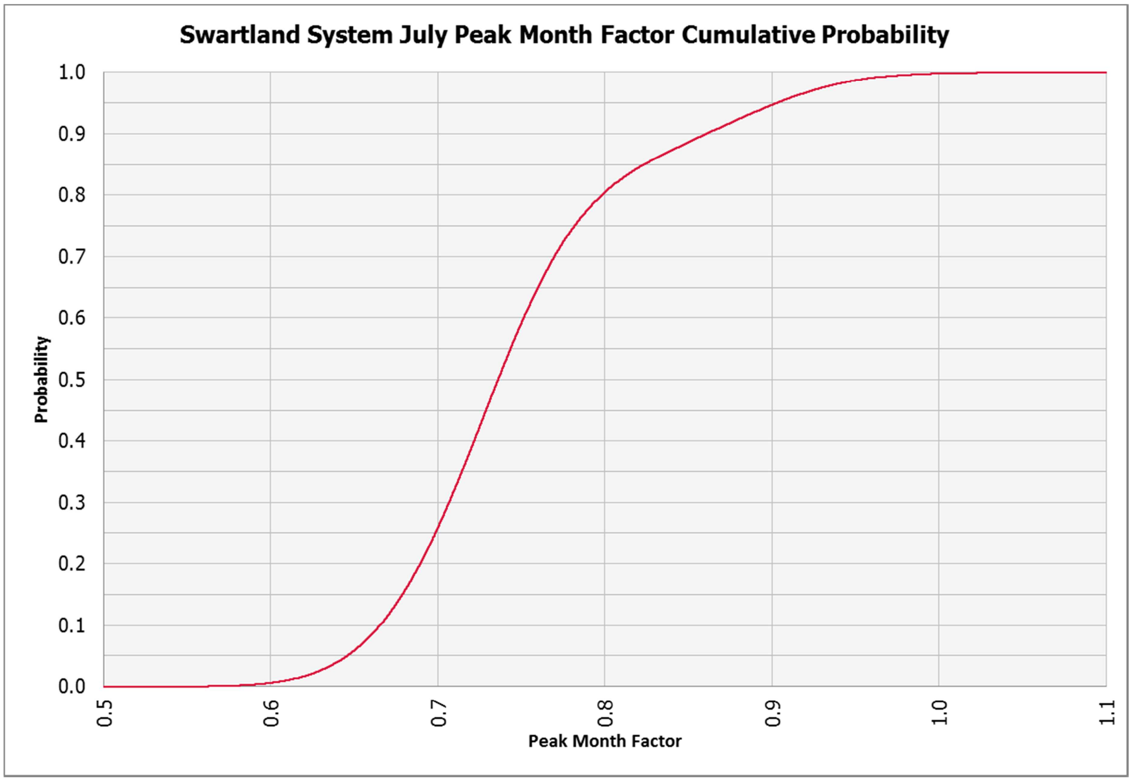

Figure A-13: Swartland system probabilistic peak month factor for July

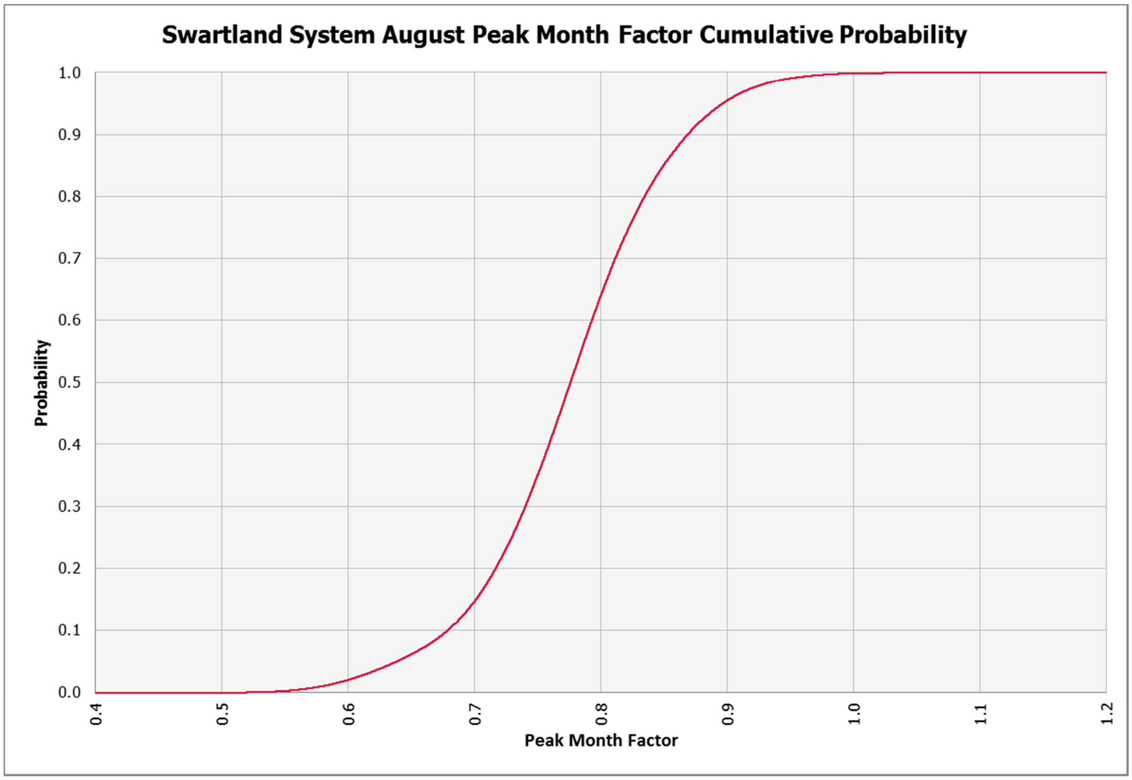

