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Stormwater Impacts on Discharge Water Quality in Licensed Drains at the Port Kembla Steelworks

A thesis submitted in fulfilment of the requirements for the award of the degree

Masters of Environmental Science by Research

from

UNIVERSITY OF WOLLONGONG

by

Louis Mathew Whant, BSc. (Chem)

Faculty of Science

2005

CERTIFCATION

I, Louis Mathew Whant, declare that this thesis, submitted in fulfilment of the requirements for the award of the Masters by Research, in the Department of Environmental Science, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Louis Mathew Whant
29th September 2005.

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ABSTRACT

This study encompassed work on four of the Environment Protection Authority (EPA) licensed discharge points at the Port Kembla Steelworks (PKSW). These included the North Gate Drain, the Main Drain, the Flat Products East No.1 Drain and the Ironmaking East Drain. This study incorporated a hydrological study of the drains, and a stormwater discharge water quality study.
The aims of the hydrological component were: to obtain an understanding of the behaviour of each of these drains during rainfall events; to determine fractions of runoff compared to rainfall volume; to determine the influence antecedent precipitation has on the discharge of each drain; and, to relate the findings to catchment type.

The aims of the water quality component were: to determine the concentrations of priority pollutants in licensed drains during wet weather and the first flush; to determine the likely source of any stormwater borne contaminants; and, to use the water quality data to determine appropriate wet weather licence limits. These aims were developed to assist in the design of further investigations involving stormwater management at PKSW. This study encompassed 16 months of stormwater monitoring and involved the collection of over 1300 samples.

The findings were that Flat Products East No.1 Drain and Iron Making East Drain displayed very similar characteristics during rainfall events. Both exhibit ‘flashy’ hydrographs, with fast response to rainfall, and steep recession curves where return to ‘baseline’ or process flow is rapid. The fraction of discharge compared to total rainfall volume (falling on the catchment) for both these drains was high (>80%). Their small catchments, containing almost entirely sealed impervious surfaces, led to very small water losses. The Flat Products East No.1 Drain and Iron Making East Drain discharge volumes, during rainfall, were found to be unaffected by antecedent rainfall.

The Main Drain was found to have a delayed response to rainfall. The Main Drain and the North Gate Drain hydrographs displayed slow receding recession curves where the elevated flow continued for hours after the rainfall events had ceased. The fraction of discharge compared to total rainfall volume (falling on the catchment) for the Main Drain was found to be small, indicating large water losses to infiltration and percolation to groundwater recharge via the relatively large grassed and unsealed, pervious areas within the catchment. An anomaly was found in this fraction for the North Gate Drain due to overestimations in discharge rates from online monitoring equipment and it is recommended this be rectified. Both the Main Drain and North Gate Drain discharge volumes were shown to be affected by antecedent rainfall conditions.

The program for the water quality component of this study, specifically targeted the water quality of the 'first flush', sampling every ten minutes during a storm event. The intensive sampling program allowed for the collection of a diverse wet weather data set not investigated previous to this study. The data showed that pollutant concentrations during wet weather are elevated compared to the historical dry weather water quality data. Confidence limits were calculated and compared to current wet weather licence limits. In some cases, the current wet weather licence limits are inadequate, and recommendations have been made for the revision of wet weather licence limits using the calculated 95% CL as a basis.

This study identified areas were there are contaminant issues during wet weather, e.g., the Main Drain Total Suspended Solids (major component coal) and the Flat Products East No.1 Drain Total Iron (major component iron prills), and also areas where there are no current drain issues during wet weather (North Gate Drain). Monitoring of pH at all specified drains in this study did not identify any pH excursions during wet weather and no evidence of elevated pH in stormwater runoff was identified. However, further monitoring will be required at North Gate Drain after the removal of current saltwater discharge.

This study, whilst specific and extensive, is limited to only four licensed discharge points at PKSW. Extrapolating the findings of this report to the remaining licensed discharge points is not recommended due to vast differences between catchments across the PKSW site, including their size, land usage, plant, associated equipment, activities and salinity. Instead it is recommended that a similar study be commenced on the remaining nine licensed drains.

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1 INTRODUCTION

In an undeveloped area, the stormwater management system is provided by nature. The stormwater cycle begins with rainfall – the storm. Stormwater usually refers to situations where the rainfall significantly exceeds the capacity of the vegetation and soil to absorb it, and the excess moves under the influence of gravity. Thus, stormwater can be described as water borne by rainfall falling on or within a catchment that moves over the land surface in significant quantities. Some of the rainwater stands where it falls on leaf or plant and evaporates; some is absorbed into the ground near the surface and feeds trees and plants, ultimately returned to the atmosphere by transpiration; some percolates deeply into the ground and replenishes the ground water supply (ULI, 1979). The remainder gradually or quickly collects into rivulets, accumulating in both quantity and speed as it hurries down the watershed through drains, causeways and streams, to its ultimate destination, rivers, lakes and the sea, to begin the cycle again.

Stormwater management in Australia is a shared responsibility between local councils, state government agencies, land developers, building contractors, industry and the local community. Current El Nino conditions and critical local dam storage levels have resulted in recent pressure to reduce water consumption. Particular focus has been placed on those whose consumption is highest (i.e., heavy industry). The overall objective of a stormwater management plan for the Port Kembla Steelworks (PKSW) is to facilitate the co-coordinated management of stormwater that maximises ecological, social and economic benefits in a sustainable way. A first step in this process is to determine the water quality from any runoff and discharges. This leads to an ultimate goal of establishing stormwater management, including capture and re-use of rainwater as part of any business planning process.

The ‘first flush’ phenomenon can be described as the initial period of stormwater runoff during which the concentrations of pollutants are substantially higher than those in the later stages of the storm event (Lee, *et al.* 2002). Characteristics of the first flush are influenced by a number of factors including: intensity and duration of the rainfall event; catchment size; catchment land usage; and antecedent rainfall. Previous studies have shown that the first flush phenomenon is a leading cause of degradation to the quality of the receiving waters (Lee, *et al*. 2002). The majority of past research has concentrated on establishing stormwater and runoff characteristics for urban and rural catchments; little attention has been paid to industrial areas. This study will focus on the first flush characteristics of a heavy industrial site, the PKSW, and is the first such study.

PKSW has 13 licensed discharge points (drains) of which a large proportion drain into Allans Creek and Port Kembla Harbour (see Figures 1.5, 1.6 and 1.7). These discharge points double as stormwater drains during wet weather, to provide drainage for general plant areas. A vast quantity of historical dry weather discharge data is available on licensed drains at the PKSW but, first flush characteristics are virtually unknown. Currently there are separate licence compliance limits for dry and wet weather conditions, little or no scientific methodology has been used for the determination of wet weather licence limits. Increasing pressure from the NSW Department of Environment and Conservation (DEC) on drain discharge water quality and site specific Pollution Reduction Programs (PRPs) have resulted in licence requirements including the monitoring of pollutant concentrations during wet weather, specifically targeting the first flush, with this data being used as a basis for establishing revised wet weather licence limits.

This study focuses on the hydrological and discharge water quality characteristics of four licensed drains at the PKSW. This study is based on a PRP (PRP98) set out in Environment Protection Licence (EPL) 6092 (Department of Environment and Conservation, 2005). The four drains included in this study are:

- North Gate Drain
- Main Drain
- Ironmaking East Drain
- Flat Products East No.1 Drain.

The analytes determined for stormwater discharge quality in this study are:

- pH
- Total Suspended Solids (TSS)
- Total Iron.

Other parameters (e.g. Cr, Cu, Sn, Pb, Hg, Cd, Zn) were initially considered for inclusion in this study but the limited information available indicated that they were of lower significance for the drains included in this project. In addition, it has been observed that these elements are normally associated with suspended solids.

The objective of this study was to address the following questions:

1. What is the relationship between rainfall and stormwater discharge at each of the drains?
2. How is the stormwater discharge affected by antecedent rainfall?
3. What are the concentrations of pollutants in licensed drains at PKSW during wet weather (first flush)?
4. What are the likely sources of any stormwater borne contamination in these drains?
5. What are appropriate wet weather license limits for drains at PKSW?

This study was completed in three steps: firstly a hydrological survey was completed looking at rainfall and discharge characteristics only; secondly, a sampling and analysis program for stormwater runoff was developed based on the findings of the hydrological study; and finally, analysis and interpretation of data was carried out in order to formulate the conclusions drawn and recommendations made in this report.

1.1 WATER AND RUNOFF

1.1.1 The Hydrological Cycle

Water is the most abundant substance at the Earth's surface (Chow, *et al*. 1988). The constant movement of this vast amount of water is known as the 'Hydrological Cycle'. Hydrology is concerned with the transport of water through the air, over the ground surface and through the strata of the Earth (Ward & Elliot, 1995). Figure 1.1 shows the 'Hydrological Cycle' demonstrating how water circulates globally through the various processes. The most obvious and visible components of the 'Hydrological Cycle' are precipitation and runoff, but the other components, including evaporation, infiltration into ground and soils, transpiration by plants, percolation into groundwater, and groundwater discharge and interflow are equally important (Ward & Elliot, 1995). As previously discussed, the first step of this study concentrates on precipitation and runoff for each of the four drains, but will also look at the other components of the 'Hydrological Cycle' to help discuss the results and findings in this report.

Please see print copy fot Figure 1.1

Figure 1.1 'The Hydrological Cycle' (from Shaw 1983)

1.1.2 Local Precipitation.

Precipitation within a catchment is primarily controlled by two factors, one local and the other regional. The regional systems are continental air masses, which are mainly responsible for the availability of moisture in the Illawarra (Cox, 1983, as reported in Clarkson, 1995). The major local influence on precipitation for these four catchments in this study is the orographic effect of the Illawarra Range. Local Rainfall increases with proximity to the Illawarra Escarpment. The highest rainfall in the region is commonly found between Mount Keira and Mount Kembla (Cox, 1983, as reported in Clarkson, 1995).

Regional differences are demonstrated in Figure 1.2, which shows the annual average 'regional' rainfall for NSW. It shows the Illawarra region as having an annual average of between 1200 and 1800 mm (Bureau of Meteorology, 2005).

Please see print copy for Figure 1.2

Figure 1.2 Average Annual Regional Rainfall for NSW (source www.bom.gov.au based on 30 years of data 1961-1990)

BlueScope Steel Limited (BSL) currently measures rainfall at 2 sites inside the PKSW: The North Gate Drain and Slab Mill Drain pluviometers. Records indicate the average annual rainfall for the PKSW site is 1100 – 1250 mm and there are approximately 120 wet days per year, with around 20 of these days having rainfall greater than 10 mm (Green, 2005). However, the Illawarra escarpment, which rises to greater than 700 m within 12 km of the coast, produces a strong orographic rainfall gradient (Nanson and Reinfelds, 2001), where the annual average rainfall is up to 1800 mm at the escarpment crests. This feature forms a locus for frequent, high intensity rainfall events, and it is theorised that a 1 in 100 year rainfall event occurs in the greater Wollongong region every 25 years (Nanson and Reinfelds, 2001). Due consideration must be given to this trend when determining appropriate wet weather licence limits and the magnitude of a rainfall event that will have to be managed effectively at the PKSW. The data collected for this study includes one such high intensity rainfall event (classed as a 1 in 5 year event), that occurred on the 4th and 5th of April 2004 where >250 mm of rain fell on the PKSW site in 48 hours. The Illawarra escarpment forms part of catchments for Allans Creek, Byarong Creek and American Creek. The Allans Creek catchment serves as the predominant freshwater drainage system into Port Kembla Harbour and flows through the PKSW site (Clarkson, 1995).

1.1.3 Hydrographs

A hydrograph describes the whole time history of the changing flow from a catchment due to a rainfall event (Shaw, 1983). Thus a hydrograph is a plot of discharge (or flow rate) vs. time. Figure 1.3 shows a typical hydrograph.

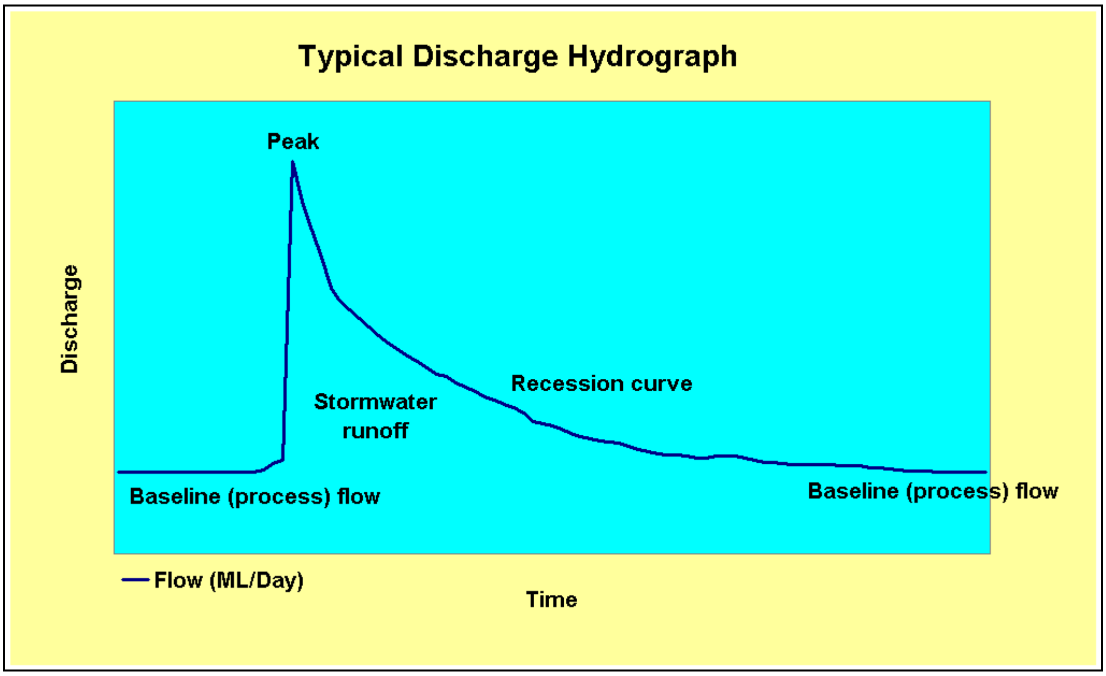


Figure 1.3 Typical Discharge Hydrograph

The hydrograph tells more about the hydrology of a small catchment than any other measurement (Ward and Elliot, 1995). The discharge hydrograph has two main components:

- The area under the hump labelled as 'Stormwater runoff' in Figure 1.3. This is produced by the volume of water derived from a rainfall event (Shaw, 1983);
- The other major component is the broad band near the time axis which represents the 'baseline', or in the case of this study, the process flow.

The area under the hydrograph, minus the baseline or process flow, represents the volume of stormwater runoff. The *rising limb*, as the name suggests, relates to the rise in the flow at the start of a rainfall event. The length of delay and steepness of the rising limb depends on the wetness of the catchment before the rainfall event, and on the intensity of the rain (Shaw 1983). The *recession curve* is the depreciation of the flow as the catchment returns to the baseline or process flow.

Forest type catchments, or catchments with large areas of dense bushland, scrub or grassed areas, tend to have recession curves where the elevated flow above the baseline can continue for days after the rainfall event. This can be caused by infiltration of stormwater into soil, percolation into groundwater recharge, losses due to evaporation and transpiration into grass and plants (Ward & Elliot, 1995).

Stormwater runoff from small, urban type catchments, in which most of the area contains sealed or impervious surfaces, often have hydrographs that are termed ‘flashy’ (Ward & Elliot, 1995). These flashy hydrographs have discharge peaks shortly after the most intense rainfall occurs, with the flow decreasing rapidly after the rainfall stops. This occurs as there is little or no stormwater loss to soil or groundwater recharge (Ward & Elliot, 1995). These differences in hydrographs for ‘natural’ and ‘urbanised’ catchments are highlighted in Figure 1.4.

Please see print copy for Figure 1.4

Figure 1.4 Hydrograph Comparisons Between Urban and Natural Catchments (taken from Warner, 1976)

1.1.4 Rainfall Volume

Assuming rainfall is uniform over the entire catchment, a rainfall volume can be calculated by taking the average depth of precipitation for a rainfall event and multiplying it by the total surface area of the catchment. This gives an indication of the volume of rain that falls on the catchment during a particular event. This theoretical value is useful in determining the fraction of water that actually leaves the catchment as runoff via the drain, river or stream, etc.

1.1.5 Antecedent Rainfall

As mentioned in Section 1.1.3, the characteristics of a hydrograph are influenced by the wetness of the catchment at the start of the rainfall event. The state of wetness of the catchment affects the amount of effective rainfall that will form direct stormwater runoff (Shaw, 1983). The more moisture there is in the ground, the less will percolate in from any storm activity as soil pores are already full, increasing the runoff (Clarkson, 1995). A general guide to the degree of moisture in the ground can be obtained from the Antecedent Precipitation Index or API (Shaw, 1983). The general equation and details on the method used for calculating API values are reported in Section 2.2.

