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Investigation of Lot Fed Cattle Drinking Water Consumption

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Abstract

Drinking water is vital for the health, welfare and productivity of lot fed beef cattle. Limited theoretical or actual data regarding cattle water consumption under the range of different conditions encountered at Australian feedlots is available. This report reviews literature pertaining to beef cattle water consumption and experimental work undertaken in Australian feedlots. Predictive water consumption models are compared and their suitability for Australian conditions is discussed. Water consumption data collected from Australian feedlots is reviewed and the main factors influencing water consumption are examined.

Executive Summary

Water is a fundamental requirement for beef cattle feedlots. In Australia, an adequate, reliable supply of quality water is needed to obtain a licence to operate a feedlot. Substantial quantities of water are used at feedlots, mainly for drinking by cattle, but also for feed processing, washing cattle before their dispatch for processing, trough cleaning, dust control, evaporation from open storage, staff amenities and effluent irrigation dilution. As drinking water is the main component of a feedlots water usage, the industry will continue to use substantial quantities of water into the future.

Current trends suggest that water will be increasingly valuable due to limited supply and higher water charges (through increasing cost recovery from water supply schemes or the inclusion of environmental factors in water pricing). Environmental sustainability is an increasingly important issue for the general public, and the water use efficiency of industries is particularly topical during the current drought conditions. A key factor for productivity and sustainability within any industry is benchmarking and continuous improvement in performance.

This report investigates lot fed cattle water consumption and annual consumption patterns. Literature relevant to feedlot cattle water consumption is reviewed, and provides theoretical and experimental information of the factors influencing drinking water consumption. Predictive water consumption models are compared and their suitability for Australian conditions is discussed. Water consumption data collected from Australian feedlots is reviewed and the main factors influencing water consumption are examined.

This study was conducted at NAPCO Pty Ltd's Wainui Feedlot and Farm between the 1st of March 2007 and the 31st of January 2008. The study was divided into two parts due to the availability of data throughout the study period. Part A investigates annual water consumption patterns from March 1st 2007 to January 31st 2008. Meteorological data in this part was obtained from a nearby Automatic Weather Station. Part B is a study of the water consumption patterns and their relationship with meteorological data obtained from the on-site weather station. Part B was conducted from December 11th 2007 to January 31st 2008.

This investigation found that the daily water consumption of lot fed cattle varied throughout the study period. The Queensland Department of Primary Industries (QDPI) estimates that lot fed cattle require on average 65L/head/day (24ML/1000head/year). However in this study, a daily maximum of 75L/head/day was measured in summer with a daily minimum of approximately 15L/head/day measured in winter. The average daily drinking water consumption for the study period was 39L/head/day. The annual water consumption of lot fed cattle is estimated by QDPI at 24ML/1000head/year. The annual consumption per 1000 head per year was estimated in this study to be 15ML/1000head/year.

The daily water consumption patterns throughout the year varied for each season. Summer and Winter had two different diurnal patterns. During summer there are two peaks whilst in winter there is generally one. In summer the cattle start drinking at sunrise and drink predominantly until 12pm where water consumption is at its peak. Consumption then drops about mid-afternoon before peaking once again at about 4-5pm. The cattle then gradually decrease their water consumption until a few hours after sunset where it is steady until midnight. In winter the cattle start drinking at sunrise and drink predominantly until 1pm-4pm where water consumption is at its peak. Consumption then drops late afternoon until a few hours after sunset where their consumption is steady until midnight. Autumn and Spring have similar daily patterns consisting of two peaks – one at midday and the second occurs around 4pm. The drop between the peaks though is generally not as significant as that in the summer pattern.

The results show that ambient temperature, black globe temperature, humidity, rainfall and dry matter intake all influence drinking water consumption. The results showed that parameters are inter-related, with climate (temperature and rainfall) influencing feed intake as well as water consumption. Ambient, black globe temperature and solar radiation were the most influential meteorological parameters on the daily drinking water consumption of lot fed cattle. Both had high correlation with the water consumption patterns. Humidity however, had an inverse relationship with the drinking water consumption patterns. When the humidity decreased, the demand for drinking water increased and visa versa.

Water consumption models by Sanders et al. (1994), Hicks et al. (1988), and Watts et al. (1994) were compared to the measured data over this study period. The analysis showed that the Sanders et al. (1994) and Hicks et al. (1988) models tended to under-estimate water consumption compared to the measured data. The Winchester and Morris model (using the *Bos indicus* data) tended to under-estimate water consumption for ambient temperatures <35^{O}C and over-predict water consumption at higher temperatures. The Parker et al. (1999) model had the highest correlation with the measured data and therefore proved to be the most effective predictive model.

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The Australian red meat industry is one of the worlds' largest producers and exporters providing $15 billion to the Australian economy annually. Part of the success of this industry is due to the vast environmental conditions in Australia that allow both temperate and tropical breeds of livestock to thrive. Australian red meat also has high credibility overseas due to our high food safety standards; traceability of stock; and minimal disease due to Australia's isolation from other parts of the world. The Australian red meat industry is divided into the production of cattle, sheep, and goat, with cattle and sheep filling the majority of the domestic market.

1.1.1 Cattle

Australia is one of the world's most efficient producers of cattle and the world's second largest exporter of beef. The gross value of Australian cattle and calf production, including live cattle exports is approximately $7.5 billion. Figure 1 shows the percentage breakdown of Australian Beef and Veal production by state. The majority of Australian beef and veal production is sourced from the east coast with 49.8% from Queensland and 21.0% from NSW. In the 2006-07 period, Australia has exported 67.1% of its total beef and veal production holding a total value of $4.9 billion (MLA, 2007a).

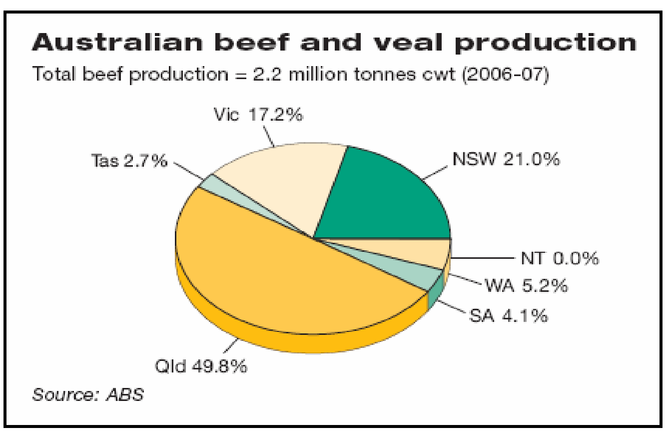

Figure 1 – Australian Beef and Veal Production (MLA, 2007a)

The major international destinations for Australian beef exports are shown in figure 2. Figure 2 shows that 41.4% of Australian beef is exported into the Japan market and 31.1% to the US market. In terms of live cattle exports though, it is the Indonesian market that holds the majority with 66.9% of live cattle being exported to there and the second highest destination for live cattle is Israel at 8.1% (MLA, 2007a).

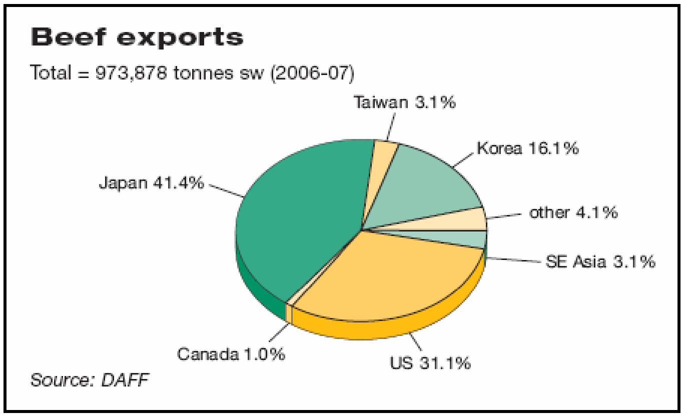

Figure 2 – Beef Exports (MLA, 2007a)

1.2 The Feedlot Industry

The growth of Australia's beef and cattle export markets led to the rapid development and expansion of the Australian feedlot Industry in the 1980's. Success in the overseas market has driven the Australian Beef Industry and has made Australian beef a major competitor on the international market.

Australian feedlots are typically a confined yard area with watering and feeding facilities where cattle are completely hand or mechanically fed with the sole purpose to maximise the amount of quality beef production. Feedlots ensure that cattle are fed a scientific combination of grain based rations to maximise both profit and the amount of quality meat output at the abattoirs (ALFA, 2002).

Throughout regional Australia there are a total of 598 accredited feedlots that hold a total capacity of 860,000 cattle. The Australian Feedlot Industry is located in regional farmland communities largely in regional southern Queensland, the northern slopes of New South Wales, and the New South Wales

Riverina. The concentration of feedlots in these regional areas is due to their requirements to have local access to cattle, grain and other roughage (ALFA, 2002).

2 Background

Water is the most valuable natural resource in Australia and the most important feed component fed to cattle. Recently with the long-term drought, more than ever, it has become of critical importance to lot feeders.

Feedlots use water for a wide range of various tasks. These tasks include drinking (88.97%), cleaning troughs (0.65%), feed mill (3.35%), evaporation from troughs (0.05%), and leakage (6.98%). These percentages are only approximate under summer conditions but give a good representation of the dispersion of water use across feedlots. Drinking water is obviously the major source of water usage on a feedlot and therefore investigating drinking water consumption patterns is particularly useful.

Little work has been undertaken to evaluate drinking water consumption of lot fed cattle. The quantity of water used in feedlots was studied in North America in the 1980's. Research in North America by Winchester and Morris (1956), Hicks et al (1988) and Parker et al. (2000) have related water intake per day to ambient temperature, dry matter intake (DMI), and other meteorological variables, such relative humidity, and rainfall. However, to date, only one limited study on drinking water requirements of lot fed cattle has been undertaken in Australia.

Sanders et al. (1994) measured the water consumption of cattle at two feedlots on the Darling Downs, Queensland from November 1993 until May 1994. They did so in an effort to understand the factors that influence the quantity and frequency of water consumption in lot fed cattle. Sanders et al. (1994) found that the models developed by Hicks et al. (1988) and Winchester and Morris (1956) poorly modelled their collected data. Hence, Sanders et al (1994) developed a relationship between drinking water consumption and a range of variables. Whilst providing a better estimate of water intake of their data, it has its limitations for predicting drinking water intake as a number of the climatic parameters required can only be obtained retrospectively i.e. daily rainfall, humidity, solar radiation.

B.FLOT.0339 a current MLA funded project aims to quantify the water and energy usage of individual activities within Australian feedlots. These include drinking water consumption, feed preparation, cattle washing and administration. The adopted approach was to instrument the water and energy network at participating feedlots with water meters to allow the usage of these activities to be measured. In the majority of the participating feedlots the water reticulation system layout did not allow direct measurement of drinking water consumption. In these cases drinking water consumption was determined by residual that is found by measuring the total consumption and then deducting the measured usage of the remaining activities.

However at the North Australian Pastoral Company (NAPCO) Wainui Feedlot and Farm, the water supplied directly to the production pens for drinking and trough cleaning, could be measured by a water meter. This water meter, when combined with a single channel data logger can log and record the water flow-rate and total flow at 3 min intervals.

This data can be presented in the time domain thus allowing water consumption patterns on a daily basis and total water usage to be reviewed. Based on previous work, the quantity of water consumed by feedlot cattle has been found to be mostly dependent on environmental conditions such as temperature and humidity, drinking water temperature; ration composition, feed intake, size of animal, breed, frequency of watering and the individual variation between the cattle.

This case study will involve a detailed review of the daily drinking water consumption measured at the Wainui Feedlot to gain a better understanding of the drinking water consumption patterns on a diurnal basis and the total volume consumed, and to compare these patterns to other available data such as meteorological data, DMI, and other cattle details such as number of head per pen. It will highlight trends and parameters that may influence drinking water consumption patterns in the feedlot over time.

This case study will be undertaken in conjunction with FSA Consulting Toowoomba and Wainui Feedlot.

2.1 Case Study Site Details

FSA Consulting is Australia's predominant environmental consultancy for intensive livestock industries. FSA Consulting is a professional consultancy that provides agricultural, environmental and engineering services to livestock industries, farmers, abattoirs, feedlots and industry. FSA has undertaken numerous research for the feedlot industry consistently on environmental issues over the past 13 years (FSA Consulting, 2007).

The data collation, analysis and reporting component of this study was undertaken at FSA Consulting's Toowoomba Office. Data collected for this study was gathered from NAPCO's Wainui Feedlot at Bowenville on the Darling Downs.

2.1.1 Wainui Feedlot

The NAPCO (North Australian Pastoral Company Pty Ltd) Wainui Feedlot and Farm is a cattle feedlot and farm situated between Dalby and Oakey on Queensland's Darling Downs. It is owned by The North Australian Pastoral Company Pty Ltd, which is one of Australia's largest, and oldest private cattle companies. For convenience the NAPCO Wainui Feedlot and Farm will now be referred to as Wainui Feedlot.

Wainui Feedlot (see figure 3) supplies both the domestic and overseas market, with approximately 70 per cent of the beef going to Japan and Korea. Currently Wainui Feedlot holds approximately 7,000 head of cattle. Each week around 200 cattle are sold, and a similar number of new cattle are inducted. It was purchased in 1985, and since then, has been developed by NAPCO into one of Australia's most modern and efficient feedlots. The Wainui aggregation includes an irrigation and dry-land farm, where grain and silage is produced for feedlot use.

Figure 3 – Aerial view of Wainui Feedlot

2.1.2 Case Study Objectives

The objectives of this case study were to:

- Develop a clear understanding of the water consumption patterns and trends over time at Wainui Feedlot.
- Comparison of water consumption patterns with other available data (DMI, meteorological conditions etc) to evaluate trends and factors that influence consumption patterns.
- Review water reticulation flow rates and peak water requirements from an industry wide design and planning perspective.
- Make recommendations from the findings on drinking water consumption measures for improved production efficiency.
- Prepare a final report outlining the project, findings and recommendations.

3 Literature Review

3.1 Introduction

There have been a number of studies undertaken by Winchester and Morris (1956), Flamenbaum et al (1986), Hicks et al (1988), Gaughan et al. (2001), Parker et al. (2000), and Tucker, Watts and Davis (2006), that have investigated the factors affecting the drinking water consumption of lot fed cattle. Such studies have been undertaken in a laboratory (Winchester and Morris), whilst others concentrated around the effect of heat stress and possible solutions to minimise heat loading on the animals (Gaughan, 2001), whilst remaining studies have been undertaken in-situ on-farm investigation.

These studies have shown that a number of factors influence the drinking water consumption. These include environmental factors such as temperature, humidity, and rainfall; but also others characteristics such as the breed of cattle, and their dry matter feed intake. Other cattle characteristics which may affect drinking water consumption included but are not limited to their breed, body size and coat type. A brief review of factors effecting drinking water consumption is presented in the following section.

3.2 Factors Effecting Drinking Water Consumption

3.2.1 Environmental Factors

The environment directly affects the cattle's daily drinking patterns, performance and even survival. It is a parameter that can significantly affect the productivity and profitability of the feedlot industry. Such environmental factors include but are not limited to ambient temperature, radiant heat, humidity, wind speed, rainfall and solar radiation. Radiant heat can be defined as an integration of air temperature, solar radiation, and air movement, to give a temperature that is indicative of what the cattle 'feel' by standing in the sun. This is a directly measured temperature inside a 'black globe'; hence it is usually referred to as black globe temperature.

Each of these environmental factors will affect the cattle's physiological state, thus affecting water consumption. High humidity, low wind speed and rainfall will tend to have the general effect of decreasing overall drinking water consumption.

There have been studies that have been undertaken regarding the effects of heat stress on lot fed cattle and minimisation solutions (Flamenbaum et al. 1986, Hicks et al. 1988, Gaughan et al. 2001). Such studies have involved the investigation of shade, sprinklers, and diet modifications, and the effectiveness they have on minimising heat stress in cattle. They also involved the development of an index representative of heat stress (HLI).

Ambient temperature is a measure of the intensity of heat. Therefore, cattle that are exposed to high ambient temperatures will inevitably become hot and will need to cool themselves. Increasing water consumption is an important method of reducing body temperature due to its involvement in the evaporative cooling process. High temperatures limit the animals' ability to dissipate heat by radiation, conduction and convection and therefore are solely dependent on the evaporative pathway.

Relative humidity may be defined as the ratio of the quantity of water vapour present in the air relative to the amount of water in the air. The potential for evaporative heat loss is influenced by the difference between the water vapour pressure at the skin surface temperature and the actual vapour pressure of the ambient air. As the humidity of the air increases, the ability to lose heat by evaporation is reduced, become zero at a relative humidity of 100%.

Radiation from the sun, sky and surroundings also contribute to the animals heat load. Unshaded cattle are exposed to direct solar radiation from the sun, solar radiation reflected from the clouds and solar radiation reflected from the ground and other surrounding objects. The animal's coats reflect a proportion of the direct solar radiation, but the cattle absorb the remainder.

The amount of heat an animal absorbs from solar radiation is influenced by the intensity of the radiation, the animals' orientation to the sun and the absorptive, reflective capacity of the animals' coat. McArthur (1987) found that radiation is directly responsible for increased skin temperature, which stimulates secretion from the sweat glands.

Wind can also have an influence on the heat transfer from an animal and its environment. Rapid air movement will enhance the evaporative heat loss only when the skin is moist and the air temperature is less than the animals skin temperature. Wind may also have an effect if the air temperature is above the animals skin temperature and will be limited if its skin lacks any moisture.

Rainfall also reduces water intake due to the associated heat loss through evaporation. Rain falls onto the animal's coat and evaporates, reducing thermal stress. The cooling effect is directly related to the depth of water penetration into the coat.

3.2.2 Breed of Cattle

Studies undertaken by Winchester and Morris (1956) show that there is a definite difference in water consumption patterns between cattle breeds. Their study related cattle's water intake per day to ambient temperature, dry matter intake (DMI) and breed. The conclusions of their studies were that *Bos Indicus* cattle drink significantly less than *Bos Taurus* breeds. Figure 4 depicts their findings relating the cattle's water intake to the ambient temperature and their dry matter intake.

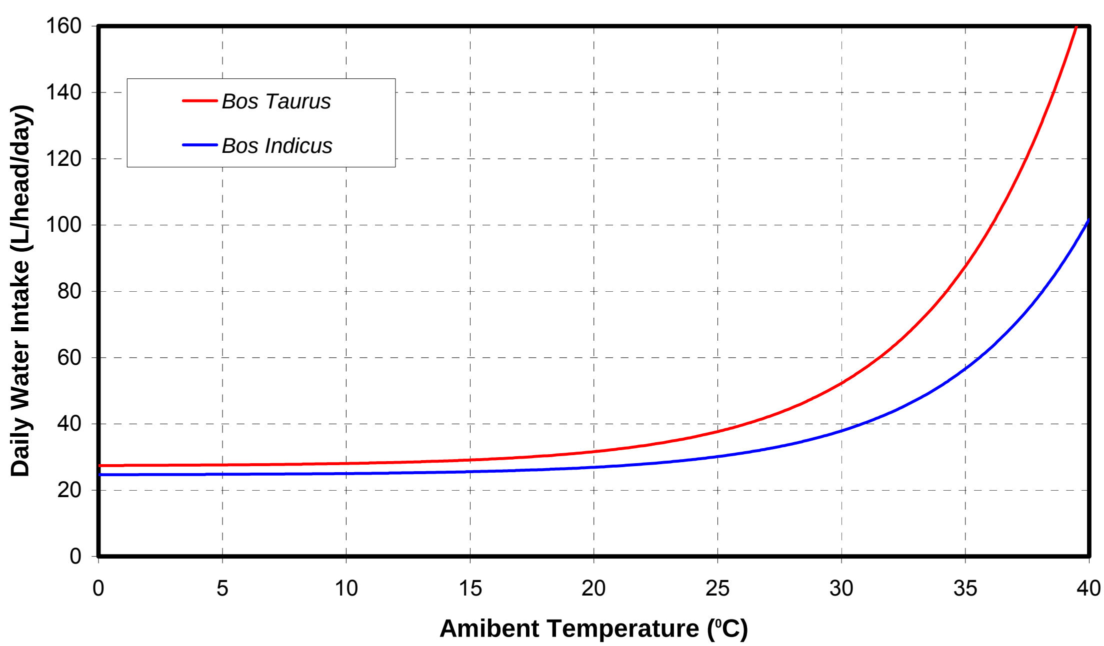

Figure 4 – Water intake expressed as a function of dry matter intake (11 kg DMI per day) and ambient temperature (Watts and Tucker, 1994).

As yet, it is not fully justified as to why Bos *Indicus* cattle drink significantly less than *Bos Taurus* breeds. However, *Bos Indicus* cattle are known to be capable of adapting to hot environments much easier than their European and British counterparts. This ability for the *Bos Indicus* to adapt to hot environments easier could explain the significant differences in water consumption between the two breeds of cattle.

Results have been recorded on the sweating capacity of different breeds showing that *Bos Indicus* cattle have a definite sweating advantage over the *Bos Taurus* cattle. This can be attributed to *Bos Indicus* cattle having a higher density of sweat glands than the European breeds (Ferguson and Dawling 1953). Allen (1961) found that when *Bos Taurus* cattle were subjected to mild environmental conditions they had a higher sweating rate than the *Bos Indicus* cattle (*Bos Indicus* didn't start sweating until temperatures exceeded 30°C). Although under more extreme conditions the *Bos Indicus* cattle had a greater sweating rate relative to the *Bos Taurus* cattle.

Robinson and Klemn (1953) showed that the *Bos Indicus* cattle have a greater tissue conductance capacity than the *Bos Taurus*, therefore enabling them to dissipate heat from the body core to the skin quickly. Also aiding in faster heat transfer is the *Bos Indicus* cattle's greater surface area to weight ratio than the *Bos Taurus* breeds (Blackshaw & Blackshaw 1991).

3.2.3 Diet Composition and Feed Intake

Since feed ingested by cattle is an added source of water, it influences the total daily consumption of water for the animal. Paquay et al. (1970), Little and Shaw (1978), Murphy et al. (1983), and Holter and Urban (1992) reported that as the dry matter content of a diet increased (therefore decreased moisture content), drinking water intake increased to compensate for less feed water intake. The dry matter percentages ranged from 62 to 88% among experiments, excluding the study of Paquay et al. (1970), in which dry matter concentration was not reported. Castle and Thomas (1975) tested the influence of forage type on water intake. They found that regardless of what forage was fed, water intake was dependent on the dry matter content of the feed.

The salt content of the cattle's diet also has an influence on their daily water consumption. This is because it is a diuretic substance, which leads to dehydration of the animal.

3.2.4 Body Size

Water intake is usually expressed as litres per head per day. Essentially it is the growing cattle that require more water with a higher quality than cattle that have finished growing. Likewise larger cattle have a lower surface area to weight ratio than leaner cattle and therefore have a lesser requirement to drink as much water as the leaner cattle.

3.2.5 Water Quality

The quality of the drinking water for the cattle can have an influence over water consumption levels. Water, depending on where it was sourced from and if it has gone through any filtering (natural or otherwise), can contain a varying combination of nutrients and minerals in various quantities. If the water is too saline, or has too much nitrate, or is highly alkaline, not only will this effect the quantity of water the cattle drink, but it could also effect their health and in some cases cause death.

Water that is too saline is the most common problem with the drinking water for cattle. Therefore it is preferable to ensure a good supply of quality drinking water at all times.

3.2.6 Water Temperature

During colder temperatures, the drinking water is generally cold unless artificially warmed and in warmer temperatures the reverse. There have been some studies undertaken that have investigated the effects of drinking water temperature on rumination rate, body temperature, feed consumption, and live weight gain.

Some studies have been completed in high temperature environments with varying temperatures of water. It was found that it is possible to reduce cattle's overall body temperature transiently for a maximum of 2.2 hours by providing chilled water (Beede, 2005). After this period of time though there seemed to be little continual cooling effect and as such it did not stop the cattle's body from rising above the upper critical temperature for heat stress. One study that was conducted by Milam et al (1986) found that chilled water increased DMI. This was complemented by another study that showed that chilled water increased DMI by 9%, and water intake was lowest with no differences noted in respiration rate.

Wilks et al (1990) conducted a trial involving water of 10ºC and 27ºC in temperature. This trial showed that cattle preferred warmer water with 97% of the total water consumed being the 27ºC water. Even under warmer environmental conditions the cattle seemed to prefer the warmer water.

So whilst cooler drinking water has a cooling effect for only a short period of time, studies have shown that it can increase DMI and reduce water intake.

3.3 Drinking Water Consumption Models

There have been attempts made to establish relationships for predicting daily water requirements for cattle. Despite these efforts there are still three basic difficulties that have hindered the accuracy in predicting such a formula:

1. The unpredictability of environmental variables such as temperature, humidity, and air movement has a considerable influence on this. Taking averages for environmental variables is sometimes done but increases the inaccuracy in the development of a relationship.

2. The individual variability of the cattle is also a hindrance when it comes to developing such a formula. Cattle will be of different age and sex and have different metabolic rates; breeds will have varying coats and will acclimatise differently; and hydration and disease tolerances will vary to the individual cattle.

3. There will also be differences in physiological conditions between the animals. Depending on the cattle, they will be at different stages in their growth and reproductive cycles; the level of productivity will differ; and their physiological responses will vary.

It would be impossible to take into consideration the effects of all these variables in a single index when developing a formula. Therefore scientists generally ignore most of these variables that make an insignificant contribution to the cattle's water consumption.

While the drinking water requirement is likely to be higher in the Central Highlands than on the Darling Downs, the total average annual water requirement for feedlots in Queensland is approximately 65L/head/day or 24ML/1000 head per year. This figure makes a small allowance for uses other than cattle drinking requirements, such as trough cleaning, minor leakages, and veterinary purposes, but does not allow for significant usage for the purposes of dust control, dilution of irrigated effluent, feed processing or evaporation from open storages.

3.3.1 Winchester and Morris

Winchester and Morris (1956) conducted a study where they developed a relation between the cattle's water intake per day, the ambient temperature, their Dry Matter Intake (DMI), and breed. Conducted in a constant temperature chamber, it was found that up to an ambient temperature of 30ºC, the rate of water consumption per unit of DMI remained fairly constant. As the temperature increased beyond this however, water consumption rose dramatically due to the increased need for evaporative cooling.

From their research, Winchester and Morris (1956) found that:

1. *Bos Taurus* cattle consumed 16L / kg of DMI
2. *Bos Indicus* cattle consumed 10L / kg of DMI

The data from the study conducted by Winchester and Morris (1956) was later used by Watts, Tucker, and Casey (1994) to develop a relationship representing the water intake for both *Bos Taurus* and *Bos Indicus* cattle:

Bos Taurus - $$WI = DMI \times (3.413 + 0.01592\, e^{0.17596T})$$

Bos indicus - $$WI = DMI \times (3.076 + 0.008461\, e^{0.17596T})$$

Where:

WI = water intake (litres per head per day)

DMI = dry matter intake (kg DM per head per day)

T = ambient temperature (degrees celsius)

Despite the development of these formula and various studies, it is a generally accepted estimation that for a 650kg animal the drinking water consumption is 65 litres/head/day.

3.3.2 Sanders et al.

Sanders et al. (1994) also conducted a study whereby he measured the water consumption of cattle at two feedlots on the Darling Downs, Queensland from November 1993 until May 1994 in an effort to understand the factors that influence the quantity and frequency of water consumption. The influence of shade, dry matter intake and other meteorological factors on water consumption was investigated and a predictive water consumption model was formulated. This was compared to other recognised water consumption models available at the time.

Cattle weights were recorded along with weekly data on diet type including main grain type, processing method, silage and roughage percentage, moisture content along with total consumption as-fed (kg) on shaded and unshaded pens. This allowed an average as-fed feed intake to be determined per head.

Sanders et al. (1994) found the most important factors that had the most significant effect on daily water consumption in decreasing order of importance to be solar radiation, relative humidity, average daily temperature, rainfall, and dry matter intake.

They developed a predictive daily water consumption model based on rainfall, dry matter intake, shading and a weather factor that is a function of average daily temperature, solar radiation and relative humidity. Their model is:

$$WC = 1.337 - 0.037 \times P + 0.687 \times DMI + (1.592 - 0.199 \times \text{shading}) \times (\text{weather})^{0.5}$$

Where:

WC = water consumption (litres per day per 100 kg LW)
DMI = dry matter intake (kg DM per day per 100 kg LW)
P = Rainfall (mm)

Weather = average daily temperature (°C) x solar radiation (MJ/m^2)/relative humidity (%)
Shading = 0 for unshaded pens, 1 for shaded pens.

Sanders et al. (1994) found that the models developed by Hicks et al. (1988) and Winchester and Morris (1956) poorly modelled their collected data. The relationship developed by Sanders et al. (1994), whilst providing a better estimate of water intake, has limitations in that the climatic parameters required can only be obtained retrospectively i.e. daily rainfall, humidity, solar radiation. As a result of their model, they showed that water consumption consistently under-predicted actual water intake by 2-3 L/SCU/day.

3.3.3 Parker et al.

Parker et al. conducted a third study in the Texas High Plains in 1998 into the water use and conservation at beef cattle yards. This was a two year study where the water usage peaks were observed during both the winter and summer months. The peak in the summer was attributed to elevated temperatures and the cattle drinking more, while the peak in the winter was because of high overflow rates to prevent ice formation in water troughs.

Daily water usage data was then collated to derive the following relationship:

$$DWU = 10.8 + [-1.52 \sin \{(2\pi/365)(D+69.5)\}]$$

With correlation $r^2 = 0.28$

Where:

DWU = daily water usage (gallons/head/day)
D=Julian day.

Total water usage for the two-year period averaged 10.83 gal/head/day (50 L/head/day). Water usage varies among feedlots because of different water trough types and differing water management practices.

3.4 Diurnal Variation in Water Consumption

Equally as important as the total volume drunk, is to ensure that the cattle have an adequate supply of drinking water at all times of the day. It is not sufficient to simply calculate how much is needed based on the yearly or even daily consumption. This is because the quantity of water cattle drink at different times of the day varies. This can be due to multiple reasons including meteorological conditions such as high temperature or humidity, feeding times or inherent cattle behavioural tendencies. The daily variation is important for water reticulation purposes.

A study undertaken by Johnson (1964) considered the diurnal trends in both water consumption and frequency of drinking with respect to temperature fluctuations. Their findings showed that more water was consumed during the day and more frequently than during the night irrespective of temperature. They also found that as temperatures rose from 0º to 40ºC, water consumption irrespective of breed, increased by only two to three times during the day, whereas night consumption rose six to seven fold.

Watts, Tucker and Casey (1994) have also studied diurnal water consumption patterns (see Figure 9), however not during heat wave conditions. Their findings supported the study undertaken by Johnson (1964) claiming that cattle consume most of their water during the day. They recognised that there is a definite periods of peak demand over a 24-hour time period and that water consumption is significantly reduced between the hours of 11pm and sunrise. The period where there is the greatest water consumption is between the hours of 9am and 8pm and therefore this is when the likelihood of water deprivation is the most significant.

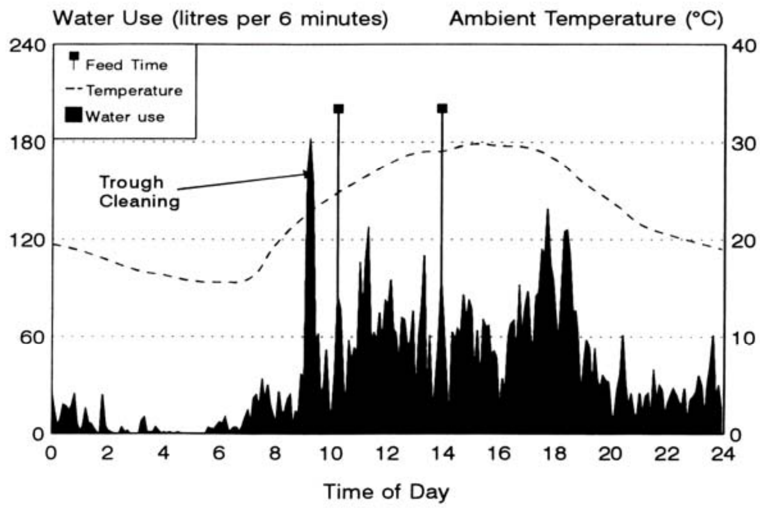

Figure 5 – Diurnal Variation in Water Intake over a 24 Hour Period at a Feedlot

The diurnal variation shown in Figure 5 is the only Australian data of its type that is currently available. All other data are from previous investigations conducted overseas where cattle environmental conditions are in some cases completely different from those in Australia.