Figure A-14: Swartland system probabilistic peak month factor for August

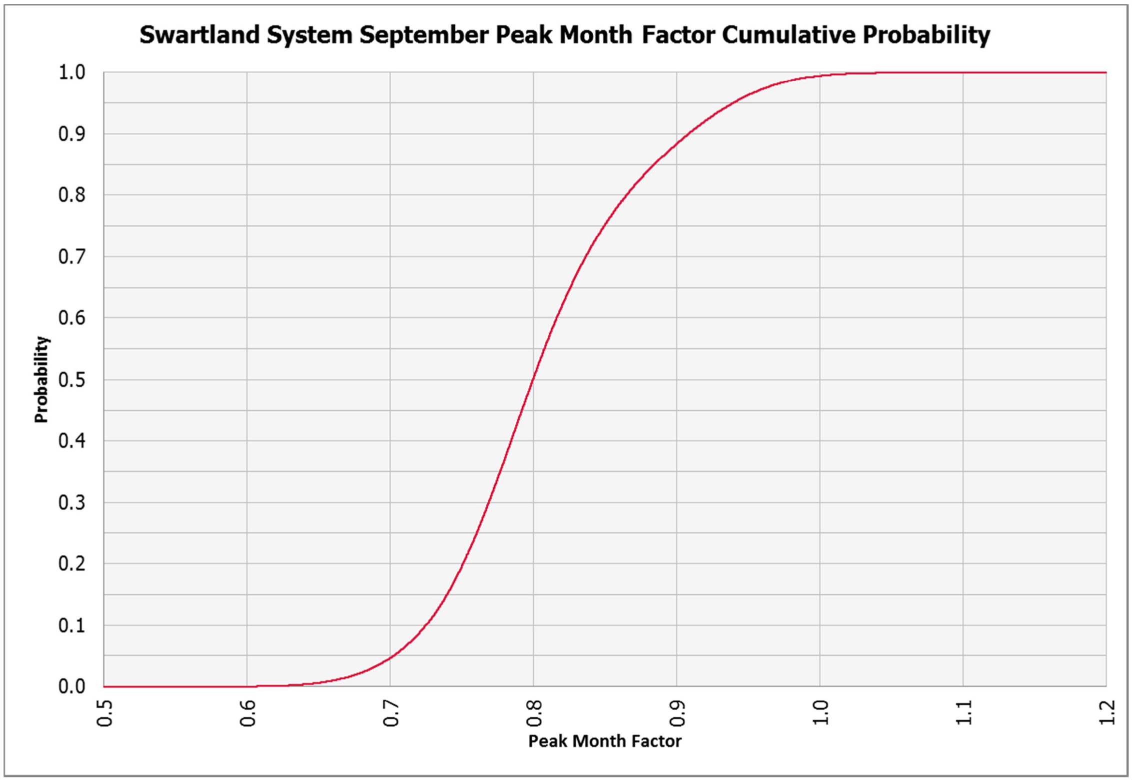

Figure A-15: Swartland system probabilistic peak month factor for September