1.2 PORT KEMBLA STEEL WORKS

The PKSW is located on the South Coast of NSW, 71 kilometres south of Sydney at latitude 34º 29'S and longitude 150º 54' E. It is Australia's largest steel plant with a 5 Mtpa production capacity. Activities and plant on site include: a sinter plant (and associated raw materials handling); two blast furnaces; steel making facilities (BOS and Slabcaster); electrical energy generation facilities; coke making facilities (including associated coal handling); recycling area and finishing mills (Flat Products Area). The Flat Products Area includes a plate mill, a hot strip mill (HSM), two electrolytic tinning lines (ET lines), a cold mill and a continuous annealing line (CA line). The overall area covered by PKSW is approximately 800 hectares.

1.2.1 Specified Drains and Catchment Descriptions

This section details the industrial activities, size and land usages within the catchments for each drain included in this study. Figure 1.5 shows an aerial photograph of the PKSW indicating the locations of each of the specified drains included in this report.

1.2.1.1 North Gate Drain

The North Gate Drain is located approximately 300 m to the east of the North Gate entrance to PKSW off Springhill Road (see Figure 1.5). Under previous normal plant operating conditions, the North Gate Drain process discharge consisted primarily of blowdown water from the Hot Strip Mills recirculated water system and saltwater. PRP118, completed in 2004, redirected the process discharges to the Slab Mill Drain and any remaining process flows in the North Gate

Drain are minor. In addition to this, early in 2005, BSL started gradual reductions in the volume of salt water entering the drain. The North Gate Drain catchment area is estimated at 983,100 m^2 (of which 477,153 m^2 lies on PKSW land). This includes much of the northern parts of the PKSW Flat Products area, and stretches into residential Mount St Thomas. The major land usages in this catchment are: heavy industrial (~35%), where much of the surface is sealed or impervious where stormwater runoff consists of roof, road and yard drainage for a large part of the Flat Products Area; urban (~30%); and approximately 35% that contains grassed or non-sealed pervious surfaces. The catchment for the North Gate Drain has been mapped, the BSL drawing number is 470394.

1.2.1.2 Main Drain

The PKSW Main Drain runs adjacent to Kembla Road (see Figure 1.5). The Main Drain Process flow consists almost entirely of cooling water from No.1 Powerhouse (~90%). The remaining 10% is water from No. 1 Open Hearth Drain, but also includes drainage from Steel Haven West, No.1 Works, urban water from Cringila, and Central Laboratory.

The PKSW Main Drain overall catchment area is approximately 3,312,500 m^2 (of which an estimated 269,357 m^2 lies within the PKSW). This catchment area covers the entire PKSW No.1 Works, the Administration, Commercial and Engineering building areas, stretching west to include parts of Cringila. It also includes coal and coke stockpile areas on the eastern side of Kembla Road, road, roof and yard drainage, Coke Ovens Retention Basin (CORB), gasholders, Project M building (now MultiServ) and ground water. The major land usages in this catchment are approximately 25% industrial area and 75% that is unsealed containing grassed, pervious surfaces. The Main Drain catchment area has been mapped as part of PRP99, and the BSL drawing number is 470395.

1.2.1.3 Ironmaking East Drain

The Ironmaking East Drain is situated near the Iron Ore unloading berth adjacent to the Sinter Plant (see Figure 1.5). It discharges into the southeastern corner of Port Kembla Inner Harbour. The Ironmaking East Drain receives process water from No.5 Blast Furnace and BOS operations via the No.4 Blast Furnace thickener. This makes up approximately 40% of the normal process flow. Process water used for cooling air compressors at Energy Services and a demineralisation plant regeneration makes up an additional 40 – 50%. The remaining flow is made up of process water from 7A Battery (settling basin), salt water cooling and sullage from Iron Ore Road and adjacent jetty.

The Ironmaking East Drain catchment area is covered with greater than 90% of heavy industrial land usage including, buildings, road, yard drainage, carparks and various other sealed impervious surfaces. The area of this catchment is estimated at 181,222 m^2. This catchment area has been mapped as required by PRP99 and the BSL drawing number is 470395.

Please see print copy for Figure 1.5

Figure 1.5 Locations of Specified Drains (source Hatch Engineering 2003)

1.2.1.4 Flat Products East No.1 Drain

The Flat Products East No. 1 Drain is located just to the south of the No.2 Products Loading berth (see Figure 1.5) and discharges into Port Kembla Inner Harbour adjacent to the 'roll-on, roll-off berth' (RO-RO berth). Under normal dry weather process conditions, the discharge is almost entirely made up of two sources: ~50% of the flow is treated effluent from the Electrolytic Tinning (ET) line wastewater treatment plant (commonly known as 'ET1') and the other ~50% is secondary saltwater cooling.

The Flat Products East No.1 Drain has a catchment which covers approximately 204,073 m^2. The land usage in this catchment is almost entirely made up of industrial area with buildings, roads, yard drainage and sealed impervious surfaces. These areas include a scrap steel storage area, a water treatment plant, and a number of buildings containing Packaging Products operations. A catchment map for this licensed drain has been created. and is found in BSL drawing number 470394.

1.3 PORT KEMBLA HARBOUR

Much of the stormwater from the PKSW ends up in Port Kembla Harbour (PKH), either by direct discharge or though Allans Creek and other local waterways.

1.3.1 General Features of Port Kembla Harbour

PKH is located on the southeastern coast of NSW, Australia (lat. 34º29' South, long. 150º54' East, see Figure 1.6). The harbour consists of an outer harbour formed adjacent to a headland on the southern end of Wollongong beach by the construction of breakwaters, and an inner harbour formed by the dredging of Tom Thumb Lagoon (SPCC, 1977). The outer harbour covers an area of about 140 hectares with depths ranging from 15 meters at the entrance to between 5 and 13 meters at the jetties. The entrance to the harbour is 300 meters wide (SPCC, 1977). The inner harbour is an all weather port, unlike the outer harbour, which loses about ten days of shipping a year due to bad weather. Entrance to the inner harbour is through a 155 meter wide channel locally known as 'the Cut' (PKPC, 1995, cited in He and Morrison, 2001). The inner harbour covers an area of 60 hectares, with depths between 8 and 12 meters (SPPC, 1977).

1.3.2 A Brief History of Port Kembla Harbour

In 1898, the Port Kembla Act authorised the resumption of land for industry and the construction of an Eastern breakwater of 600 meters long (He, 1995). The construction of a Northern breakwater was approved in 1912, along with an extension of the Eastern breakwater to 1200 meters. The construction of the breakwaters was virtually completed by 1937 (Hanson, 1982, cited in He, 1995). Industries soon became established around the harbour and in 1908 a copper refining and smelting works was constructed (ERS Group), followed by a copper cable and tube manufacturing plant in 1914 (Metal Manufacturers Pty Ltd). In 1928 Hoskins Iron and Steel Works was established, which later became Australian Iron and Steel (AIS). A rail link was established between Moss Vale and Port Kembla to take advantage of the high quality local coal, and the first steel was produced at Port Kembla in 1931 (He, 1995; SPCC, 1977). In 1935 AIS became a subsidiary of Broken Hill Proprietary Ltd (BHP) and acquired land around Tom Thumb Lagoon to allow for major expansion of the Steel Works (He, 1995). Between 1936 and 1938 a number of additional industries were established on the harbour foreshores including Lysaghts Works Ltd., AIS Coke Ovens and a by-products plant. AIS continued to grow, and by 1955 had the largest output of any Steel Works in Australia (SPPC, 1977; Hanson, 1982 cited in He, 1995).

Please see print copy for Figure 1.6

Figure 1.6 Location and Features of Port Kembla Harbour (source New South Wales Department of Information Technology and Management, 2000)

Most of these companies continue to operate today, albeit with different names: today AIS is called Bluescope-Steel Ltd., ERS is now Port Kembla Copper Pty. Ltd. and Lysaghts Works is now Bluescope-Steel's Springhill Works.

As heavy industry built up around PKH, waste and effluents from theses industries were discharged into the harbour. This practice remained and continued to be virtually unchecked until the NSW 'Clean Waters Act' was introduced in 1970 (He, 1995). Although harbour pollution is a serious problem, the implementation of pollution control programs has dramatically reduced the emissions from heavy industry and the marine environment of the harbour has improved. He (1995) found that between the 1970's and 1990's significant reductions in the concentrations of toxic wastes and heavy metals in the water of the harbour, along with decreases of contaminants in fish. The pollution of PKH remains a topic of interest not only for the many people who live and work in the area, but also for the NSW Environment Protection Authority, Wollongong City Council, the local heavy industries within the immediate vicinity, and a number of local community groups such as the Port Kembla Harbour Environment Group (PKHEG).

1.3.3 Port Kembla Harbour Discharge Inputs

There are a large number of both industrial wastewaters and stormwater discharges that enter Port Kembla Harbour. The main non-marine inputs into the inner harbour come from Allans Creek which empties into the western basin, and Gurangaty Creek which enters into the harbour in the far north of the Eastern Basin (Figure 1.7). Allans Creek includes wastewater and stormwater from a number of Bluescope-Steel's EPA licensed drains including the No.2 Blower Station Drain, the Slab Mill Drain, the Flat Products East No.2 Drain, the No.5 Blast Furnace Drain, the Plate Mill Drain, the Main Drain, the Slabcaster Drain and the 21 Area Drain. In addition to this, Bluescope-Steel has licensed drains entering the harbour adjacent to the Sinter Plant (Ironmaking East Drain) and the Ro-Ro Berth (Flat Products No.1 Drain).

Gurangaty Creek includes wastewater and stormwater from various sources including Wollongong City Centre stormwater, Tomb Thumb Lagoon, and discharge from Bluescope-Steel's North Gate Drain (via Tom Thumb Lagoon).

The major discharges to the outer harbour are the result of stormwater and effluent from the neighbouring industries. The Outer Harbour Stormwater Drain enters the outer harbour around 100 meters west of No.2 Jetty and includes various stormwater inputs from the surrounding area.

Darcy Road Drain enters the harbour between No.2 and No.3 Jetty and consists of wastewater effluent from Port Kembla Copper and the Orica fertilizer plant. Figure 1.7 shows the locations of the major effluent and stormwater discharges into Port Kembla Harbour.

Please see print copy for Figure 1.7

Figure 1.7 Stormwater and Industrial Discharge Inputs into Port Kembla Harbour

1.4 CURRENT STORMWATER ISSUES

This section will discuss current stormwater issues and recent research on stormwater discharge quality.

1.4.1 Stormwater Borne Contamination

Contamination borne by stormwater originates from a variety of sources inclusive of the rainfall itself. It is a widely known fact that heavy metal contaminants in stormwater tend to be associated with particulate matter, with a preference being shown for the finer particles (Walker and Hurl, 2002). As noted earlier, a number of factors influence the water quality discharged during the first flush including intensity and duration of the rainfall event, catchment size, catchment land usage, and antecedent rainfall (Lee, *et al*. 2002). The types of contaminants likely to be in stormwater runoff from a heavy industrial site such as the PKSW will also depend largely on these factors. Of these, perhaps the most important are: type of plant and associated activities within the catchment; and the major type of land usage (pervious and/or impervious surfaces). Section 1.2.1 contains detailed catchment descriptions and industrial activities carried out within them for each of the discharge points included in this study. Using this information, a sound approximation of the likely source of any stormwater borne contaminants could be made. However, as mentioned previously, past research on stormwater discharge and water quality has been focussed towards urban and rural areas, very little literature is available related to industrial areas; thus, the first flush characteristics of a heavy industrial site such as the PKSW are virtually unknown. As a consequence, the background review of literature for this study was limited almost exclusively to urban catchments without heavy industry.

1.4.2 Urban Stormwater

The Australian community is becoming increasingly concerned about the protection of the environment. The water industry is responding to this challenge by looking for new and improved methods of managing water resources. Of the 22,000 GL per year of water supplied in Australia, 70% is used by the agricultural sector and only 8% by the urban domestic sector (Mitchell, *et al.* 2001). The balance (22%) is used by the industrial and commercial sectors. Current urban water management practices aim to remove stormwater and wastewater efficiently from urban areas (Mitchell, *et al.* 2001). An alternative approach is to consider stormwater and wastewater as a potential resource to substitute for a portion of the water imported via the reticulated supply system. A first step in this approach is to understand the quality and availability of the water to be recycled, treated and reused.

1.4.2.1 Urban Stormwater Contamination

Urbanisation generally increases pollutant concentrations and water temperatures in streams, with increased runoff volumes contributing to the common elevation of pollution loadings (Forbes Rigby, 1999) The greatest increase in pollutant loadings generally occurs following frequent storm events due to more significant increase in runoff volumes under urbanised conditions. Storms produce sufficient rainfall to induce runoff with high enough energy to mobilise many pollutants found in urbanised catchments. Conditions such as the replacement of natural drainage systems with concrete channels and underground pipes produce a marked increase in the speed with which urban runoff reaches the receiving waters (Forbes Rigby, 1999).

Sources of contaminants in urban stormwater are most frequently diffuse sources where control options are limited (Forbes Rigby, 1999). Recent studies (e.g., Lee, *et al.* 2002, Brezonick and Stadelmann, 2002, Taebi and Droste, 2004, Pitcher, *et al.* 2004) have focussed on the more common of these sources - soil erosion, accumulation and wash off of atmospheric dust, motorway/street stormwater, fertilizers and pesticides, pavement runoff and sanitary wastewater. However, a proportion of the stormwater contaminant load in the urban system is a result of illegal discharge of trade waste, illegal dumping, poor site controls and poor management practices, on a community wide basis (Forbes Rigby, 1999).

The following is an overview of the main pollution types and is derived from the Sydney Coastal Councils Stormwater Pollution Control Code for Local Government (taken from Forbes Rigby, 1999).

- *Oil, Grease and Petroleum Products* derived from road surfaces, commercial and industrial processes, service stations and motor repair shops and marina activities. Oil, grease and other petroleum products are toxic to aquatic life (marine, brackish and freshwater).

- *Nutrients* derived from fertilisers and detergents, including phosphorus and nitrogen, can (in high concentrations) cause excessive growth of aquatic plants and can lead to eutrophication of ponds, streams and the poorly flushed estuaries. Golf courses and suburban gardens are major sources of nutrients.

- *Biochemical Oxygen Demand (BOD)* is the measure of the organic pollution of water, expressed as the amount of oxygen (in milligrams of oxygen per litre of water) that is taken up when bacteria break down a sample of organic matter. Overloading of streams and lakes with natural organic material (leaves, sticks, etc.) or rusting metal can lead to the removal of large quantities of oxygen from the receiving waters and may result in fish kills.

- *Pesticides and Herbicides* are transported into the stormwater systems on a catchment wide basis. They are derived from household and industrial use and are toxic in large quantities and some pesticides can bioaccumulate in the food chain.

- *Toxins* such as the heavy metals lead, mercury, zinc, and copper can concentrate in sediment and bioaccumulate in the food chain. Atmospheric discharges from industry and vehicle emissions (including lead petrol emissions) are major sources of road surface runoff contamination. Lead and tin compounds are also used as plasticisers and stabilisers in PVC. Organic compounds such as *tributyl-tin* are used in anti-fouling paint at marinas and on boat hulls used which can cause damage to marine flora and fauna.

- *Bacteria and Viruses* include pathogens that can cause disease in bathing waters and make shellfish consumption unsafe. The major sources of pathogens in stormwater are sewage overflows, defective sewerage systems, and septic systems in unsewered areas, illegal connections to stormwater drains and other animal waste.

- *Sediment and Suspended Solids* washed from building sites and soil erosion can have an adverse impact on aquatic ecosystems. These pollutants destroy habitat for fish by excluding light from the water required for plant and algal growth and by smothering plants and animals living on the bottom of the receiving water body.

- *Non-putrescible/Inorganic Litter* including fast food packaging, plastics, aluminium cans, paper and other disposable wastes can wash off urban areas (such as shopping centres). As this litter accumulates in the waterways it becomes aesthetically unpleasing, mainly collecting in the aquatic vegetation. Some of this litter can be ingested by or entangle wildlife, causing death.

- *Putrescible/Organic Litter* including leaves and twigs, dumped garden waste and food can contaminate stormwater. Depending on the land use within a catchment, stormwater may contain as much as 60-80% natural litter.

- *Chemicals that alter Water Acidity (pH units)* cause native flora and fauna to die and may favour opportunistic pests and weed species. The increase of reduction in acidity may mobilise toxic chemicals, including heavy metals (i.e., lead, cadmium, chromium, aluminium, iron, nickel, selenium and arsenic) oxides of nitrogen and sulphur in the water body and other inert chemicals deposited in bottom sediments of waterways.

Perhaps looking at roadway or street runoff from an urban area can draw the closest comparison between the discharge characteristics of an urban catchment and an industrial catchment. While an urban area does not have heavy industrial activities and associated plant and raw material stockpiles, both roadway/street urban areas and heavy industrial sites contain catchments where the major land cover is sealed and impervious. In addition, the large number of traffic movements within each type (albeit different sized vehicles) is not dissimilar. Stormwater runoff from motorways contains contaminants from the road surface, arising from wear and tear of vehicle parts and additives in oil and petrol (Pitcher, *et al.* 2004). Often the runoff contains significant quantities of dissolved metal elements, particulate bound metal elements, suspended, colloidal and volatile fractions of particulates (Sansalone, *et al.* 1996).