4 Materials and Methods

This study will investigate the drinking water consumption and diurnal variation in drinking water consumption by lot fed cattle at the Wainui feedlot. The Wainui feedlot is located at Bowenville between Dalby and Oakey on Queenslands Darling Downs (see Figure 6).

Figure 6 – Location of NAPCO Wainui Feedlot in Southern Queensland

The study involved the weekly collection of data from the Wainui feedlot site. This data included metered water usage of the production pens water supply, meteorological data from the on-site Automatic Weather Station, and cattle performance data. The water usage has been metered and recorded since March 2007. However, due to problems with the on-site weather station, meteorological data from March 2007 to December 2007 was not available to compare. However meteorological data from a nearby Automatic Weather Station is available and has been used for the period March to December 2007, the water consumption trends have been undertaken based on cattle numbers, DMI and meteorological data from an off-site Automatic Weather Station. In the period following December 2007 though, an intensive study of water consumption and diurnal variation was undertaken using on-site meteorological data and cattle information to be gathered and used to analyse water consumption patterns. This data was then compared to predicative models that have previously been developed.

4.1 Production Pen Water Reticulation System

This case study, is concerned only with the water supplied to the production pens. The production pen reticulation system consists largely of the main tank with a secondary tank connected as a backup. This second tank is connected to the same pump network but only becomes effective if the main tank is running dry (see Figure 7). These tanks supply the water supply to the production pens. The maximum potential flow that the pumps can deliver is 1800L/min.

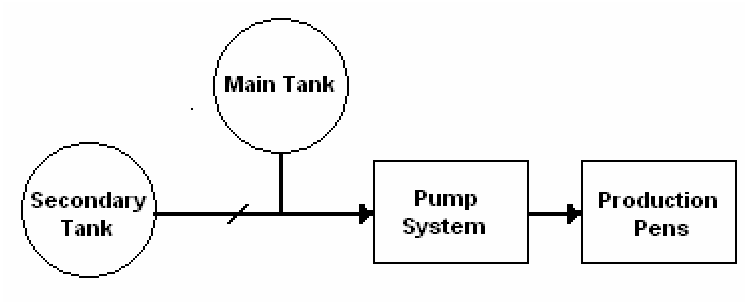

Figure 7 – Tank Setup

The water troughs (see Figure 8) in the production pens at Wainui Feedlot have a float valve system installed that allows the trough to automatically fill when the water level drops. The float valve system involves a device that floats on the surface of the water in the troughs, which acts as a switch to turn on the water supply when needed. As the water level falls, the device falls, allowing the supply of water fill the trough. As the water level rises again, this device rises, cutting off the water supply into the trough.

Figure 8 – Production Pen Trough

The production pen water troughs are made of concrete and measure 3 m long x 0.495 m wide x 0.24 m deep (see Figure 9). They have a holding capacity of 326 litres and provided an average drinking space of 27 mm/head. The troughs at Wainui Feedlot are cleaned on average every three days, typically Wednesdays and Saturdays. A loss of 559 litres of water per trough results during each clean. If the total number of trough are cleaned (38), this translates into a total loss of 19.01 kilolitres of water due to cleaning troughs once.

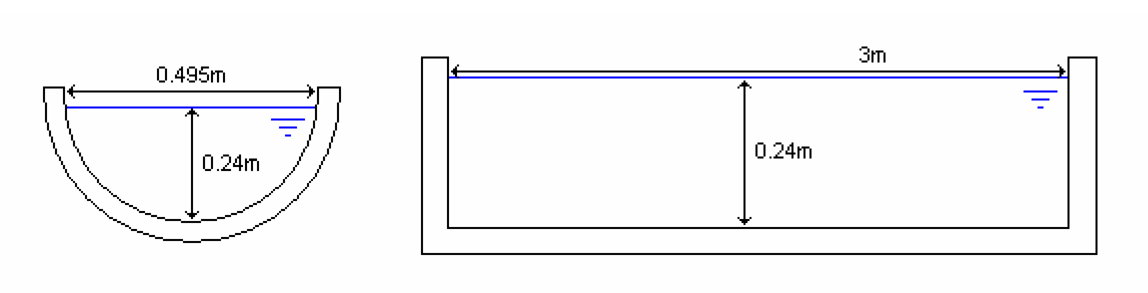

Figure 9 – Trough Dimensions

4.2 Instrumentation

The water supply to the production pens at the Wainui Feedlot was measured with a water meter (see Figure 10). The water meter had a single channel logger installed to log a pulse signal from the meter. The logger recorded the date, time and counted the pulses between a user defined 3-minute logging period. It then translated the data into a flow rate and total flow per minute. The data from the meter was downloaded via computer every week.

Figure 10 – Water Meter at Wainui Feedlot

Meteorological data required for this case study was obtained from the on-site 2m Automatic Weather Station (see Figure 11). Data that was obtained included, ambient temperature, black globe temperature, relative humidity, rainfall, wind direction, and wind speed.

Figure 11 – Wainui Automatic Weather Station

4.3 Data Collection

4.3.1 Water Data

The water data was obtained from the single channel data logger connected to the installed water meter (see Figure 12). To download the water data from the logger, dedicated proprietary data logger software ('Flowcom') was used. A laptop was connected by way of a serial cable to the logger. The download process took approximately 5 minutes to complete.

Figure 12 – FloLog flow rate logger

4.3.2 Meteorological Data

The Automatic Weather Station (AWS) recorded meteorological parameter readings at 1-minute intervals. An average of these readings were then recorded every 10 minutes hourly, maximum and minimum values were recorded daily, and instantaneous values at 9 am recorded.

The meteorological parameters recorded included:

- Ambient Temperature (ºC)
- Black globe Temperature (ºC)

- Relative Humidity (%)
- Wind Speed (km/hr)
- Wind Direction (degrees)
- Solar Radiation (MJ/sq.m)
- Barometric Pressure (hecta Pascals)
- Rainfall (mm)

Powered by a 12-volt battery, the AWS had a data logger that recorded the stations data. Every week, this meteorological data was downloaded from the weather station. The downloaded data was transferred from the data logger to a laptop using proprietary *Environdata 'Easiaccess'* software.

4.3.3 Cattle Data

Cattle data such as number of head per pen, days on feed (DOF), entry weight, estimated weight, and details of dry matter intake (DMI), are recorded in control reports. Control reports for every week of the study period were obtained from the feedlot manager. The required cattle data including number of head, live weight, and DMI were then extracted from each daily control report and entered into an excel spreadsheet.

Wainui feedlot has 44 production pens. Over the duration of the study period an average of 38 pens held cattle. The lowest current capacity is 4 head whilst the highest is 335 head in a pen. The average cattle's entry weight ranges from 295 to 479 kg with an average of 398 kg, and an average of 10.7 kg of DMI / day was rationed to the cattle over the study period.

The average number of head in the Wainui Feedlot over the study period was about 7600 head, with a minimum of 6329 head and a maximum of 8872 head on feed.

5 Results and Discussion

5.1 Collation of Raw Data

The collected water, meteorological and cattle data was collated in an Excel spreadsheet. The data was also plotted to determine water consumption patterns throughout the year. In Excel, the water data was collated daily to indicate the diurnal variation in water consumption. Meteorological data was then plotted against this data and trends and relationships were established.

Dates	Available Data
1st March – 11th December 2007	• Offsite Automatic Weather Station • Cattle Information • Logged Water Consumption
11th December 2007 – 31st January 2008	• Onsite Automatic Weather Station • Cattle Information • Logged Water Consumption

Table 1 – Available Data

Continuous meteorological data was not available from the on-site weather station at the Wainui Feedlot from March to December 2007 (see Table 1). Therefore alternative meteorological data had to be sourced from the closest available Automatic Weather Station. Hence, the data has been analysed in two parts. Part A investigates annual water consumption patterns from March 1st 2007 to January 31st 2008. Meteorological data in this part was obtained from a nearby Automatic Weather Station for use from December 11th to the end of the study period. Part B will be a study of the water consumption with meteorological data obtained from the on-site weather station. Part B was conducted from December 11th 2007 to January 31st 2008.

5.2 Part A – Annual Water Consumption Analysis

5.2.1 Daily Water Consumption

For the period March 2007 to February 2008, the daily drinking water consumption per head was collated. Daily consumption per head was estimated by dividing the total volume of water measured by the total head on feed on that day. The daily water consumption and maximum daily temperatures for this period are presented in Figure 13.

The daily water consumption does not include the estimated water usage associated with trough cleaning. Trough cleaning is typically undertaken on Wednesday and Saturday between 7am and 9am. The water usage associated with trough cleaning was estimated to be in the order of 19 kL per trough-cleaning day, assuming all of the 38 production pens drinking troughs were cleaned. Therefore the total volume of water measured on Wednesdays and Saturdays was reduced by the estimated trough cleaning usage.

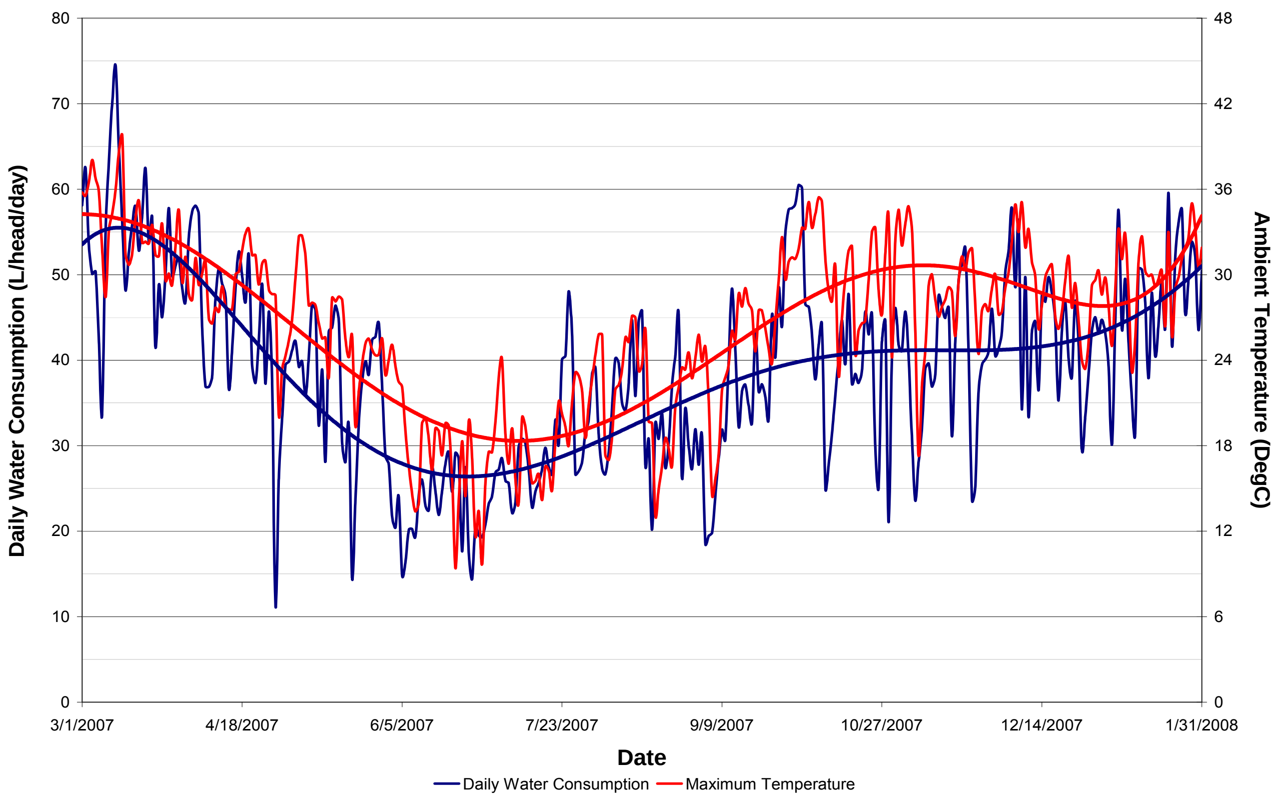

Figure 13 – Daily Water Consumption per Head

A blue polynomial regression trend line representing the average daily water consumption per head is presented in Figure 13. A red polynomial regression trend line representing the average maximum temperatures throughout the year is also presented in Figure 13. A comparison of these regression lines shows the maximum daily temperature to have a high correlation with the daily water consumption per head throughout the year. The maximum daily temperature follows the same polynomial regression as the drinking water consumption data graphed in Figure 13. In general an increase in the maximum temperature for a day will result in greater water consumption. Where this does not result, there are other factors that have a significant influence on the daily water consumption per head per day such as rainfall.

For this period, the month of March (the end of summer) recorded an average drinking water consumption per head of around 55L/head/day. The highest drinking water consumption per head recorded was 75L/head/day on the 11^{th} of March. From April the daily water consumption levels gradually drop as the temperature falls to June/July (in winter), when they are at their lowest. The average drinking water consumption per head during June/July was about 25L/head/day with a minimum recorded of 14.4L/head/day on the 26^{th} of June. As temperatures increase, from the end of July the cattle start to increase their water consumption. Between September and November the average drinking water consumption level is relatively constant. Drinking water consumption increased from an average of 40L / head / day mid December to the end of the study period.

The total monthly water consumption per 1000 head on feed was determined and is shown in Figure 14. The greatest monthly usage was in the order of 1.7ML in March and the lowest was 0.7ML in June. For the period March to December, the total water consumption is 11.9ML per 1000 head. When extrapolated to a yearly figure, the total water consumption is approximately 15ML / 1000 head per year. This compares with the QDPI estimate of 24ML /1000 head per year. Hence, it is very important to further quantify monthly drinking water consumption as this may impact on feedlot water licensing requirements in the future.

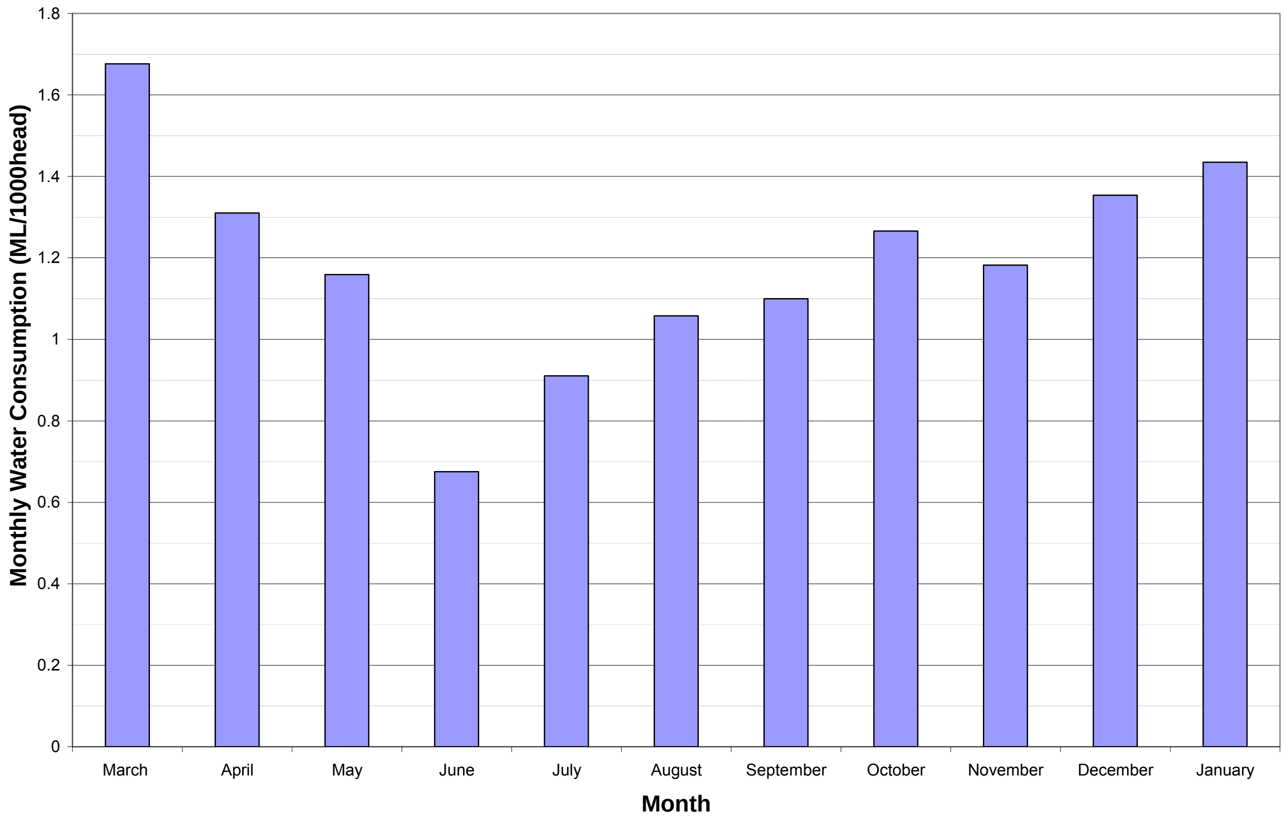

Figure 14 – Monthly Water Consumption per 1000 head

The number of head and live weight at the feedlot on any given day varies, therefore the water consumption data recorded was standardised to a per 100kg of live weight basis to allow comparison with other recorded data such as Sanders et al. (1994). Water Consumption per 100kg of live weight is illustrated in Figure 15.

A polynomial regression trend line representing the average daily water consumption per 100kg live weight throughout the year is also shown in Figure 15. It is illustrative of the average variation in the daily water consumption per 100kg live weight throughout the study period. Figure 19 shows that the variation between consecutive days can be significant.

Figure 15 shows that the maximum recorded cattle's daily water usage was 14.6L of water per 100kg live weight (74.5L/head/day) on the 11th of March and the minimum recorded was 2.2L

(11.2L/head/day) of water per 100kg live weight on the 28th of April. Between July and December the water consumption then averages between 5-10L per 100kg of live weight.

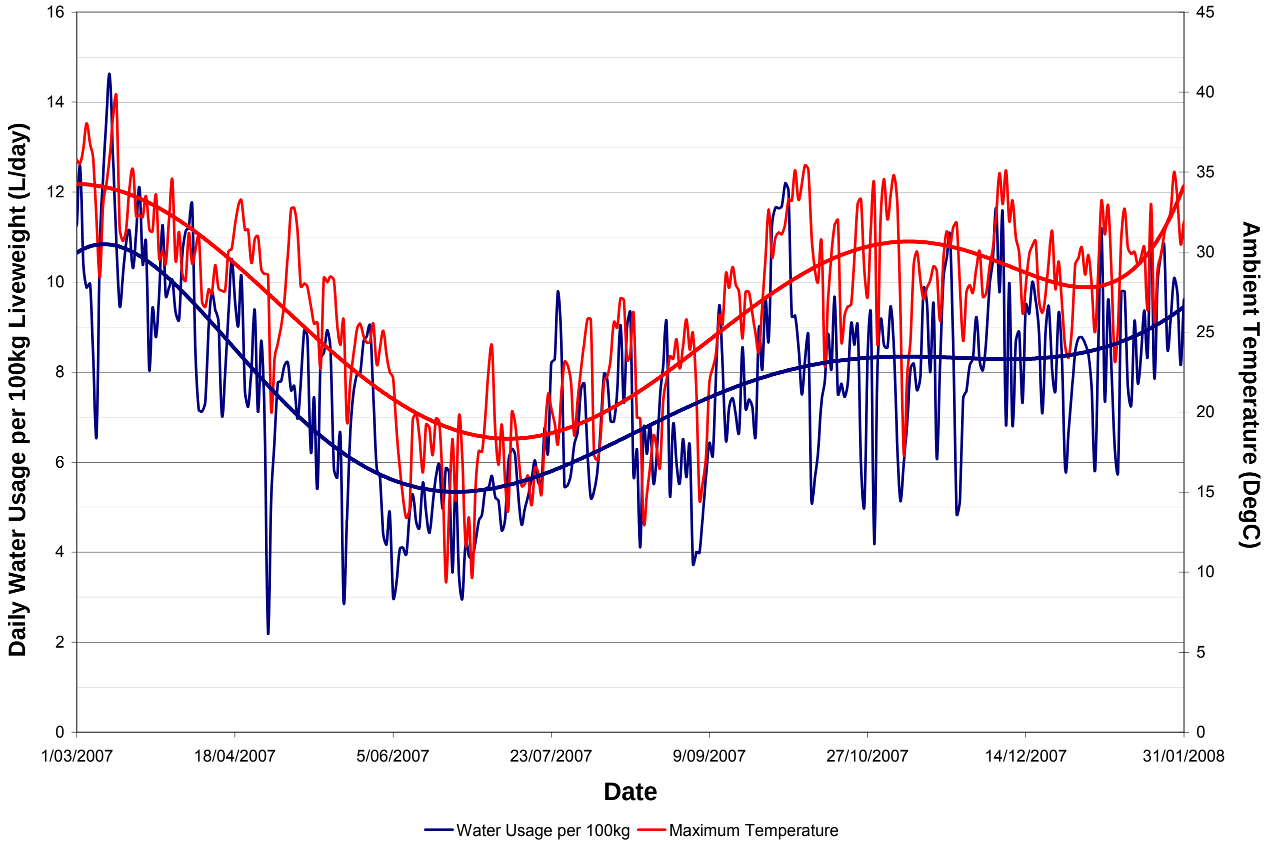

Figure 15 – Daily Water Consumption per 100kg Live Weight

5.2.2 Water Delivery Flowrate

The pumping system flow rates are measured and recorded by the data logger. This information can be used to develop an annual representation for the daily demand of cattle drinking water. The peak daily demand can be compared with the pumping capacity of the water reticulation system to determine if sufficient capacity is available to deliver water. The current pumping capacity of the reticulation system is 1800L/min.

Peak flow rates can also be used by industry for feedlot planning and design and/or by independent feedlots during expansion or review of system requirements. Figure 16 shows the daily peak flow rates from the 1st of March 2007 to the 31st January 2008.

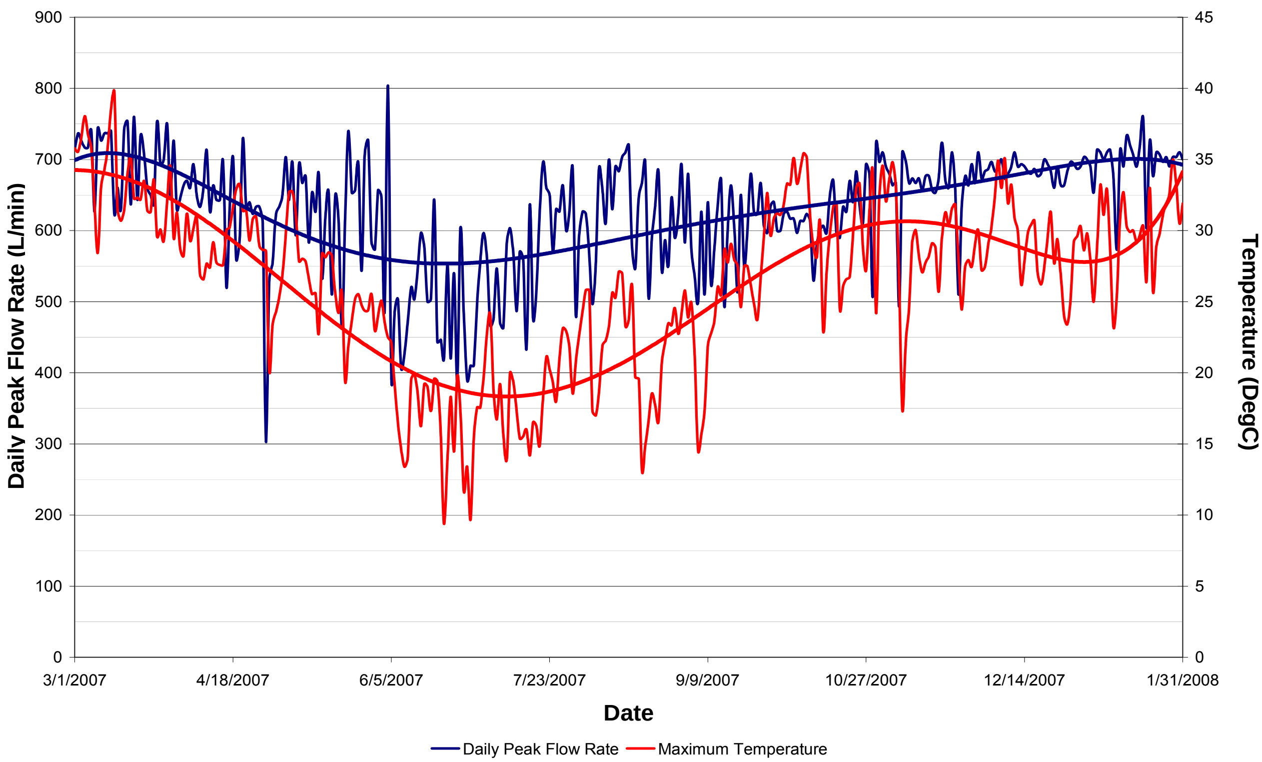

Figure 16 – Daily Peak Flow Rates

A polynomial regression trend line indicating the daily peak flow rates is also presented in Figure 16. It is illustrative of the average variation in daily peak flow rates throughout the study period. The greatest peak flows are measured in March and December when consumption is at its highest, with minimum peak flow rates recorded in June and July. Figure 16 also shows that there is more variation in the peak flow rates recorded between May and September than between the March-April and the October-December periods. Excluding the single extremity in May where the flow rate peaks at 800L/min, the peak maximum flow rate peaks in summer between December and March are around 700 L/min. The peak flow rate is then at its minimum during winter between June and July where it averages either side of 500L/min.

5.2.3 Daily Variation in Water Consumption

The daily variation in water consumption has been investigated over the study period. Daily variation influences the demand throughout the day, and is an important design component of the feedlot water supply and reticulation system. Daily water consumption patterns were assessed by plotting water consumption flow rates throughout the day. The study period was divided into consecutive periods, each seven days in length, however only a selection of dates are presented in this report.

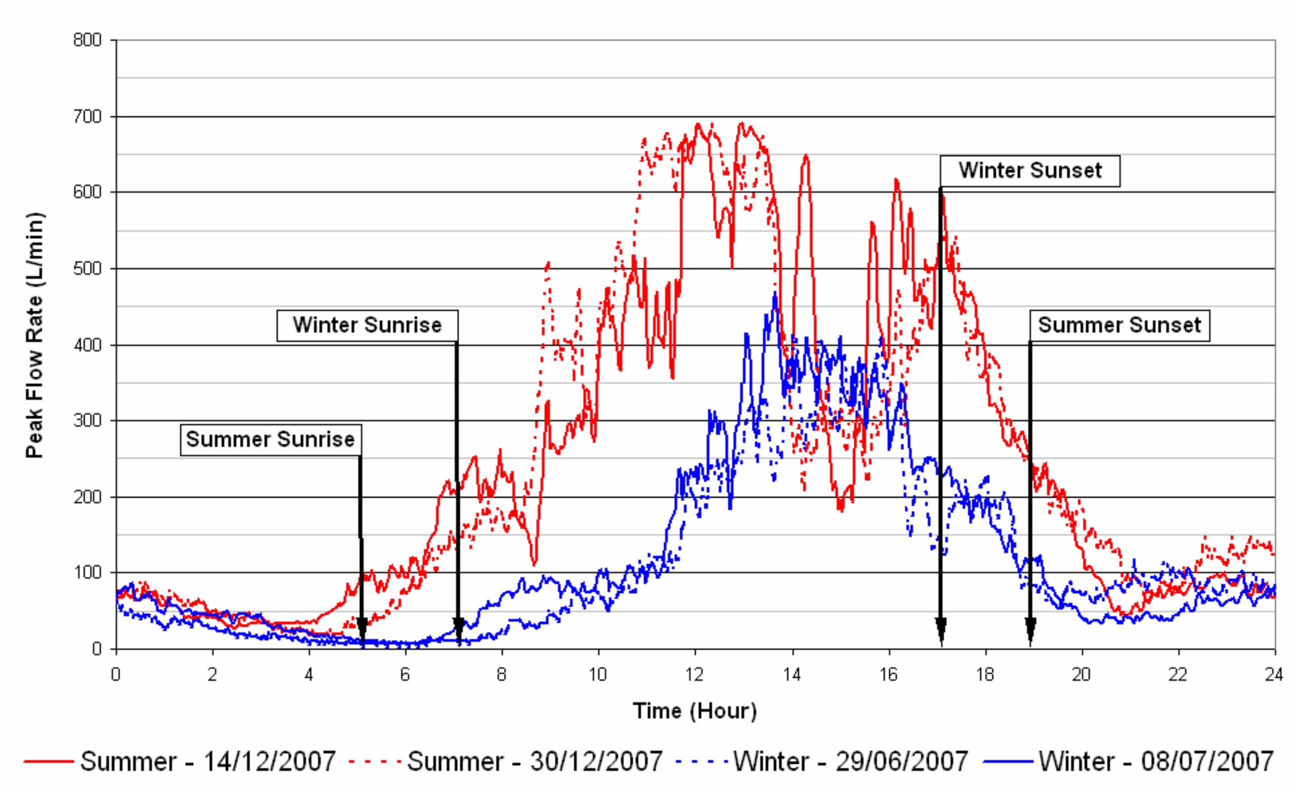

Figure 17 – Diurnal Comparison between Summer and Winter

Figure 17 shows the difference in daily variation between typical days in summer and winter. Two days from summer and two days from winter are shown to illustrate that the data is representative of summer and winter days. The 29th of June and the 8th of July were selected as the winter days for this comparison as the temperature on these days are average winter temperatures. Figure 17 shows that the winter daily variation follows the same general pattern, characterised by a single peak and a continuous consumption period between 1 and 4pm.

The 14th and 30th of December were selected as the summer days for this comparison as the temperature on these days are average summer temperatures, and they can also be seen to follow the same general pattern. However, these patterns are characterised by two distinct peaks, one between 10-14 hours, and the other between 16-18 hours. The 14th of December had no rainfall, a maximum of 27.9°C and a daily water consumption of 352kL (47.7L/head/day). Whereas the 30th of December had no rain, a maximum of 28.5°C, and 356kL (45.1L/head/day) of drinking water was consumed by the cattle.

During the two summer days, Figure 17 shows two distinct peaks. The occurrence of these peaks can alter due to varying meteorological conditions. The temperature may take longer to warm up on some days more than others or rainfall may occur. In summer the cattle start drinking at sunrise and drink predominantly until 12pm where water consumption is at its peak. Consumption then drops about mid-afternoon before peaking once again at about 4-5pm. The cattle then gradually decrease their water consumption until a few hours after sunset where it is steady until midnight.

In winter the cattle start drinking at sunrise and drink predominantly until 1pm-4pm where water consumption is at its peak. Consumption then drops late afternoon until a few hours after sunset where their consumption is steady until midnight.

Figure 17 shows that the summer and winter patterns are significantly different. The average peak flow rate on the winter days was 126L/min whilst on the summer days it was 242L/min. The maximum peak flow rate on the winter days was 467L/min and the maximum on the summer days was 689L/min. Figure 17 shows that the peak flow rate demands are much greater during the summer period that during winter. The time during which the demand for drinking water rapidly increases and decreases at the beginning and end of the day also alters between the two seasons. It can be seen that during the summer the demand for drinking water rapidly starts to increase between 5 and 10am whilst during winter the demand slowly increases until 12am before rapidly increasing between 12pm and 1pm.

These differences in when the demand for drinking water increases can be justified by the temperature conditions and solar radiation. The demand during winter increases later and decreases earlier than during the summer period, since the cooler weather is present later in the morning and comes in earlier at night. Therefore the cattle are not under any significant amount of heat stress, which leads to little increase in water intake during these periods.

Figures 18 and 19 show that these variations between Summer and Winter are representative of the selected days in Figure 21. One week from Winter (Figure 18) and one week from Summer (Figure 19) confirm this observation. For more graphs see Appendix B.