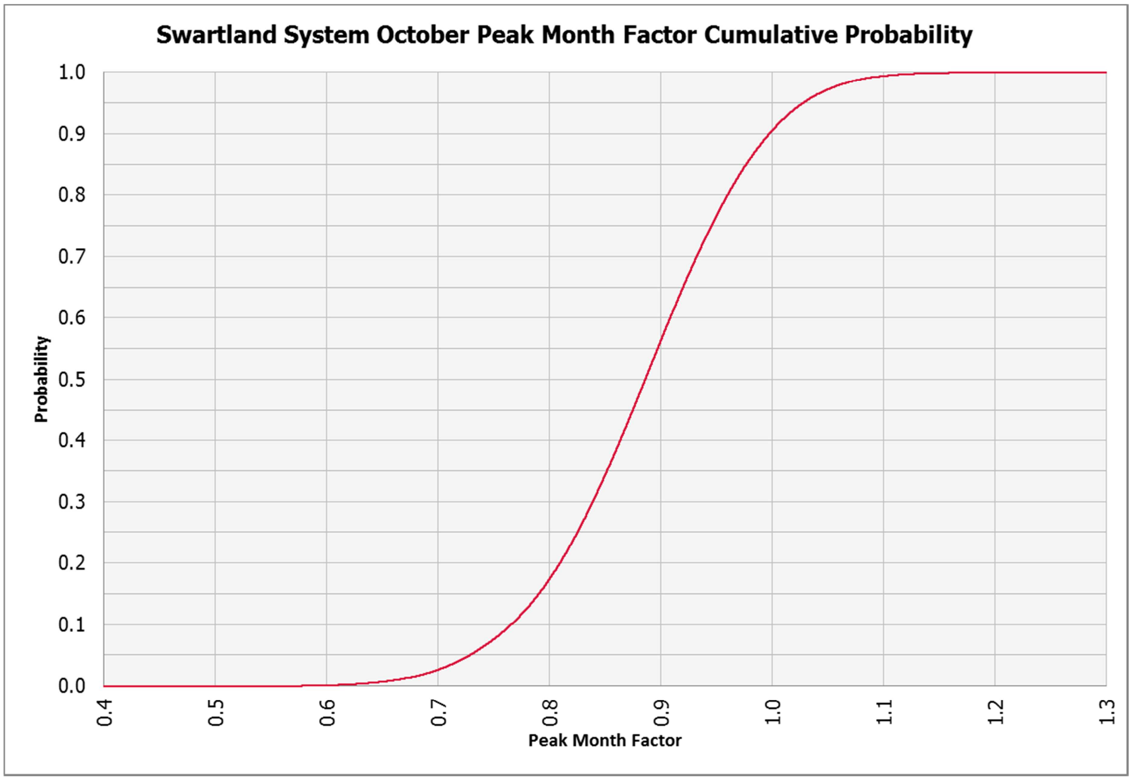

Figure A-16: Swartland system probabilistic peak month factor for October

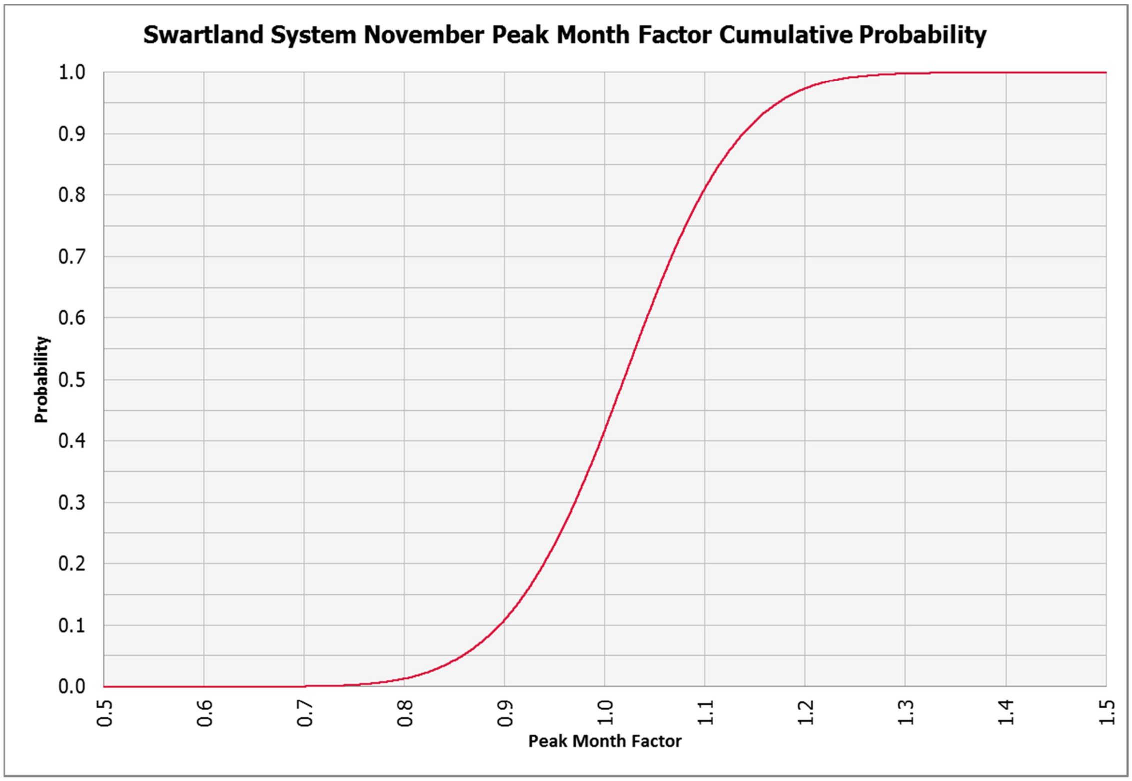