Heavy metals contained in this runoff include vanadium, chromium, manganese, zinc, cobalt, nickel, copper, aluminium, cadmium and lead (Pitcher, *et al.* 2004). Tyre wear is a source of zinc and cadmium. Brake wear is a source of copper, lead, chromium and manganese. aluminium, copper, nickel and chromium can be attributed to engine wear and fluid leakage, while vehicular component wear and detachment is a source of iron, aluminium chromium and zinc (Sansalone, *et al.* 1996). Sansalone, *et al.* 1996 studied fractionation of heavy metals in particulate runoff from an urban roadway with an average daily traffic count of 150,000 vehicles. Results indicated the particulate bound metal elements wash off response was a function of the rainfall intensity, and copper, cadmium, zinc and nickel were mainly in a dissolved (ion complex) form while iron and aluminium are found mainly in particulate bound forms.

Barbosa and Hvitved-Jacobsen (1999) studied stormwater runoff from a highway with an average daily traffic count of 6000. The total catchment of the study area was 5790 m^2 with 2500 m^2 sealed and impervious. The drainage from this catchment was via a single stormwater outlet, which discharged into an infiltration pond with overflow to a creek. Results from the study found that cadmium and chromium concentrations were usually less than detection limits, while copper concentrations were found between 0.01 and 0.05 mg/L, lead from 0.01 to 0.2 mg/L, and Zinc from 0.05 to 1.5 mg/L. Significant first flushes were observed, where the first 50% of runoff volume for each event typically transported up to 69% of the TSS.

1.4.3 Pollutographs

As a hydrograph (detailed in Section 1.1.3) is a plot of discharge (or flow rate) vs. time, a pollutograph describes the whole time history of the change in water quality constituents discharged from a catchment during a rainfall event. Thus a pollutograph is a plot of pollutant concentration vs. time. Figure 1.8 shows a typical urban pollutograph, where a substantial concentration peak is present at the initial stages of the rising hydrograph indicating a first flush has occurred. Rainfall is shown for illustrative purposes.

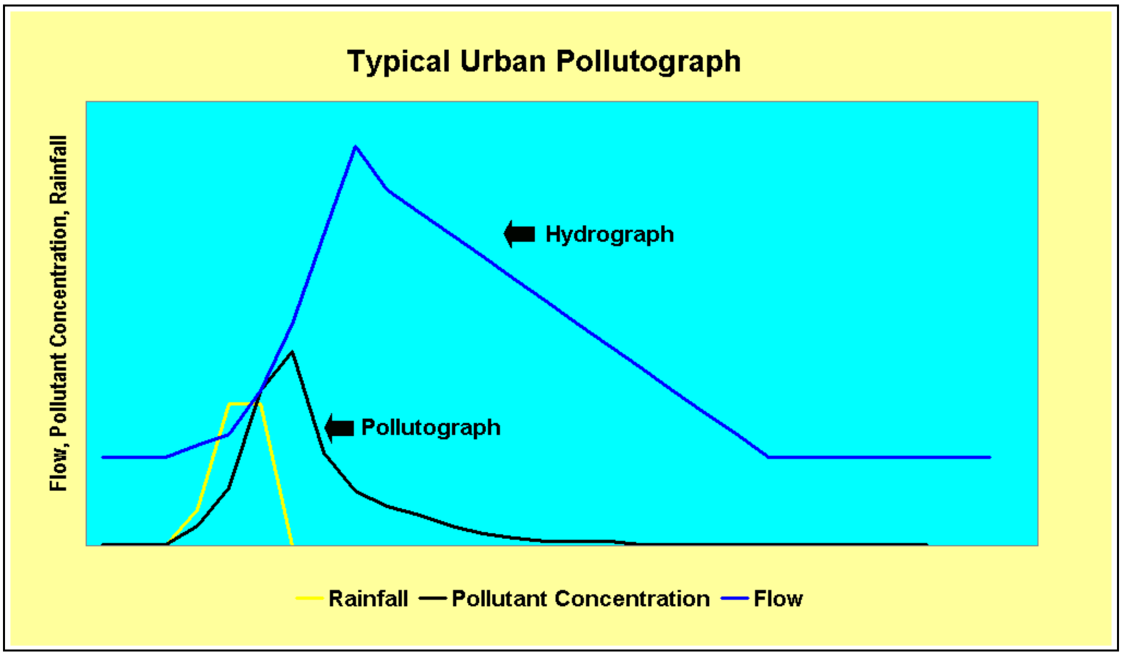


Figure 1.8 Typical Urban Pollutograph

1.4.4 The First Flush Phenomenon

The initial period of stormwater runoff during which the concentrations of pollutants are substantially higher than during the later periods is known as the first flush (Deletic and

Maksumovic, 1998; Gupta and Saul, 1996). During the first flush, enormous quantities of pollutants are often discharged into receiving waters (Lee and Bang, 2000). Stormwater runoff, in particular the first flush, has been identified as one of the leading causes of degradation in the quality of receiving waters (Lee, *et al.* 2002). Research has concluded that the first flush results in a substantial concentration peak at the beginning of storm events. However, the concentration peak may vary for different pollutants during the same storm event, or the same catchment during different storm events (Gupta and Saul, 1996). In general, parameters that influence the first flush are catchment area, nature of land usage within the catchment, rainfall intensity, impervious surface area and antecedent dry weather period (Wanielista and Yousef, 1993).

One definition of a significant first flush has been described as a situation when at least 80% of the total pollutant mass is being transported in the first 30% of the discharge volume (Bertrand-Krajewski, *et al*. 1998); however, research has shown that a first flush of this magnitude is often rare.

Several methods of analysis have been proposed to evaluate the first flush (Lee, *et al*. 2002). Analysis of the first flush has been based on the relationship between the cumulative mass curve and the cumulative runoff volume (Sansalone, *et al*. 1998), or the percentage deviation of the curve from the diagonal has been used as a measure for the strength of the first flush (Gupta and Saul, 1996), or calculated correlation coefficients between cumulative pollutant mass and cumulative runoff volume (Bertrand, *et al.* 1998).

Receiving water bodies tend to respond relatively slowly to storm water inflows compared to the rate at which constituent concentrations change during a storm event (Lee, *et al*. 2002). The use of an event mean concentration is appropriate for evaluating the effects of stormwater runoff on receiving waters (Lee, *et al*. 2002). As sampling in this study was specific to the first four hours of a first flush (sampling for this study is detailed in Section 2.4), this study will use the arithmetic mean and standard deviation for assessing the water quality of stormwater discharge in the specified drains. Among the distributions used in stormwater quality assessment the log normal distribution is particularly common (Van Buren, *et al*. 1997). When undertaking statistical analysis of the stormwater data collected for this study, all calculations are based on the log normal distribution (see Section 2.6).

In summary, current local weather conditions and critical dam storage levels have placed pressure on heavy industry to reduce water consumption and to capture and reuse stormwater. A stormwater management plan for the PKSW is to facilitate the co-coordinated management of stormwater that maximises ecological, social and economic benefits in a sustainable way. The first step in this process is the determination of water quality from any runoff and discharges. The 'first flush' phenomenon where initial pollutant concentrations are substantially higher than those at the later stages of a rainfall event is known to be a leading cause of degradation to the quality of receiving waters. The majority of recent stormwater research has focussed on urban catchments with little attention paid to the first flush stormwater discharge quality of a heavy industrial site such as PKSW.

The next section will detail the materials and methodology used whilst undertaking this study.

2 MATERIALS AND METHODOLOGY

The content of this chapter demonstrates the methods used for generating hydrographs, how runoff volumes were calculated, calculation of API values and the source of the data used. This section also details the materials and methods used for the sampling and analysis of water samples taken for this study and the statistical methodology used for determination of appropriate wet weather licence limits.

2.1 HYDROGRAPHS AND DISCHARGE VOLUMES.

2.1.1 Manly Hydraulics Laboratory

The data required for the hydrological assessments is rainfall intensity per unit time and discharge per unit time. Manly Hydraulics Laboratory (MHL), supply BSL with online information for 13 licensed drains across the PKSW. MHL has onsite instrumentation that collects 'real time' data monitoring and logging various parameters including; pH, temperature, dissolved oxygen, flow and rainfall continuously. Engineers, chemists, environmental professionals and managers use this information right across the plant. This data is available on the BSL discharge monitor web page: http://marlin.mhl.nsw.gov.au/fl2fax/bhpk00491.html (username and password authorisation are required). Figures 2.1 and 2.2 show MHL instrumentation at the North Gate Drain.

Please see print copy for Figure 2.1	Please see print copy for Figure 2.2
Figure 2.1 Overview of North Gate Drain	**Figure 2.2 MHL Instrumentation at North Gate Drain**

The data collected by the onsite monitors are sent via telecommunications to a data base server and can be downloaded in hourly, 30 minute or 15 minute intervals.

2.1.2 Generation of Hydrographs

Hydrographs were generated by first downloading flow and rainfall data from the MHL database into a Microsoft Excel spreadsheet. Graphs were then constructed by plotting flow against time for each storm event. Figure 2.3 shows an example of typical hydrograph for the North Gate Drain.

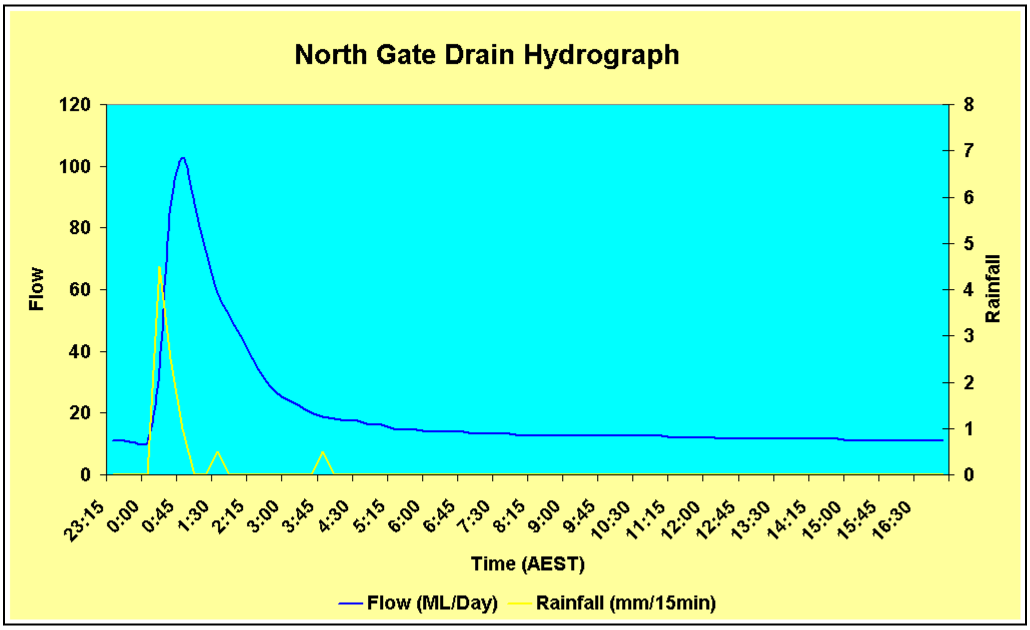


Figure 2.3 – Typical North Gate Drain Hydrograph

2.1.2.1 Calculation of Discharge Volumes

The volume of the discharge or area under the hydrograph was calculated by the sum of the component parts for each individual data point used to generate the hydrograph. The 15 minute flow data from the MHL database was converted ML/min (from ML/Day). From this the volumes discharged over each 15 minute interval (component parts) were calculated and added together to form the total for the storm event. The volume due to normal process discharge was determined by averaging the flow in the drain for the preceding 2 hours before the rain event, and using the same calculation as described above. The total volume due to stormwater runoff is then determined by subtracting the process discharge volume from the total discharge volume. Figure 2.4 shows a pictorial representation and an example calculation is given below:

e.g., Flow = 124.5 ML/Day

= 0.08646 ML/min

Volume (15 min) = 0.08646 ML/min X 15

= 1.297 ML

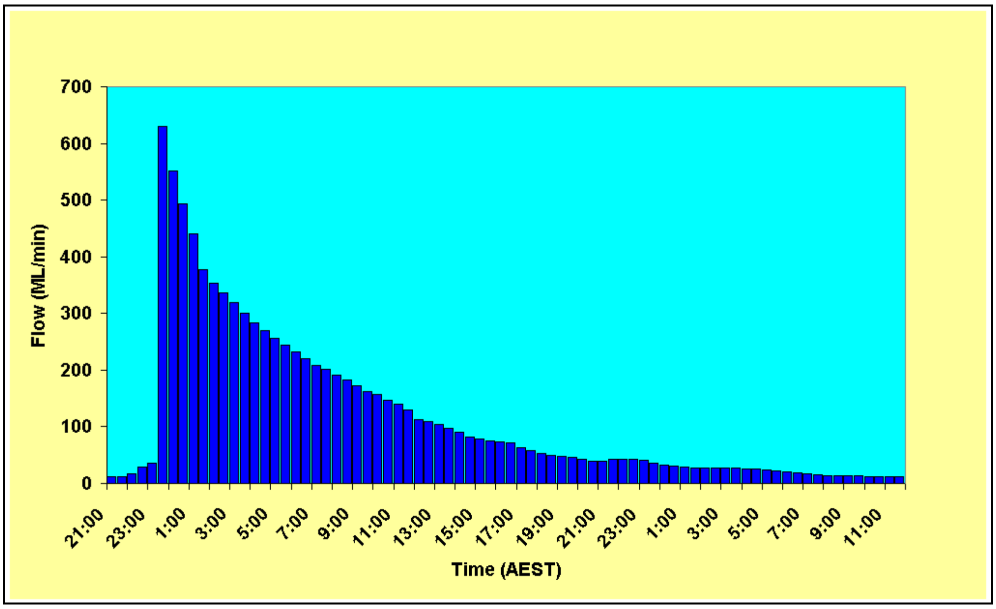


Figure 2.4 – Pictorial Representation for Calculation of Discharge Volumes

2.2 Calculating API Values

A general guide to the degree of moisture in the ground can be obtained from the Antecedent Precipitation Index or API (Shaw, 1983). Antecedent Precipitation Values were calculated for each rainfall event using the general formula shown below.

$$\mathbf{API = 0.92{*}P_1 + (0.92)^2{*}P_2 + (0.92)^3{*}P_3 + \ldots\ldots\ (0.92)^n{*}P_n}$$

Where P_1 = precipitation from the present storm event, P_2 = precipitation from the previous day, P_3 = precipitation from 2 days previously etc.

2.3 Drawings and Topographical Maps.

In order to determine the direction of stormwater flow and establish catchment areas for each of the drains, a number of drawings and maps were consulted. These, along with personal communication with Mr Bruce Green (Environmental Analyst BSL), and Mr Kevin Goss (Environmental Engineer BSL), were used to map catchments for each of the four drains. Once the catchment areas were established the surface areas for each catchment were calculated by using scale drawings. The types of surfaces within each catchment were determined from aerial photographs of the area and verified with 'ground truthing'. Table 2.1 lists the maps and drawings consulted.

Please see print copy for Table 2.1

Table 2.1 Maps and Drawings Used to Define Catchments and Calculate areas.

2.4 AUTOMATIC SAMPLING EQUIPMENT

As sampling was specific for this study, rainfall activated automatic samplers and associated equipment suitable for the type of sampling required were installed at each of the specified drains. Attached to each autosampler were: a pluviometer (to both log rainfall data and activate the sampler) and a solar panel (to ensure battery pack was sufficiently charged to operate the peristaltic sampling pump).

2.4.1 Location of Autosamplers

Where practical, the automatic samplers were installed to sample at or as close as possible to the licensed point of discharge. The strainers were placed at a level of approximately 300 mm below the surface of the water in each drain. The selected locations ensured samples taken were representative of the water quality in the drain. Figures 2.5 - 2.8 show the sampling equipment installed at each of the sites.

Please see print copy for Figure 2.5

Figure 2.5 Autosampling Equipment at the North Gate Drain (licensed point #86).

Please see print copy for Figure 2.6

Figure 2.6 Autosampling Equipment at the Main Drain (licensed point #88).

Please see print copy for Figure 2.7

Figure 2.7 Autosampling Equipment at the Ironmaking East Drain (upstream of licensed point #89).

Please see print copy for Figure 2.8

Figure 2.8 Autosampling Equipment (top left of figure) at the Flat Products East No.1 Drain (licensed point #83).

Figure 2.5 (North Gate Drain) shows the autosampler set up immediately adjacent to the western concrete channel of the drain and samples were taken directly below the autosampler.

Figure 2.6 (Main Drain) shows the equipment installed at the top of the stairs leading to the sampling platform (not shown). Samples were taken directly below the platform at the licensed point of discharge.

Figure 2.7 (Ironmaking East Drain) shows the sampling equipment set up on a concrete pad adjacent to the drain approximately 50 meters up steam from the licensed point of discharge. Samples were taken directly below the location of the autosampler.