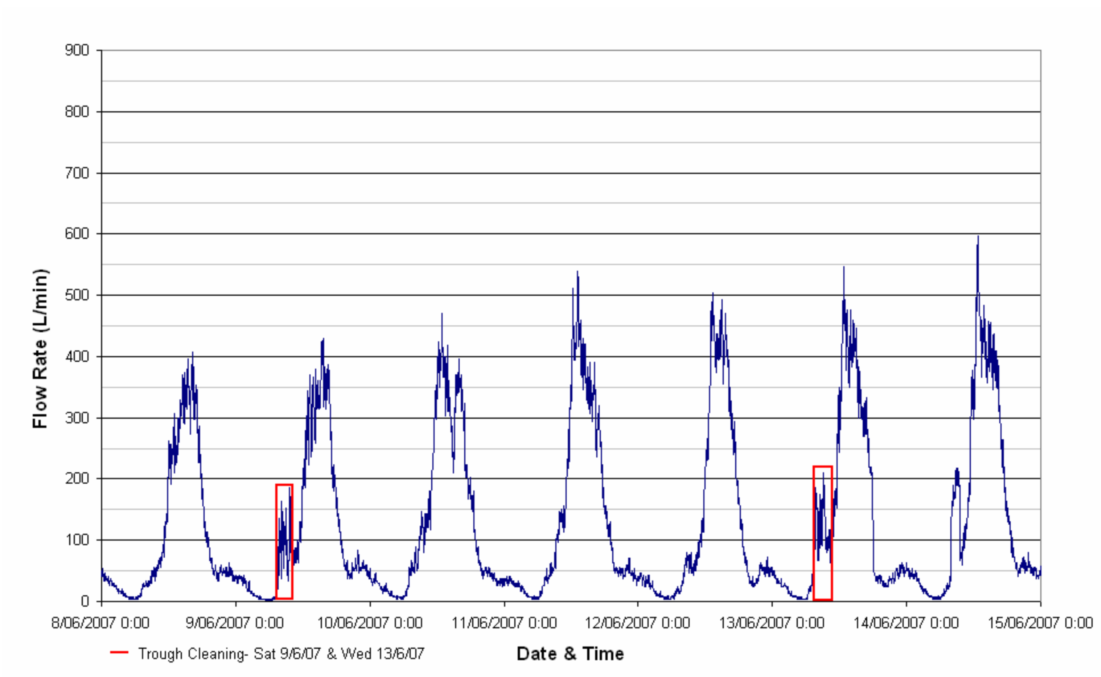

Figure 18 – Diurnal variation from 8th-14th July 2007

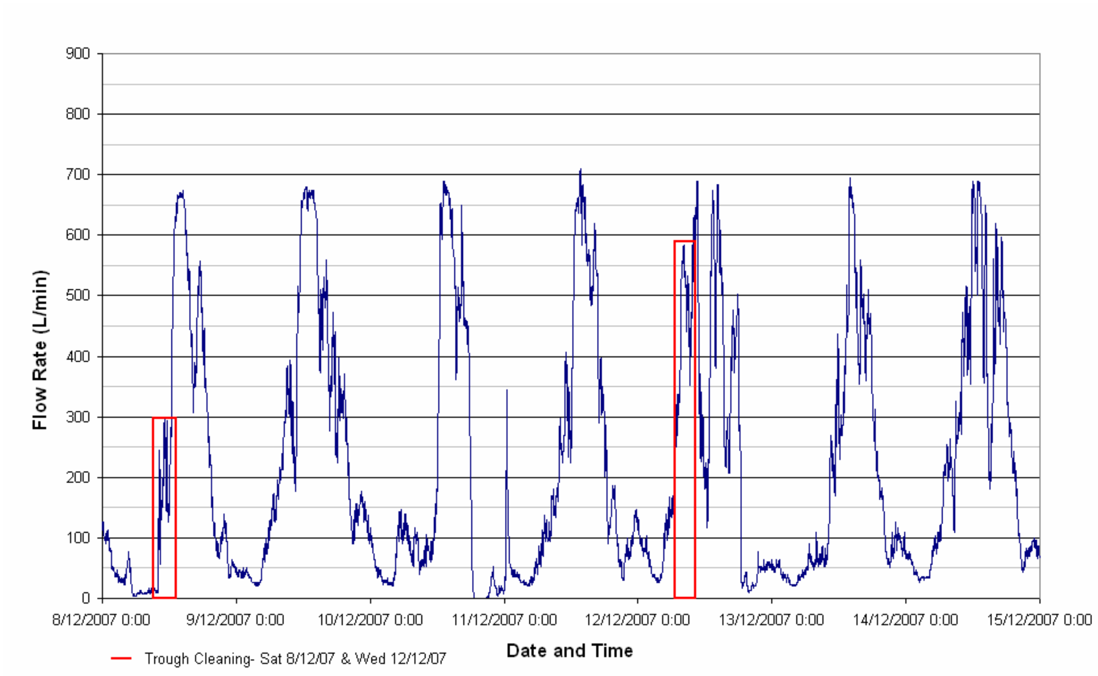

Figure 19 – Diurnal Variation from 8th-14th December 2007

In Figure 18, which shows the peak flow rates for one week during July, the average peak flow rate ranges from 400-600L/min per day. In Figure 19 however, showing a weeks flow rates during December, the average peak flow rate ranges from 650-700L/min per day. These figures show that there is a significant difference between the average winter day compared to the average summer day. During summer there is the main peak in the middle of the day followed by a lesser peak in the middle of the afternoon, whereas this does not occur in the winter. Instead, in winter there is a more consistent drinking pattern in the middle of the day.

The diurnal variation between Autumn and Spring was also compared (see Figure 20). Two typical days from Spring and two typical days from Autumn are shown to illustrate that the data is representative of Spring and Autumn days. The 12th and 13th of April were selected as the Autumn days for this comparison as the temperatures on these days were average Autumn temperatures. Figure 20 shows that they both follow the same general pattern and peak flow rate magnitudes throughout the days. The 8th and 9th of October were selected as the Spring days for this comparison as the temperature on these days were average Spring temperatures, and they can also be seen to follow the same general pattern and peak flow rate magnitudes throughout both of the days.

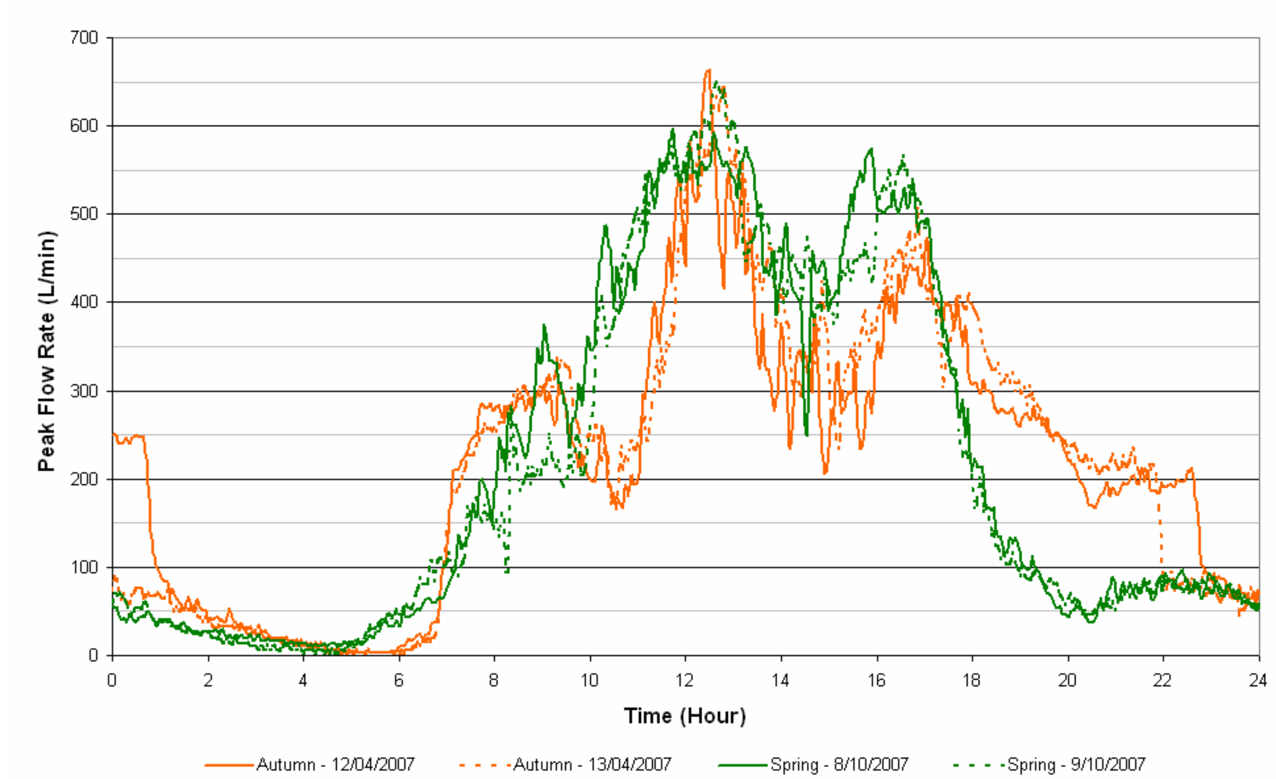

Figure 20 – Diurnal Comparison between Autumn and Spring

Unlike the Winter and Summer patterns, Figure 20 shows the diurnal water consumption patterns for Spring and Autumn are very similar. The maximum peak flow rate that occurs during Spring is 650L/min whilst the maximum that occurs during Autumn is 663L/min. The average peak flow rate that occurs during Spring is 213L/min whilst the average that occurs during Autumn is 220L/min.

During the Spring and Autumn periods, the drinking water demand starts to increase between 5-6am until midday when it is at its peak. It then starts to decline between 5-6pm. It can be seen in Figure 20 that there are two distinct periods of cattle water consumption throughout a 24-hour period. Between the hours of approximately 10am and 6pm is when cattle drinking water consumption is at its peak. However between the hours of 11pm and sunrise, the cattle drinking water consumption demand is at its lowest.

Figures 21 and 22 show that the daily variations between Autumn and Spring presented in Figure 20 are representative of their seasons. One week each from Autumn (Figure 21) and Spring (Figure 22) confirm this.

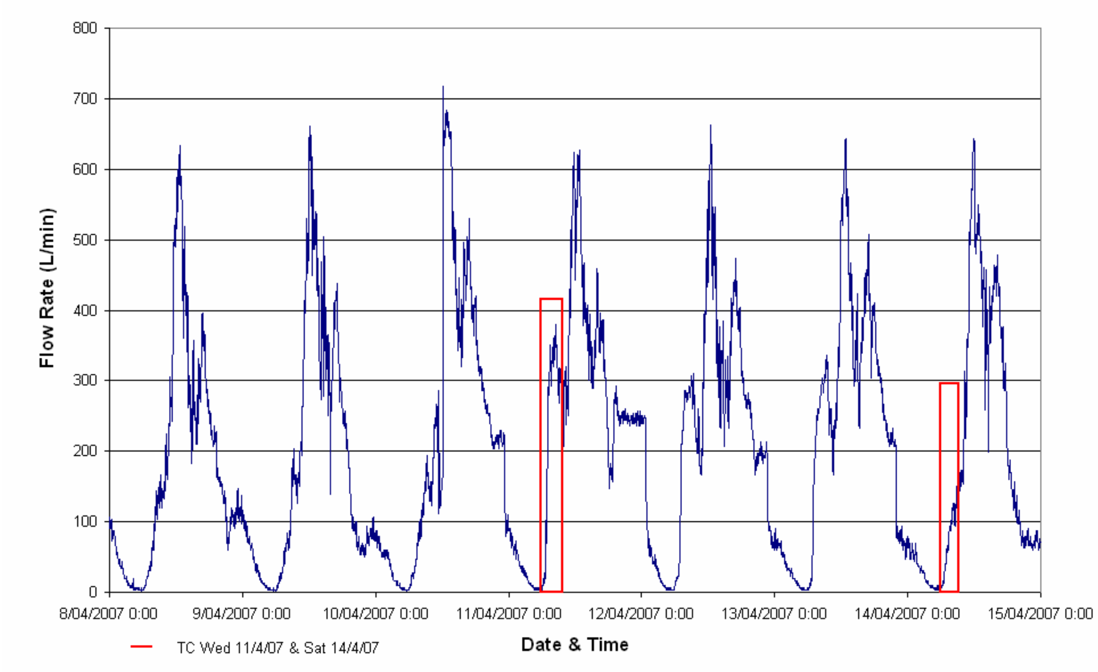

Figure 21 – Daily Variation from 8th to 14th April

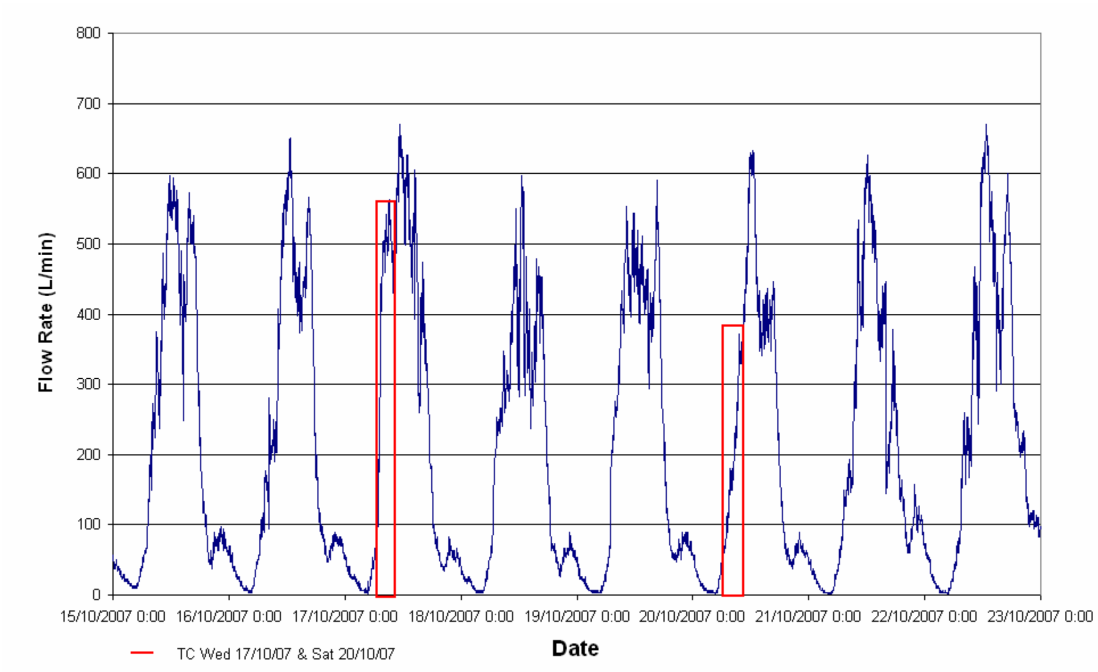

Figure 22 – Daily Variation from 15th to 22nd October

In Figure 21, which shows the peak flow rates for one week during April, the average peak flow rate ranges from 600-700L/min for any given day. In Figure 22 however, shows a weeks flow rates during October, the average peak flow rate during any given day is 550-650L/min. These figures show that there is not a significant variation in either the water consumption 'patterns' or the magnitude of the quantity of water the cattle consume between the Spring and Autumn months.

The cleaning of the production pens drinking troughs will also affect the drinking water consumption patterns. This can be seen in Figure 21 and 22 as the increased usage between 7-9am on the 11th and 14th of April and the 17th and 20th of October. The production pens drinking troughs are cleaned regularly on Wednesdays and Saturdays. Assuming all 38 production pen troughs are cleaned, 19.01kL of water is used to clean all the troughs. However, given only one trough is cleaned at one time and a standard trough-cleaning flow rate is 4.5 L/s, then it is possible that the cattle drink more during this period due to the cleanliness of the trough and freshness of the water. This does have some affect but is not significant.

Figures 23 and 24 show two days, the 15th of October (Figure 23) on which the drinking toughs were not cleaned, and the 17th of October (Figure 24) on which the drinking troughs were cleaned.

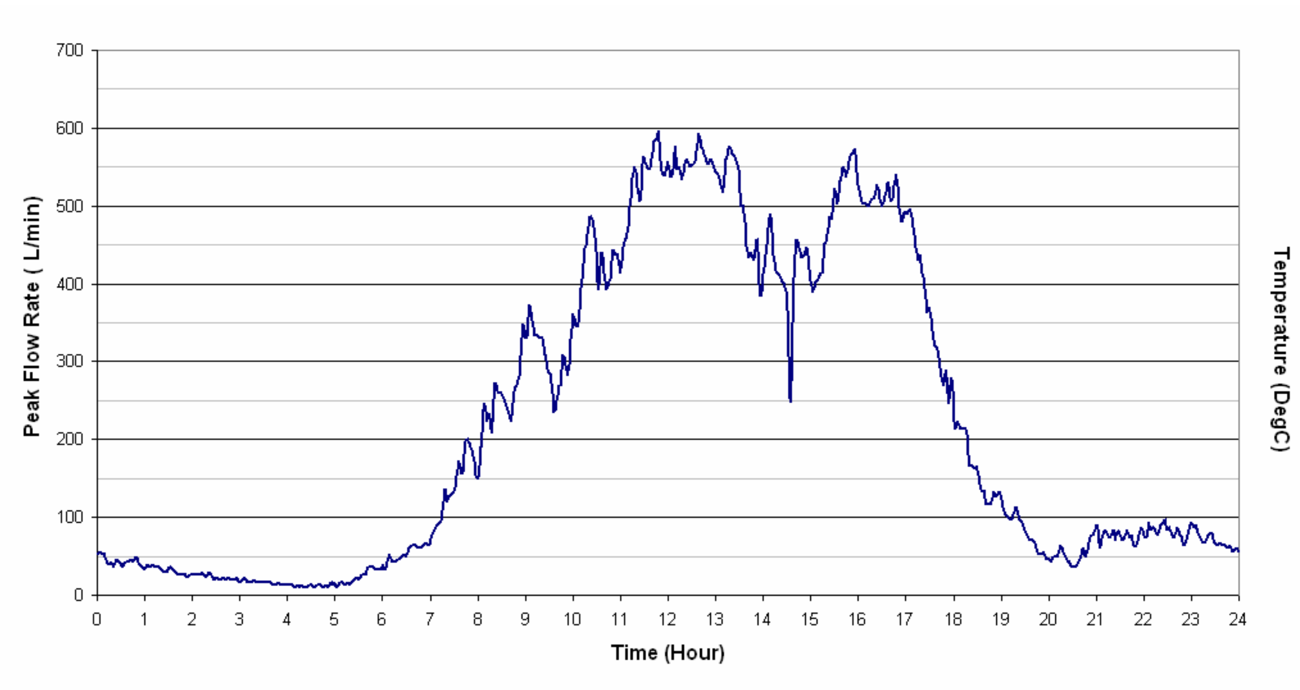

Figure 23 – Diurnal Water Consumption on October 15th 2007

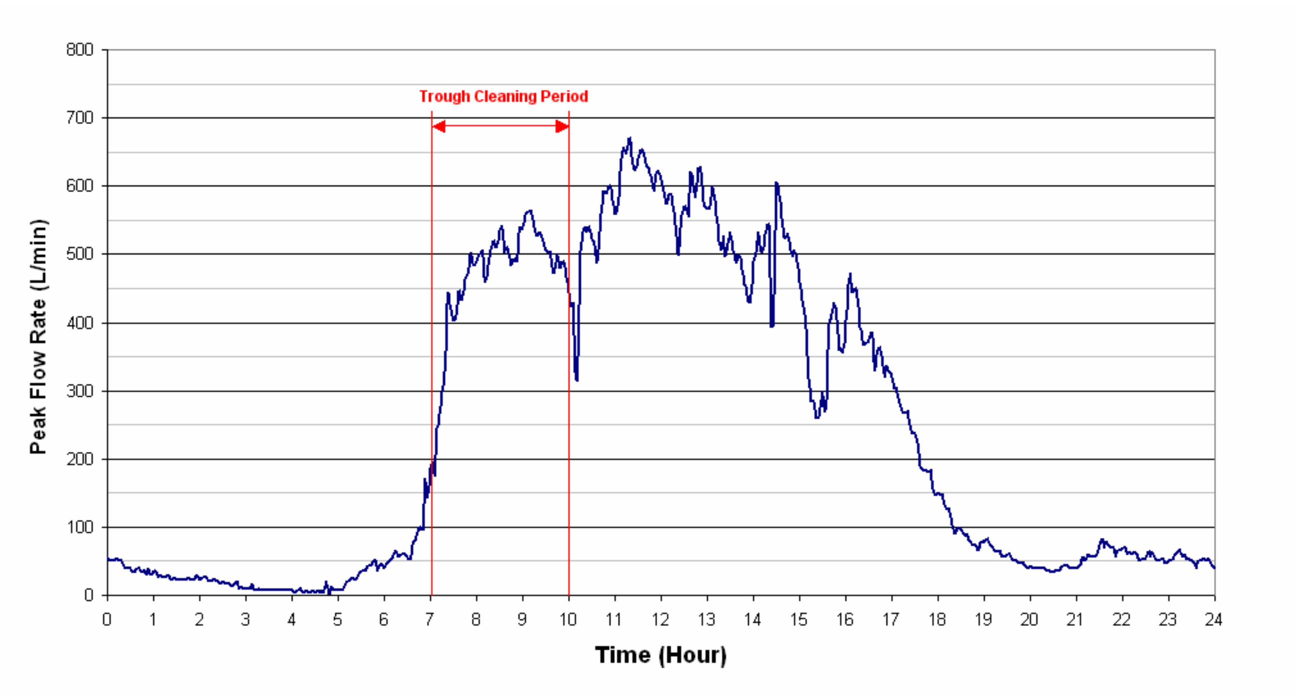

Figure 24 – Diurnal Water Consumption on 17th October 2007

From Figures 23 and 24 it can be observed that on days when the drinking troughs are cleaned, the demand for water increases much more rapidly in the morning than on days when cleaning of the troughs does not take place.

Also, during the winter months, the cleaning peaks are more pronounced since the amount of water used for cleaning purposes does not alter but the quantity of water consumed is less. These are highlighted by the red rectangles in Figures 21 and 22.

5.2.4 Comparison of Drinking Water Consumption Models

A number of predictive water consumption models have been developed. Some of these models include Sanders et al. (1994), Parker et al. (1999) and Winchester and Morris (1956). Since on-site meteorological data was only available between 11th December and 31st January, the comparison of measured drinking water consumption and these models was undertaken during this period only.

5.2.4.1 Sanders et al. (1994) Model

Sanders et al. (1994) model was compared to measured daily water consumption data collected at Wainui Feedlot. Their relationship was used with onsite meteorological data to predict daily water consumption at Wainui Feedlot.

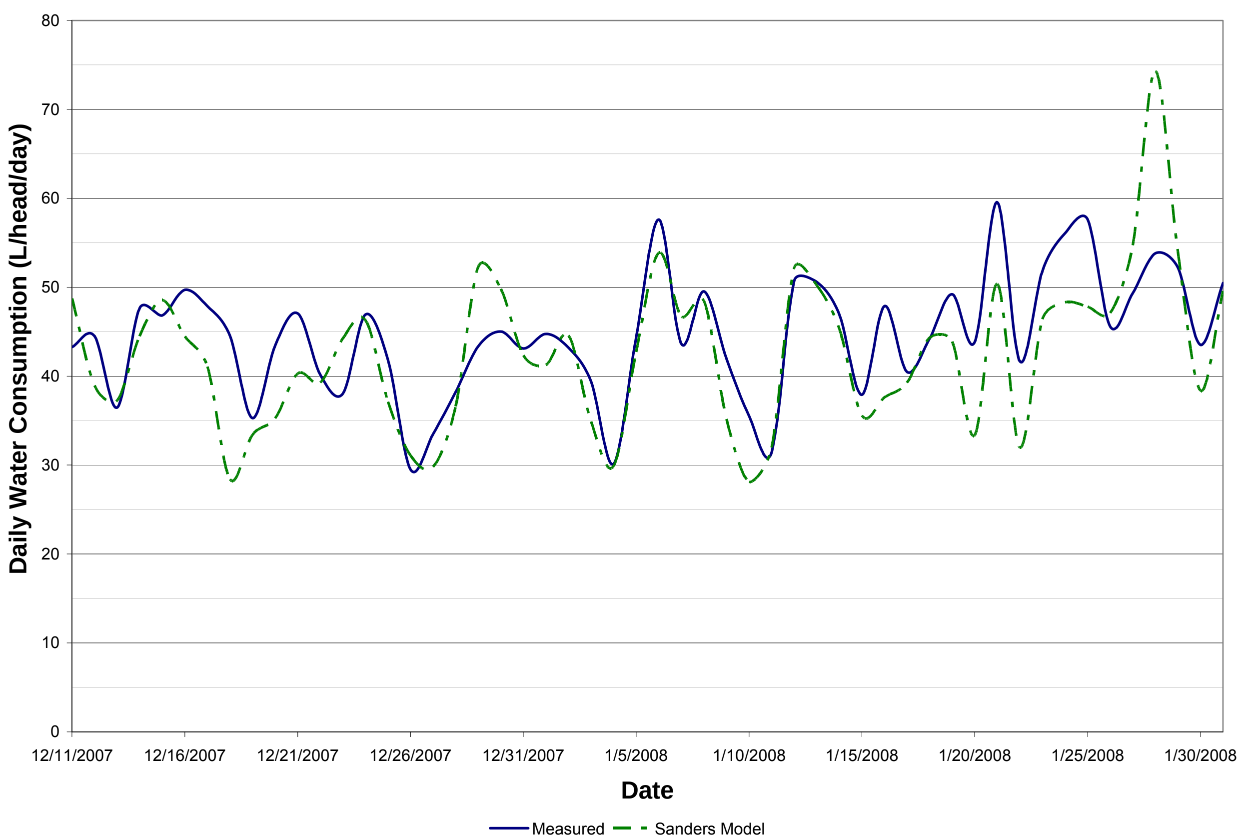

Figure 25 – Comparison of Wainui Feedlot with Sanders Model

Figure 25 illustrates the predicted drinking water consumption by Sanders et al. (1994) model and the actual drinking water consumption as measured during this study.

In Figure 25, the measured daily water consumption was standardised to a per 100kg of live weight for comparison with Sanders et al. (1994) model. The Sanders et al. (1994) model closely follows the measured drinking water pattern, however Figure 25 shows that Sanders et al. (1994) model consistently averages 1-2 L / 100kg of live weight less than the measured daily water consumption. This equates to 5.16-10.32 L / head / day less than the measured consumption level.

5.2.4.2 Parkers Model

Parker et al. (1999) conducted a study in the Texas High Plains in 1998 into the water use and conservation at beef cattle yards. Using this relationship and on-site meteorological data, the Parker et al. (1999) estimated drinking water consumption can be compared with the measured drinking water consumption at Wainui Feedlot. This comparison is shown in Figure 26.

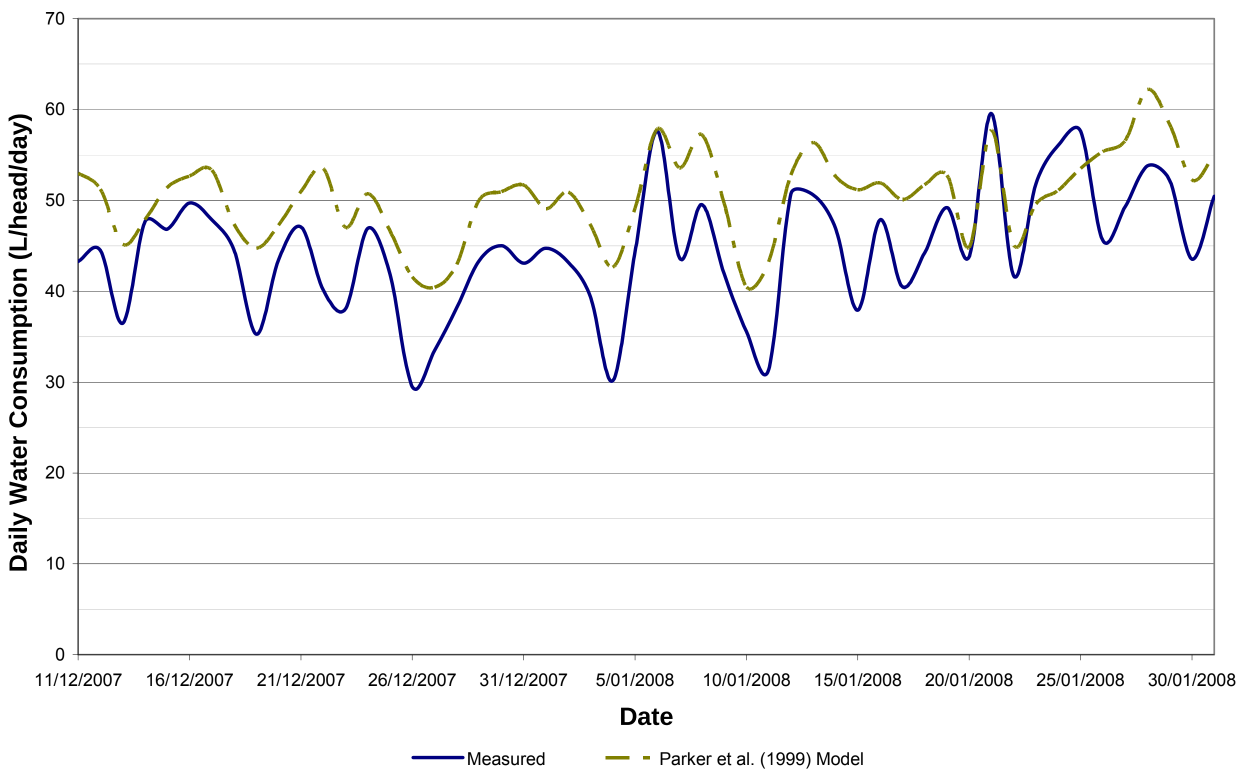

Figure 26 – Comparison of Wainui Feedlot with Parker et al. (1999) Model

Figure 26 shows that when the Parker et al. (1999) model predicts a peak drinking water consumption, the measured drinking water consumption also peaks. Unlike the Sanders et al. (1999) model which under predicts these patterns, Parker et al. (1999) model over predicts drinking water consumption patterns. Parker et al. (1999) model on average overestimates the measured water consumption patterns between 10-15L/head/day, with a minimum of 3.5L/head/day and a maximum of 22.1L/head/day above the measured levels.

5.2.4.3 Winchester and Morris Model

Winchester and Morris (1956) developed a relationship in a laboratory context relating water intake per day and ambient temperature, dry matter intake and breed. Figure 27 compares the estimated drinking water intake for *Bos Taurus* and *Bos Indicus* cattle from Winchester and Morris (1956) with the measured drinking water consumption at Wainui Feedlot.

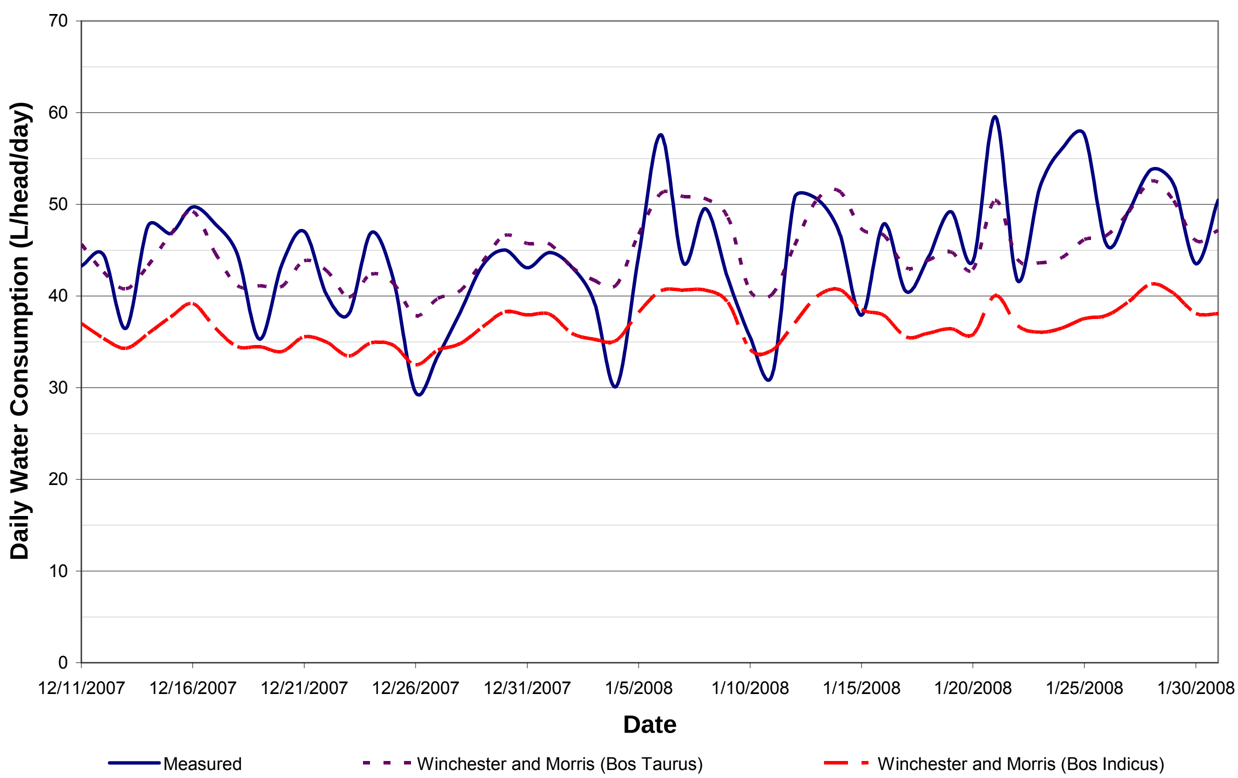

Figure 27 – Comparison of Daily Water Consumption Patterns of Wainui Feedlot and Winchester and Morris's Models

Figure 27 illustrates that the Winchester and Morris's models for water intake correlate poorly with the measured drinking water consumption patterns. The *Bos Taurus* relationship more closely predicts the level of drinking water consumption than the *Bos Indicus*.