Figure A-17: Swartland system probabilistic peak month factor for November

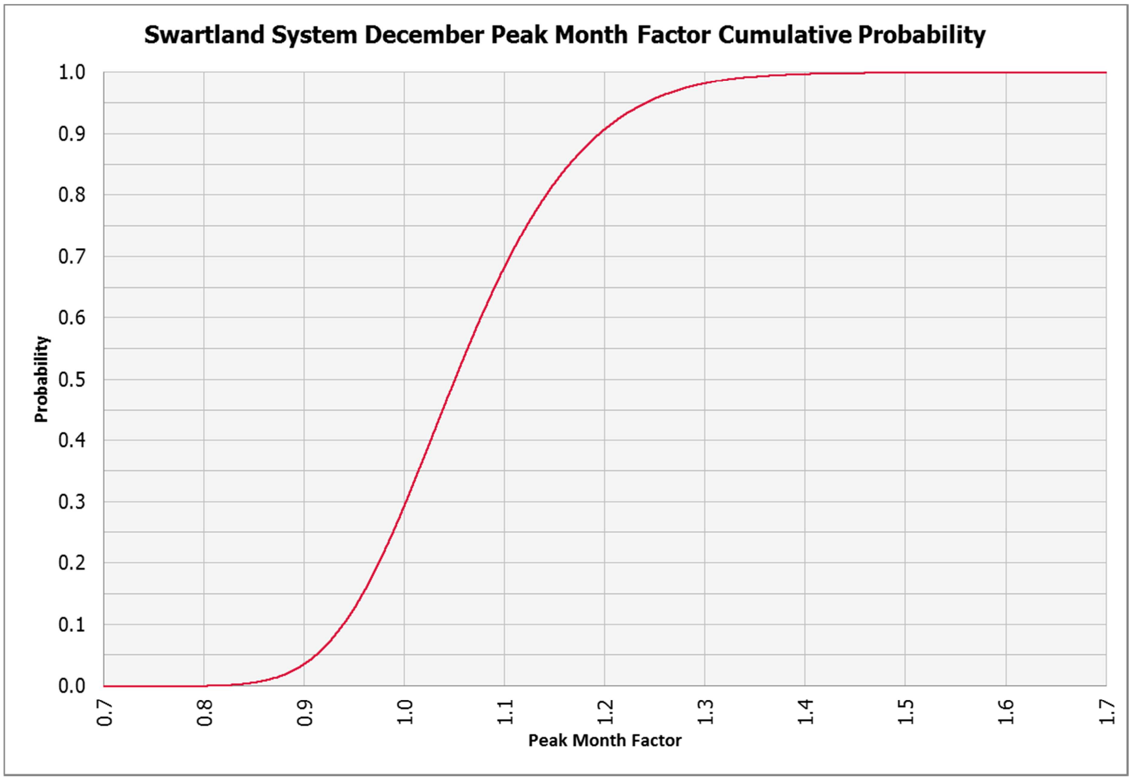

Figure A-18: Swartland system probabilistic peak month factor for December