Figure 2.8 (Flat Products East No.1 Drain) shows the autosampler installed at the top of the steps (top left of picture) that lead to the licensed point of discharge. A sampling hose was run parallel to the stairs and samples were taken at the licensed point of discharge.

2.4.2 Sampling Program Parameters

Wet weather sampling specifically for this study commenced in November 2003. Initially the autosamplers were configured to sample when the pluviometer recorded any rainfall. This was basically a ‘commissioning’ process to ensure the autosamplers were installed correctly, working correctly and to become familiarised with their operation. A small number of rainfall events were monitored for each drain initially and the data collected from these is included in this report. From 1st December 2003 onwards, the autosamplers were programmed to sample when the pluviometer recorded 10 mm or more of rainfall in a 4 hour period. These parameters were based on the NSW EPA definition of wet weather conditions (‘weather conditions in which 10 or more millimetres of rain falls within a 24 hour period’ Environment Protection Licence 6092, 2005) and catchment hydrology (i.e., analysis of rainfall vs. discharge volumes) for each drain. This ensured samples gathered were indicative of a significant rainfall event where potential contaminants within a catchment are mobilised, discharged and the capture of the 'first flush'.

2.4.3 Number of Samples Collected

Sampling specific for this study commenced in November 2003, and ceased in March 2005. During these 17 months, over 1300 water samples were collected and analysed.

2.5 ANALYSIS OF SAMPLES

All samples collected for this study were analysed by BSL's Laboratory Services in the Waters Analysis section. This is a National Association of Testing Authorities (NATA) accredited laboratory (accreditation number 632). Detection limits for analysis were sufficiently sensitive to measure concentrations at both ANZECC 2000 Guidelines (Marine Aquatic Ecosystems) and Recreational Water Quality Guidelines. The pHs of samples were determined using an Orion pH meter, TSS was determined gravimetrically and Total Fe was analysed by Inductively Coupled Plasma (ICP) Spectrometry.

The methods used for the analysis of the samples are listed below.

- pH, APHA(1998) Section 4500-H^+
- TSS, APHA (1998) Section 2540D (detection limit 2 mg/L)
- Total Fe, APHA (1998) Section 3120B (detection limits 0.01 mg/L)
- Total Fe sample pre-treatment, APHA (1998) Section 3030F

All of the analysis methods followed are listed in Department of Environment and Conservation (2004).

In addition to water quality analysis, particulate samples were retained from TSS analyses and further analysed using light microscopy for particle identification. This was undertaken in an attempt to identify the point source of pollutants within the catchment. This analysis was also carried out at BSL's Laboratory Services.

2.6 CALCULATION OF WET WEATHER CONFIDENCE LIMITS

In order to make recommendations on the removal or revision of wet weather licence limits, confidence intervals were calculated based on the mean, standard deviation and distribution of the results collected. The confidence intervals calculated are based on a 'log normal' distribution and the following equation:

$$\text{CL for } \mu = X \pm z\sigma.$$

Where μ = true mean wet weather sample result, X = measured mean of samples taken, z = deviation from the mean and σ = measured standard deviation of samples taken.

It must be noted an assumption is made that sampling and analysis is completed in the absence of bias and the measured standard deviation σ, is equal to the true standard deviation. This was considered to be the situation in this study.

2.6.1 Analysis of Variance

A single factor analysis of variance (ANOVA) test was carried out to determine if the historical data set, and the data set collected for this study, were statistically different. The ANOVA test was completed for each parameter at each drain and the results appear in Appendices F – I.

2.6.2 Additional requirements for PRP98

PRP98, as set out in EPL 6092, details additional requirements for sampling, measuring and reporting data collected for this study. Each additional requirement is addressed below:

i. *The intensity, frequency and duration characteristics must be noted for each rainfall event monitored.*

This requirement is addressed in Appendices A-D. Each hydrograph is accompanied by a summary table listing the duration of monitoring, maximum and average rainfall intensity, duration of the rainfall event, total volume of rainfall for the period monitored and TSS and total Fe maxima.

ii. *A stormwater flow hydrograph must be produced for each storm monitored. This will also indicate the extent to which the full rising stage of the hydrograph has been monitored.*

All rain events monitored are represented by hydrographs, which appear in Appendices A-D. Online drain monitoring equipment provides ‘real time’ discharge information at licensed discharge points across PKSW. The flow data used to produce the hydrographs was taken from Manly Hydraulics Laboratory’s (MHL) website: http://www.mhl.nsw.gov.au/fl2fax/bhpk00491.html. User name and password authorisation are required.

iii. *The concentrations of the specified parameters should be measured at intervals not exceeding 10 minutes during the rising stage of the stormwater flow hydrograph.*

As stated previously in Section 2.1.2, the autosamplers were programmed to sample at 10 minute intervals. Each autosampler carousel contained 24 bottles giving 4 hours of continuos water quality monitoring.

iv. *The monitoring should be illustrated using pollutographs.*

Each hydrograph is accompanied by a pollutograph where the concentration of each parameter (pH, TSS and Total Fe) is plotted against time.

v. *The limits of detection of any laboratory analysis must be sufficiently sensitive to measure concentrations at the current ANZECC in-stream target levels.*

As previously stated in Section 2.2, BSL's Laboratory Services performed the analysis of all samples for this study. Detection limits for analysis are sufficiently sensitive to measure concentration at both ANZECC 2000 Guidelines (Marine Aquatic Ecosystems) and Recreational Water Quality Guidelines.

The following chapter contains the results from the hydrological and water quality study of licensed drains included in this study.

3 RESULTS AND DISCUSSION

This chapter presents and discusses the results and data set collected to answer the objectives and make recommendations as detailed in Chapter 1. The first section of this chapter will focus on hydrology of the four drains, the second will present the results from the water quality study and the third section presents calculated confidence limits from the statistical analysis of the water quality data.

3.1 DRAIN HYDROLOGY

This section details the hydrological results from this study; it includes hydrographs, relationships between rainfall and discharge volume and the effect of antecedent rainfall at each of the drains.

3.1.1 North Gate Drain Hydrology

3.1.1.1 Hydrographs and Response to Rainfall

Figures 3.1 and 3.2 are hydrographs for the North Gate Drain during typical wet weather conditions.

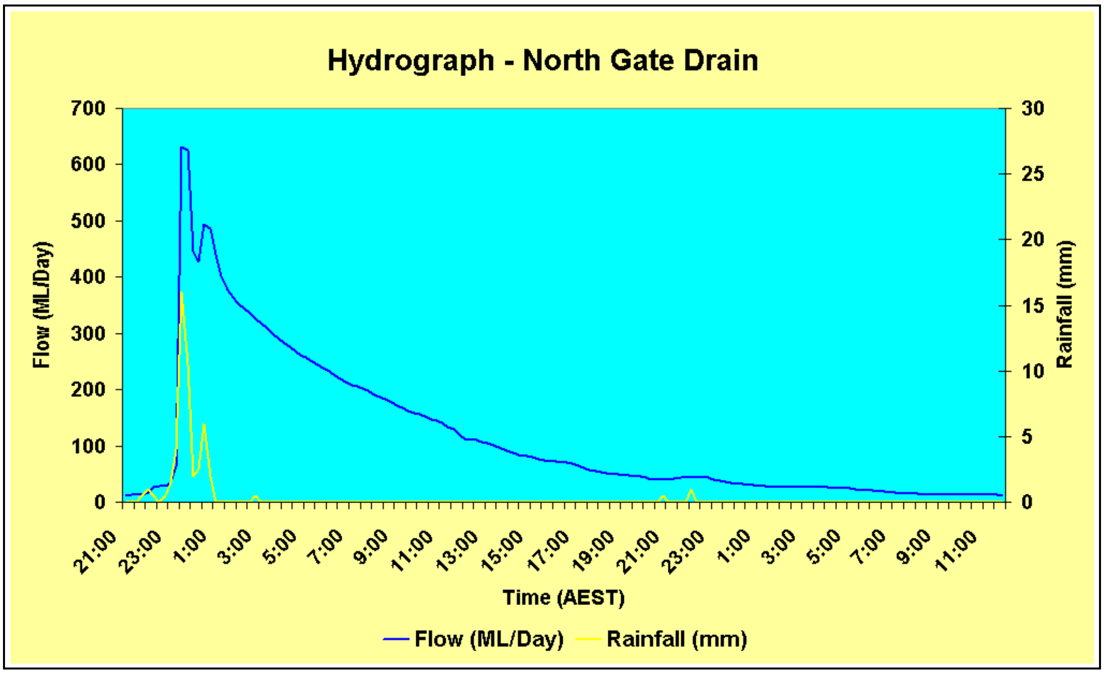


Figure 3.1 Typical North Gate Drain Hydrograph 1.

The hydrographs have very steep rising limbs and peak discharge (flow) rates shortly after the most intense rainfall of the event. This is typical of small urban type catchments (Ward and Elliot, 1995). This rapid response to rainfall sees the time difference between peak rainfall and peak discharge being not more than 15 minutes in most cases. This is most likely due to the sealed sections of this catchment being close to the point of discharge. An interesting feature of the North Gate Drain hydrographs is the gradient of the recession curve. The discharge of the North Gate drain does not return to the 'baseline' or process flow for some hours, or even days after the rainfall event. This delayed return to process flow can be attributed to the size of the catchment (983,100 m^2 – large by industry standards) and also suggests water is retained by infiltration and percolation into the ground, discharging slowly over time.

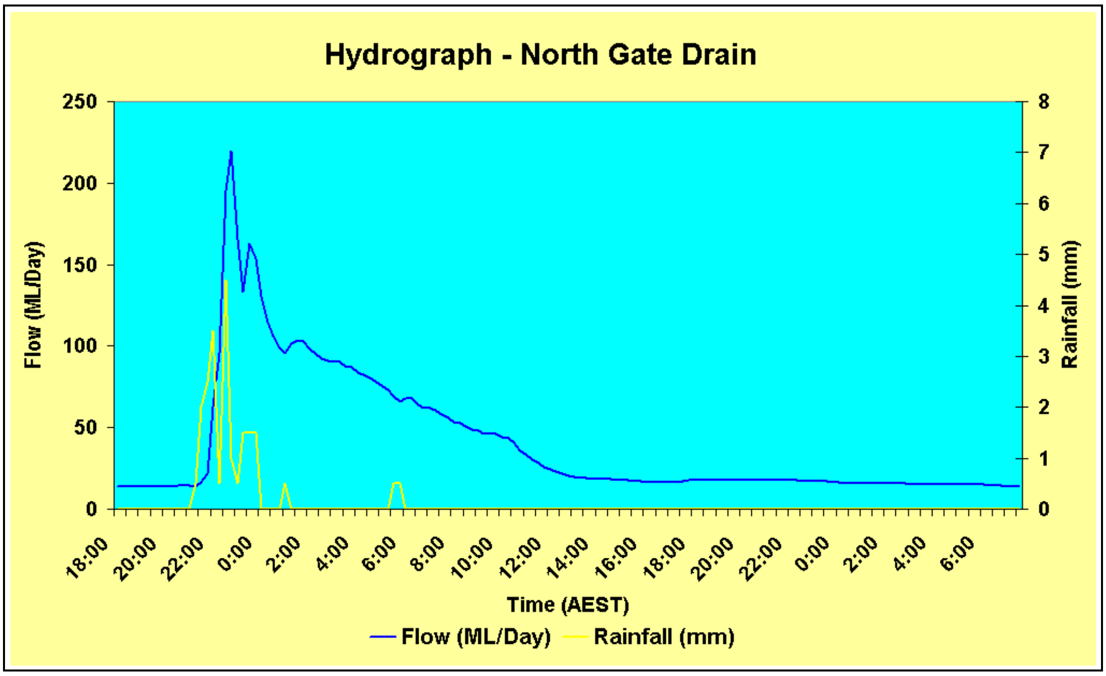


Figure 3.2 Typical North Gate Drain Hydrograph 2.

3.1.1.2 Rainfall and Discharge Volume

The relationship between rainfall and stormwater discharge volume is shown in Figure 3.3. The 'line of best fit' is included showing a linear regression of 0.71. There is a distinct outlier (point 67 mm, 438 ML) that if removed, dramatically improves the linear regression (to 0.85). However, outliers cannot be discounted, and this outlier may be explained by local rainfall variation within the catchment or antecedent rainfall conditions. An interesting feature of this graph is that the line of best fit does not intercept the y-axis (discharge volume) at zero, indicating at times no observable increase in flow is seen during smaller rainfall events. The most likely explanation for this feature is the loss of water to various processes within the hydrological cycle before an increase in discharge is observable. By setting the discharge volume as zero and solving the equation of the line of best fit, the amount of rainfall that is required before an increase in discharge is recordable can be approximated. For the North Gate Drain this value was found to be 11.5 mm. The sampling program parameters for the water quality analysis were based on this information.

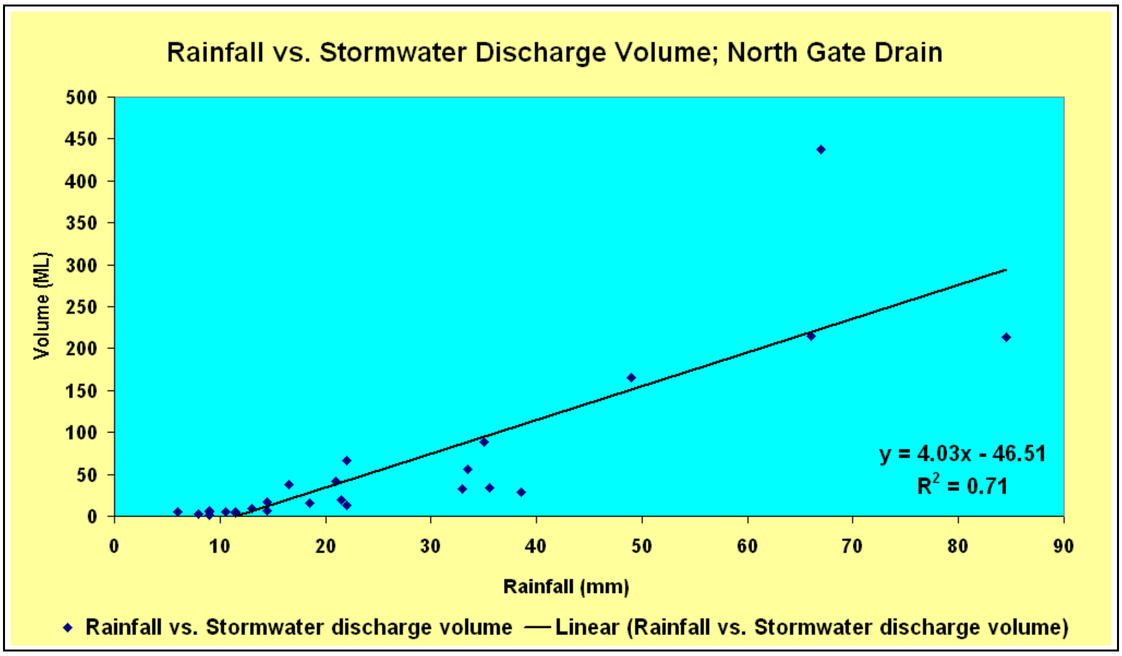


Figure 3.3 Rainfall vs. Stormwater Discharge Volume – North Gate Drain

3.1.1.3 Rainfall Volume and Stormwater Discharge Volume

Assuming the rainfall is uniform over the catchment and there is no water loss to any processes within the 'hydrological cycle', a plot of rainfall volume against the stormwater discharge volume would have a gradient of 1, i.e., all the rainfall falling on the catchment would be discharged via the drain. Figure 3.4 shows the plot of rainfall volume falling on the North Gate catchment against the discharge volume. The most interesting feature of this is the slope of the 'line of best fit'. This linear relationship has a gradient of 4.1. This indicates that the discharge volume leaving the drain is at least 4 times the volume of rain falling on the catchment. Based on the calculated size of the catchment this is impossible. This anomaly has been investigated by BSL engineers and it was found that the water level (or head over weir) had been grossly overestimated by MHL and the type of weir structure which exists at the North Gate Drain is inadequate for the size of the drain (pers. comm. Greg Smith, 2004).