5.2.4.4 Model Comparison

The relationships developed by Sanders et al (1994) estimates daily water consumption in L/100kg live weight, whilst Parker et al (1999) model estimates daily water consumption in L/head/day. For comparison, the models can be scaled to the same units, which make it simple to compare the two with data collected from Wainui Feedlot. The Sanders et al. (1999) model was converted to L/head/day based on the average live weight of cattle in the lot whilst Parker et al. (1999) and Winchester and Morris (1956) models are expressed as a function of L/head/day.

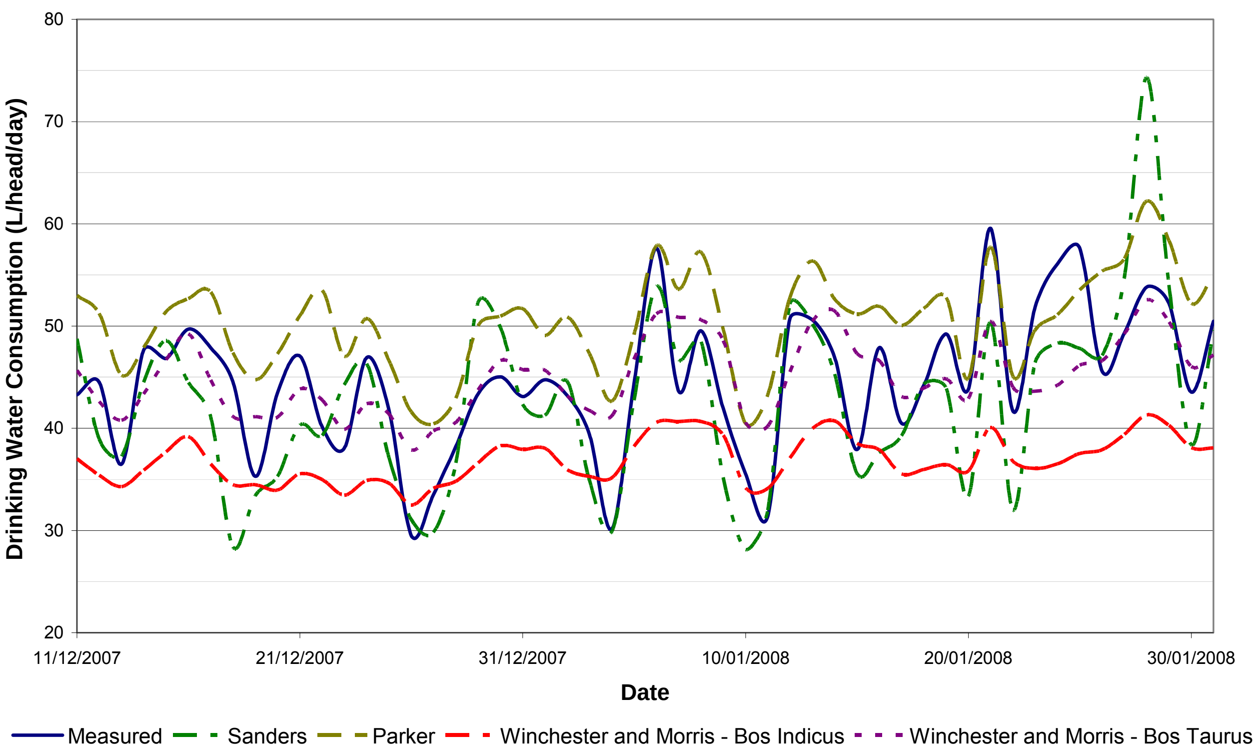

Figure 28 – Comparison of Daily Water Consumption Estimated by Models with the Daily Water Consumption at Wainui Feedlot

Figure 28 shows that when Sanders et al. (1994) model is scaled to the same units as Parkers et al. (1999) model, the two can be easily compared with the measured daily water consumption. Sanders et al. (1994) model consistently under predicts the daily water consumption by an average of 2-5L / head but has a reasonable correlation with daily water consumption patterns. Its coefficient of determination is 0.53. Parkers et al. (1999) model, however, consistently over predicts the daily water consumption by an average of 5-7 L / head but has a higher correlation of determination of 0.63.

Winchester and Morris's (1956) Bos Taurus and Bos Indicus models are identical with the exception of a constant difference between the two models. The Bos Taurus model, whilst it does not consistently follow the Wainui Feedlot's consumption patterns properly, data is in a similar range with a coefficient of determination of 0.49. The Bos Indicus model however, under-predicts and does not follow the Wainui Feedlot's consumption patterns with a coefficient of determination of 0.43.

Therefore, taking all four models into account, Parker et al. (1999) model is the most accurate in representing the cattle drinking water consumption patterns at Wainui Feedlot. Although it over-predicts the water consumption patterns, it does generally follow the same consumption pattern as Wainui Feedlot. A constant could be added to Sanders et al. (1994) model to achieve an improved accuracy in modelling the drinking water consumption. However the Sanders model relies on meteorological parameters, which can only be obtained retrospectively and hence, has limited use as a predictive model. Therefore the Parker et al. (1999) model is the best available model for predicting the measured cattle drinking water consumption at Wainui feedlot.

5.3 Part B – Intensive Water/Meteorological Analysis

Onsite meteorological data was not available from March to December 2007. Therefore during this period, daily variation was not investigated. Onsite Automatic Weather Station data was available from the 11th December to the 31st January 2008. During this period the daily variation of water consumption was made with meteorological variables. These variables include ambient temperature, black globe temperature, humidity, dry matter intake, and rainfall.

5.3.1 Influence of Temperature on Daily Water Consumption

Ambient temperature has a significant effect on the animals' physiological state. This results in behavioural changes in terms of their drinking water consumption patterns. The greater the temperature, the more water they will consume – both for re-hydration and cooling purposes. Therefore, during cooler periods, the animals will require water only for hydration purposes to maintain correct bodily functions.

Two weeks data is presented in Figures 29 and 30 showing the relationship between ambient and black globe temperature and drinking water consumption. Figure 29 shows these relationships for a week from December 11th 2007 to December 17th 2007. Figure 30 shows these relationships for a week from January 1st 2008 to January 7th 2008.

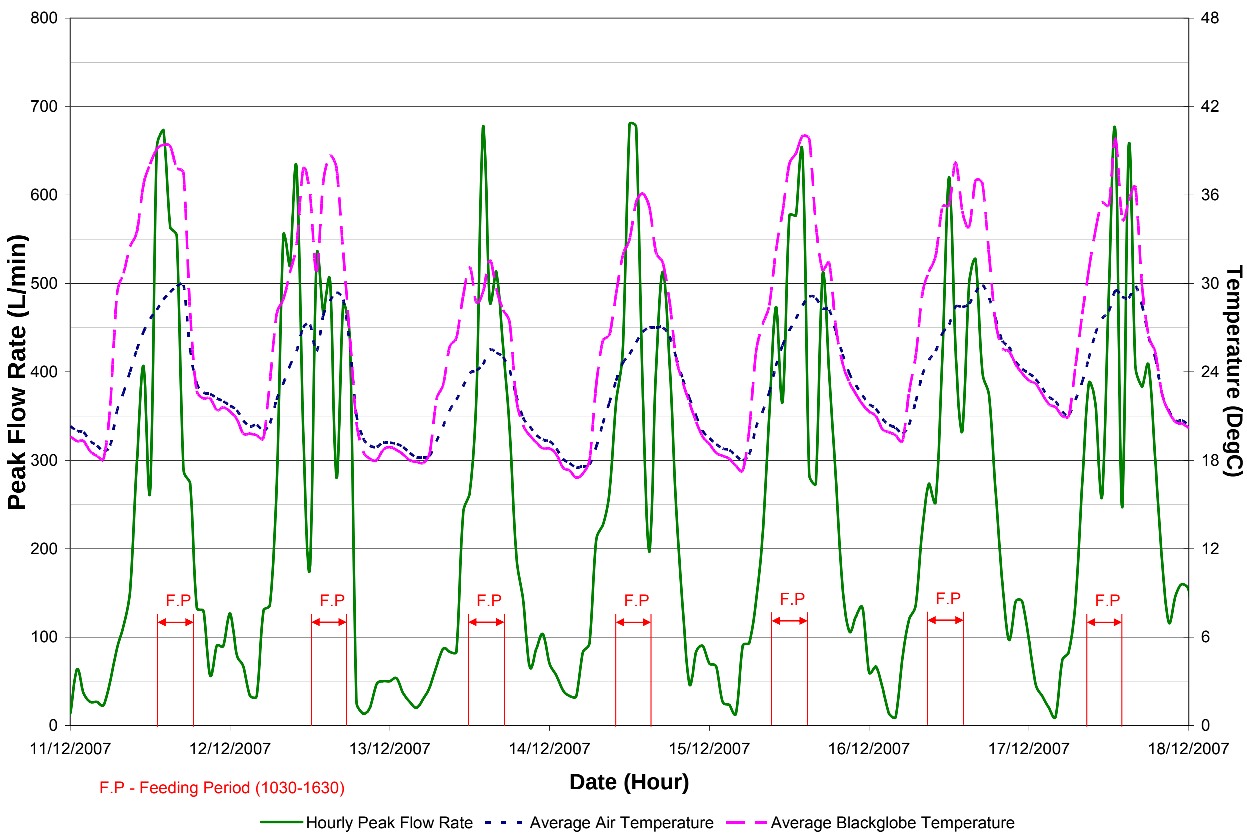

Figure 29 – Daily Water Consumption vs. temperature from December 11th-17th 2007

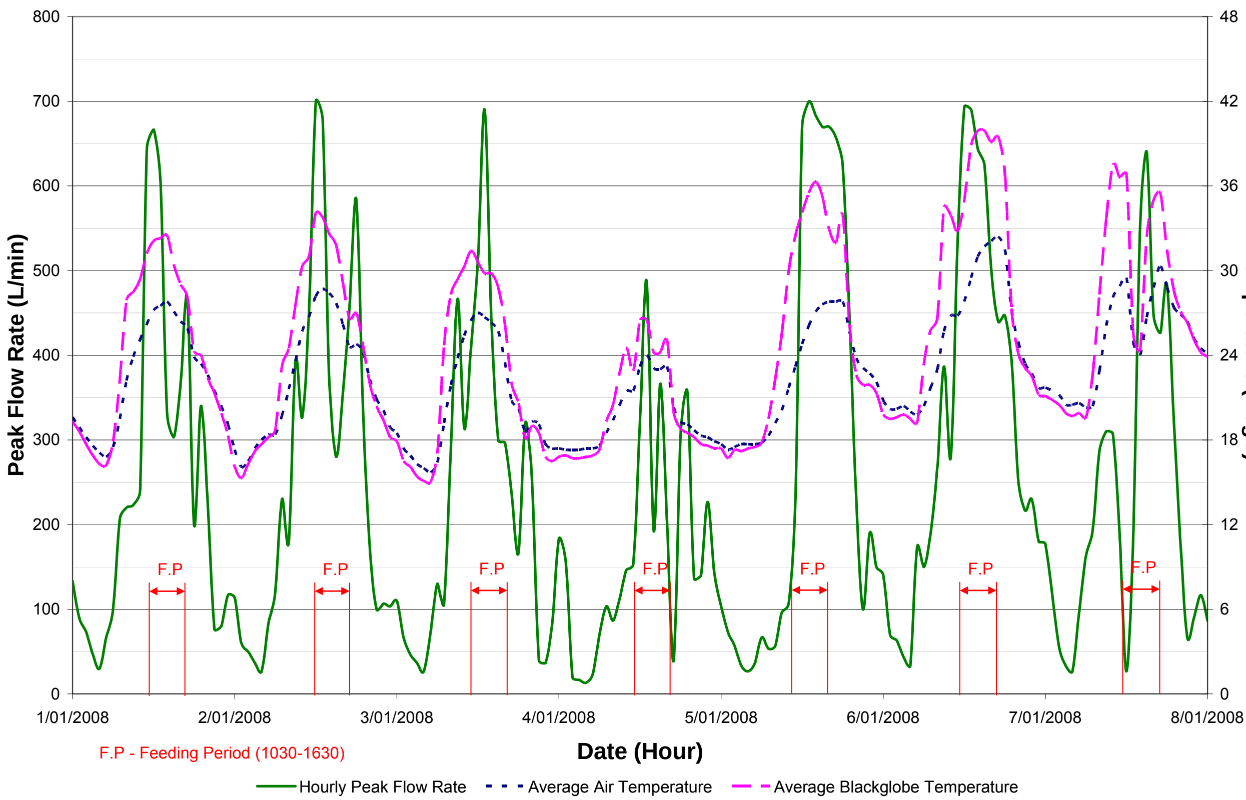

Figure 30 – Daily Water Consumption vs. Temperature from January 1st-7th 2007

The black globe temperature generally has a greater correlation with daily drinking water patterns than ambient temperature. This is due to black globe temperature being more representative of what the animals 'feel' - therefore having a more significant influence on the daily drinking water consumption patterns.

In both Figure 29 and Figure 30, the average air temperature and the average black globe temperature follow a similar pattern but simply vary by a few degrees. Between the hours of 19:00 and 5:00, both ambient air and black globe temperatures correlate extremely well and are at their lowest values. Likewise, so are the peak flow rate measurements during these hours. As the peak flow rate increases after sunrise a corresponding increase in drinking water consumption is measured. Typically the peak flow rate is measured at the peak black globe temperature.

Hence, this is why the black globe temperature is used in the calculation of the Heat Load Index (HLI) rather than the air temperature because it has a greater influence on cattle drinking water consumed. The HLI is representative of the stress the cattle are experiencing due to the black globe temperature and other environmental conditions. Since an increase in heat stress is associated with increased water intake, the HLI is highly influential of the drinking water consumed by the lot fed cattle. Further graphs are shown in Appendix B.

5.3.2 Influence of Relative Humidity on Daily Water Consumption

Figures 31 and 32 show the relationship between relative humidity and drinking water consumption. Unlike temperature, which peaks generally during the middle hours of the day, relative humidity peaks during the middle of the night, and the early hours of the morning. Figures 31 and 32 show when the relative humidity peaks, the peak flow rate is a minimum and visa versa when the humidity is at a minimum. This is evident on every day illustrated in Figures 31 and 32, showing that this is not just a coincidence but instead a significant trend. So relative humidity has an inverse influence with the diurnal water consumption pattern. Further weekly data is shown in Appendix B.

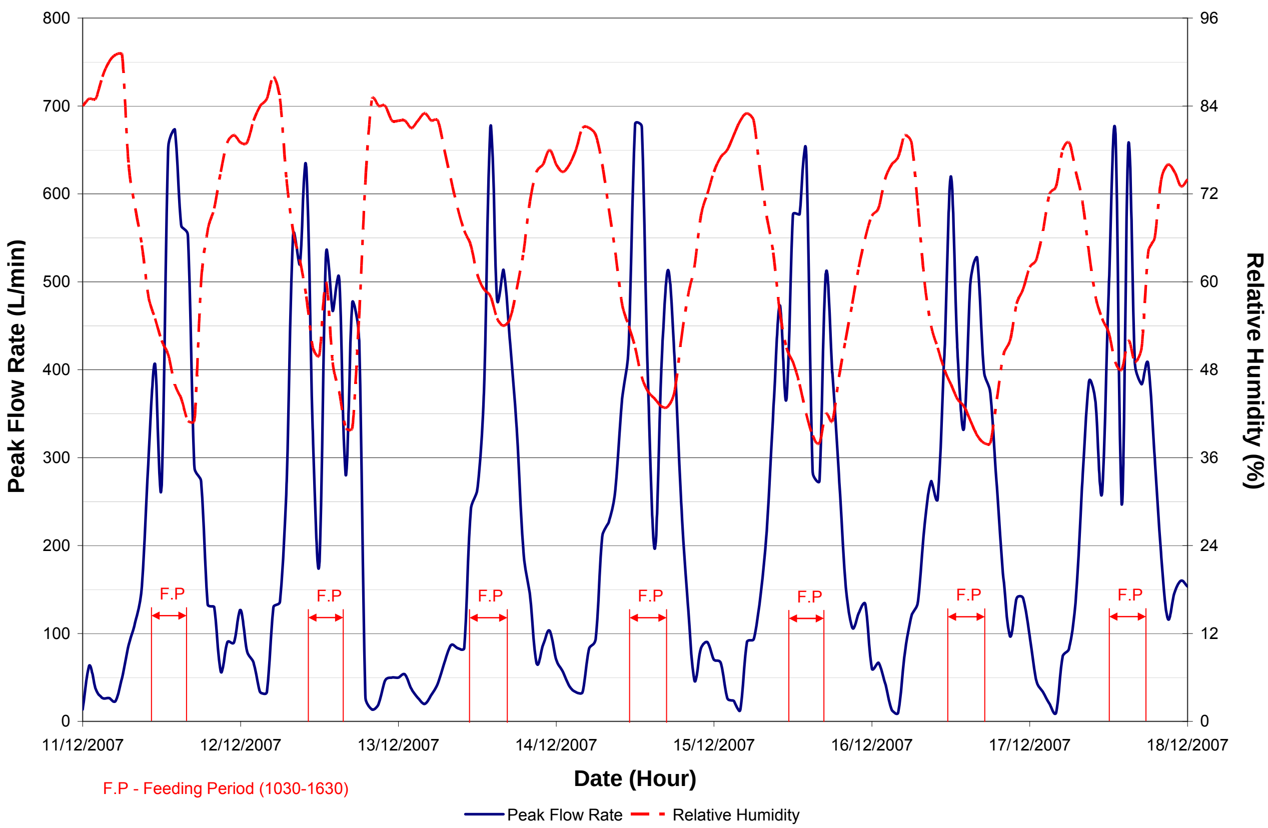

Figure 31 – Influence of Relative Humidity on Daily Water Consumption from December 11th-17th 2007

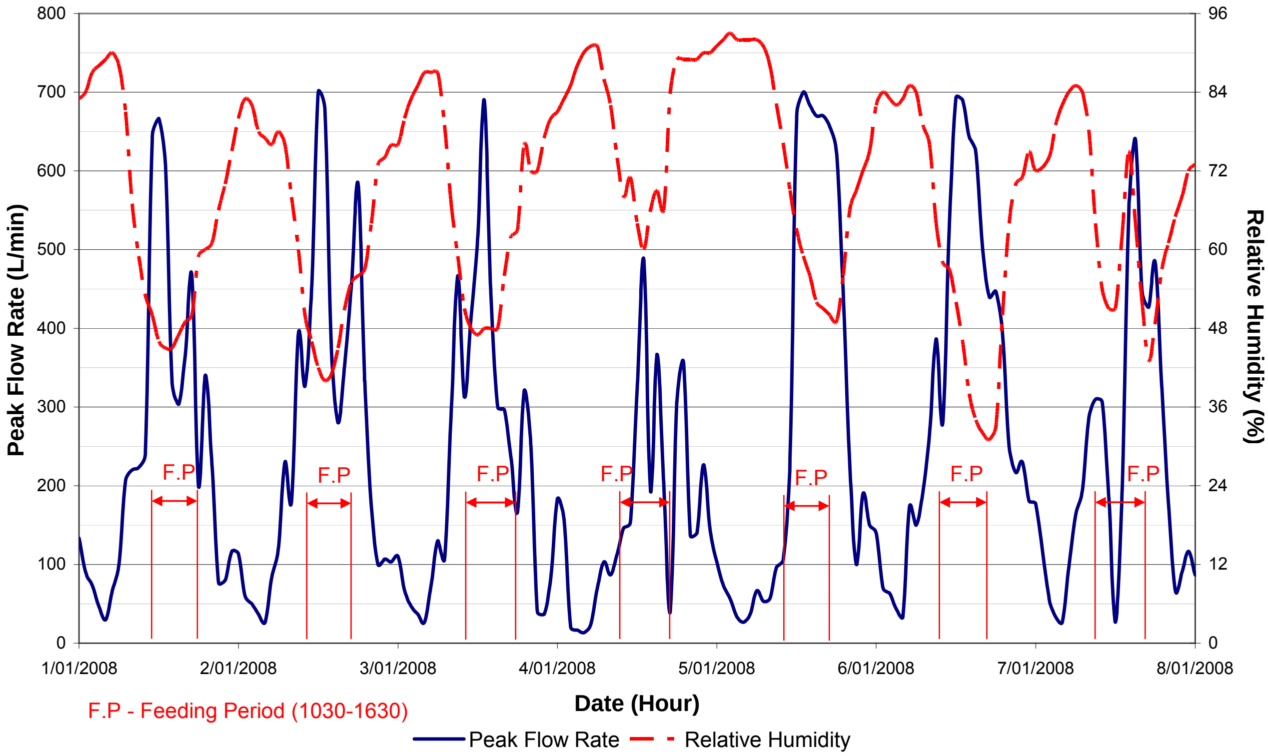

Figure 32 – Influence of Relative Humidity on Daily Water Consumption from January 1st-7th 2007

5.3.3 Influence of Solar Radiation on Daily Water Consumption

Solar radiation is radiant energy emitted by the sun that creates electromagnetic energy. When the direct radiation is not blocked by clouds, it is experienced as sunshine, a combination of sunlight and heat. The heat on the body of the cattle that is directly produced by the radiation, should be distinguished from the increase in air temperature.

As expected, there is a strong correlation between the solar radiation daily patterns and the daily peak flow rate patterns. Figure 33 shows a weekly period commencing 11th December 2007 and finishing on the 17th December 2007 whilst Figure 34 shows a weekly period commencing 1st January and finishing on the 7th January 2008. As solar radiation increases so to does the daily water consumption peak flow rates. Therefore we can conclude that solar radiation is one variable that has a considerable affect on cattle drinking water levels.

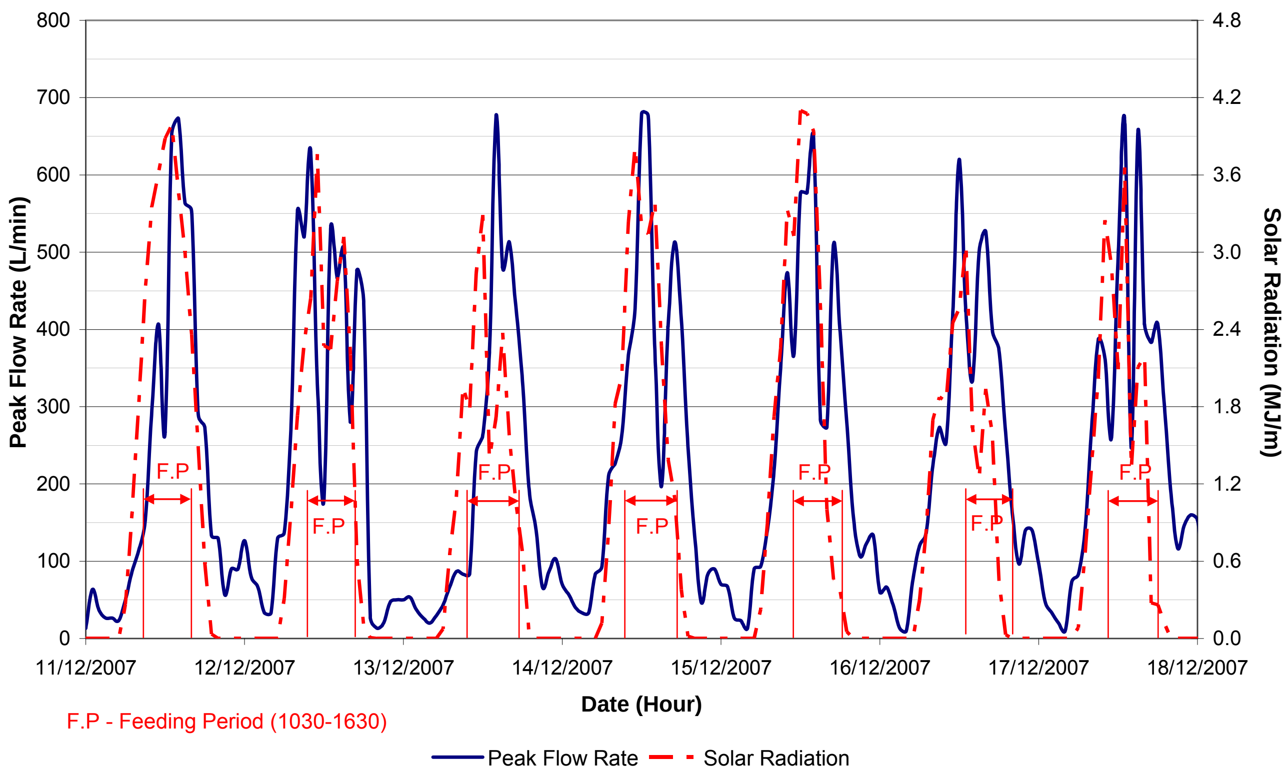

Figure 33 – Influence of Solar Radiation of Daily Drinking Water Consumption from December 11th-17th 2007

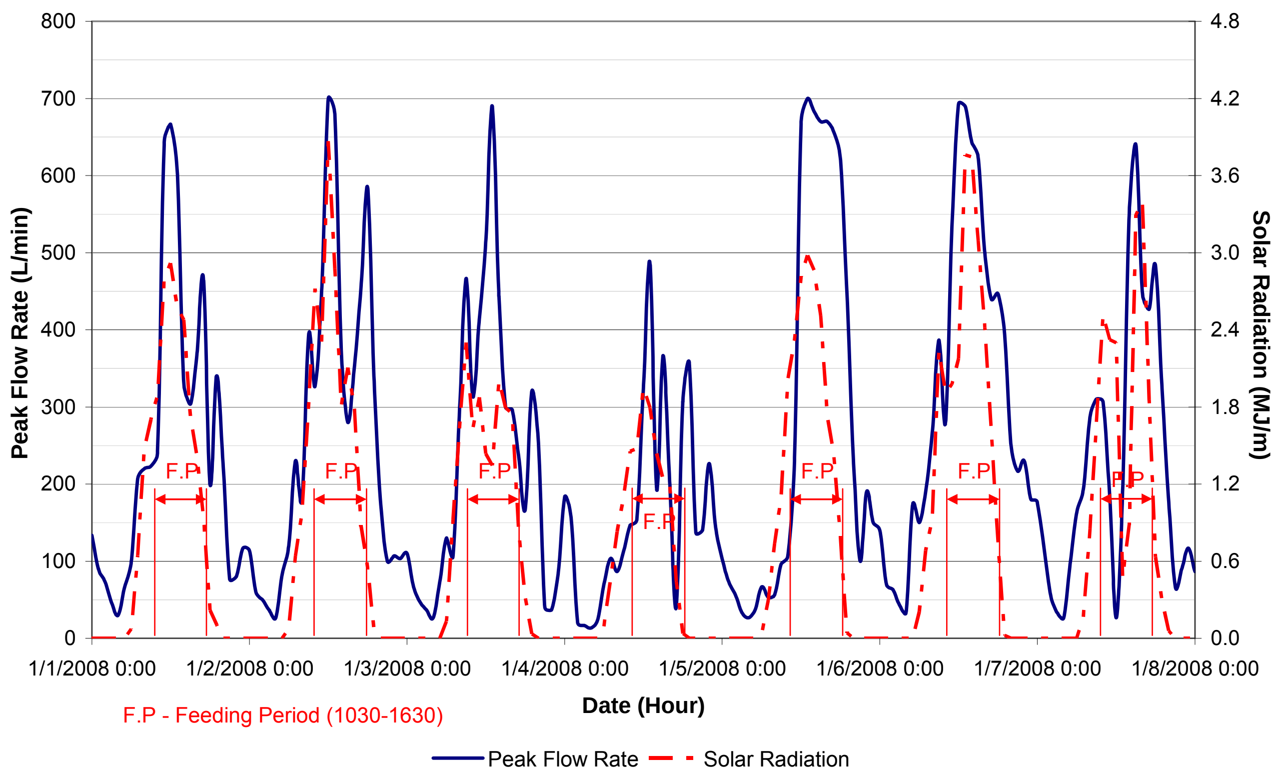

Figure 34 – Influence of Solar Radiation of Daily Drinking Water Consumption from January 1st-7th 2007

5.3.4 Influence of Rainfall on Daily Water Consumption

Rainfall also has an influence on the daily water consumed by cattle. If rainfall is significant, it will keep the troughs filled even if the cattle are drinking, hence reducing the water measured by the water meter.

From Figures 35 and 36 it appears that during rainfall, the drinking water consumption is reduced. However this rainfall occurred during the night which raises uncertainty as to whether this reduction in drinking water consumption is part of the daily diurnal pattern or due to rainfall. Therefore, due to a lack of significant rainfall data a definitive conclusion can not be established.