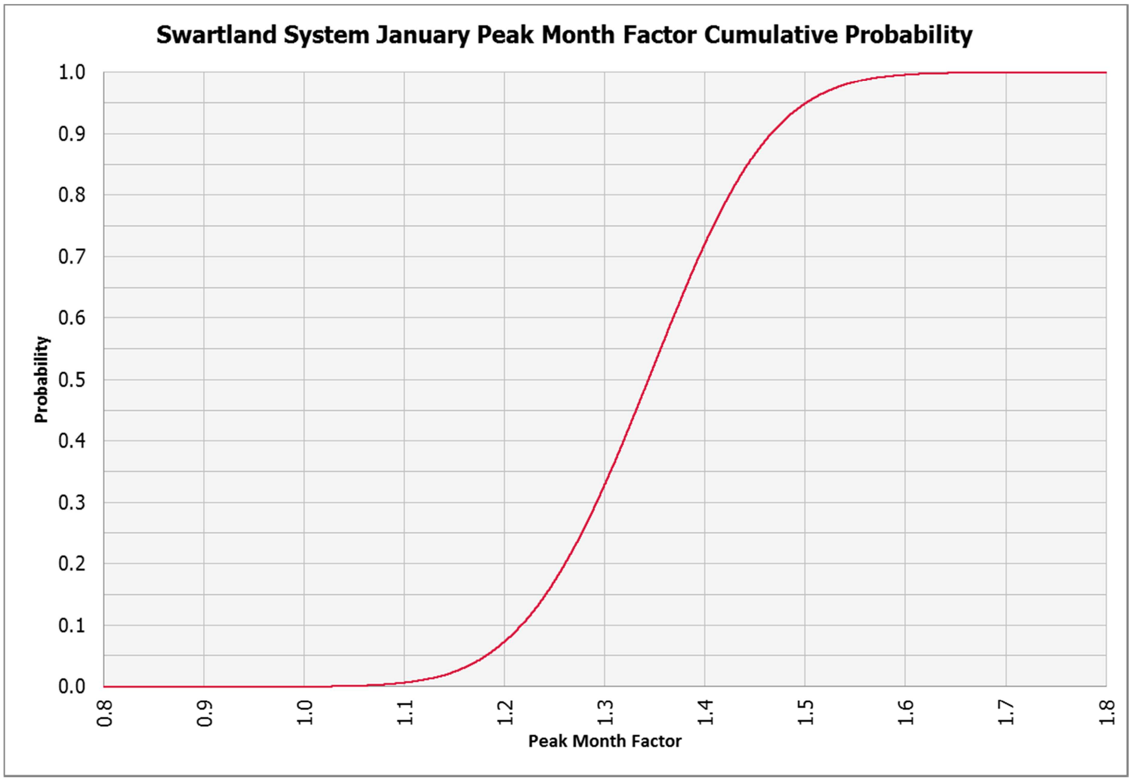

Figure A-19: Swartland system probabilistic peak month factor for January

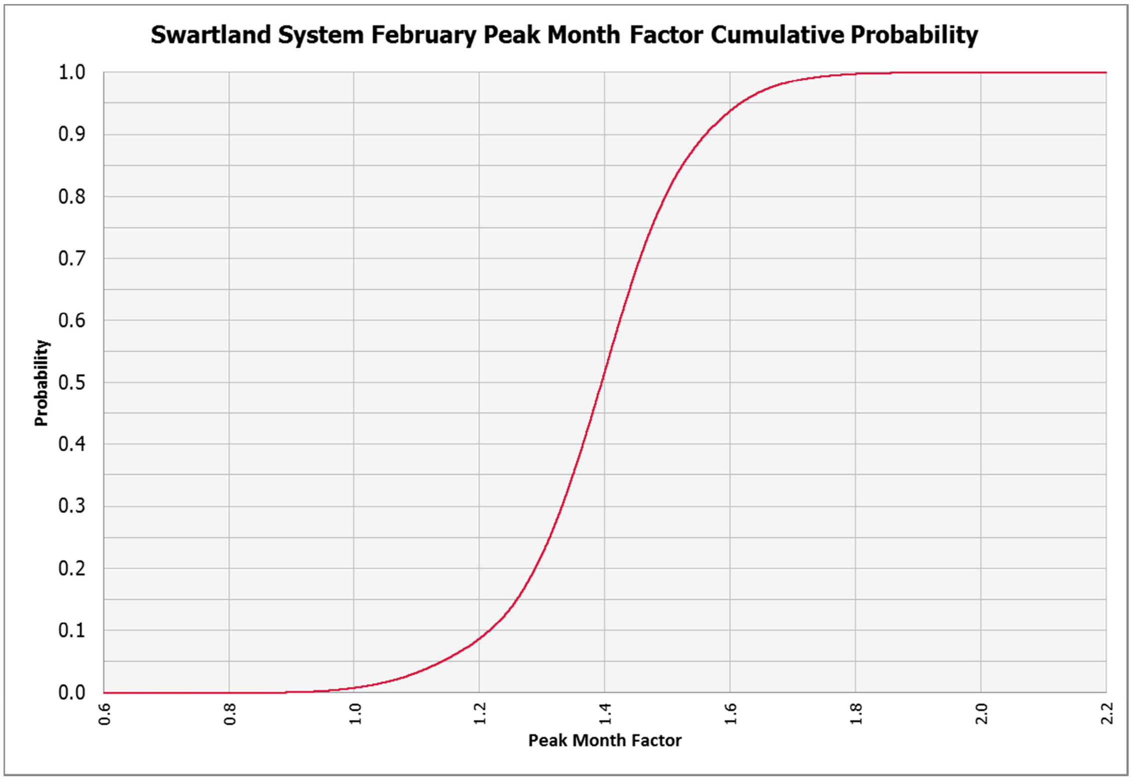