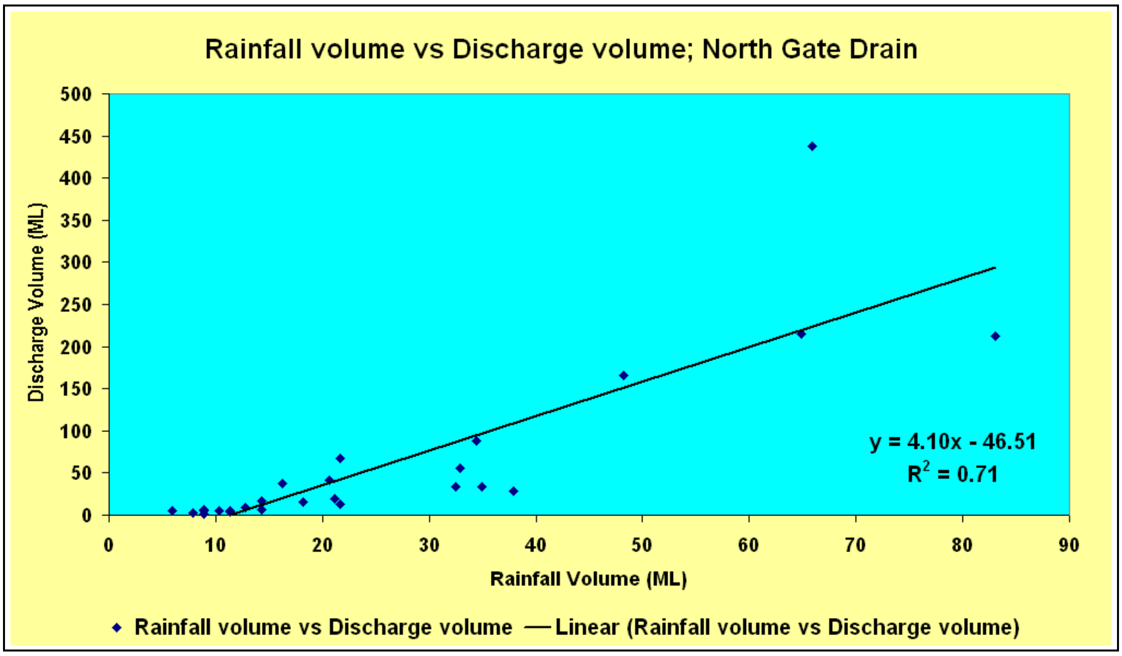


Figure 3.4 Rainfall Volume vs. Stormwater Discharge Volume – North Gate Drain

3.1.1.4 Antecedent Rainfall Effects

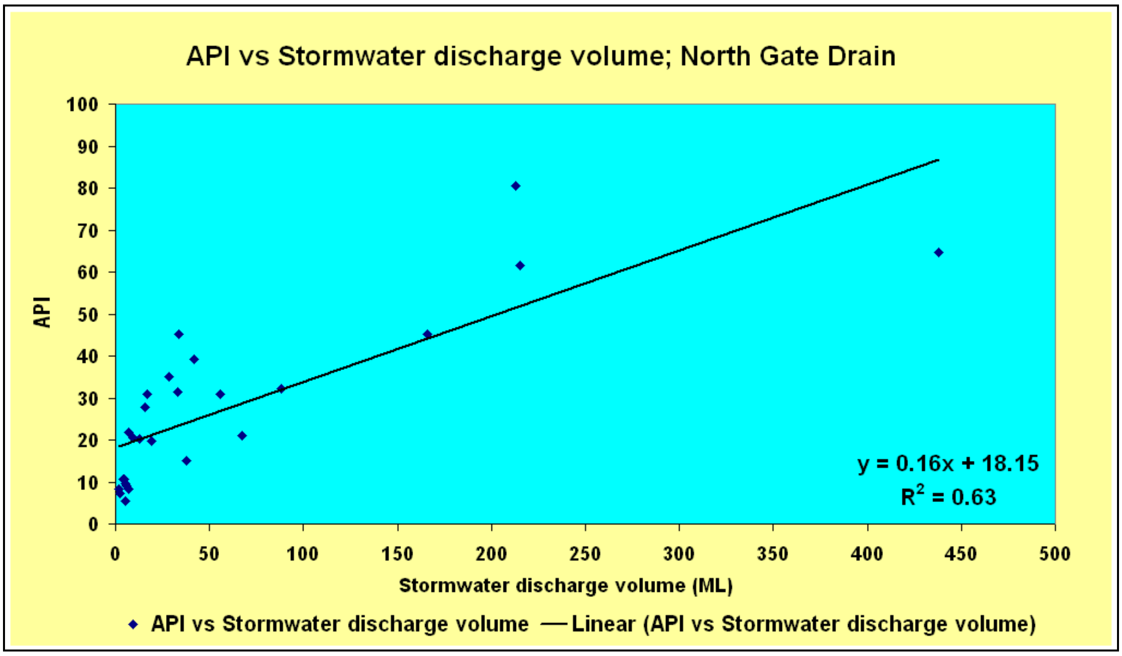


Figure 3.5 Antecedent Precipitation Index vs. Discharge Volume - North Gate Drain

Figure 3.5 is the plot of Antecedent Precipitation Index against stormwater discharge volume. This graph shows a systematic increase of discharge and API (regression 0.63). More data would be useful in strengthening this linear regression but this systematic increase indicates that preceding rainfall and moisture condition of the catchment affects the discharge volume directly.

This feature is consistent with the land usage within the North Gate Drain catchment containing approximately 35% (~300,000 m^2) grassed areas or pervious surfaces. Such relationships are not uncommon in urban type catchments (Ward and Elliot 1995).

3.1.2 Main Drain Hydrology

3.1.2.1 Hydrographs and Response to Rainfall

Figure 3.6 is a typical discharge hydrograph for the PKSW Main Drain during a rainfall event. The features of the Main drain hydrograph are not dissimilar to features seen in forest type or 'natural' catchments (Ward and Elliot, 1995). The response to rainfall is somewhat slow, with peak discharge (flow) coming some time after the peak rainfall intensity. The recession curve shows it takes many hours (in most cases more than 4) for the flow to return to 'baseline' or process conditions. This slow response and shape of recession curves can be attributed to the size of the catchment (3,312,500 m^2 – very large by industry standards) and the surfaces within it, being largely unsealed and pervious to moisture.

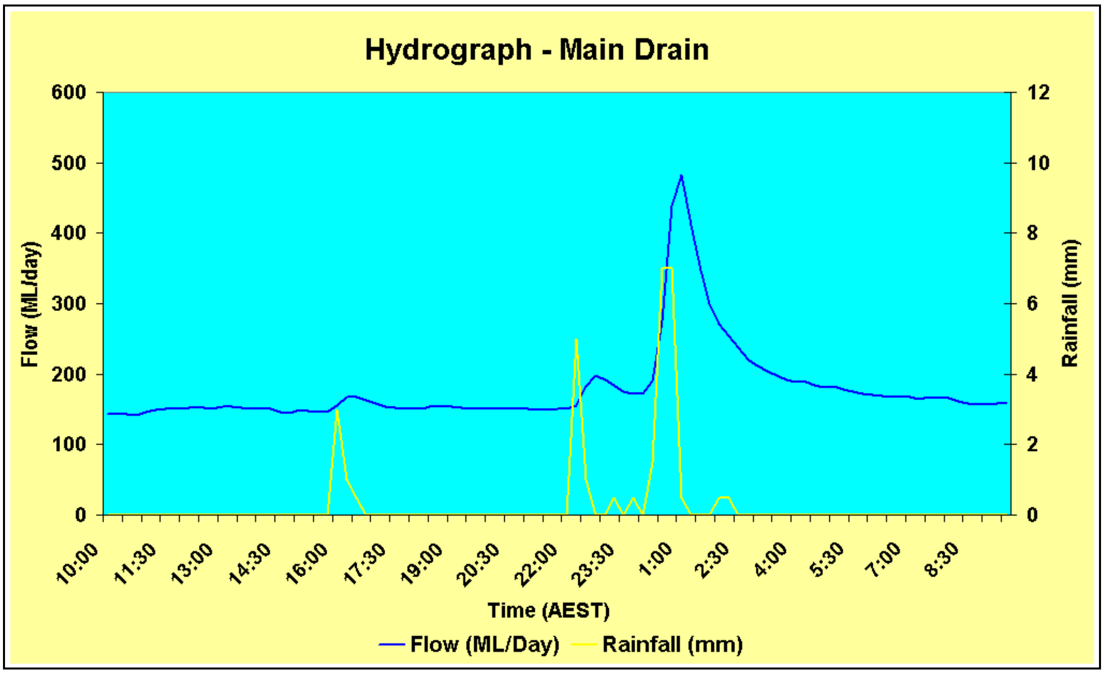


Figure 3.6 Typical Main Drain Hydrograph 1

3.1.2.2 Rainfall and Discharge Volumes

The relationship between rainfall and stormwater discharge volume for the Main Drain is shown in Figure 3.7. The linear regression for the data is 0.79, which indicates there is a linear relationship between rainfall and discharge for the steelworks the Main Drain. As was seen in the corresponding plot for the North Gate Drain there are outliers. Once again these outliers cannot be disregarded, but can best be explained by varying API conditions and rainfall variation across the BlueScope Steel Port Kembla site. The rain gauge located at the North Gate Drain is approximately 4 kilometres from the Main Drain (see Figure 1.5).

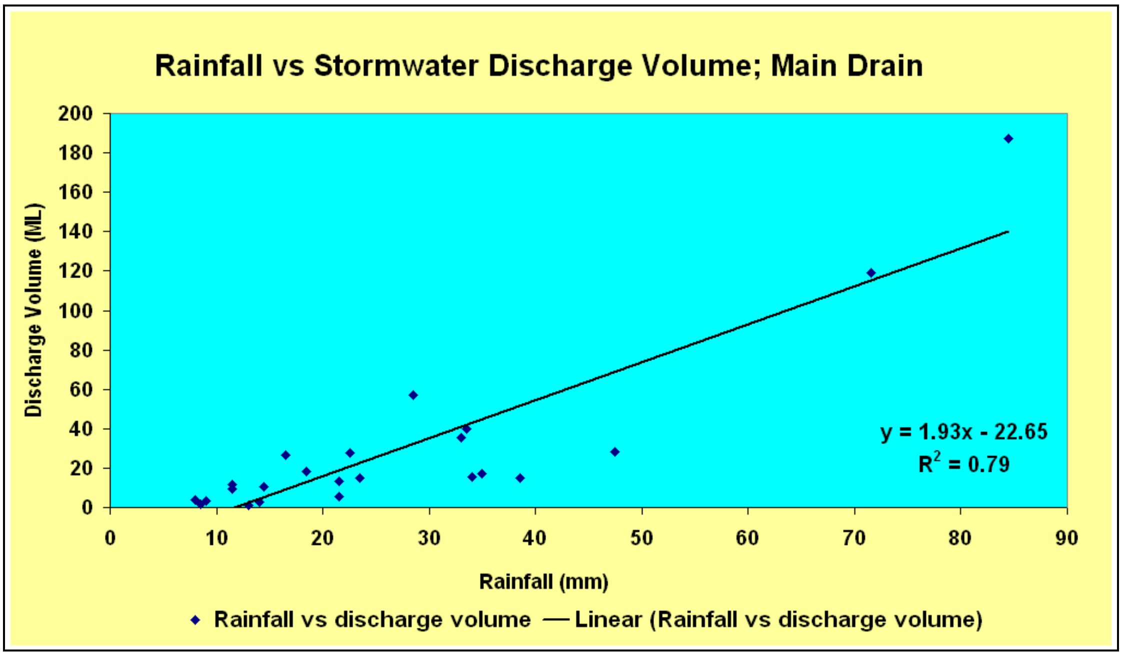


Figure 3.7 Rainfall vs. Stormwater Discharge Volume - Main Drain

3.1.2.3 Rainfall Volume and Stormwater Discharge Volume

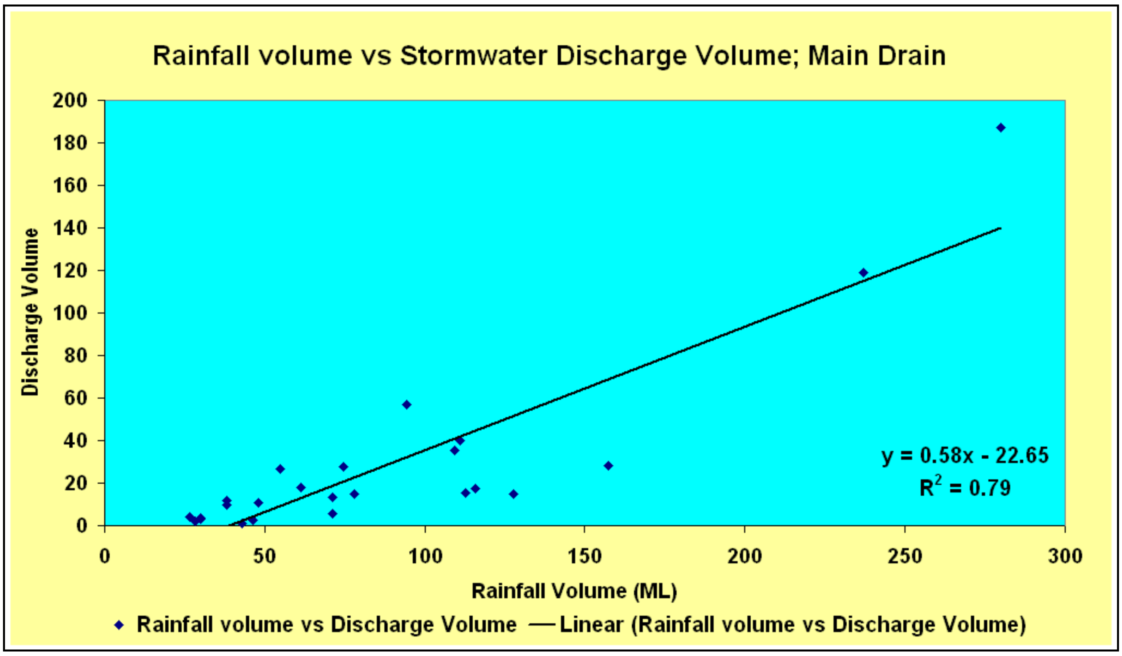


Figure 3.8 Rainfall Volume vs. Stormwater Discharge Volume - Main Drain

Figure 3.8 is a plot of rainfall volume against discharge volume for the Main Drain. The 'line of best fit' shows a linear regression of 0.79 and a slope of 0.58. This indicates that on average the fraction of water discharged through the drain is only 58% of the total rainfall volume falling on the catchment. These losses are most likely due to infiltration and percolation into the large areas of grassed and unsealed pervious surfaces within the Main Drain catchment.

3.1.2.4 Antecedent Rainfall Effects

With large areas that are pervious to moisture, it would be expected that antecedent rainfall and ground moisture conditions would affect discharge volumes at the Main Drain for a particular rainfall event. Figure 3.9 shows this to be the case. There is a positive systematic increase in the discharge volumes as the API increases for the Main Drain catchment. The linear regression (0.67) is not strong and more data, particularly at higher discharges would be useful in confirming this API effect for the Main Drain.

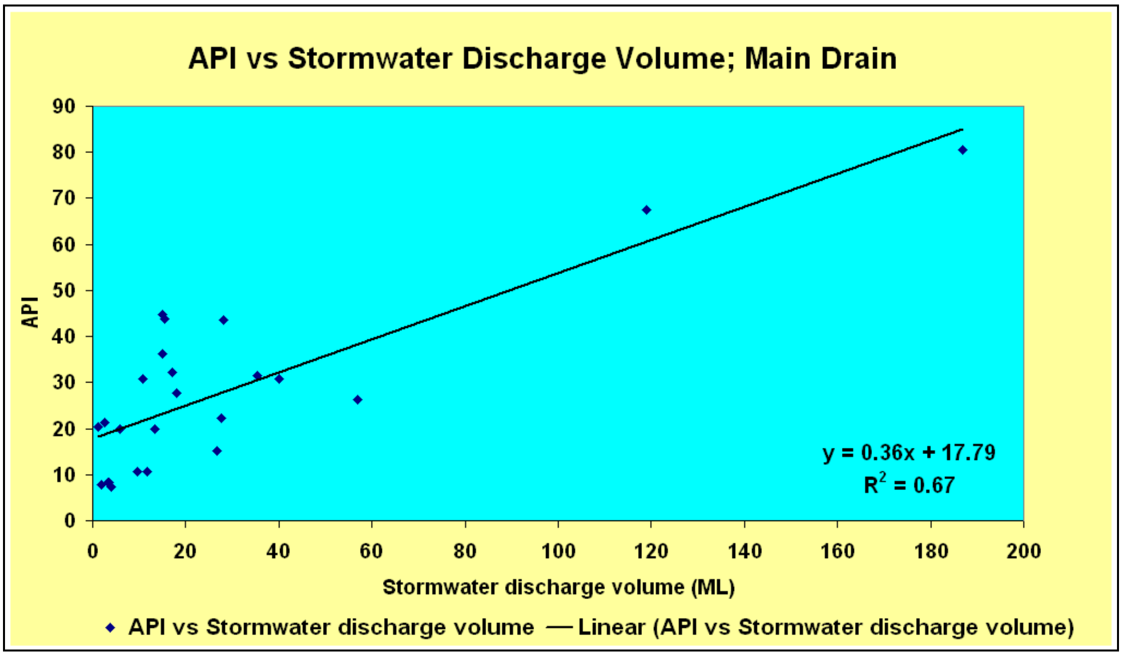


Figure 3.9 Antecedent Precipitation Index vs. Stormwater Discharge Volume - Main Drain

3.1.3 Ironmaking East Drain Hydrology

3.1.3.1 Hydrographs and Response to Rainfall

Figures 3.10 and 3.11 are typical discharge hydrographs for the Ironmaking East Drain. These hydrographs show that the Ironmaking East Drain has a fast response to rainfall with the highest flows recorded within 15 minutes of the highest rainfall intensity. The flow also decreases rapidly after the rainfall stops, and 'baseline' or process flow returns within 30 minutes of the rainfall ceasing in most cases. These 'flashy' features are typical of small, urbanised catchments detailed in Section 1.1.3. The Ironmaking East Drain has a small catchment with greater than 90% sealed impervious surfaces; the features of these hydrographs are consistent with this catchment type.