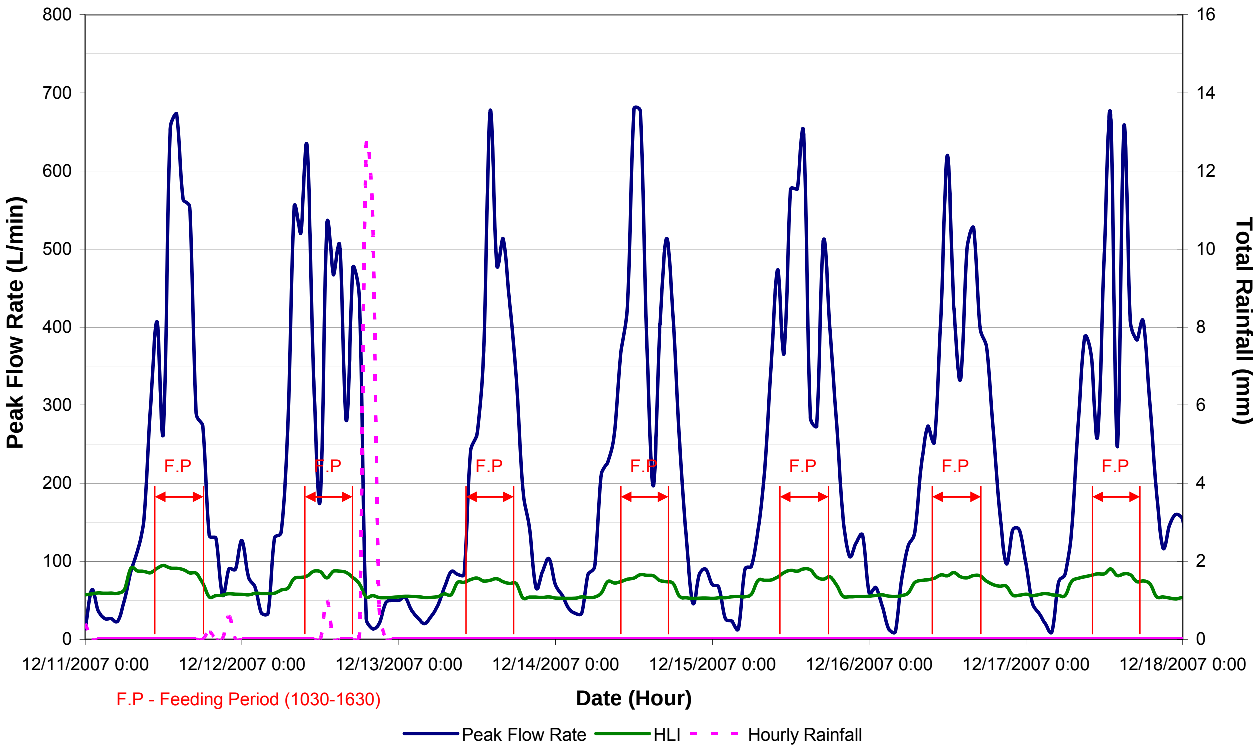

Figure 35 – Influence of Rainfall on Water Consumption from December 11th-17th 2007

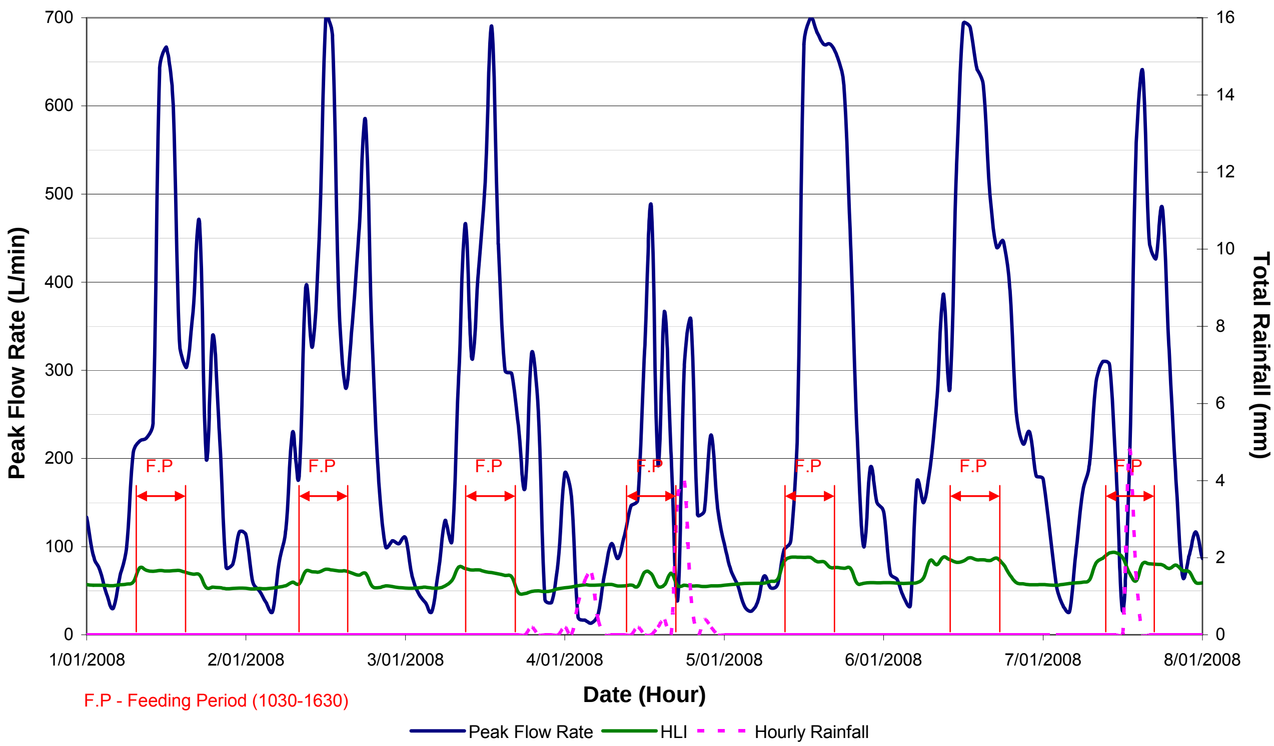

Figure 36 – Influence of Rainfall on Waer Consumption from January 1st-7th 2007

5.3.5 Influence of Dry Matter Intake on Daily Water Consumption

Cattle are between once and twice a day. Feeding time starts around 10:30am with the feeding trucks depositing one third to fifty percent of the cattles daily feed in the pens feed bunks. The trucks deposit the remaining feed once this first round is completed usually finishing around 4pm. The percentage of Dry Matter Intake (DMI) that they receive throughout the day also has an influence on the cattle's' daily water consumption. This is because, if the percentage of DMI is low, then there is a greater content of water in the feed mix, which reduces the need for water intake.

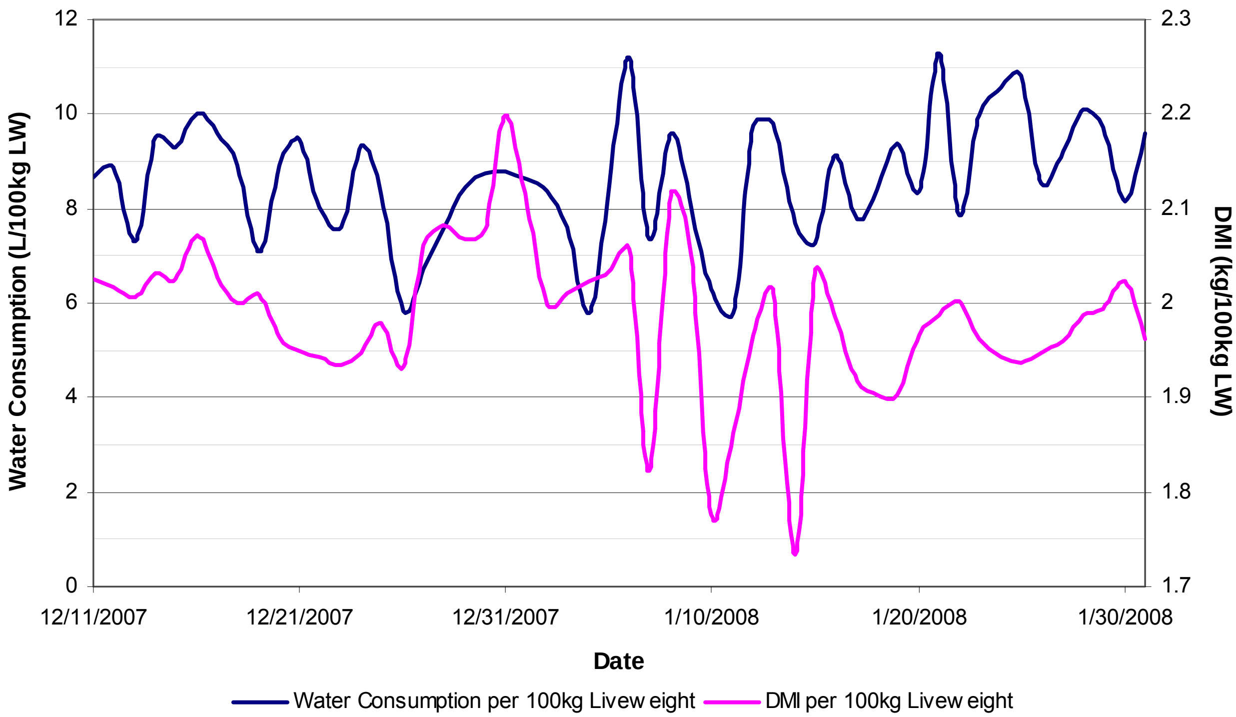

Figure 37 – Influence of Dry Matter Intake on Daily Water Consumption

Figure 37 shows the correlation between the DMI and the water consumed per 100kg live weight per day. It can be observed that the DMI consumption has an influence on the water consumption, as DMI rises, so does the water consumption. However, the significance of its influence on water consumption is not constant i.e. there are other factors contributing to the water consumption variation.

5.3.6 Influence of HLI and Daily Water Consumption on Diurnal Patterns

The air temperature, black globe temperature, and solar radiation all have an influence on the daily consumption patterns.

The Heat Load Index (HLI) was developed as an indicator of the environmental heat load placed on cattle. This index uses black globe temperature rather than ambient temperature, and takes into account radiation effects such as solar radiation as well as air temperature. Figure 38 shows that the Heat Load Index (HLI) has a reasonable correlation with the peak flow rate throughout a 24-hour period. As the HLI increases between 6 and 10 am, so does the water consumption rate. Similarly when the HLI decreases towards the end of the day so does drinking water consumption between 5 and 8pm.

The HLI is more indicative of the peak flow rate variations throughout the day than the ambient or black globe temperatures, as other variables such as solar radiation and Wind speed are accounted for in its calculation.

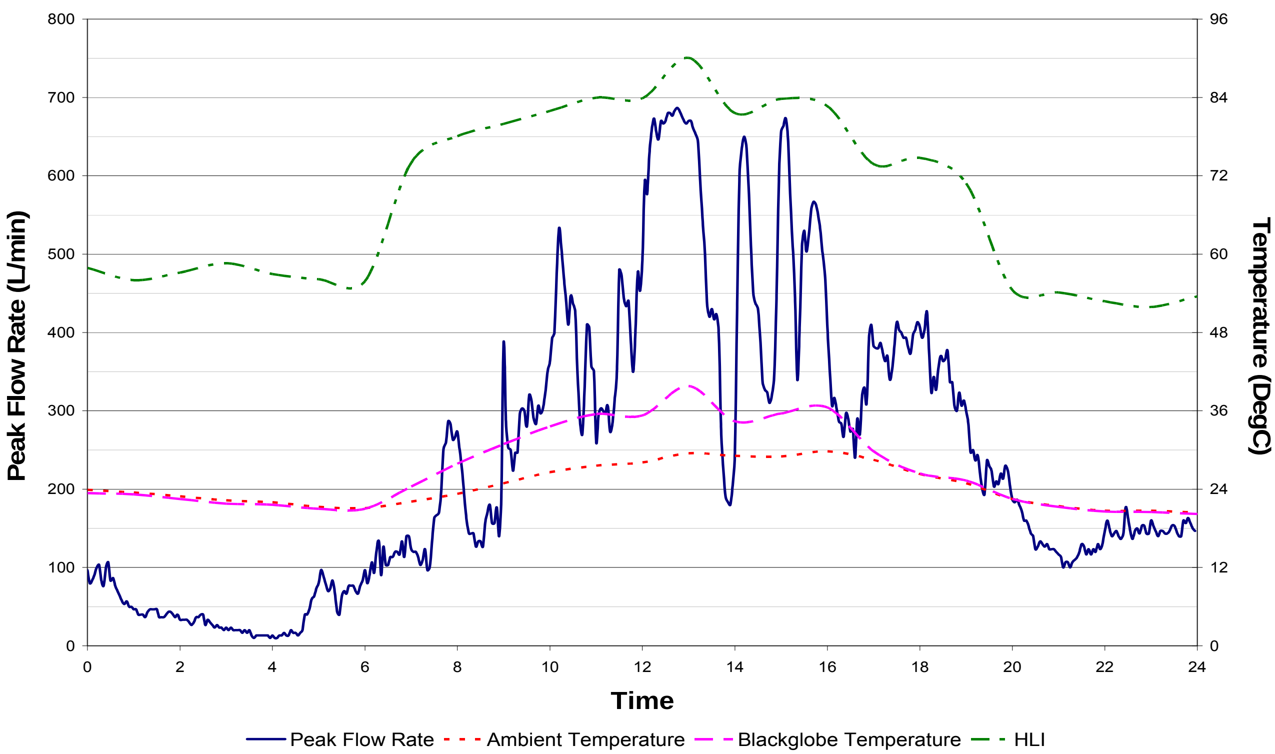

Figure 38 – Diurnal Water Consumption on 17th December 2007

6 Conclusions and Recommendations

This investigation found that the daily water consumption of lot fed cattle varied throughout the study period. QDPI estimates that lot fed cattle require on average 65L/head/day. However in this study, a daily maximum of 75L/head/day was measured with a daily minimum of approximately 15L/head/day measured in winter. The average daily water consumption for the study period was 39L/head/day. The annual water consumption of lot fed cattle is estimated by QDPI at 24ML/1000head/year. The annual consumption per 1000 head per year estimated in this study to be 15ML/1000head/year. Hence it is important from an industry perspective that annual drinking water consumption is measured to provide information for industry regulations.

The flow rates for the production pen reticulation system were also investigated during this study period. At present the pumps used for pumping water from the tanks to the production pens have a maximum potential of 1800L/min. This exceeds the maximum flow rate that is actually required by the pens of 740L/min. Therefore in terms of pump capacities there is no need for alterations unless with the expansion of Wainui Feedlot the demand will exceed 1800L/min at some point in time. In this case, a new pump alternative would need to be considered.

It was found that ambient, black globe temperature and solar radiation have the highest correlation and therefore influence on the drinking water consumption patterns of lot fed cattle. A change in either one of these meteorological variables generally resulted in a respective change in the cattle's drinking water consumption. Humidity however had an inverse relationship with the drinking water consumption patterns of the cattle. The water consumption was highest in the middle of the day

Previous research conducted both in Australia and North America was compared with the measured data. The model developed by Sanders et al. (1994) has a high correlation of determination of has a high correlation with the measured data, it however does not serve as a reliable predicative model since it is dependent on meteorological parameters which can only be obtained retrospectively such as rainfall and solar radiation. It was found that the relationship derived by Parker et al. (1999) best modelled the data collected. However, the continuation of data collection and the development of a predictive model for Australian conditions would improve the integrity of this water consumption data since this study was only conducted during one ear over an eleven-month period.

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Geoff Cornford (Feedlot Manager)
Meg Kummerow (Feedlot Administrator)

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9 Appendices

APPENDIX A: Annual Peak Flow and Daily Water Usage Data

March:

Daily March Data

Date	Time	Peak Flow Rate (L/min)	Total Daily Usage (kL)
3/1/2007	13:33	713.33	452.26
3/2/2007	13:42	736.67	514.33
3/3/2007	13:09	726.67	459.60
3/4/2007	12:33	716.67	382.13
3/5/2007	12:33	716.67	369.32
3/6/2007	13:09	740.00	309.02
3/7/2007	12:30	626.67	265.71
3/8/2007	12:42	743.33	395.08
3/9/2007	12:06	726.67	463.35
3/10/2007	11:48	736.67	532.50
3/11/2007	12:36	736.67	529.15
3/12/2007	13:15	740.00	453.41
3/13/2007	11:42	623.33	389.92
3/14/2007	12:27	660.00	354.66
3/15/2007	12:21	630.00	365.94
3/16/2007	12:54	743.33	384.08
3/17/2007	11:39	753.33	417.89
3/18/2007	11:54	636.67	350.57
3/19/2007	13:03	760.00	370.85
3/20/2007	12:42	643.33	405.96
3/21/2007	12:12	733.33	369.02
3/22/2007	12:18	706.67	368.23
3/23/2007	13:45	660.00	293.51
3/24/2007	12:30	650.00	363.79
3/25/2007	12:45	636.67	301.66
3/26/2007	13:06	753.33	332.98
3/27/2007	12:51	693.33	387.83
3/28/2007	12:18	700.00	353.90
3/29/2007	13:03	750.00	339.76
3/30/2007	12:06	650.00	359.53
3/31/2007	11:36	726.67	354.51

April:

Daily April Data

Date	Time of Peak	Peak Flow Rate (L/min)	Daily Water Usage (kL)
1/04/2007	12:12	630.00	302.2
2/04/2007	12:42	646.67	345.5
3/04/2007	11:57	663.33	364.8
4/04/2007	12:42	670.00	388.2
5/04/2007	12:48	660.00	389.3
6/04/2007	12:24	693.33	297.3
7/04/2007	13:09	650.00	270.7
8/04/2007	12:42	633.33	251.3
9/04/2007	12:06	660.00	256.8
10/04/2007	12:12	713.33	313.5
11/04/2007	12:45	626.67	345.9
12/04/2007	12:27	663.33	314.8
13/04/2007	12:48	643.33	317.9
14/04/2007	11:57	643.33	265.1
15/04/2007	12:09	696.67	267
16/04/2007	11:42	520.00	306.8
17/04/2007	12:30	630.00	352.6
18/04/2007	10:09	703.33	353
19/04/2007	12:21	560.00	312.6
20/04/2007	12:24	590.00	364.7
21/04/2007	12:48	730.00	293.2
22/04/2007	12:18	633.33	251.1
23/04/2007	12:36	640.00	276.9
24/04/2007	12:42	623.33	321.9
25/04/2007	11:54	633.33	264.3
26/04/2007	12:12	633.33	297.1
27/04/2007	13:27	610.00	258.7
28/04/2007	18:33	303.33	101.9
29/04/2007	14:12	530.00	186.3
30/04/2007	13:21	553.33	231.5

May Data:

Daily May Data

Date	Time of Peak	Peak Flow Rate (L/min)	Total Daily Usage kL
1/05/2007	12:54	623.33	286.37
2/05/2007	12:09	633.33	308.26
3/05/2007	12:54	650.00	298.78
4/05/2007	13:12	703.33	306.73
5/05/2007	12:45	643.33	303.81
6/05/2007	12:57	696.67	283.51
7/05/2007	13:36	593.33	244.16
8/05/2007	12:51	693.33	273.69
9/05/2007	12:39	666.67	334.12
10/05/2007	12:30	676.67	311.25
11/05/2007	13:03	583.33	229.18
12/05/2007	13:48	653.33	293.76
13/05/2007	13:18	626.67	192.08
14/05/2007	13:03	680.00	291.95
15/05/2007	12:42	533.33	303.10
16/05/2007	13:00	616.67	334.39
17/05/2007	13:42	653.33	300.45
18/05/2007	12:48	510.00	220.88
19/05/2007	13:12	650.00	241.60
20/05/2007	13:33	613.33	245.86
21/05/2007	15:54	463.33	108.35
22/05/2007	16:03	616.67	177.59
23/05/2007	13:06	740.00	269.03
24/05/2007	14:06	653.33	285.56
25/05/2007	14:33	656.67	304.60
26/05/2007	13:00	693.33	325.53
27/05/2007	14:45	543.33	328.72
28/05/2007	13:48	710.00	349.60
29/05/2007	13:39	726.67	363.17
30/05/2007	13:36	583.33	320.18
31/05/2007	13:45	573.33	240.69

June Data:

Daily June Data

Date	Time of Peak	Peak Flow Rate (L/min)	Daily Water Usage (kL)
1/06/2007	13:42	656.67	235.48
2/06/2007	13:30	646.67	203.21
3/06/2007	12:45	486.67	166.30
4/06/2007	16:33	803.33	192.69
5/06/2007	15:36	393.33	118.67
6/06/2007	17:03	486.67	130.59
7/06/2007	16:51	503.33	155.90
8/06/2007	16:21	406.67	153.78
9/06/2007	15:27	426.67	165.90
10/06/2007	12:54	470.00	183.88
11/06/2007	13:15	520.00	191.49
12/06/2007	13:24	503.33	175.88
13/06/2007	12:45	546.67	191.17
14/06/2007	12:42	596.67	210.58
15/06/2007	12:51	576.67	193.80
16/06/2007	13:03	500.00	190.95
17/06/2007	12:33	503.33	194.47
18/06/2007	14:06	643.33	216.35
19/06/2007	14:12	443.33	226.52
20/06/2007	16:45	446.67	209.74
21/06/2007	14:18	420.00	226.34
22/06/2007	13:45	553.33	225.69
23/06/2007	14:10	420.00	160.37
24/06/2007	12:39	540.00	211.73
25/06/2007	14:48	390.00	129.00
26/06/2007	16:57	603.33	110.25
27/06/2007	16:45	483.33	175.85
28/06/2007	16:12	390.00	149.57
29/06/2007	14:00	410.00	157.24
30/06/2007	16:45	410.00	191.46

July Data:

Daily July Data

Date	Time of Peak	Peak Flow Rate (L/min)	Daily Water Usage (kL)
1/07/2007	13:27	496.67	183.00
2/07/2007	15:39	556.67	187.00
3/07/2007	13:09	596.67	214.30
4/07/2007	13:27	560.00	236.40
5/07/2007	13:03	466.67	228.00
6/07/2007	13:39	476.67	218.60
7/07/2007	13:03	546.67	235.00
8/07/2007	13:39	470.00	176.80
9/07/2007	13:45	463.33	186.90
10/07/2007	13:27	583.33	234.20
11/07/2007	12:54	603.33	261.00
12/07/2007	12:57	566.67	248.20
13/07/2007	13:12	486.67	223.30
14/07/2007	13:42	570.00	216.20
15/07/2007	12:39	560.00	197.90
16/07/2007	16:57	433.33	206.30
17/07/2007	12:57	636.67	237.80
18/07/2007	13:06	476.67	238.50
19/07/2007	12:45	516.67	220.60
20/07/2007	14:54	623.33	252.90
21/07/2007	13:27	696.67	289.40
22/07/2007	12:48	660.00	257.10
23/07/2007	12:42	650.00	332.20
24/07/2007	16:15	570.00	352.10
25/07/2007	13:21	630.00	394.60
26/07/2007	13:42	626.67	354.30
27/07/2007	13:00	663.33	250.20
28/07/2007	12:30	600.00	227.80
29/07/2007	12:36	626.67	236.90
30/07/2007	13:18	686.67	257.30
31/07/2007	16:06	480.00	289.40

August:

Daily August Data

Date	Time of Peak	Peak Flow Rate (L/min)	Daily Water Usage (kL)
1/08/2007	12:09	593.33	293.97
2/08/2007	12:18	626.67	300.67
3/08/2007	12:57	623.33	264.54
4/08/2007	12:48	566.67	206.52
5/08/2007	12:21	496.67	201.50
6/08/2007	13:15	553.33	221.60
7/08/2007	12:45	686.67	285.71
8/08/2007	12:45	656.67	311.57
9/08/2007	13:00	610.00	307.26
10/08/2007	13:21	700.00	322.88
11/08/2007	13:03	630.00	287.55
12/08/2007	12:33	690.00	304.19
13/08/2007	13:00	683.33	359.71
14/08/2007	12:51	703.33	319.93
15/08/2007	12:45	710.00	369.35
16/08/2007	13:21	720.00	378.39
17/08/2007	16:06	576.67	255.86
18/08/2007	13:24	546.67	260.08
19/08/2007	16:36	646.67	165.35
20/08/2007	17:21	666.67	264.33
21/08/2007	17:06	696.67	267.51
22/08/2007	17:15	506.67	282.47
23/08/2007	17:27	586.67	232.14
24/08/2007	15:36	633.33	277.18
25/08/2007	13:51	683.33	308.66
26/08/2007	16:54	543.33	333.49
27/08/2007	14:15	586.67	366.80
28/08/2007	12:21	550.00	236.99
29/08/2007	12:39	646.67	284.06
30/08/2007	12:54	590.00	246.56
31/08/2007	16:42	623.33	263.25

September:

Daily September Data

Date	Time of Peak	Peak Flow Rates (L/min)	Daily Water Usage (kL)
1/09/2007	12:39	693.33	275.50
2/09/2007	12:27	583.33	236.29
3/09/2007	12:54	680.00	261.68
4/09/2007	12:30	573.33	173.91
5/09/2007	15:21	536.67	162.57
6/09/2007	15:54	500.00	166.09
7/09/2007	16:27	626.67	220.71
8/09/2007	15:15	510.00	232.34
9/09/2007	12:12	640.00	252.61
10/09/2007	12:39	523.33	239.09
11/09/2007	13:27	576.67	328.62
12/09/2007	12:36	636.67	376.93
13/09/2007	15:00	670.00	319.81
14/09/2007	13:51	493.33	269.96
15/09/2007	11:51	600.00	276.18
16/09/2007	12:51	663.33	272.60
17/09/2007	12:33	603.33	249.37
18/09/2007	16:03	513.33	248.07
19/09/2007	11:48	650.00	301.80
20/09/2007	12:36	550.00	254.19
21/09/2007	12:45	600.00	285.80
22/09/2007	11:21	680.00	255.77
23/09/2007	11:27	623.33	229.99
24/09/2007	12:18	623.33	307.91
25/09/2007	11:57	666.67	304.97
26/09/2007	10:45	606.67	321.67
27/09/2007	12:18	596.67	291.11
28/09/2007	13:21	633.33	430.87
29/09/2007	11:15	640.00	435.60
30/09/2007	13:06	600.00	431.06

October:

Daily October Data

Date	Time of Peak	Peak Flow Rate (L/min)	Daily Water Usage (kL)
1/10/2007	11:51	600.00	426.85
2/10/2007	10:36	623.33	447.54
3/10/2007	11:03	626.67	425.60
4/10/2007	11:42	616.67	330.08
5/10/2007	14:12	616.67	359.45
6/10/2007	11:45	596.67	316.94
7/10/2007	12:06	613.33	278.12
8/10/2007	12:36	613.33	303.84
9/10/2007	11:21	623.33	323.65
10/10/2007	13:27	613.33	172.67
11/10/2007	16:51	530.00	190.87
12/10/2007	15:42	580.00	252.88
13/10/2007	12:00	600.00	256.48
14/10/2007	12:00	606.67	288.56
15/10/2007	11:45	596.67	313.14
16/10/2007	12:39	650.00	301.10
17/10/2007	11:21	670.00	340.67
18/10/2007	12:33	596.67	265.87
19/10/2007	16:36	590.00	303.70
20/10/2007	12:21	633.33	276.79
21/10/2007	12:15	626.67	287.92
22/10/2007	12:39	670.00	344.74
23/10/2007	14:00	640.00	333.68
24/10/2007	12:21	683.33	330.30
25/10/2007	14:51	636.67	221.70
26/10/2007	16:03	610.00	209.69
27/10/2007	13:57	693.33	325.29
28/10/2007	12:18	676.67	343.53
29/10/2007	15:45	506.67	159.87
30/10/2007	12:54	723.33	313.26
31/10/2007	13:00	696.67	335.82

November:

Daily November Data

Date	Time of Peak	Peak Flow Rate (L/min)	Daily Water Usage (kL)
1/11/2007	13:15	710.00	331.03
2/11/2007	13:18	690.00	369.68
3/11/2007	13:36	680.00	389.70
4/11/2007	16:36	663.33	346.51
5/11/2007	16:21	666.67	247.95
6/11/2007	17:24	493.33	179.38
7/11/2007	12:48	710.00	193.22
8/11/2007	13:51	696.67	244.42
9/11/2007	12:33	666.67	295.58
10/11/2007	12:54	673.33	319.91
11/11/2007	13:00	666.67	280.25
12/11/2007	11:48	673.33	291.69
13/11/2007	12:39	656.67	350.64
14/11/2007	11:45	676.67	360.09
15/11/2007	12:30	676.67	351.97
16/11/2007	12:06	656.67	361.38
17/11/2007	10:48	653.33	262.85
18/11/2007	13:42	673.33	329.78
19/11/2007	13:15	723.33	371.03
20/11/2007	12:48	670.00	366.82
21/11/2007	12:24	660.00	399.73
22/11/2007	11:09	710.00	314.18
23/11/2007	14:42	660.00	180.23
24/11/2007	18:03	510.00	210.38
25/11/2007	12:27	633.33	277.16
26/11/2007	12:18	676.67	294.87
27/11/2007	11:54	663.33	290.13
28/11/2007	12:30	693.33	315.91
29/11/2007	13:24	666.67	341.05
30/11/2007	8:15	710.00	300.45

December:

Daily December Data

Date	Peak Time	Peak Flow Rate (L/min)	Total Water Usage (kL)
1/12/2007	11:15	673.33	325.58
2/12/2007	13:03	683.33	321.77
3/12/2007	14:02	686.67	353.59
4/12/2007	12:33	696.67	360.76
5/12/2007	15:03	683.33	413.17
6/12/2007	11:30	686.67	344.45
7/12/2007	10:33	700.00	398.12
8/12/2007	14:27	673.33	281.61
9/12/2007	12:33	680.00	380.84
10/12/2007	13:12	690.00	249.28
11/12/2007	13:39	710.00	312.32
12/12/2007	10:39	690.00	340.18
13/12/2007	13:54	693.33	269.72
14/12/2007	12:03	690.00	352.21
15/12/2007	13:24	683.33	365.08
16/12/2007	12:36	680.00	350.58
17/12/2007	12:45	686.67	341.58
18/12/2007	11:00	676.67	317.87
19/12/2007	10:36	680.00	277.09
20/12/2007	14:21	700.00	343.68
21/12/2007	12:24	693.33	372.07
22/12/2007	13:51	683.33	336.52
23/12/2007	13:30	660.00	300.73
24/12/2007	12:12	690.00	370.92
25/12/2007	13:06	663.33	330.73
26/12/2007	11:30	663.33	252.30
27/12/2007	12:24	683.33	264.60
28/12/2007	11:30	696.67	301.95
29/12/2007	13:00	693.33	361.50
30/12/2007	12:21	686.67	355.77
31/12/2007	12:06	690.00	340.47

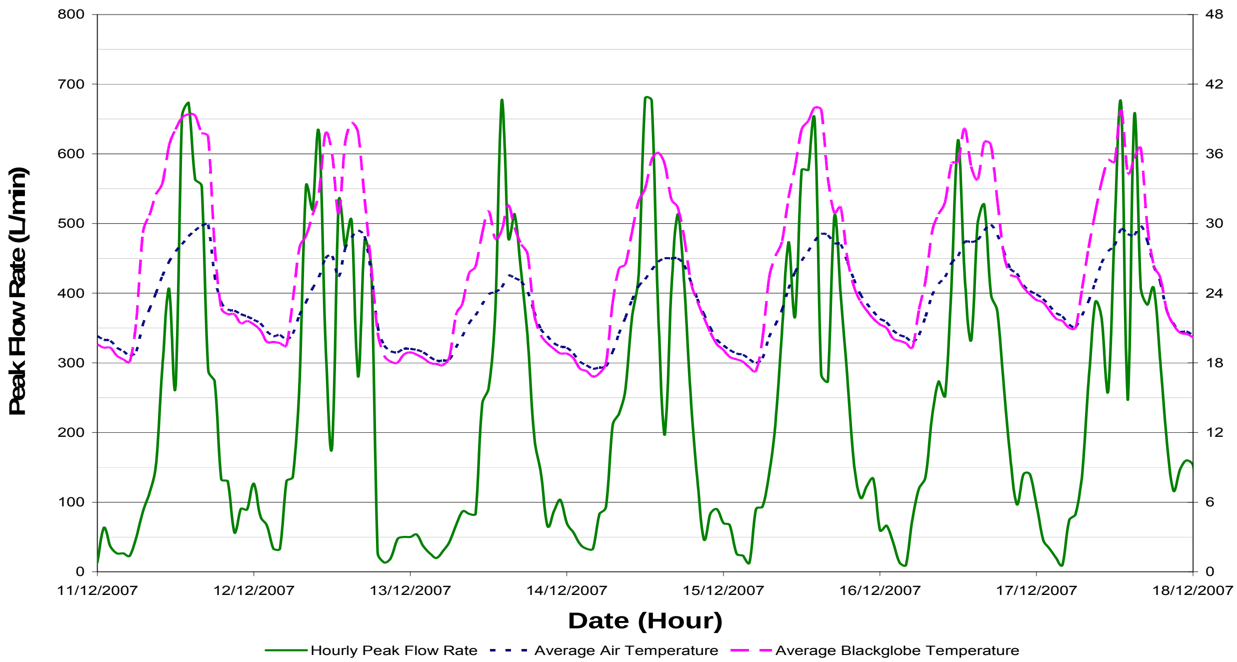
January:

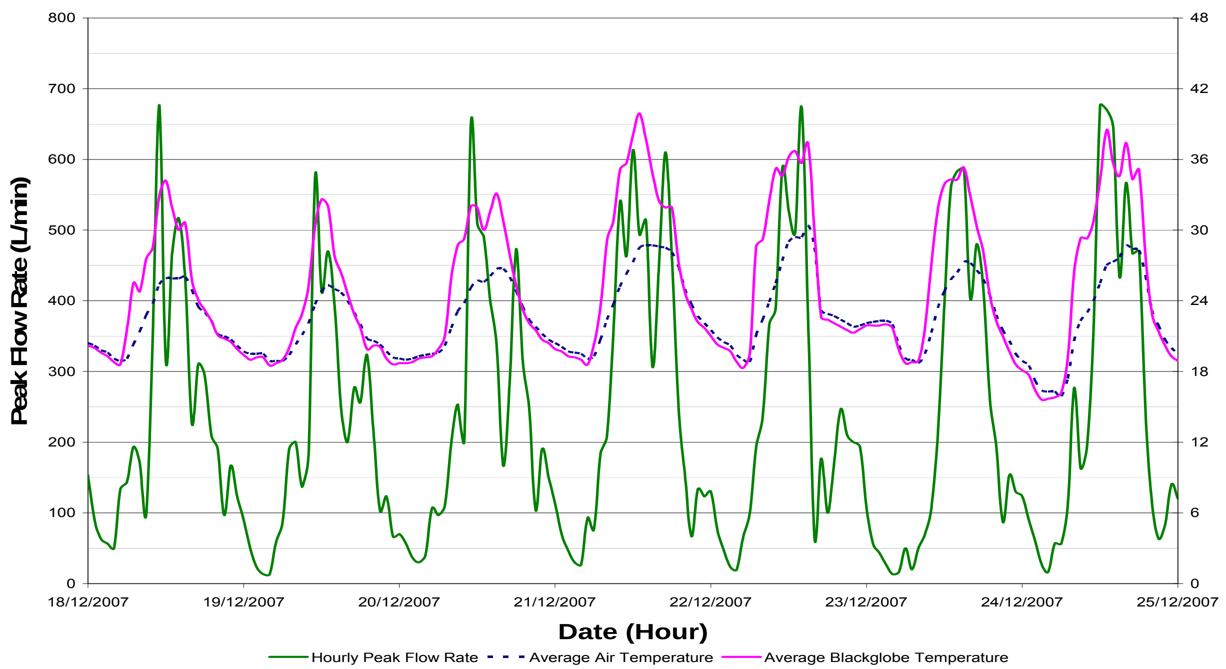
Daily January Data

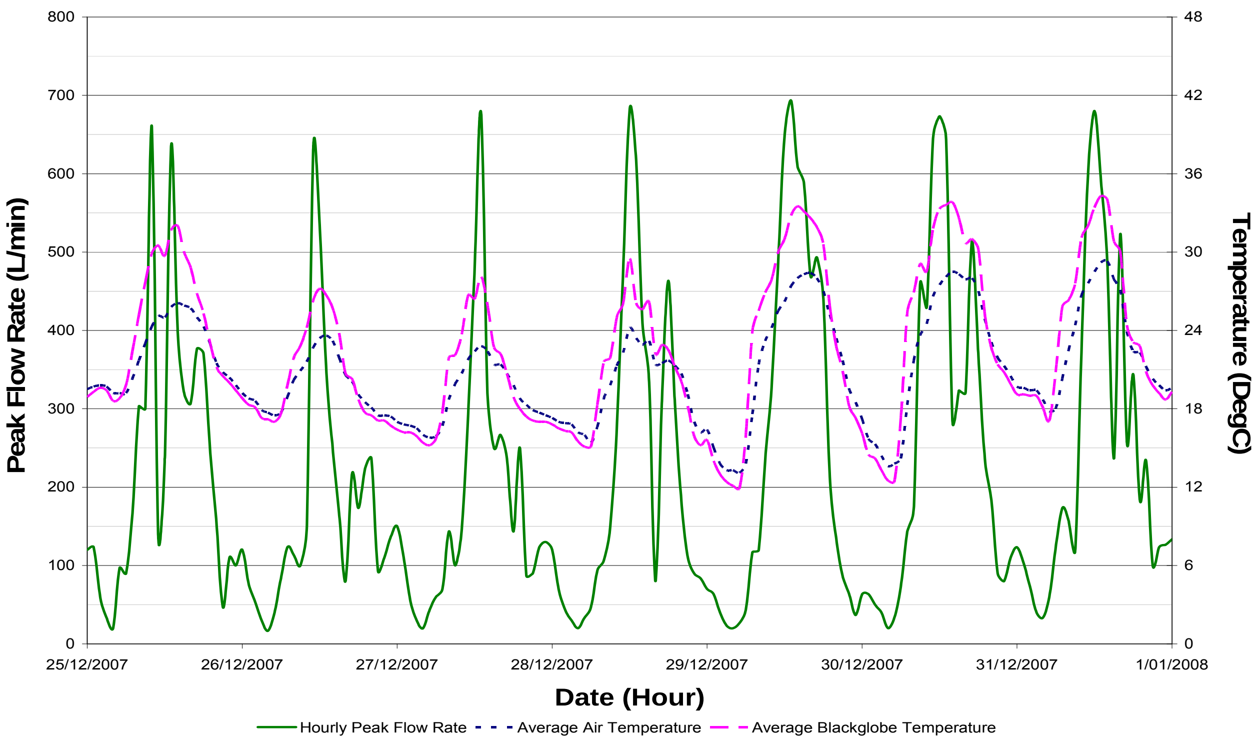
Date	Peak Time	Peak Flow Rate (L/min)	Total Water Usage (kL)
1/1/2008	11:36	703.33	353.44
1/2/2008	12:00	700.00	388.46
1/3/2008	12:45	690.00	336.98
1/4/2008	13:21	653.33	257.75
1/5/2008	13:24	713.33	398.37
1/6/2008	12:06	710.00	464.87
1/7/2008	10:24	700.00	345.95
1/8/2008	11:24	710.00	392.76
1/9/2008	13:48	713.33	351.44
1/10/2008	16:54	673.33	281.53
1/11/2008	13:36	573.33	272.26
1/12/2008	11:42	713.33	439.46
1/13/2008	14:27	690.00	426.27
1/14/2008	12:06	733.33	388.74
1/15/2008	12:51	720.00	313.98
1/16/2008	13:06	706.67	396.55
1/17/2008	10:39	690.00	353.47
1/18/2008	12:33	720.00	386.01
1/19/2008	12:42	756.67	429.58
1/20/2008	13:03	603.33	371.89
1/21/2008	12:03	726.67	497.15
1/22/2008	13:21	676.67	342.17
1/23/2008	12:33	710.00	419.47
1/24/2008	13:06	706.67	408.44
1/25/2008	11:36	696.67	419.60
1/26/2008	13:39	703.33	331.90
1/27/2008	12:06	690.00	359.20
1/28/2008	11:54	703.33	378.92
1/29/2008	12:27	703.33	363.27
1/30/2008	10:45	710.00	292.43
1/31/2008	11:48	700.00	366.19

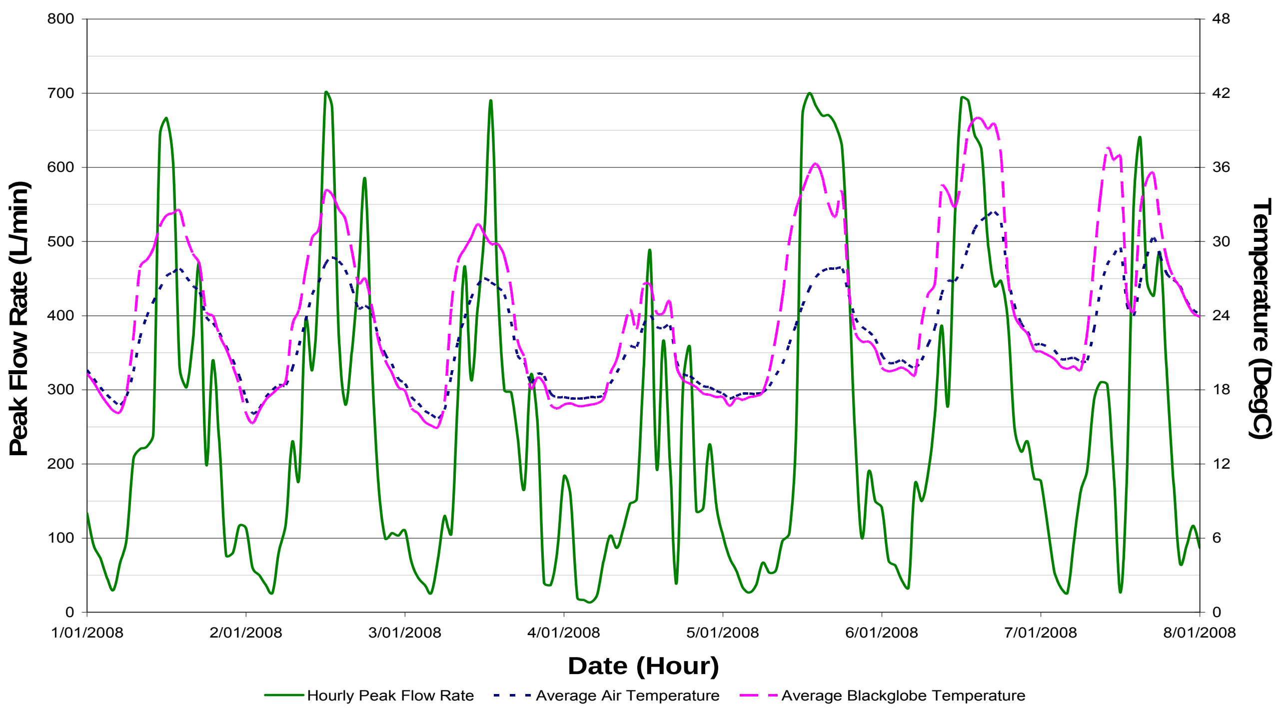
APPENDIX B: Influences on Daily Water Consumption

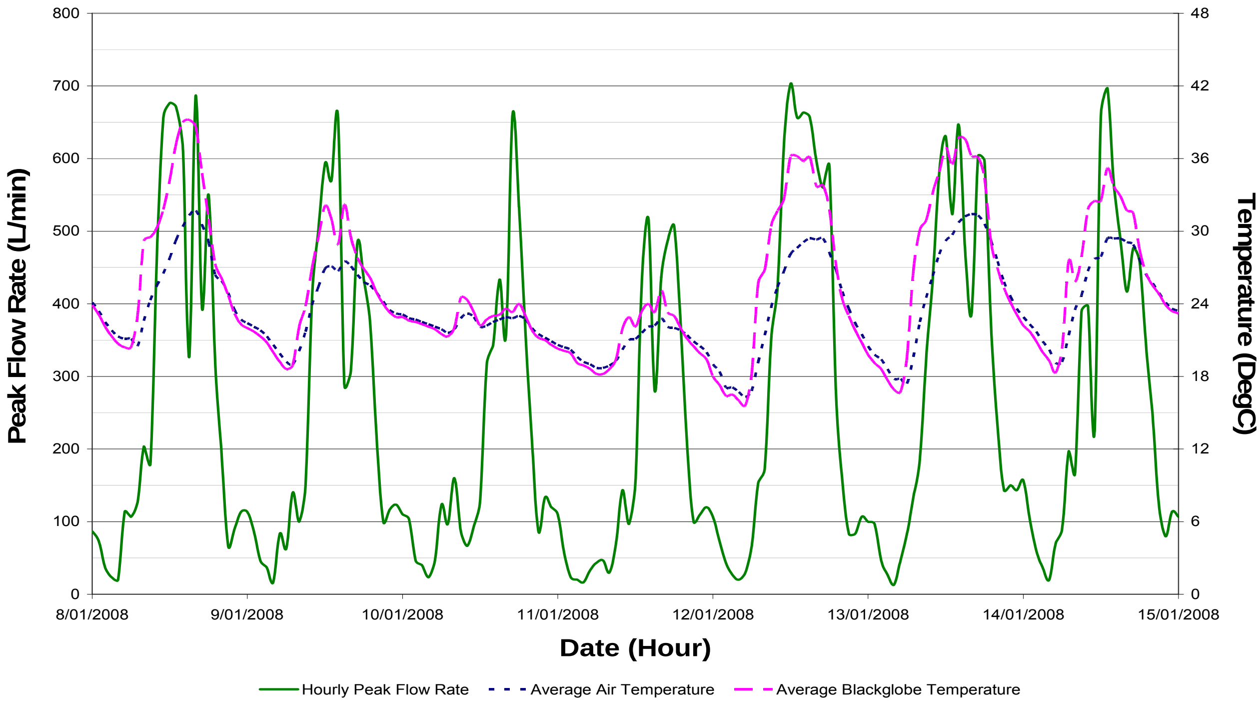
Influence of Temperature:

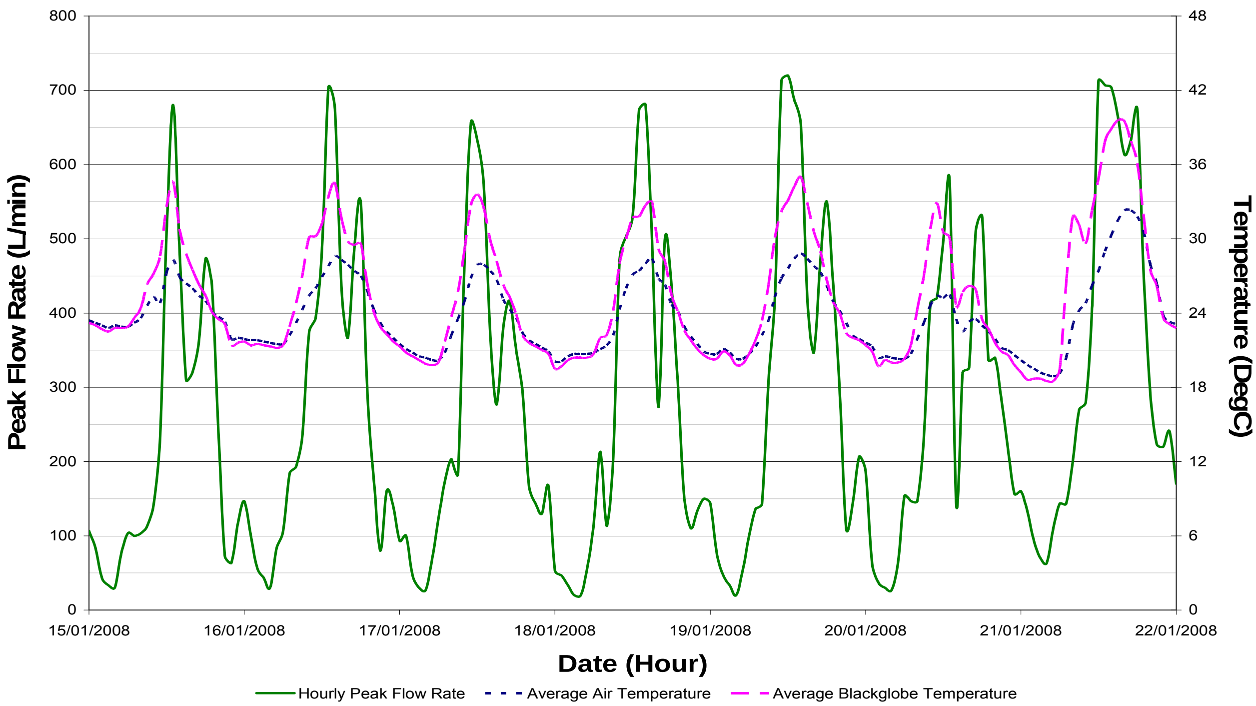


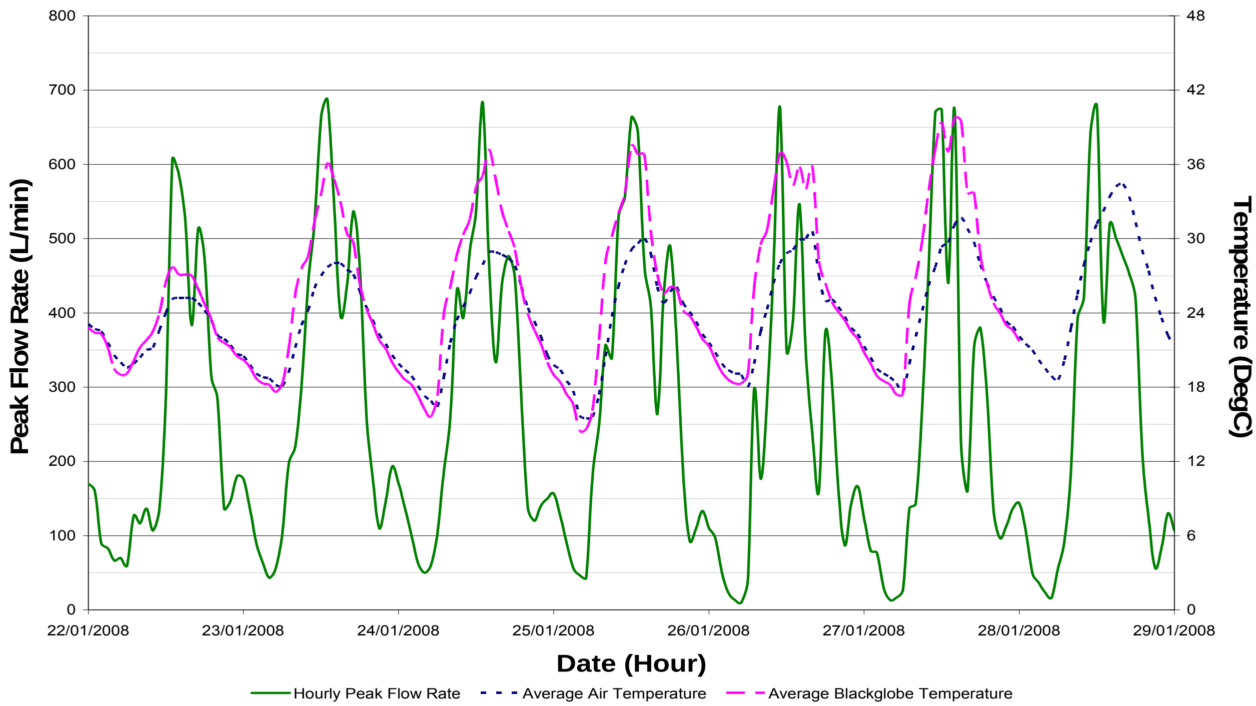


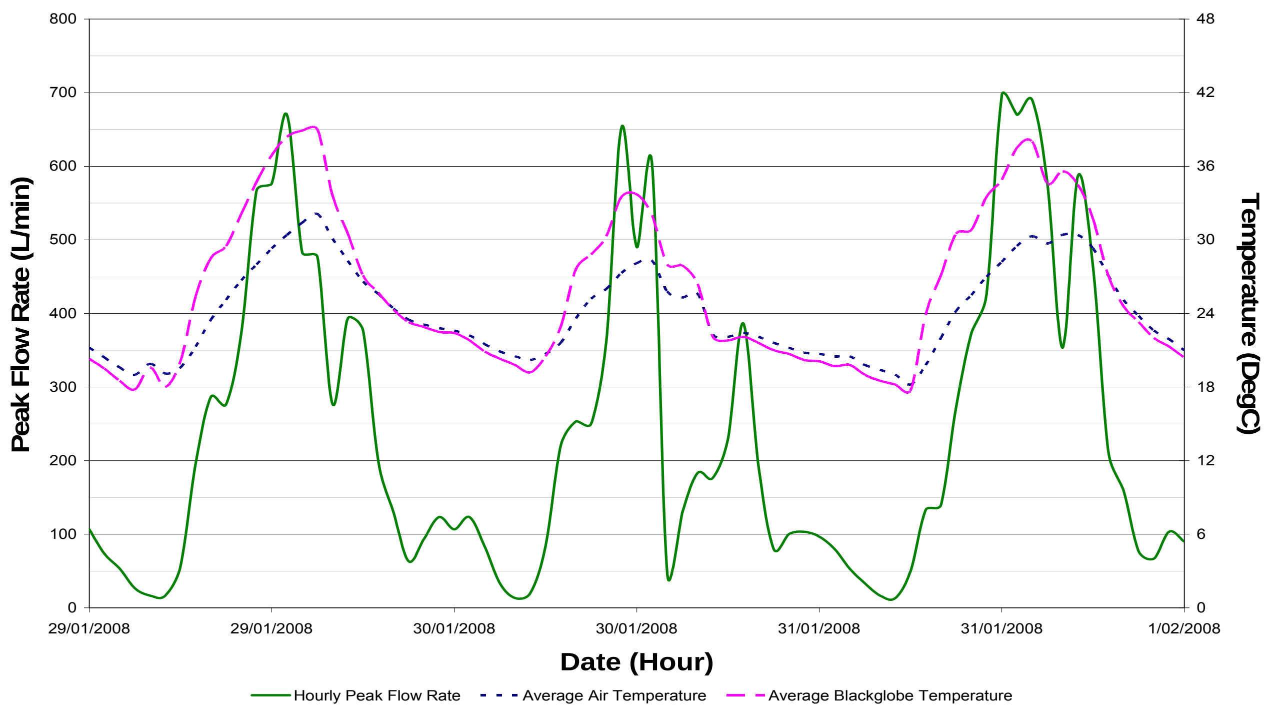

800
700
600
500
400
300
200
100
0
48
42
36
30
24
18
12
6
0
Peak Flow Rate (L/min)
Temperature (DegC)
25/12/2007
26/12/2007
27/12/2007
28/12/2007
29/12/2007
30/12/2007
31/12/2007
1/01/2008
Date (Hour)
Hourly Peak Flow Rate
Average Air Temperature
Average Blackglobe Temperature


800
700
600
500
400
300
200
100
0
48
42
36
30
24
18
12
6
0
Peak Flow Rate (L/min)
Temperature (DegC)
1/01/2008
2/01/2008
3/01/2008
4/01/2008
5/01/2008
6/01/2008
7/01/2008
8/01/2008
Date (Hour)
Hourly Peak Flow Rate
Average Air Temperature
Average Blackglobe Temperature

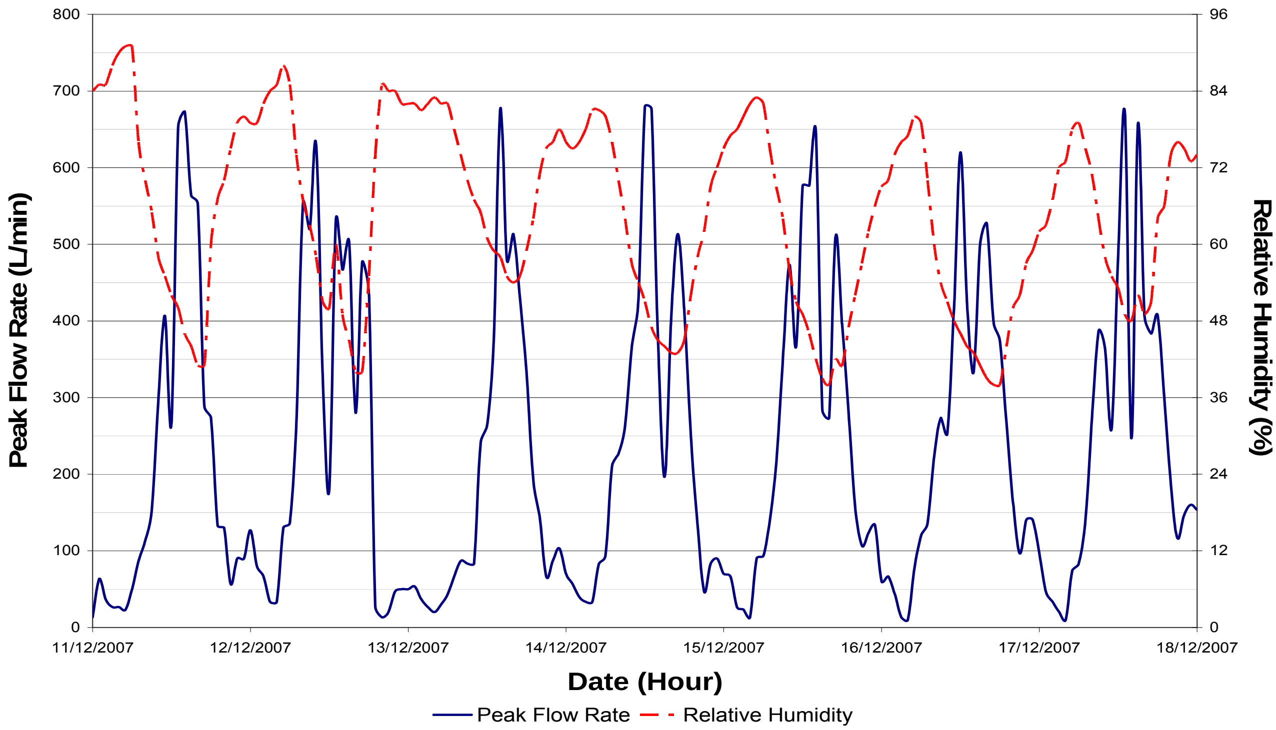

Peak Flow Rate (L/min)
Temperature (DegC)
Date (Hour)
8/01/2008
9/01/2008
10/01/2008
11/01/2008
12/01/2008
13/01/2008
14/01/2008
15/01/2008
Hourly Peak Flow Rate
Average Air Temperature
Average Blackglobe Temperature

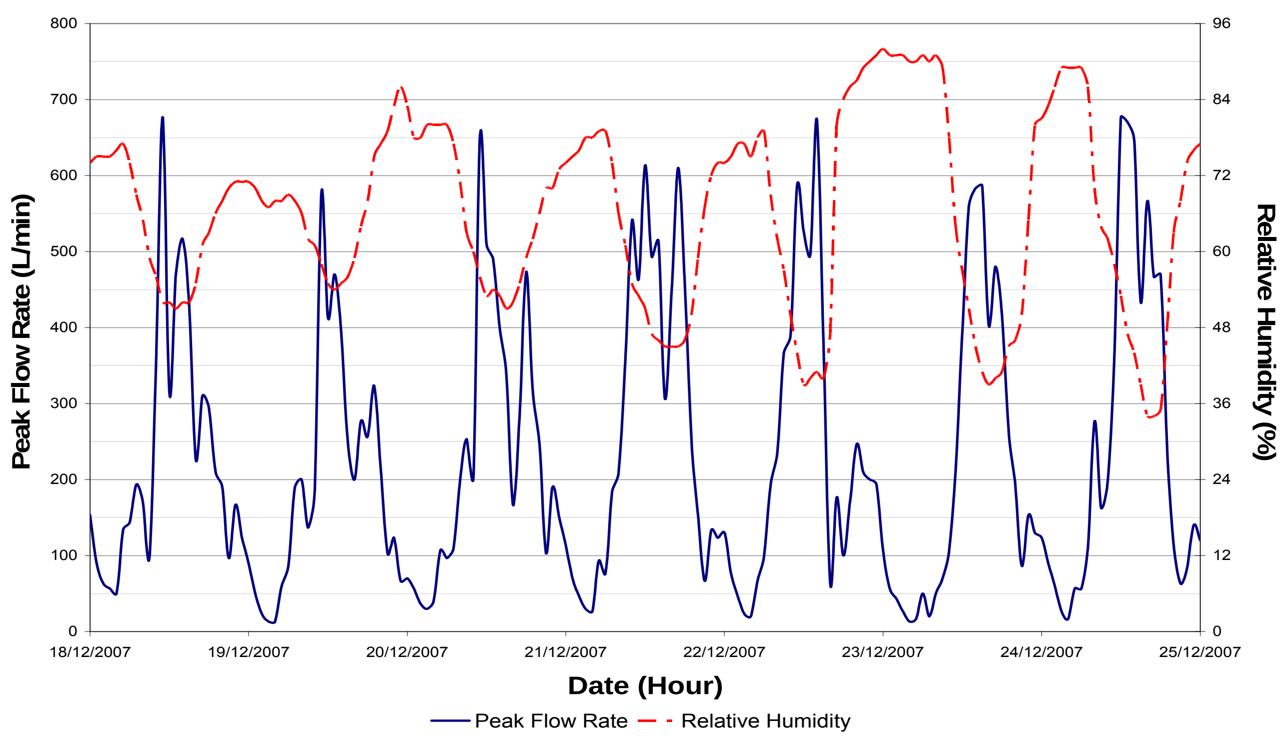

Peak Flow Rate (L/min)
Temperature (DegC)
Date (Hour)
15/01/2008
16/01/2008
17/01/2008
18/01/2008
19/01/2008
20/01/2008
21/01/2008
22/01/2008
Hourly Peak Flow Rate
Average Air Temperature
Average Blackglobe Temperature

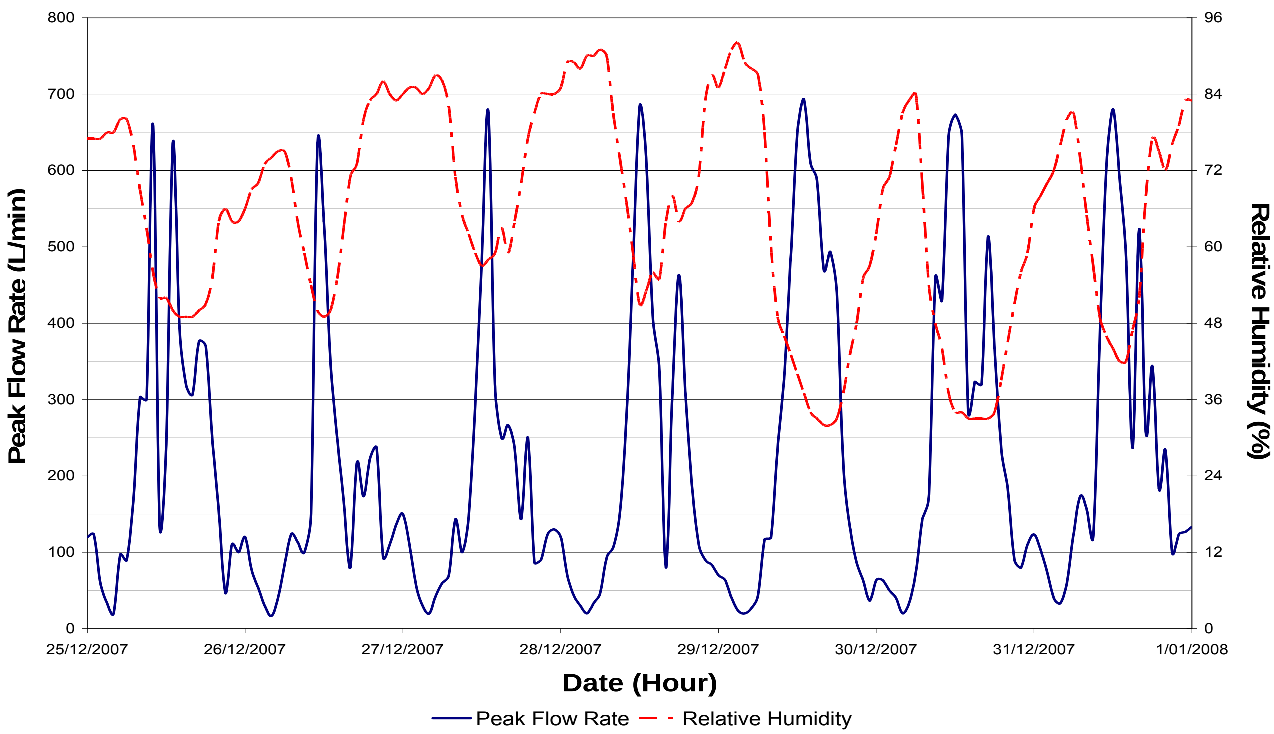

Peak Flow Rate (L/min)
Temperature (DegC)
Date (Hour)
22/01/2008
23/01/2008
24/01/2008
25/01/2008
26/01/2008
27/01/2008
28/01/2008
29/01/2008
Hourly Peak Flow Rate
Average Air Temperature
Average Blackglobe Temperature

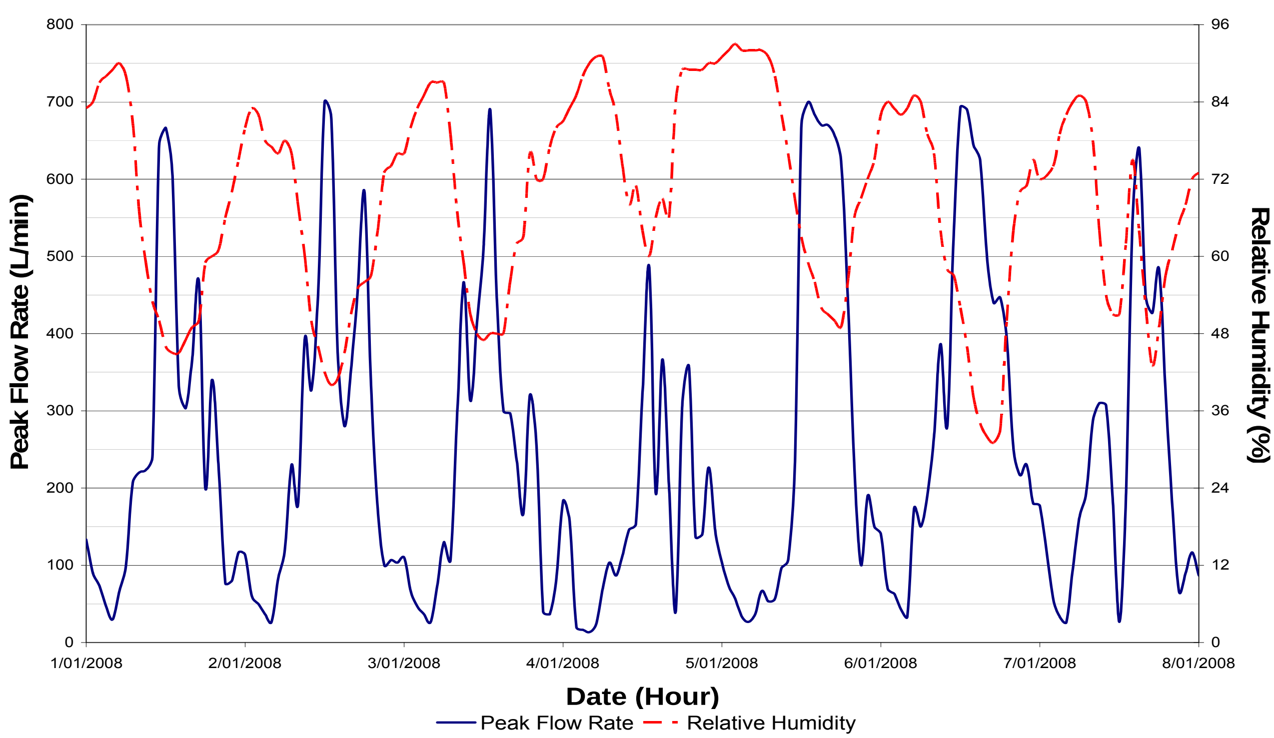

Peak Flow Rate (L/min)
Temperature (DegC)
Date (Hour)
29/01/2008
29/01/2008
30/01/2008
30/01/2008
31/01/2008
31/01/2008
1/02/2008
Hourly Peak Flow Rate
Average Air Temperature
Average Blackglobe Temperature