Figure A-20: Swartland system probabilistic peak month factor for February

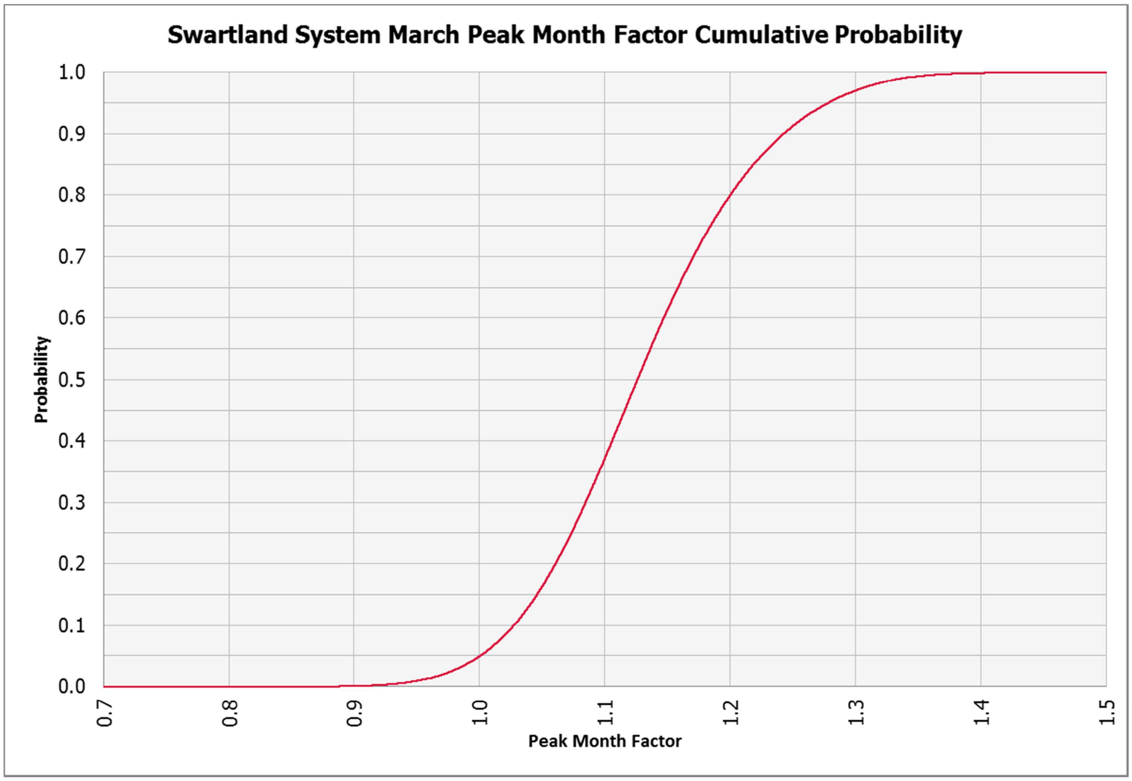

Figure A-21: Swartland system probabilistic peak month factor for March