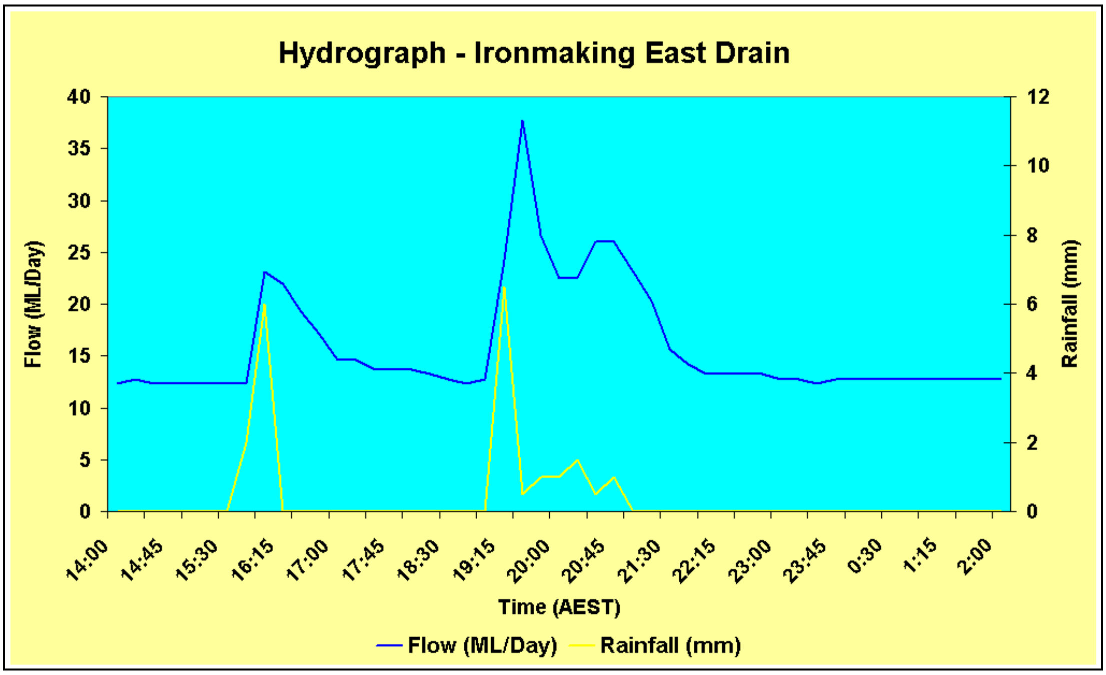


Figure 3.10 Typical Ironmaking East Drain Hydrograph 1

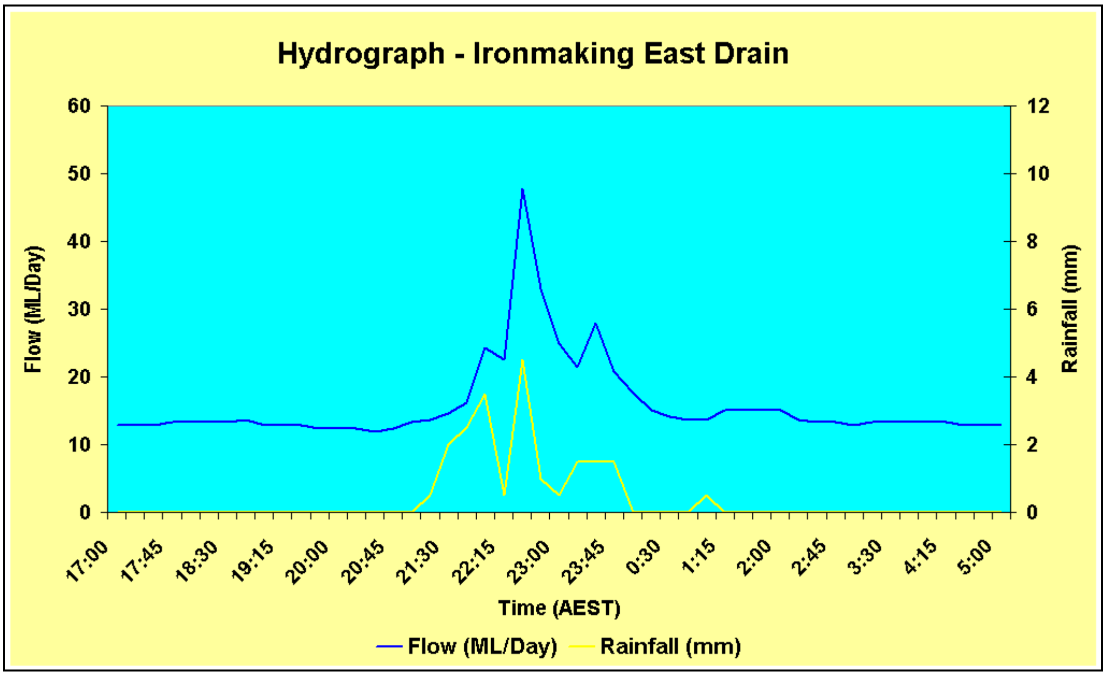


Figure 3.11 Typical Ironmaking East Hydrograph 2

3.1.3.2 Rainfall and Discharge Volume

Figure 3.12 shows there is a strong linear relationship between rainfall and discharge volume for this drain ($R^2 = 0.83$). The removal of a distinct outlier (47.5 mm, 2.53 ML) further improves this regression coefficient (0.92). This outlier can be best explained by differences in rainfall across the site, and any effects antecedent rainfall may have on the state of the catchment.

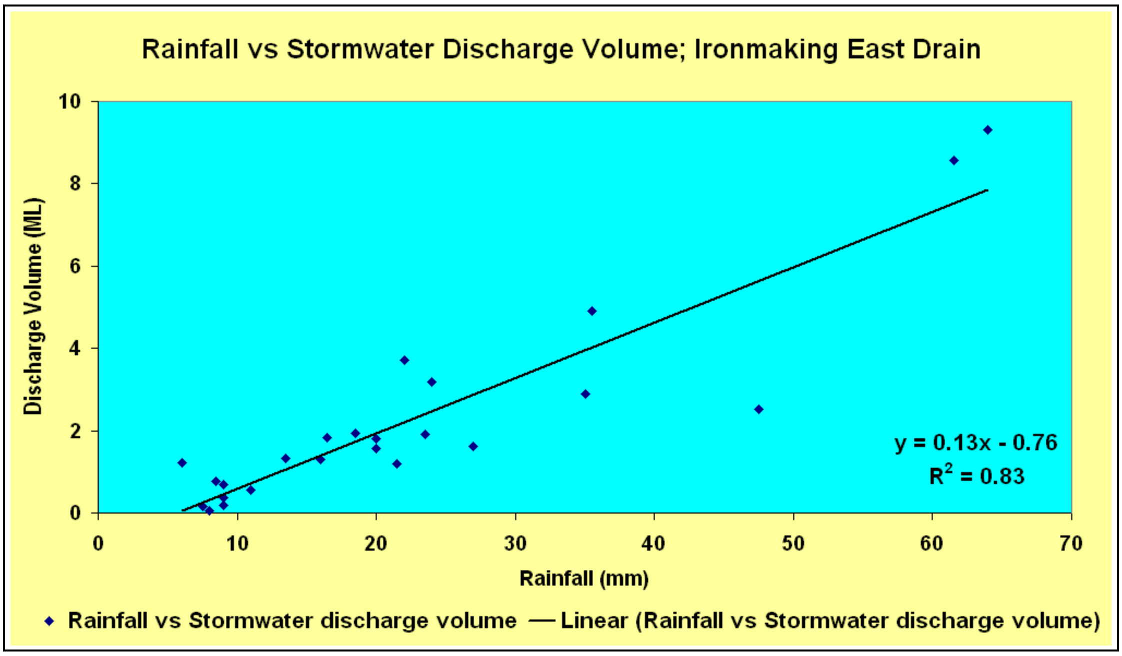


Figure 3.12 Rainfall vs. Discharge Volume - Iron Making East Drain

3.1.3.3 Rainfall Volume and Stormwater Discharge Volume

The plot of rainfall volume vs. stormwater discharge volume is shown in Figure 3.13. The slope of this linear relationship indicates that the fraction of water leaving the drain as runoff is 0.83 times (or 83% of) the total rainfall that fell on the catchment. This high fraction of discharge compared to the rainfall volume can be attributed to the nature of the Ironmaking East Drain Catchment. The catchment is relatively small (162,500 m^2) and is almost completely sealed and impervious. This high discharge fraction indicates there are only small water losses, which are most likely not due to infiltration or percolation (because the catchment is largely impervious), but rather evaporation.

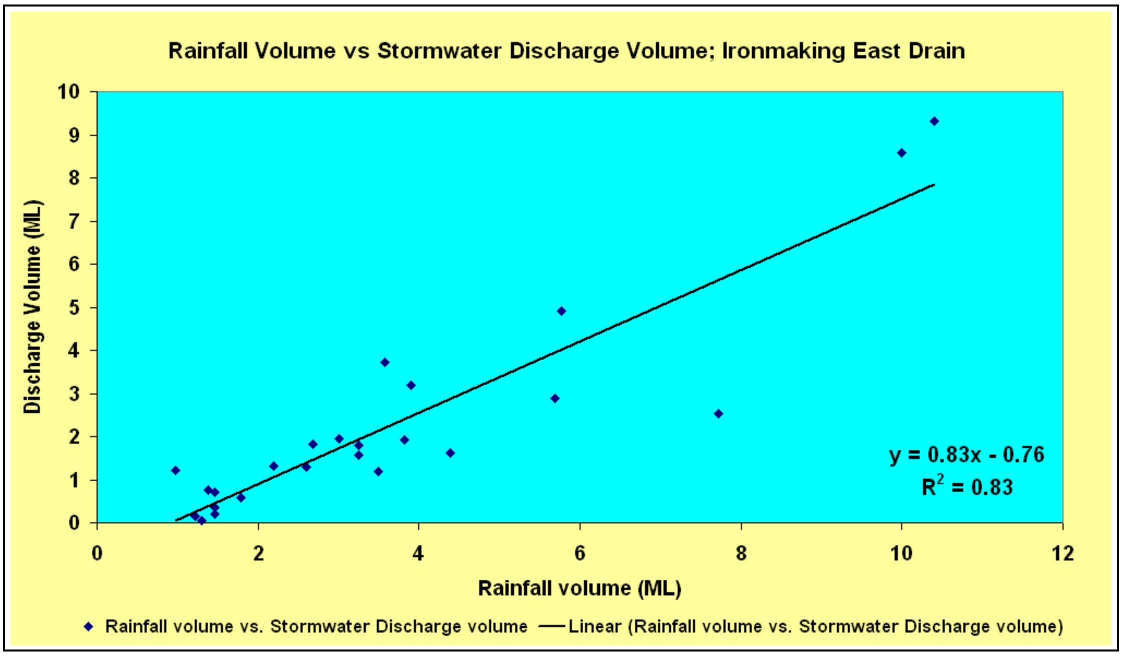


Figure 3.13 Rainfall Volume vs. Stormwater Discharge Volume - Iron Making East Drain.

3.1.3.4 Antecedent Rainfall Effects

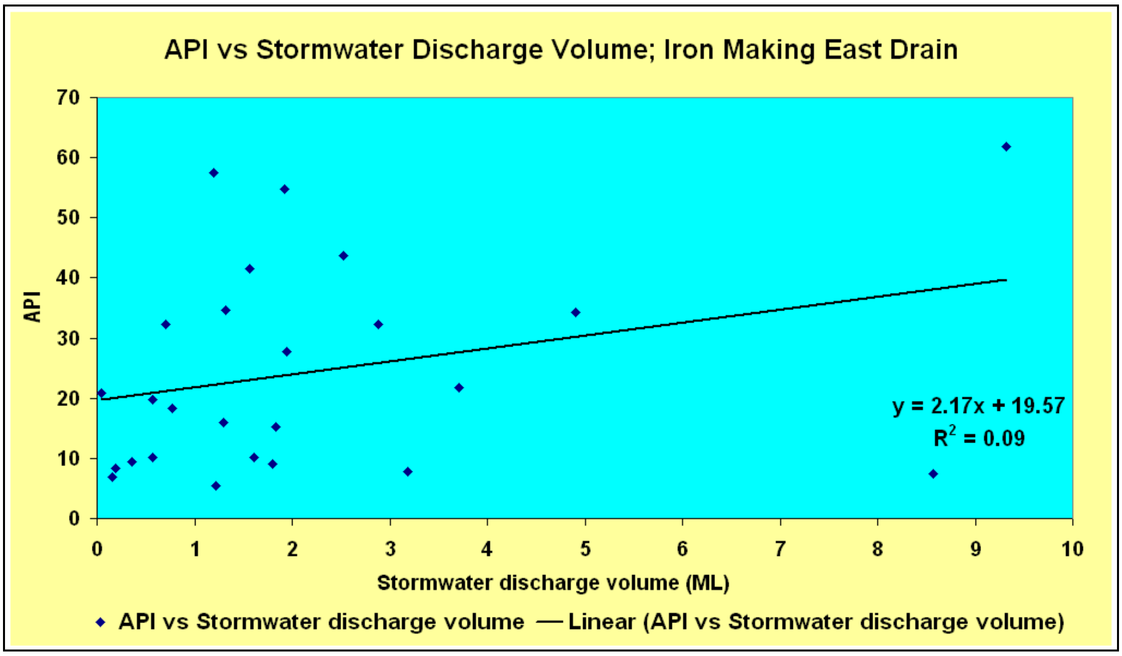


Figure 3.14 Antecedent Precipitation Index vs. Discharge Volume - Ironmaking East Drain.

The results presented in Figure 3.14 show there is no real relationship between the Antecedent Precipitation Index (API) and discharge volume for the Ironmaking East Drain. The data points are very scattered and the linear regression coefficient (R^2) is very poor (0.09). This plot is not unlike the API vs. Discharge plot for the Flat Products East No.1 Drain (Figure 3.19). As noted earlier, the Ironmaking East Drain catchment has virtually no areas where infiltration and percolation of water into the ground can affect the wetness or moisture of the catchment, thus API does not significantly affect the discharge volume.

3.1.4 Flat Products East No.1 Drain Hydrology

3.1.4.1 Hydrographs and Response to Rainfall

The hydrographs generated for the Flat Products East No.1 Drain have sharp rising limbs and an almost instantaneous response to rainfall. Peak discharge (flow) rates occur at the same time, or within 15 minutes of the most intense rainfall. The recession curve is also sharp, and flow returns to the normal process discharge within 30 minutes of the rainfall ceasing in most cases. These 'flashy' hydrographs are typical of small urban type catchments as described in Section 1.1.3, having major land usage consisting of sealed impervious surfaces such as; roads, car parks, buildings, etc. Figures 3.15 and 3.16 are typical discharge hydrographs for the Flat Products East No.1 Drain. An interesting feature of these hydrographs is that rainfall and discharge appear to 'mirror' each other with instantaneous response in discharge to a change in rainfall intensity.