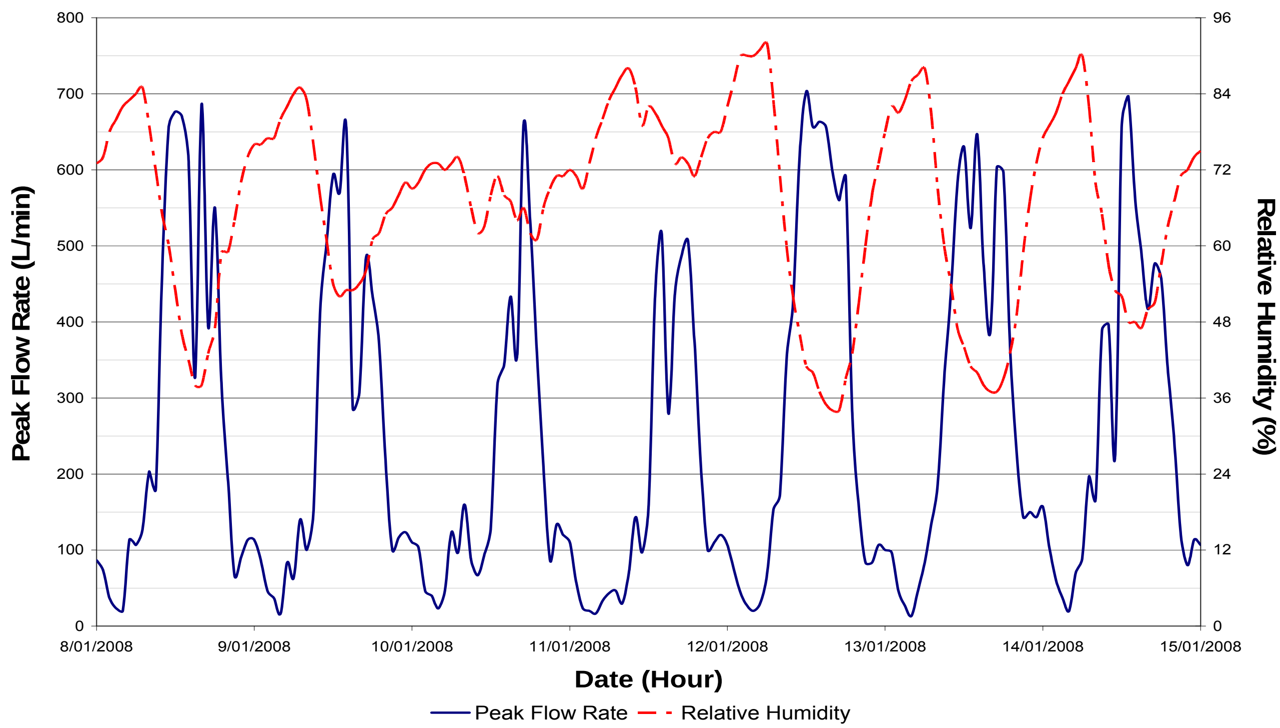
Influence of Relative Humidity:

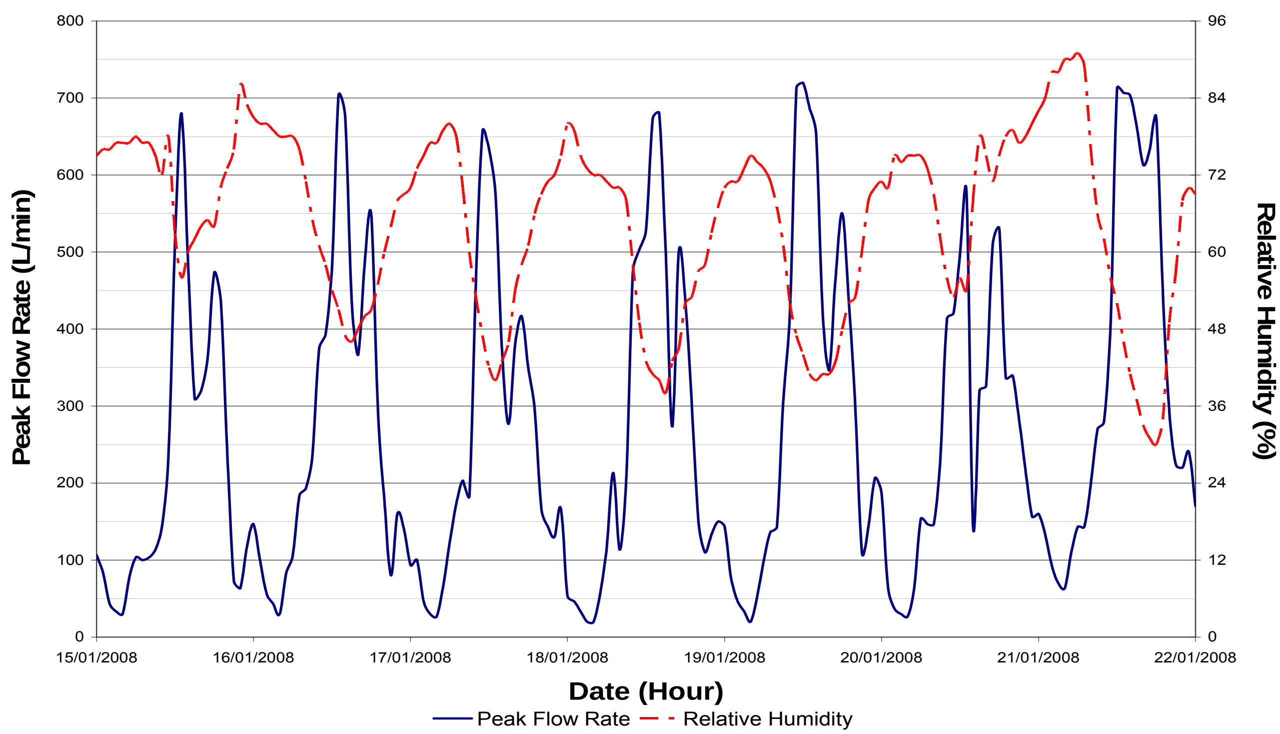


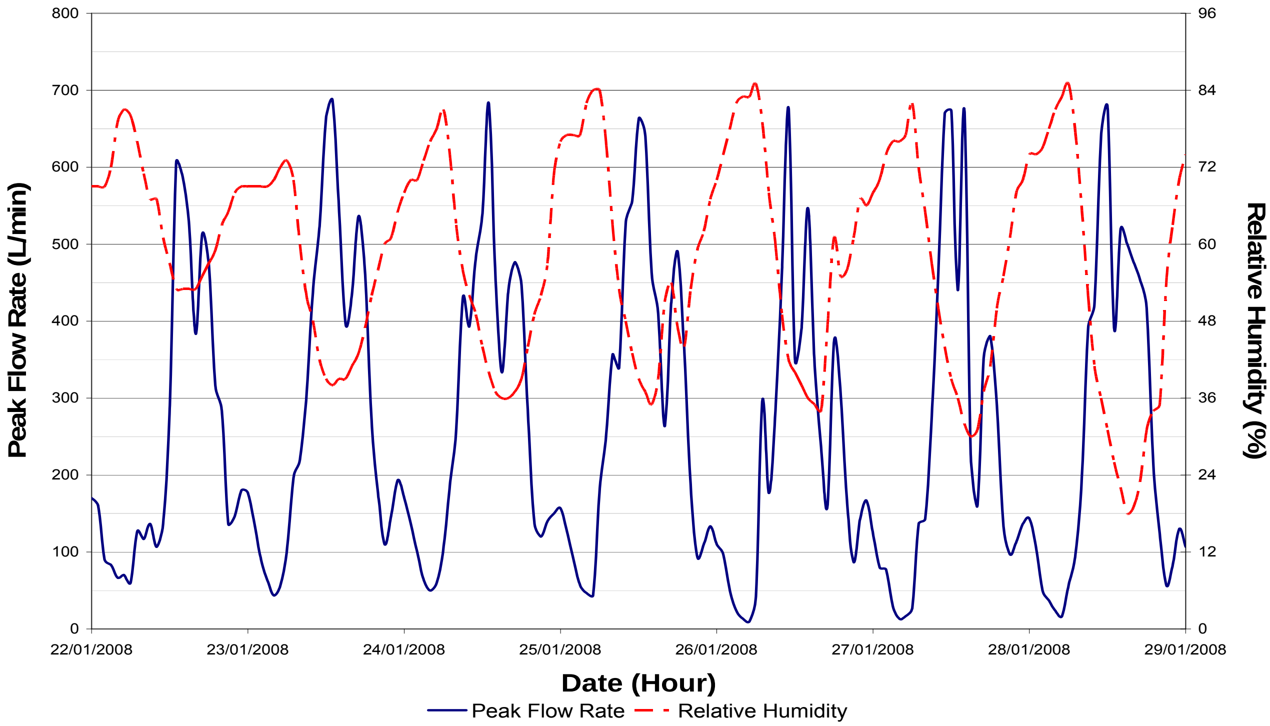


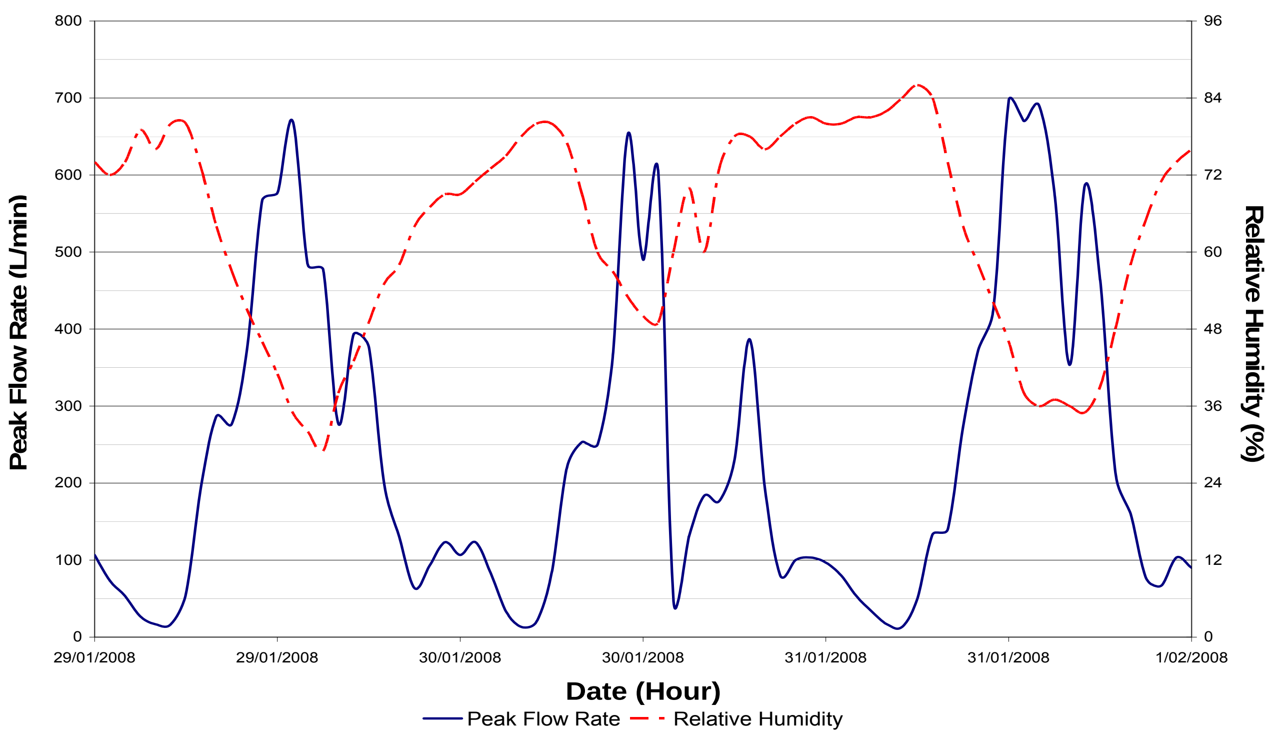

Peak Flow Rate (L/min)
Relative Humidity (%)
800
700
600
500
400
300
200
100
0
96
84
72
60
48
36
24
12
0
25/12/2007
26/12/2007
27/12/2007
28/12/2007
29/12/2007
30/12/2007
31/12/2007
1/01/2008
Date (Hour)
Peak Flow Rate
Relative Humidity


Peak Flow Rate (L/min)
Relative Humidity (%)
800
700
600
500
400
300
200
100
0
96
84
72
60
48
36
24
12
0
1/01/2008
2/01/2008
3/01/2008
4/01/2008
5/01/2008
6/01/2008
7/01/2008
8/01/2008
Date (Hour)
Peak Flow Rate
Relative Humidity

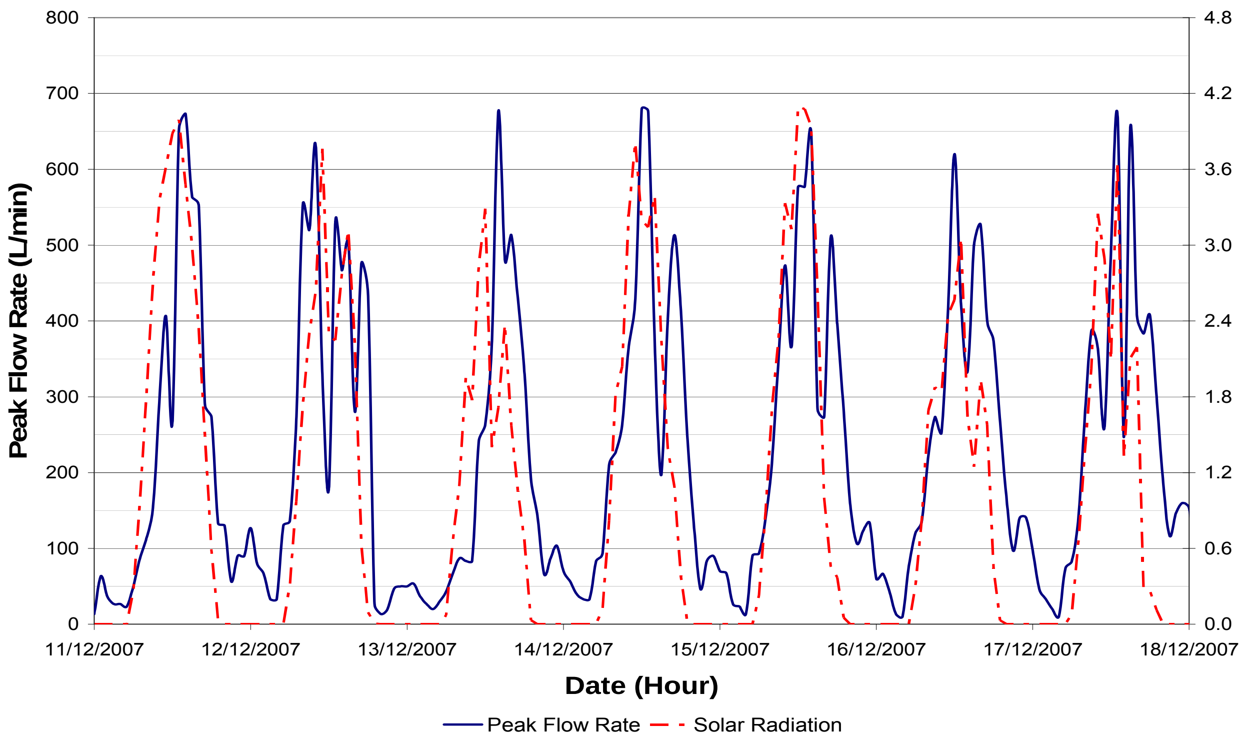

Peak Flow Rate (L/min)
Relative Humidity (%)
800
700
600
500
400
300
200
100
0
96
84
72
60
48
36
24
12
0
8/01/2008
9/01/2008
10/01/2008
11/01/2008
12/01/2008
13/01/2008
14/01/2008
15/01/2008
Date (Hour)
Peak Flow Rate
Relative Humidity

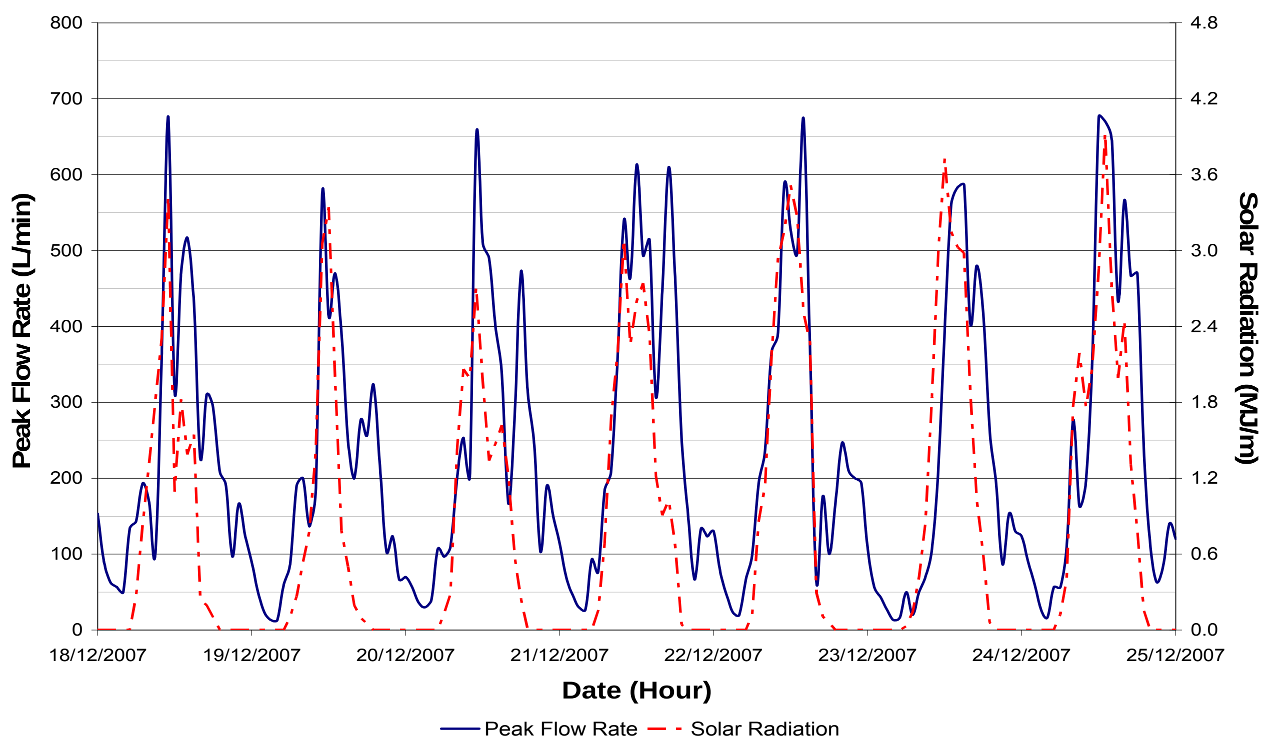

Peak Flow Rate (L/min)
Relative Humidity (%)
800
700
600
500
400
300
200
100
0
96
84
72
60
48
36
24
12
0
15/01/2008
16/01/2008
17/01/2008
18/01/2008
19/01/2008
20/01/2008
21/01/2008
22/01/2008
Date (Hour)
Peak Flow Rate
Relative Humidity

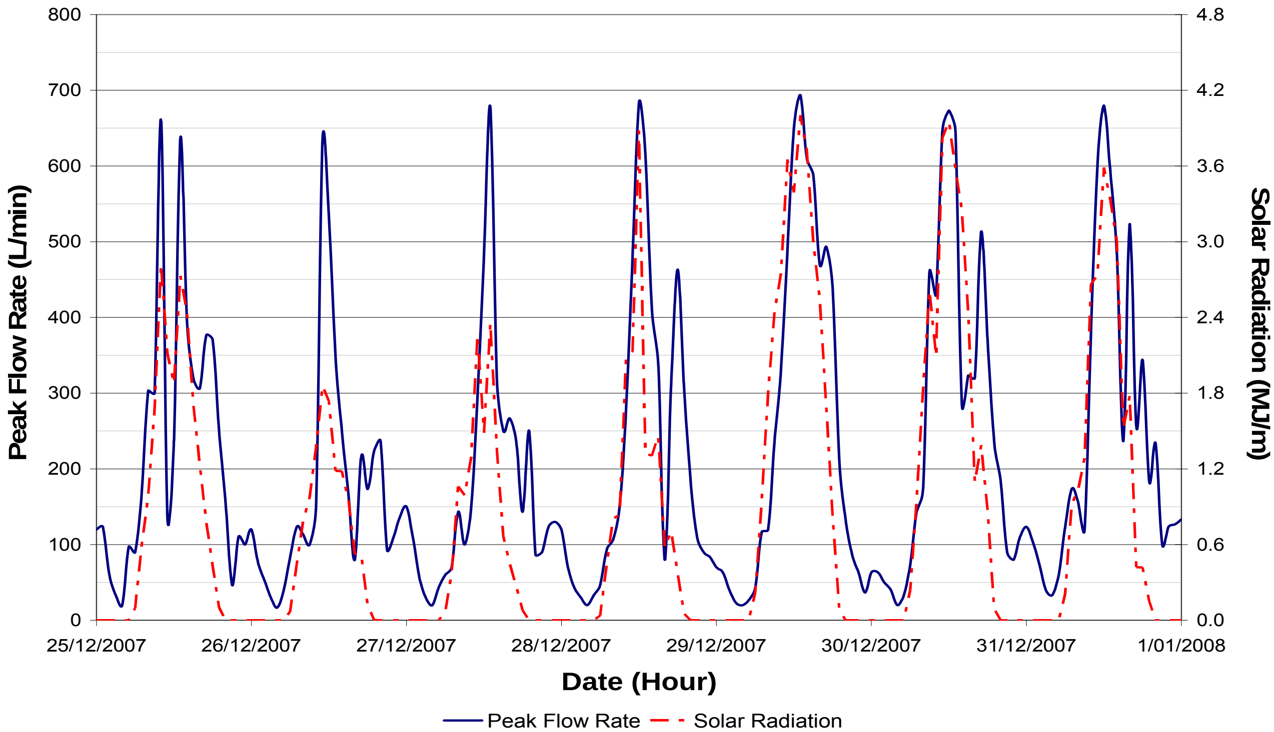

800
700
600
500
400
300
200
100
0
Peak Flow Rate (L/min)
96
84
72
60
48
36
24
12
0
Relative Humidity (%)
22/01/2008
23/01/2008
24/01/2008
25/01/2008
26/01/2008
27/01/2008
28/01/2008
29/01/2008
Date (Hour)
Peak Flow Rate
Relative Humidity

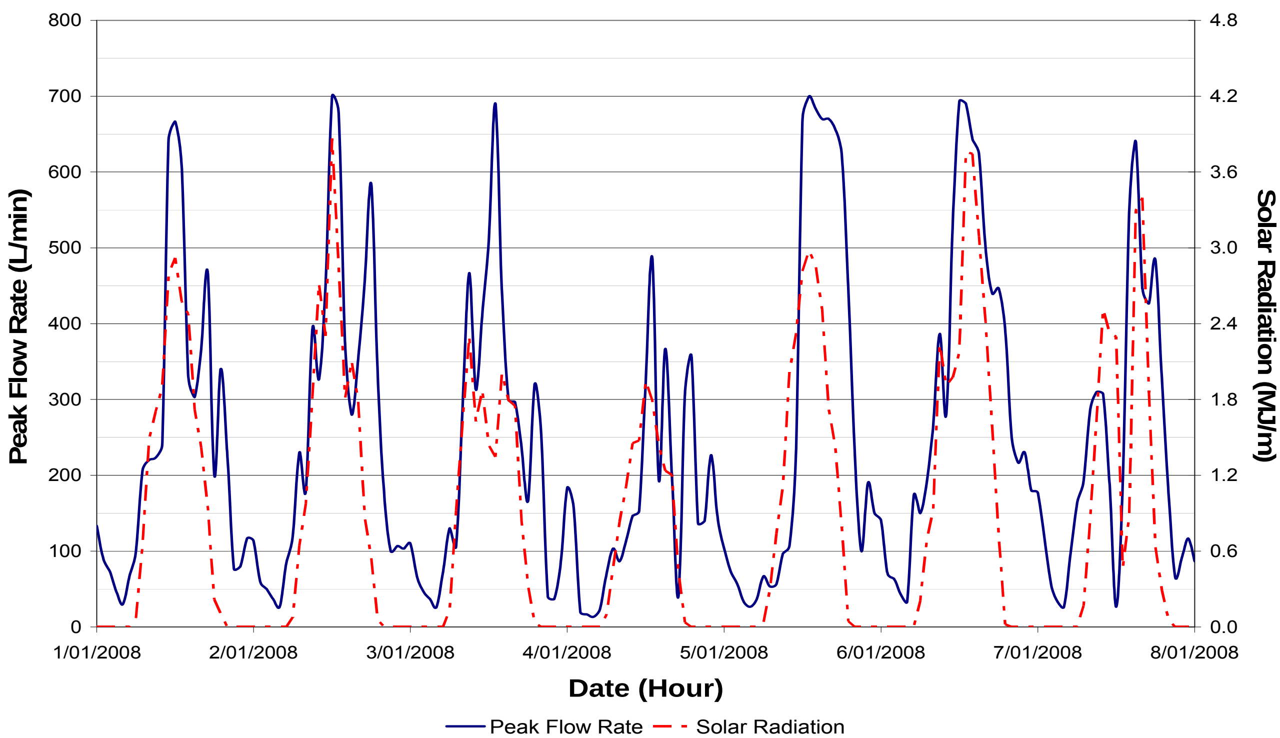

800
700
600
500
400
300
200
100
0
Peak Flow Rate (L/min)
96
84
72
60
48
36
24
12
0
Relative Humidity (%)
29/01/2008
29/01/2008
30/01/2008
30/01/2008
31/01/2008
31/01/2008
1/02/2008
Date (Hour)
Peak Flow Rate
Relative Humidity