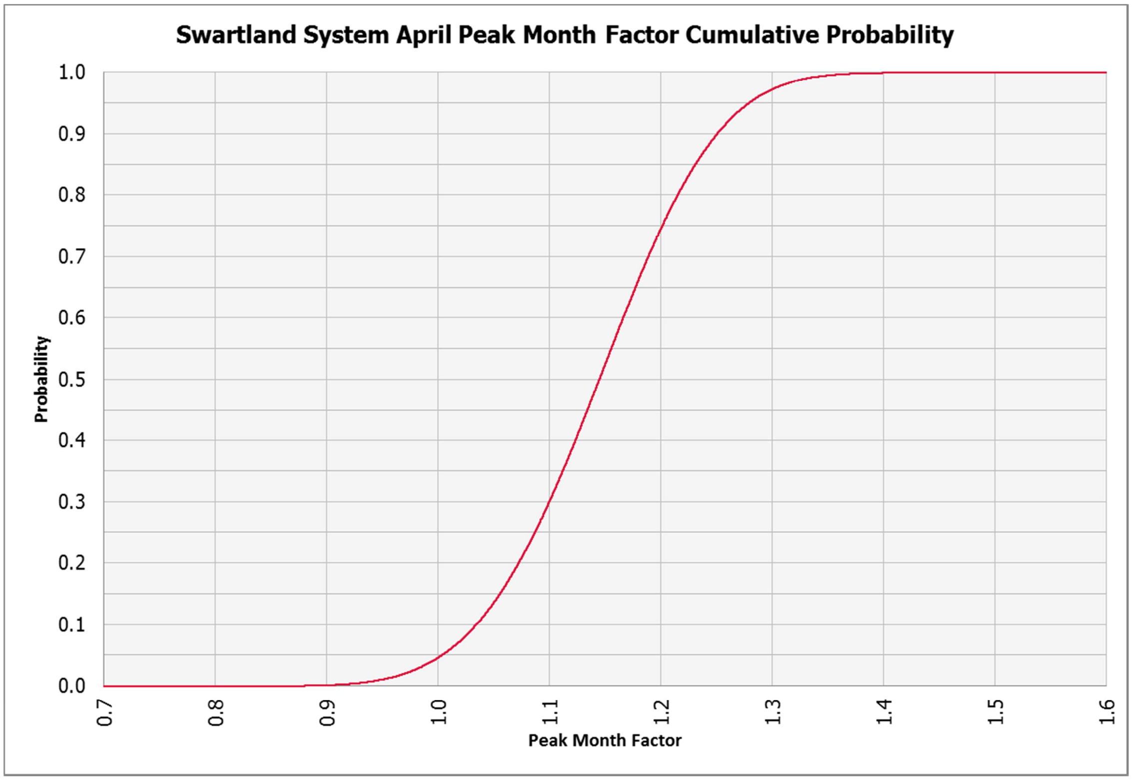

Figure A-22: Swartland system probabilistic peak month factor for April

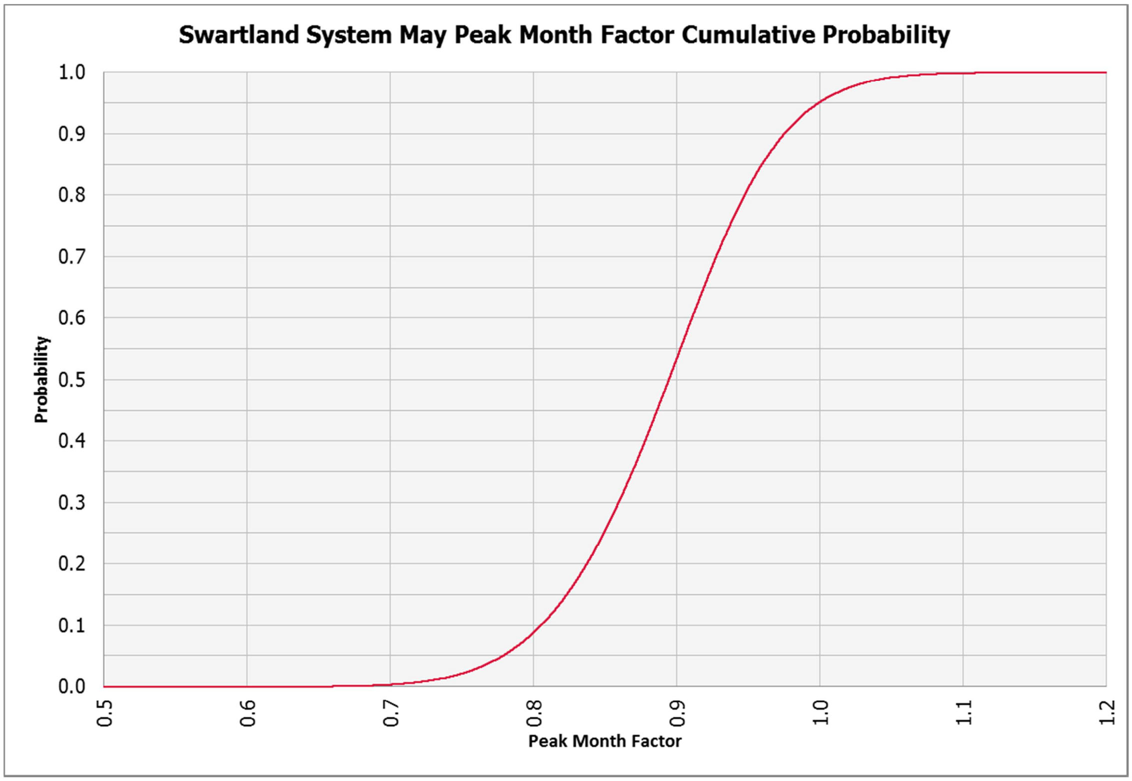