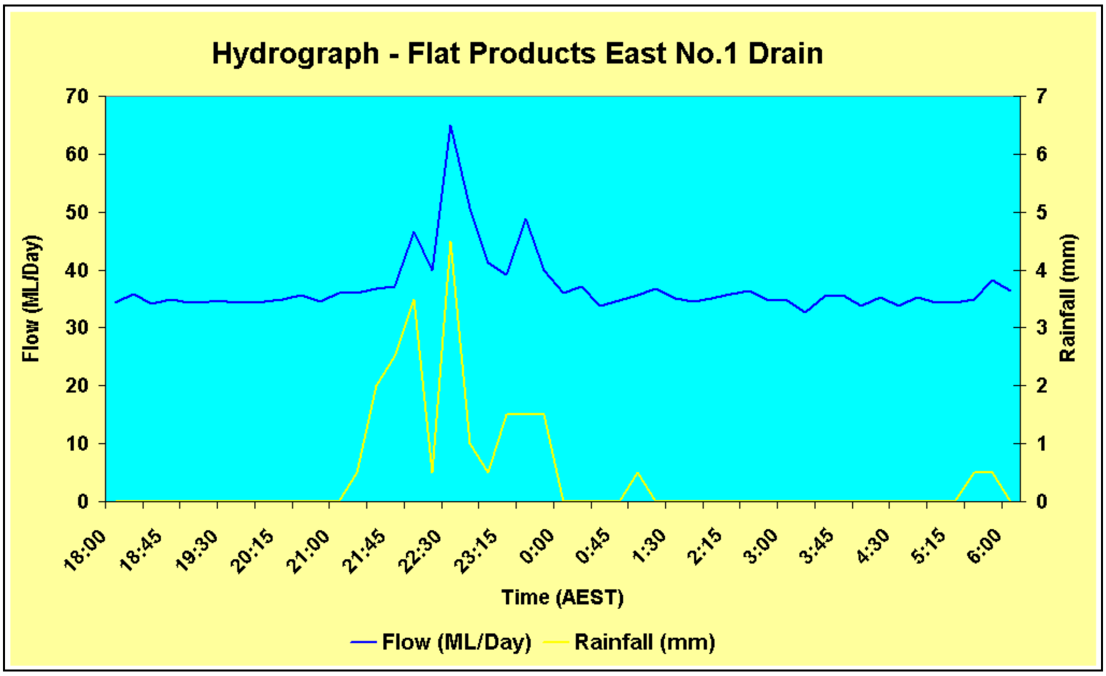


Figure 3.15 Typical Flat Products East No.1 Drain Hydrograph 1

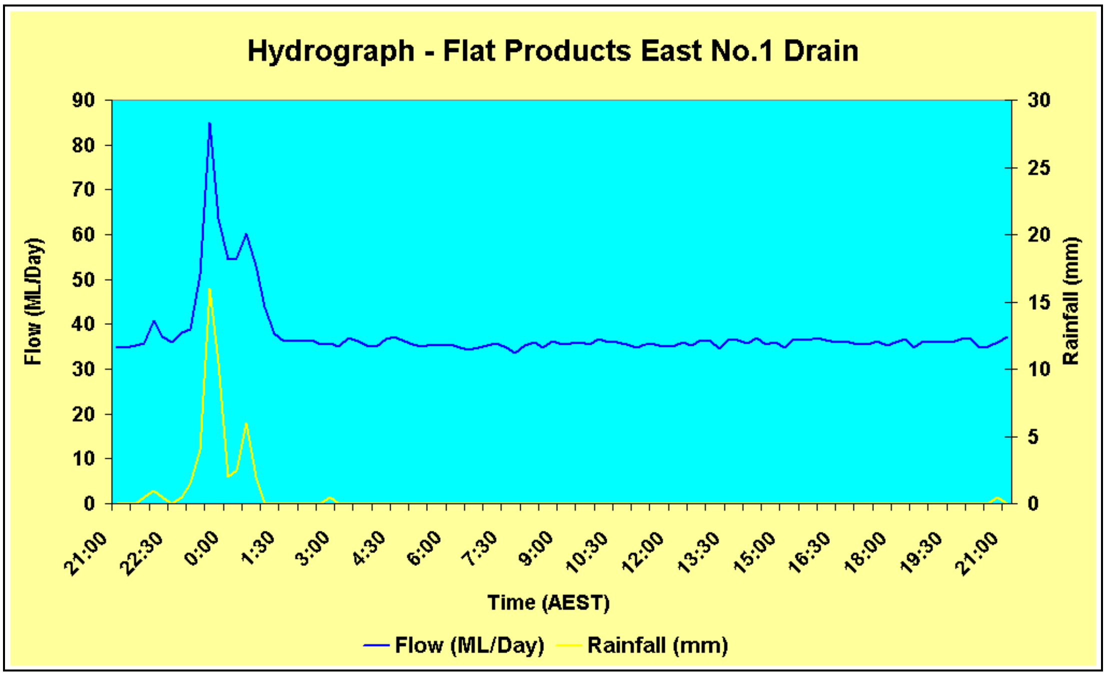


Figure 3.16 Typical Flat Products East No.1 Drain Hydrograph 2

3.1.4.2 Rainfall and Discharge Volume

The relationship between rainfall and discharge for the Flat Products East No.1 Drain is shown in Figure 3.17. The linear regression for the data is strong (R^2= 0.80).

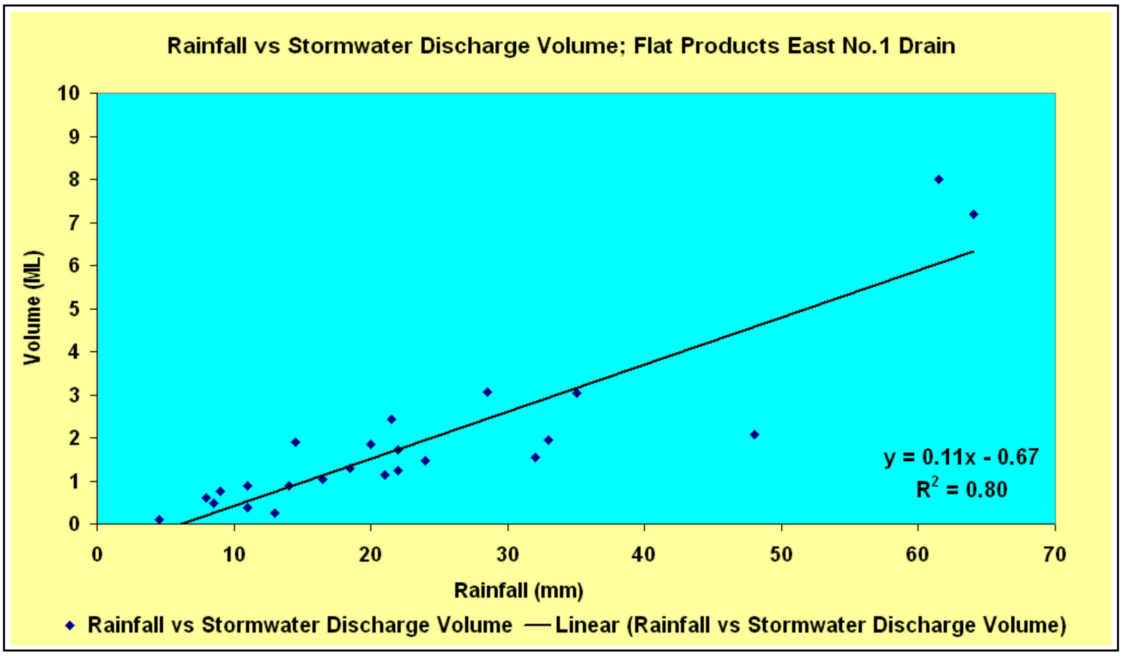


Figure 3.17 Rainfall vs. Stormwater Discharge Volume - Flat Products East No.1 Drain.

This strong linear regression is expected as the Flat Products East No.1 Drain catchment is relatively small (114,000 m^2) and has few areas where water loss can occur. Once again, as seen in the other drains, this plot contains outliers. These cannot be excluded but the same factors need to be considered, i.e., rainfall variation across the site and the API index.

3.1.4.3 Rainfall Volume and Stormwater Discharge Volume

The graph of rainfall volume vs. discharge volume for the Flat Products East No.1 Drain (Figure 3.18) has a slope of 0.96 (see equation displayed on chart). This indicates that very little water is lost to the catchment or other hydrological processes, with 96% leaving the drain as stormwater runoff, based on this data. This is consistent catchment type of this drain, major features being small and almost entirely sealed and impervious (no percolation or infiltration can occur). The small losses of water are most likely due to evaporation.

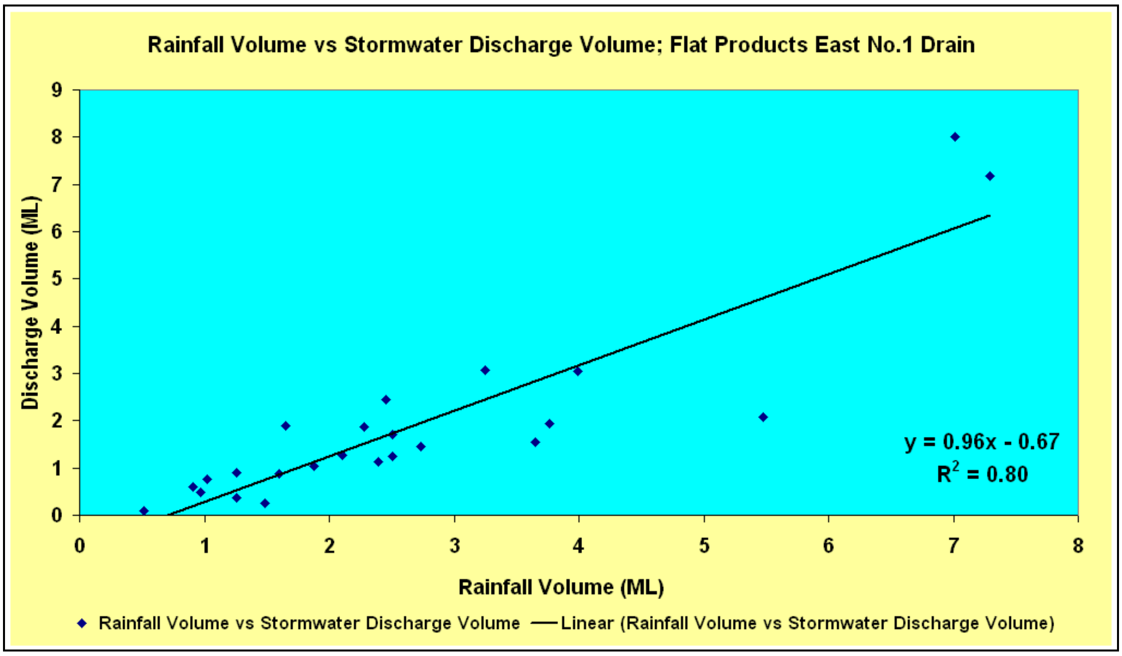


Figure 3.18 Rainfall Volume vs. Stormwater Discharge Volume - Flat Products East No.1 Drain

3.1.4.4 Antecedent Rainfall Effects

Figure 3.19 shows the plot of API and stormwater discharge volume for the Flat Products East No.1 Drain. The data points are very scattered and the linear regression coefficient is poor (0.45). This indicates there is no real relationship between antecedent rainfall and discharge volume for this drain. This feature can be attributed to the surface characteristics of the catchment. There is little or no chance of water infiltrating into the ground. This, along with the large portion of incoming rainfall that leaves the catchment via the drain (Figure 3.18, 0.96), shows that the preceding rainfall and moisture condition of the catchment does not affect the discharge volume.

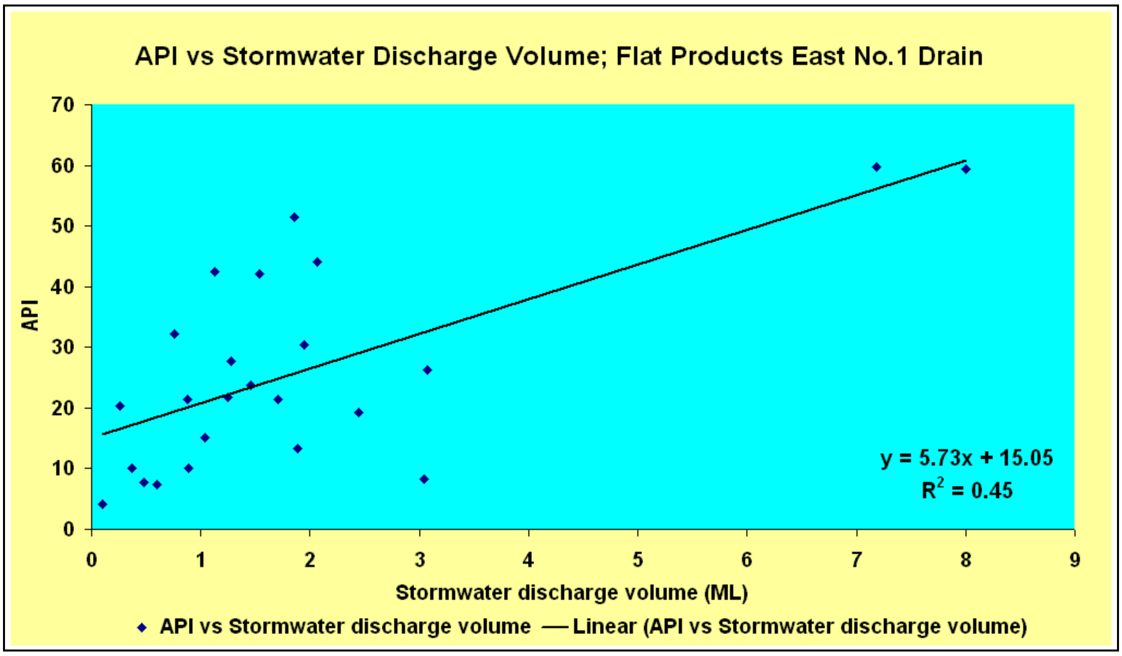


Figure 3.19 Antecedent Precipitation Index vs. Stormwater Discharge Volume - Flat Products East No.1 Drain.

As the hydrological study of the drains progressed it was clear there were two distinct types of catchments encountered, each having different size, land usage and hydrological behaviour. One type had a relatively small surface area consisting almost entirely of sealed, impervious surfaces, and the other had much larger surface area and significant portions of the catchment consisting of grassed areas and surfaces pervious to moisture.

The Flat Products East No.1 Drain and the Ironmaking East Drain both have relatively small catchment areas (114,000 and 162,520 m^2 respectively) and major land usage that are sealed impervious surfaces such as, roads, buildings, carparks and heavy industrial areas. Characteristics of the hydrographs produced for these two drains were very similar, both having a fast response to rainfall where peak discharge was within 15 minutes of peak rainfall intensity. These hydrographs also displayed very steep rising limbs and recession curves, with ‘baseline’ (process) flow returning within 30 minutes after the rain event in most cases. These ‘flashy’ features are typical of urban catchments as described in Section 1.1.3. The fraction of total rainfall volume (falling on the catchment) that is discharged as runoff via the drain is quite high for both drains (0.96 for the Flat Products East No.1, 0.82 for the Ironmaking East Drain). This characteristic is due to the nature of the catchments where infiltration and percolation losses are negligible, and the likely water loss is due to evaporation only. These drains did not show a relationship between Antecedent Precipitation Index (API) and discharge volume; thus, the moisture condition of the catchment does not affect the discharge volume for these two drains.

The Main Drain and the North Gate Drain both have catchments that cover relatively large (industrial) areas (3,312,500 and 983,100 m^2 respectively). Land usages within these catchments include large portions which are grassed, unsealed and pervious. The hydrographs produced from rainfall events for these drains are not dissimilar, both having very slow receding recession curves. 'Baseline' or process flows do not return for hours, even days after the rainfall has ceased. There are differences however; the North Gate Drain showed a fast response to rainfall and the Main Drain response was delayed. This difference could be due to the sealed areas of the North Gate Drain catchment being close to the discharge point, and the fact that the Main Drain is approximately 3 times larger. This will need further investigation to clarify. The fraction of total rainfall volume discharged as runoff for the Main Drain was much lower than for the Flat Products East No.1 and Ironmaking East Drains. This value of 0.58 indicates there are large water losses via infiltration and percolation into the unsealed areas of the catchment. The fraction of total rainfall volume for the North Gate Drain was determined to be 4.l. This is impossible, and this anomaly is almost certainly due to overestimations in flow rate and inadequate weir structure. Both the Main Drain and the North Gate Drain showed systematic increases of discharge volume with an increase in Antecedent Rainfall index. This indicates preceding rainfall events and moisture condition of the catchment do have an effect on the discharge volume for these drains.

3.2 Concentrations of Specified Parameters During Wet Weather

This section presents and discusses the results from the analysis of the water quality samples taken for this study.

3.2.1 Mean Data Comparisons

In order to compare the mean dry and wet weather water quality for each drain, the available data was spilt into 3 categories: All historical data (between December 1996 and March 2005), 'Wet' historical data (taken as samples where ≥ 10 mm of rain fell on day before or day of sampling, between December 1996 and March 2005) and data from this study where samples were collected specifically targeting the 'first flush' of a storm event. An ANOVA test was carried out on the historical data, and data collected for this study in order to determine if the data sets were statistically different. Results from the ANOVA tests are presented in Appendices F – I. Historical water quality data for PKSW drains are available from BSL's Environment Department (BlueScope Steel Limited, 2005).

3.2.1.1 North Gate Drain

Figure 3.20 is a graphical representation of mean values for the specified contaminants at the North Gate Drain. A slight increasing trend for TSS at the North Gate Drain with wet weather can be seen; the mean historical result is 9.2 mg/L which increases to 13.3 mg/L for 'wet' historical samples and 20.6 mg/L for samples collected for this study. An ANOVA test (Appendix F) shows that the first flush TSS data in this study were significantly higher than the historical data. Virtually no change in concentration is seen for Total Iron, and the data collected for this study is not statistically different to the historical Total Iron data (Appendix F). No significant difference in pH with wet weather was seen at the North Gate Drain for samples collected as part of this study.

3.2.1.2 Main Drain

There is a pronounced trend of increased TSS concentration with wet weather for the PKSW Main Drain. As seen in Figure 3.21 the mean TSS concentration in the Main Drain for all historical data is 11.0 mg/L whereas the mean of data collected for this study is 83.5 mg/L. An ANOVA test showed that the first flush TSS data were significantly higher than historical data. The TSS data set for the Main Drain (this study data) also has a very large standard deviation (170.6 mg/L see Table 3.1). This increasing trend is also evident for Total Iron with a mean of 2.2 mg/L for this study. It must be noted, however, that the historical data set for the Main Drain Total Iron contained samples collected between September 1998 and January 1999 only, and the data sets are not statistically different (Appendix G). Statistical analysis of the pH data showed the historical data is different to data collected for this study (Appendix G), however, these small pH differences (historical 8.1, this study 7.9) have little or no environmental consequence.