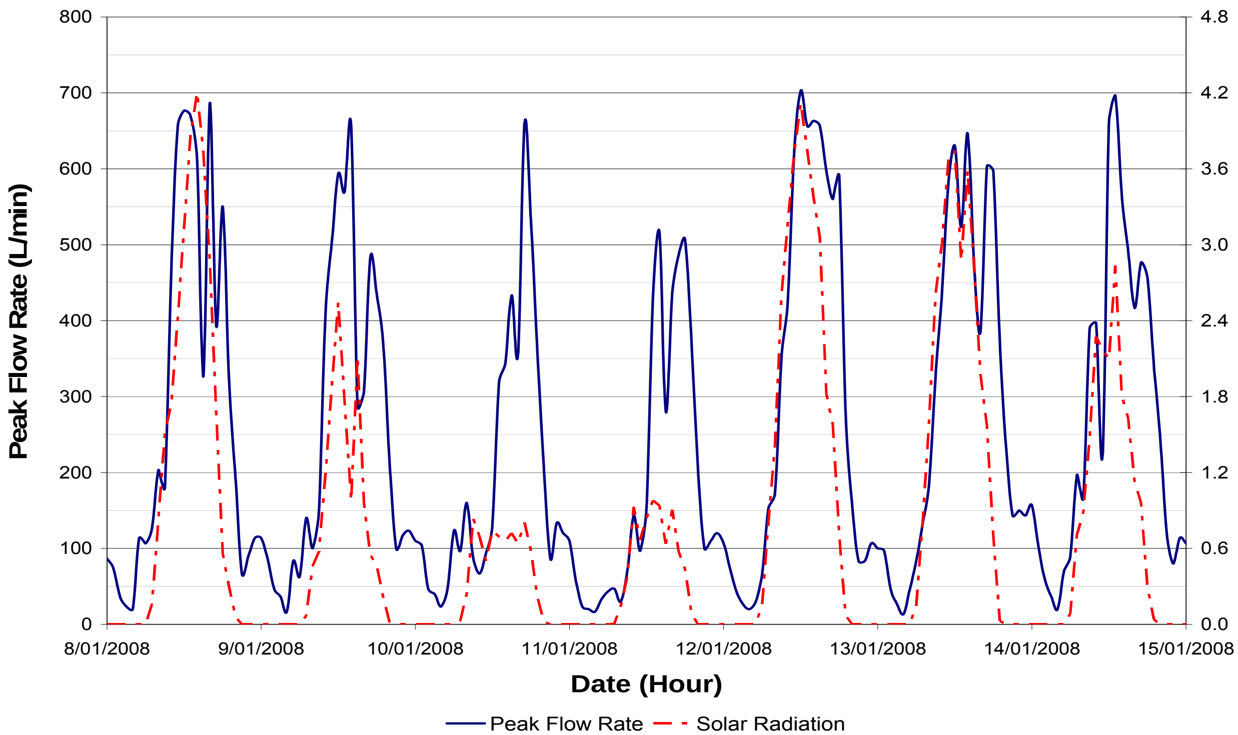
Influence of Solar Radiation

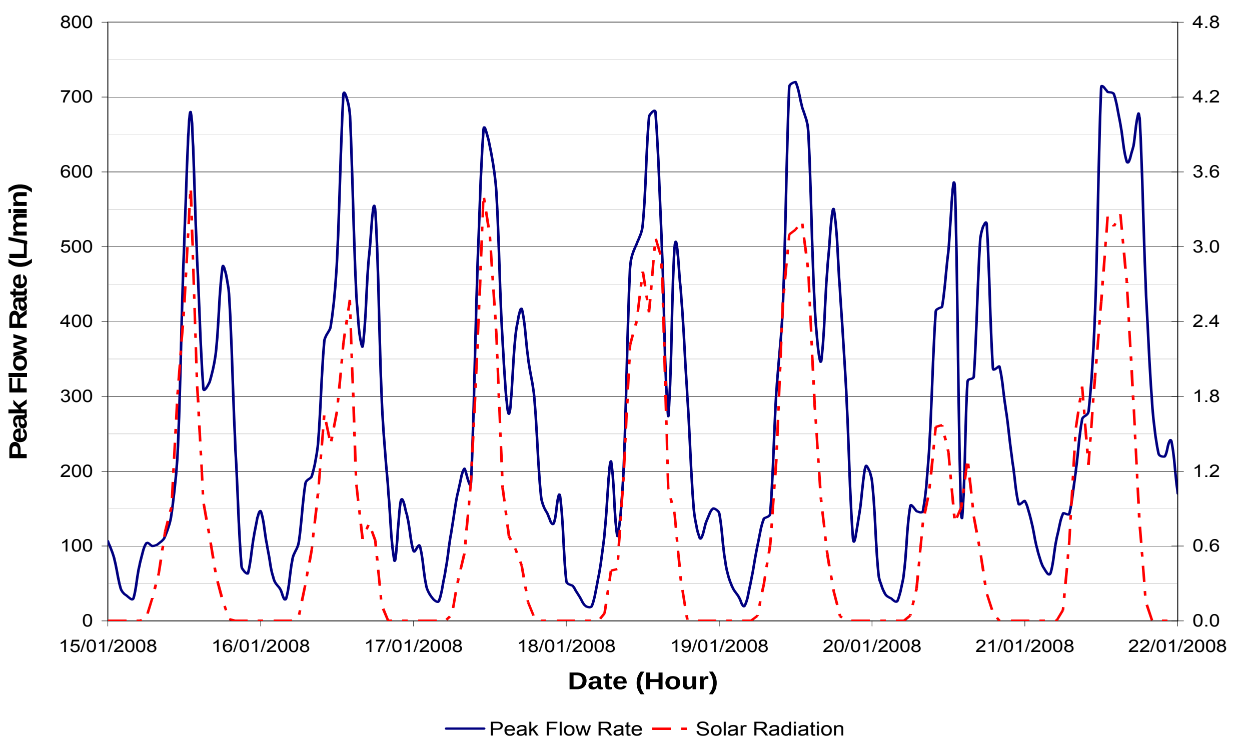


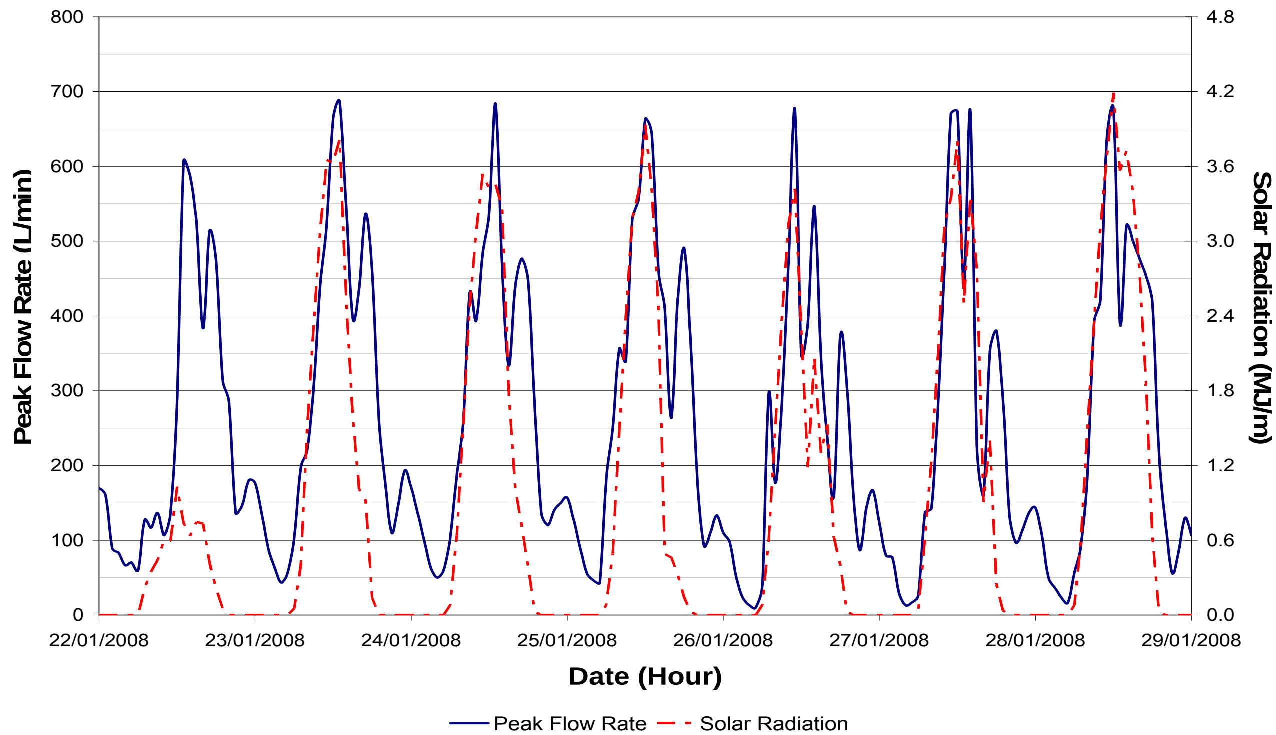


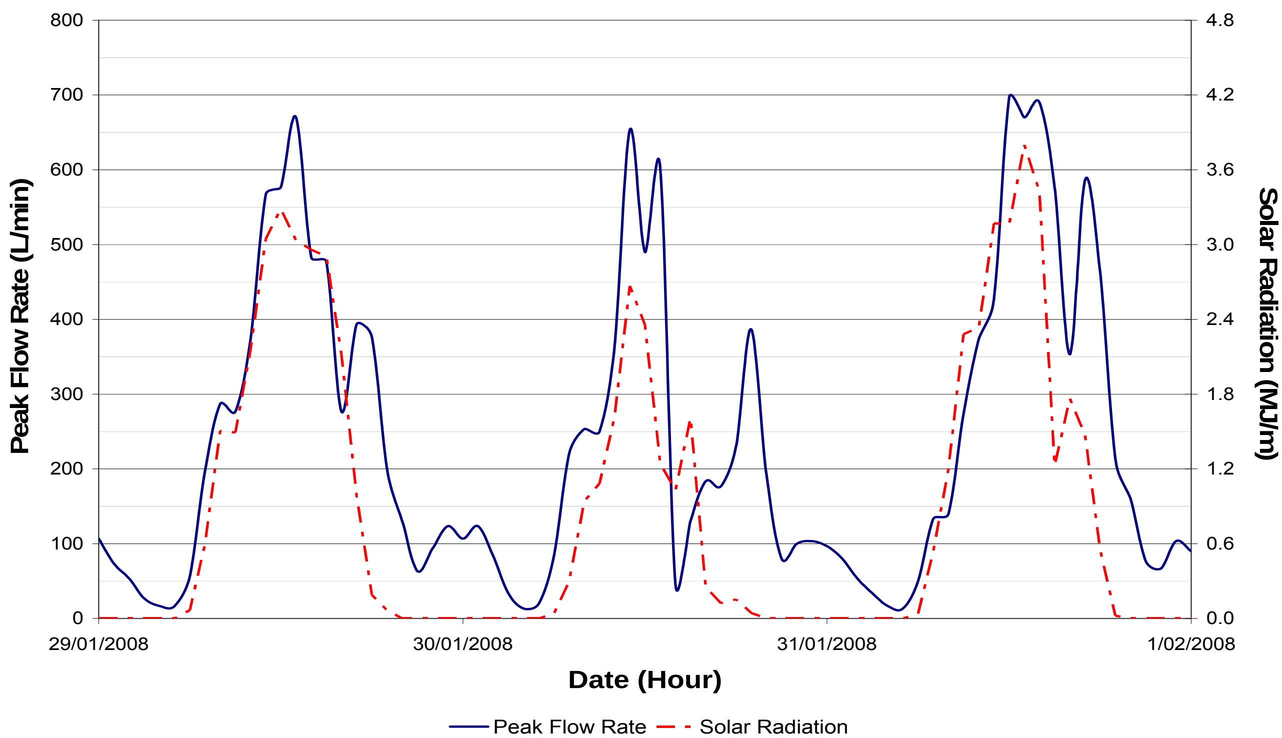

Peak Flow Rate (L/min)
Solar Radiation (MJ/m)
800
700
600
500
400
300
200
100
0
4.8
4.2
3.6
3.0
2.4
1.8
1.2
0.6
0.0
25/12/2007
26/12/2007
27/12/2007
28/12/2007
29/12/2007
30/12/2007
31/12/2007
1/01/2008
Date (Hour)
Peak Flow Rate
Solar Radiation


Peak Flow Rate (L/min)
Solar Radiation (MJ/m)
800
700
600
500
400
300
200
100
0
4.8
4.2
3.6
3.0
2.4
1.8
1.2
0.6
0.0
1/01/2008
2/01/2008
3/01/2008
4/01/2008
5/01/2008
6/01/2008
7/01/2008
8/01/2008
Date (Hour)
Peak Flow Rate
Solar Radiation

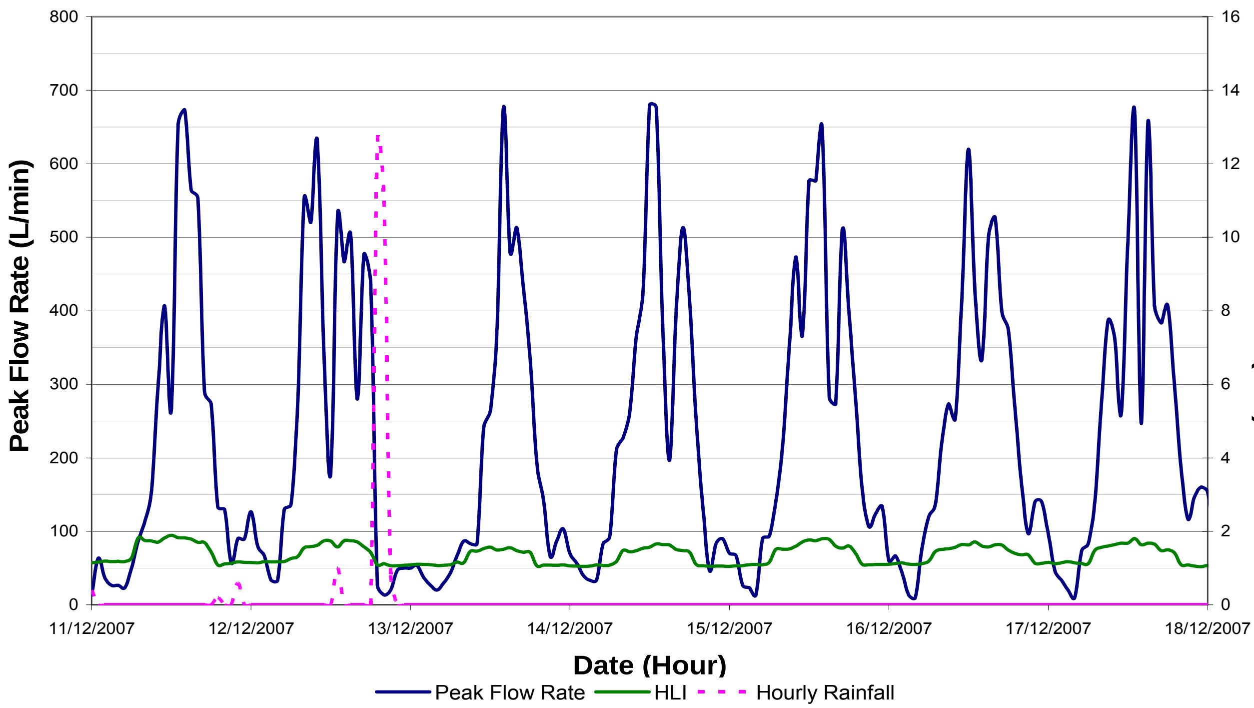

Peak Flow Rate (L/min)
Solar Radiation (MJ/m)
Date (Hour)
8/01/2008
9/01/2008
10/01/2008
11/01/2008
12/01/2008
13/01/2008
14/01/2008
15/01/2008
Peak Flow Rate
Solar Radiation

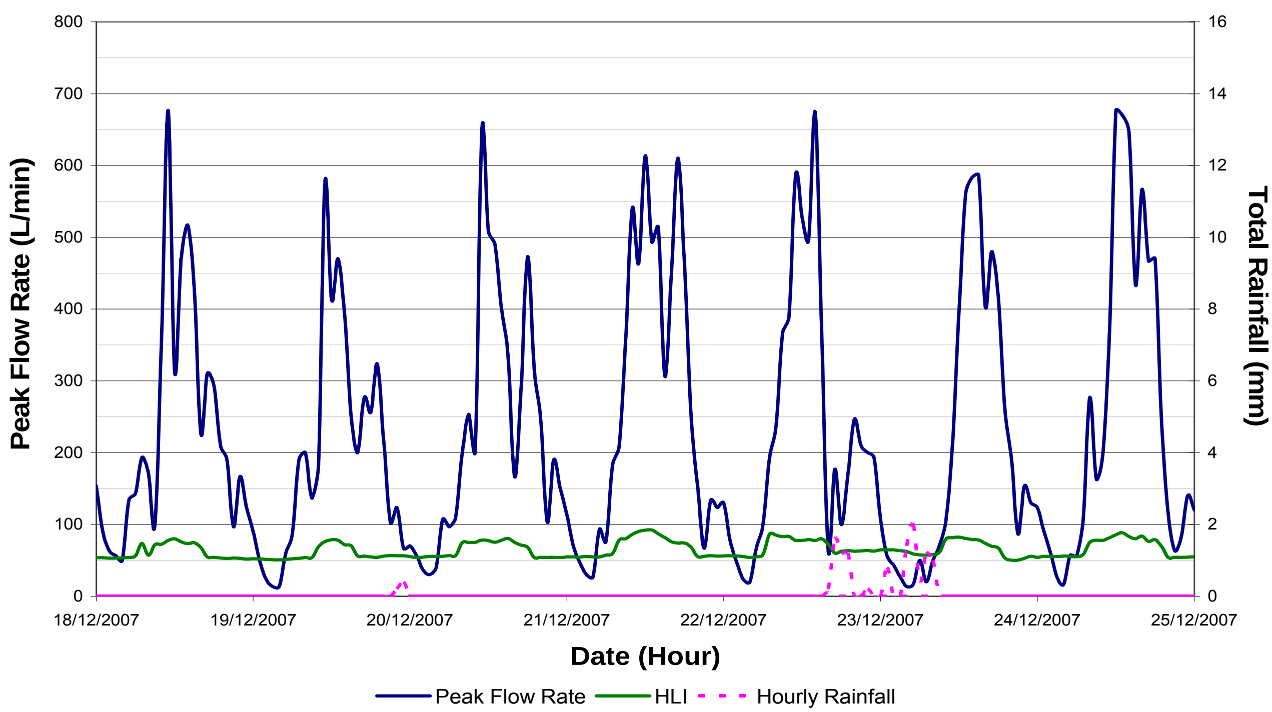

Peak Flow Rate (L/min)
Solar Radiation (MJ/m)
Date (Hour)
15/01/2008
16/01/2008
17/01/2008
18/01/2008
19/01/2008
20/01/2008
21/01/2008
22/01/2008
Peak Flow Rate
Solar Radiation

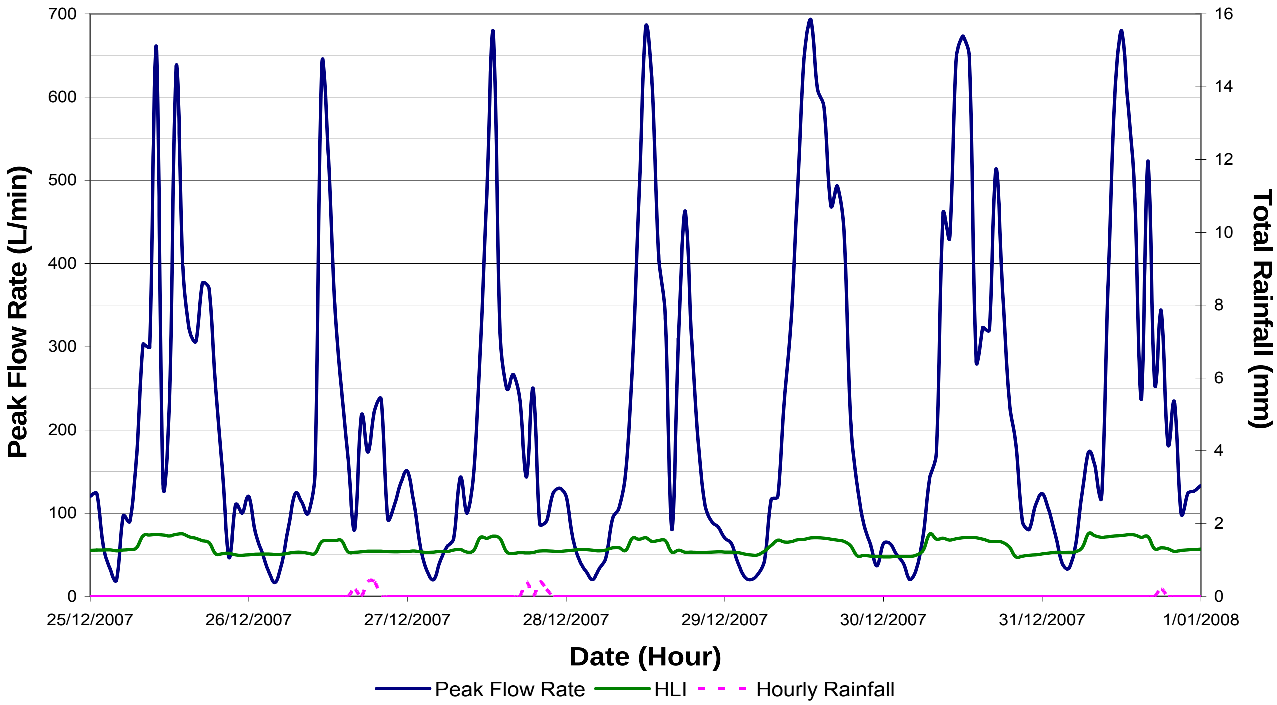

Peak Flow Rate (L/min)
800
700
600
500
400
300
200
100
0
Solar Radiation (MJ/m)
4.8
4.2
3.6
3.0
2.4
1.8
1.2
0.6
0.0
22/01/2008
23/01/2008
24/01/2008
25/01/2008
26/01/2008
27/01/2008
28/01/2008
29/01/2008
Date (Hour)
Peak Flow Rate
Solar Radiation


Peak Flow Rate (L/min)
800
700
600
500
400
300
200
100
0
Solar Radiation (MJ/m)
4.8
4.2
3.6
3.0
2.4
1.8
1.2
0.6
0.0
29/01/2008
30/01/2008
31/01/2008
1/02/2008
Date (Hour)
Peak Flow Rate
Solar Radiation

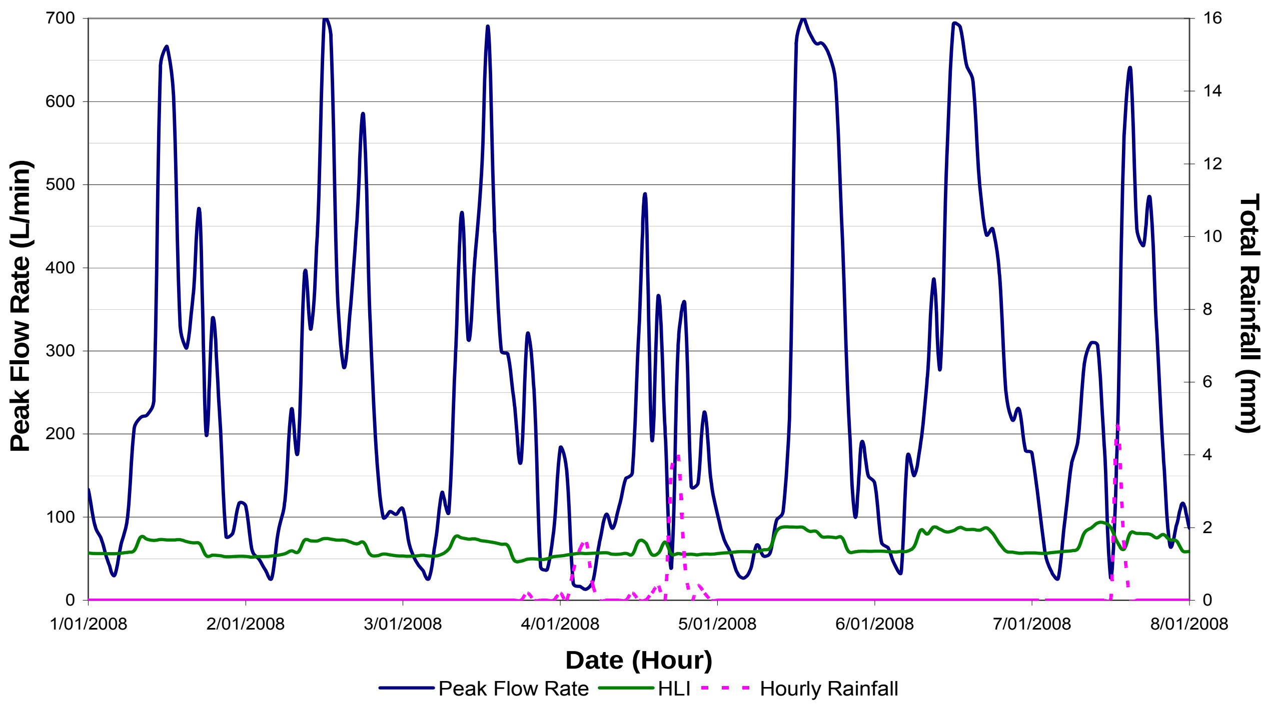
Influence of Rain



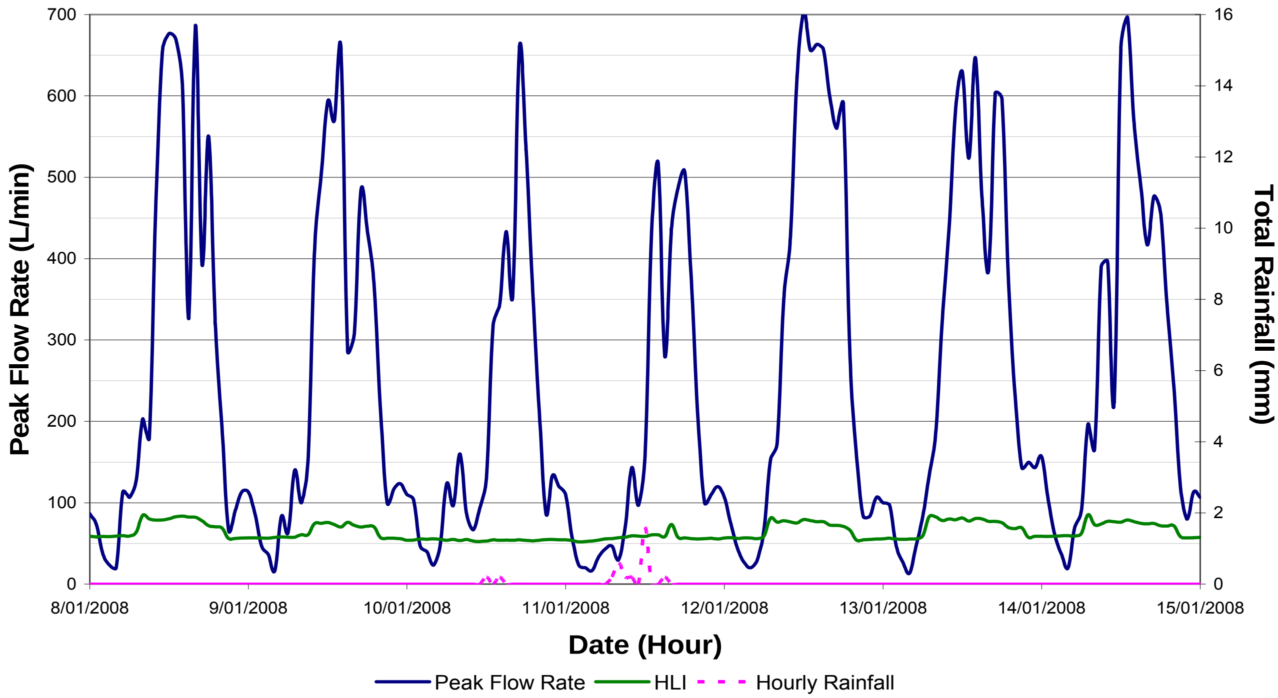




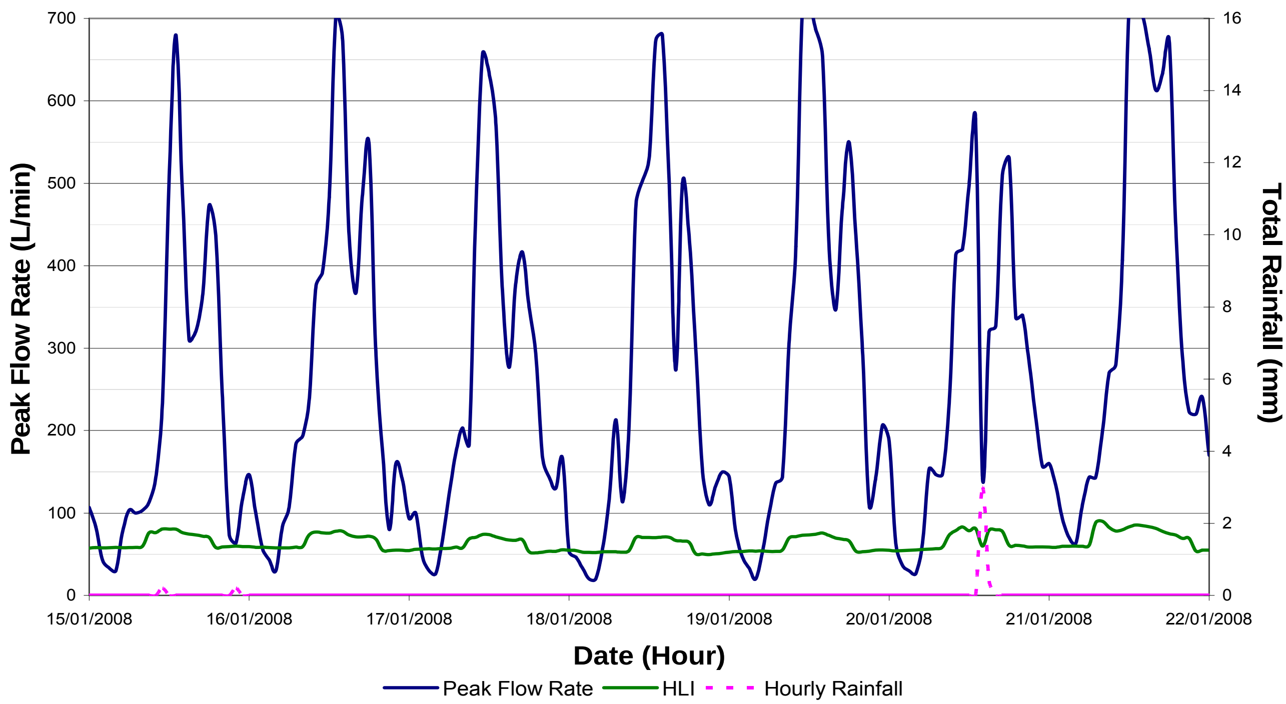
Peak Flow Rate (L/min)
Total Rainfall (mm)
0
100
200
300
400
500
600
700
0
2
4
6
8
10
12
14
16
25/12/2007
26/12/2007
27/12/2007
28/12/2007
29/12/2007
30/12/2007
31/12/2007
1/01/2008
Date (Hour)
Peak Flow Rate
HLI
Hourly Rainfall



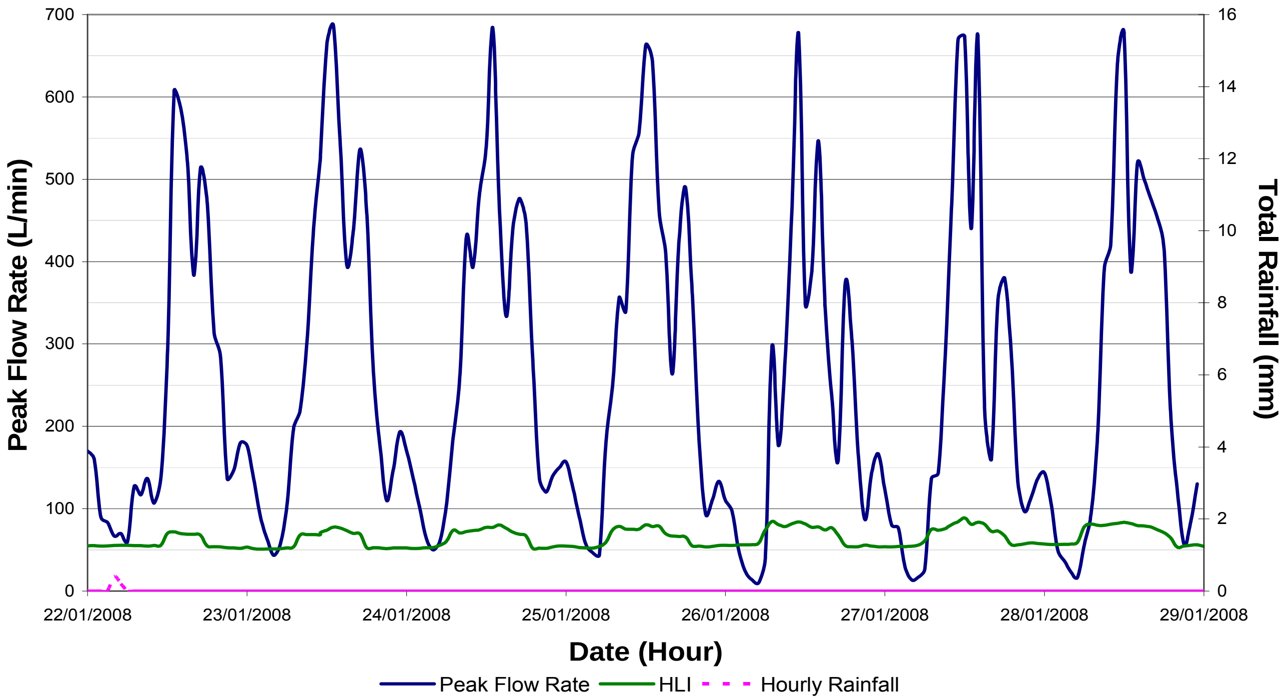
Peak Flow Rate (L/min)
Total Rainfall (mm)
0
100
200
300
400
500
600
700
0
2
4
6
8
10
12
14
16
1/01/2008
2/01/2008
3/01/2008
4/01/2008
5/01/2008
6/01/2008
7/01/2008
8/01/2008
Date (Hour)
Peak Flow Rate
HLI
Hourly Rainfall

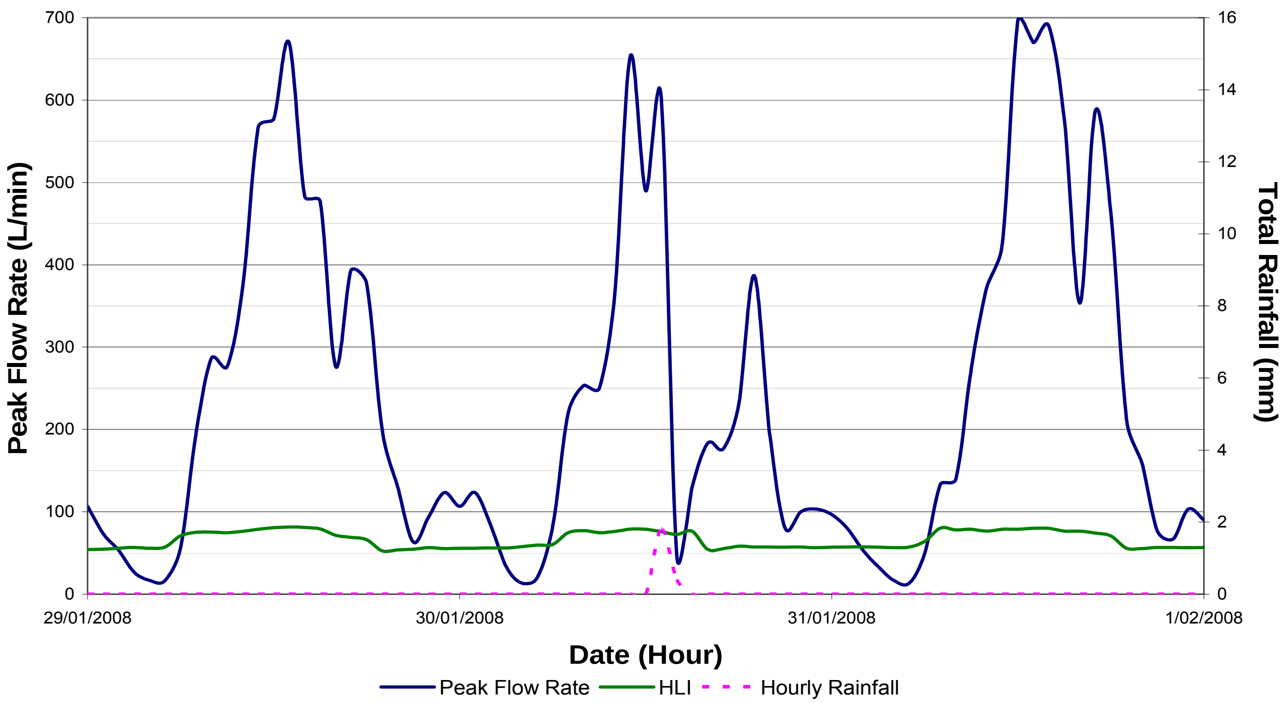


Peak Flow Rate (L/min)
Total Rainfall (mm)
Date (Hour)
8/01/2008
9/01/2008
10/01/2008
11/01/2008
12/01/2008
13/01/2008
14/01/2008
15/01/2008
Peak Flow Rate
HLI
Hourly Rainfall



Peak Flow Rate (L/min)
Total Rainfall (mm)
Date (Hour)
15/01/2008
16/01/2008
17/01/2008
18/01/2008
19/01/2008
20/01/2008
21/01/2008
22/01/2008
Peak Flow Rate
HLI
Hourly Rainfall


Peak Flow Rate (L/min)
Total Rainfall (mm)
Date (Hour)
22/01/2008
23/01/2008
24/01/2008
25/01/2008
26/01/2008
27/01/2008
28/01/2008
29/01/2008
Peak Flow Rate
HLI
Hourly Rainfall


Peak Flow Rate (L/min)
Total Rainfall (mm)
Date (Hour)
29/01/2008
30/01/2008
31/01/2008
1/02/2008
Peak Flow Rate
HLI
Hourly Rainfall