Figure A-23: Swartland system probabilistic peak month factor for May

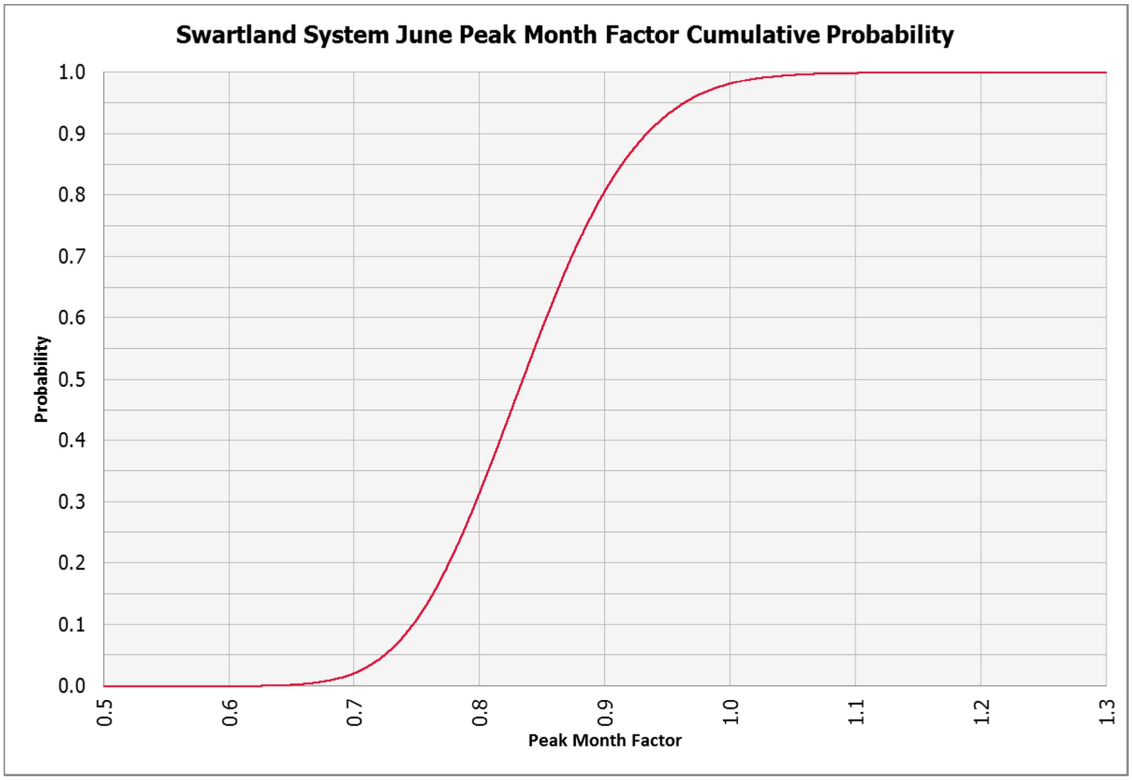

Figure A-24: Swartland system probabilistic peak month factor for June