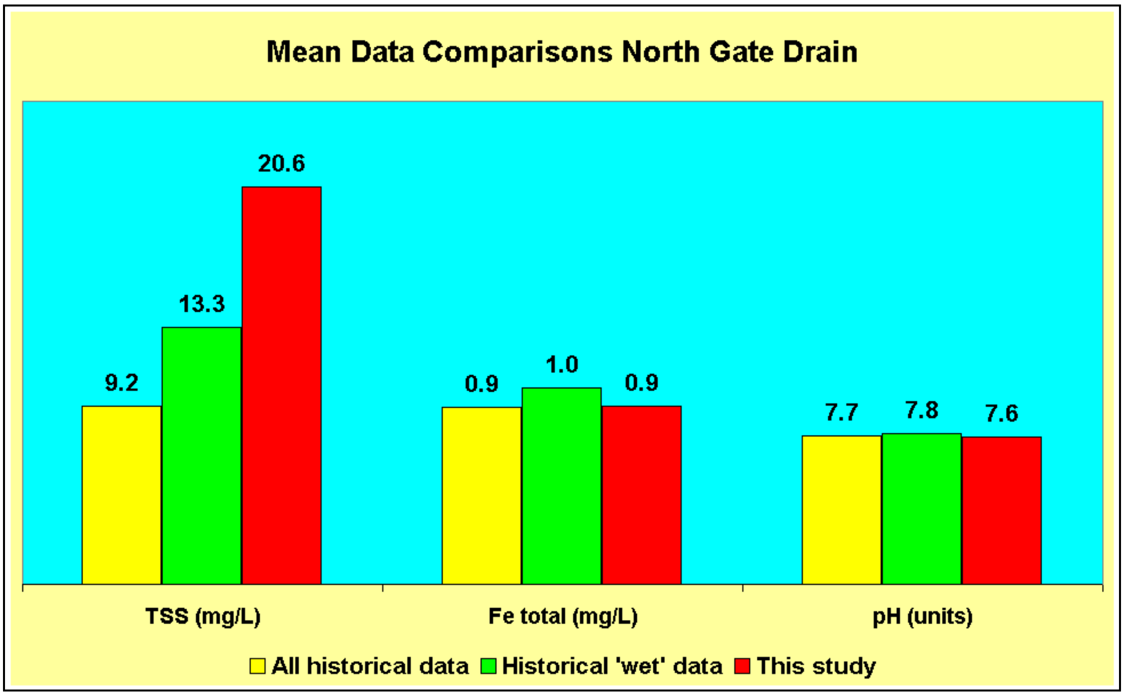


Figure 3.20 Mean Water Quality Data Comparison for Specified Parameters at North Gate Drain

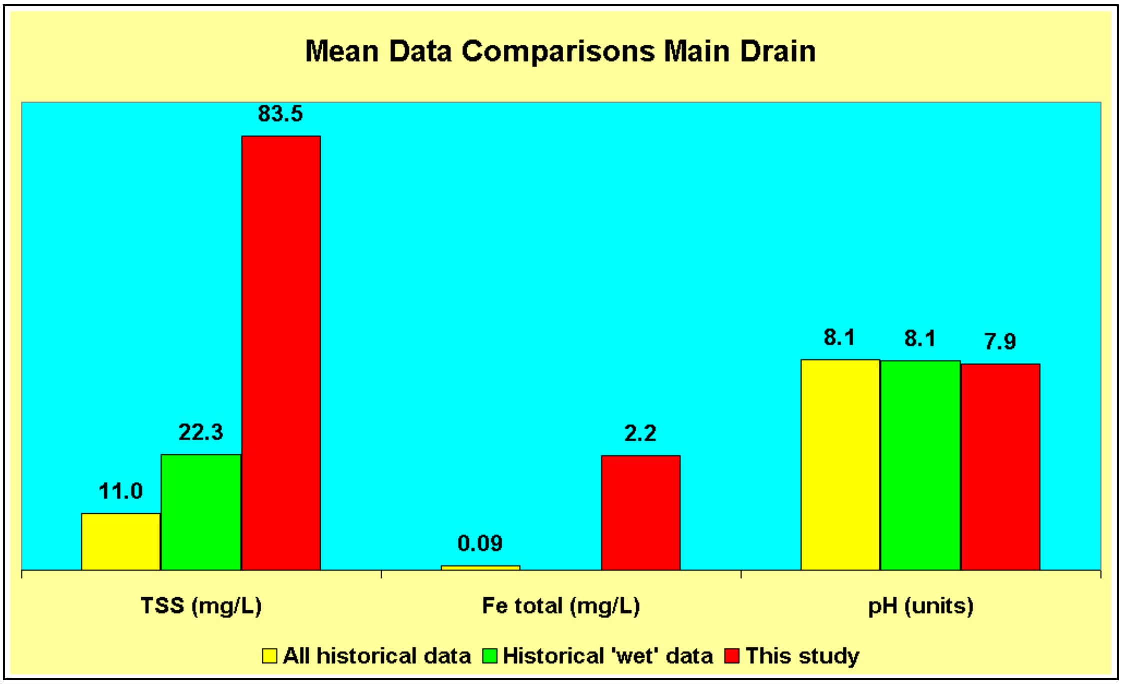


Figure 3.21 Mean Water Quality Data Comparison for Specified Parameters at Main Drain

3.2.1.3 Ironmaking East Drain

Figure 3.22 shows the mean data comparisons for TSS, Total Iron and pH at the Ironmaking East Drain. A clear increase in the mean data for TSS is seen at the Ironmaking East Drain. The mean TSS for historical samples is 13.1 mg/L compared to the mean of 35.4 mg/L for data in this study – the first flush data were statistically significantly higher (Appendix H). A similar increase, although not as pronounced, is followed in the Total Iron data with the historical mean concentration of 1.1 mg/L and the mean concentration for samples collected as part of this study being 2.1 mg/L. Once again, the small changes in pH (historical 8.3, this study 8.0) are of minimal environmental consequence.

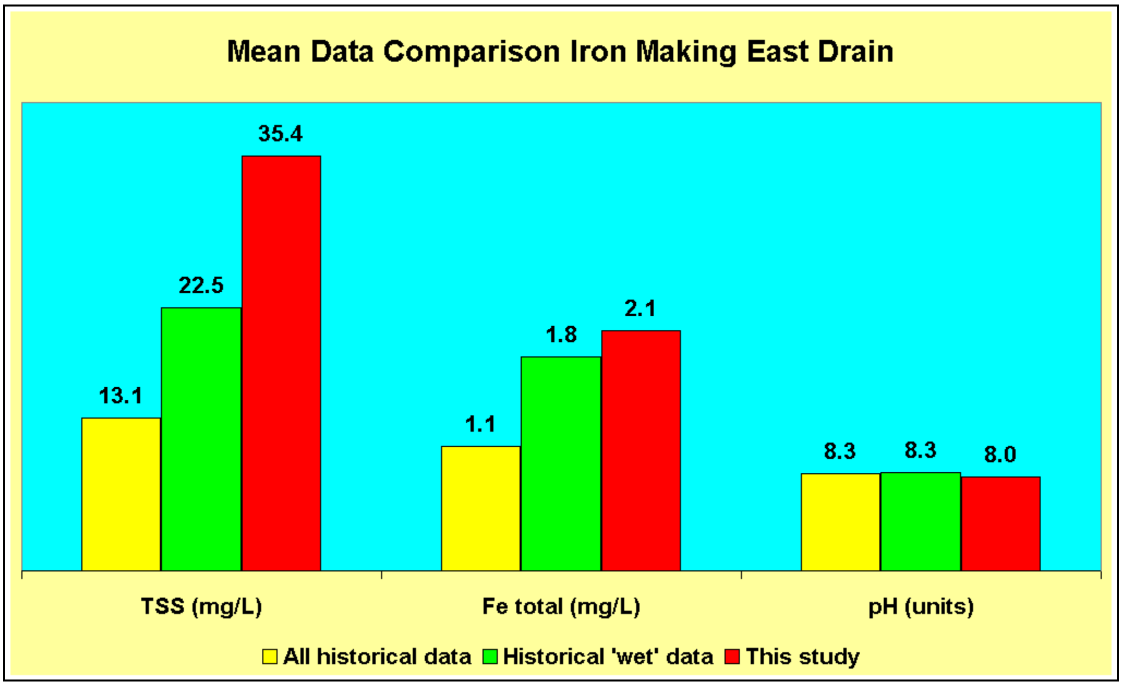


Figure 3.22 Mean Water Quality Data Comparison for Specified Parameters at Ironmaking East Drain

3.2.1.4 Flat Products East No.1 Drain

Figure 3.23 shows the comparison of the mean data for TSS, Total Iron and pH at the Flat Products East No.1 Drain. The mean data collected for this study shows a sharp increase in concentration for both TSS and Total Fe. The ANOVA test (Appendix I) shows that the historical data, and data collected for this study, the first flush data (this study) are statistically significantly higher than the historical values. The mean TSS concentration for this study is 40 mg/L and the mean Total Iron concentration is 3.1 mg/L. As in the previous drains, no significant difference in the pH was observed between the data sets.

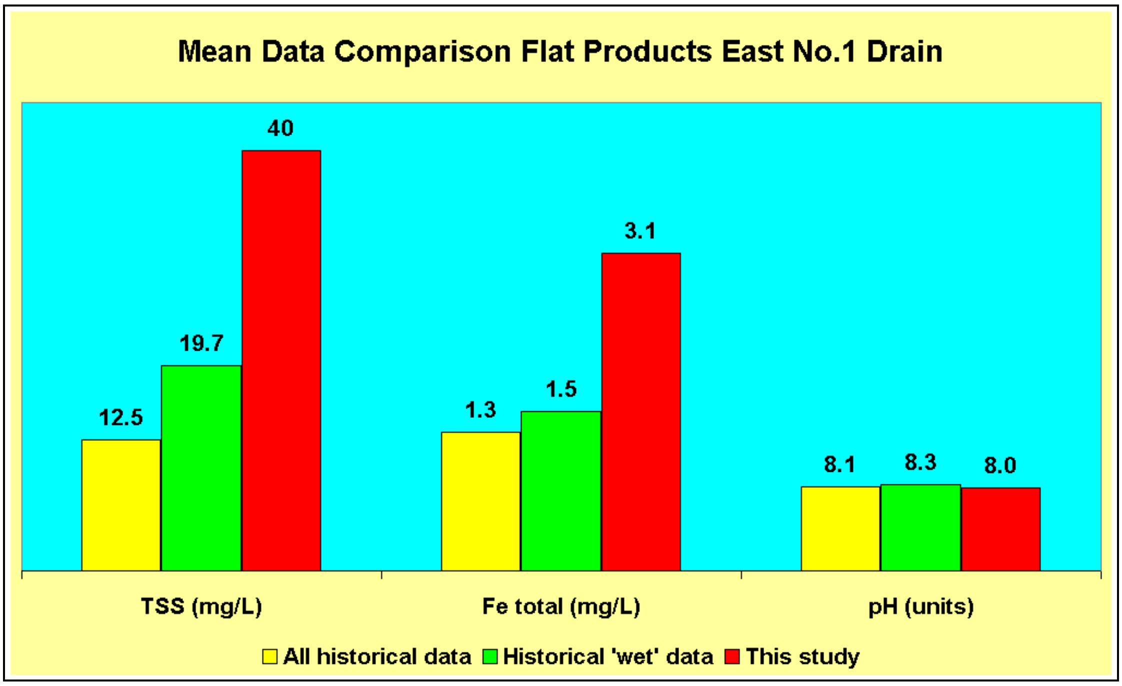


Figure 3.23 Mean Water Quality Data Comparison for specified parameters at Flat Products East No.1 Drain

3.2.2 Water Quality Data Summary

Tables 3.1 – 3.3 contain a summary of all data collated for this study listing the mean and standard deviation for each parameter by drain. Included in the tables are: maximum values for both historical data (between Dec '96 and Mar '05) and water quality data collected for this study; the current wet weather licence limit for each parameter at each drain; and the number of samples collected during this study.

Table 3.1 contains the TSS data summary. The historical TSS concentrations for each drain are similar (~10 mg/L) and the standard deviation is not large in comparison to the mean. The data collected for this study shows quite a contrast where the mean TSS values are quite different and the standard deviation is often quite large compared to the mean.

The 'dry' weather and 'wet' weather TSS data are not very different for the North Gate Drain. The historical mean TSS concentration for the North Gate Drain is 9.2 mg/L with a maximum of 176 mg/L. The mean concentration of wet weather sampling is 20.6 mg/L with a maximum of 77 mg/L. Neither of these maximum results is above the current wet weather licence limit of 200 mg/L and, in both cases, the standard deviation is not large when compared to the mean.

As mentioned in Section 3.2.1.2, the Main Drain TSS data shows there is a large increase in TSS concentration with wet weather. The mean of 83.5 mg/L for samples collected in this study also has a very large standard deviation (170.6 mg/L) and maximum recorded concentration of 1322 mg/L is well above the current wet weather licence limit of 200 mg/L. This large standard deviation is attributed to the distribution of TSS sample results (from laboratory detection limits up to 1322 mg/L) and magnitude of first flush effects at this site where high intensity large volume rainfall events led to high TSS concentrations. Sampling continued beyond December 2004 to collect an even larger data set (408 samples) as it was evident from preliminary data collected up until June 2004 that the Main Drain TSS concentrations were elevated in wet weather.

The Ironmaking East Drain and the Flat Products East No.1 Drain both show increases in TSS with the onset of wet weather. The standard deviation is also large when compared to the mean; the Ironmaking East Drain has a mean TSS concentration of 35.4 mg/L during wet weather and a standard deviation of 51.6 mg/L based on 299 samples. The Flat Products East No.1 Drain has a mean of 40.4 mg/L with a standard deviation of 49.9 mg/L. Both the Ironmaking East Drain and Flat Products No.1 Drains have recorded maximum concentrations over the current wet weather licence limit of 200 mg/L.

In considering these results it should be noted that the sampling undertaken for this study will identify the maximum results, targeting the 'worst case' scenario and 'first flush' of a storm event. Almost always, these high values are only seen in 'point concentrations' at the very start of the rainfall event and rarely last more than a number of minutes (< 30).

TSS (mg/L)	Mean Historical[1] dry weather result	Mean wet weather result (this study)	No. of Wet Weather Samples	Max[2]. Recorded Historical[1] data	Maximum[2] recorded this study	Current Wet Weather license limit
North Gate Drain	9.2 (11.6*)	20.6 (13.8*)	262	176	77	200
Main Drain	11.0 (13.8*)	83.5 (170.6*)	408	250	1322	200
Iron Making East Drain	13.1 (24.0*)	35.4 (51.6*)	299	610	602	200
FPE No.1 Drain	12.5 (13.2*)	40.4 (49.9*)	405	151	412	200

Table 3.1 TSS Data Summary Table for PKSW Drains

* Standard Deviation
[1] Between Dec '96 and Mar '05
[2] Minimum concentrations below laboratory detection limits

Table 3.2 contains a data summary table for Total Iron at each drain. The mean historical dry weather data for each drain is similar (~1 mg/L), with the exception of the Main Drain (0.09 mg/L). However, this result for the Main Drain Iron is based on a very small data set as mentioned previously in Section 3.2.1.2. The North Gate Drain wet weather data for Total Iron is similar to the historical dry weather data with both the mean concentration and standard deviation being low. The maximum-recorded Total Iron concentration for this study at the North Gate Drain of 3.6 mg/L is below the current wet weather licence limit of 5.0 mg/L. Wet weather monitoring of Total Iron in the Main Drain returned a mean of 2.2 mg/L with a relatively large standard deviation of 5.3 mg/L. The maximum recorded concentration was 41.3 mg/L. This data suggests there is a source of Iron within the Main Drain catchment area mobilised by rainfall conditions. Currently there is no licence limit for Total Iron in the Main Drain.

The Ironmaking East Drain wet weather data shows a small increase for Total Iron compared to the historical dry weather data (2.1 mg/L vs. 1.1 mg/L), and the standard deviation is not particularly large (2.6 mg/L). The maximum recorded Total Iron concentration of 16.6 mg/L is below the current wet weather licence limit.

Fe total (mg/L)	Mean Historical[1] dry weather result	Mean wet weather result (this study)	No. of Wet Weather Samples	Max[2]. Recorded Historical[1] data	Maximum[2] recorded this study	Current Wet Weather license limit
North Gate Drain	0.9 (0.6*)	0.9 (0.7*)	262	5.2	3.6	5
Main Drain	0.09 (0.10*)	2.2 (5.3*)	408	0.37	41.3	N/A
Iron Making East Drain	1.1 (1.5*)	2.1 (2.6*)	299	24.0	16.6	20
FPE No.1 Drain	1.3 (1.7*)	3.0 (6.2*)	405	11.0	61.1	20

Table 3.2 Total Iron Data Summary Table for PKSW Drains

* Standard Deviation
[1] Between Dec '96 and Mar '05
[2] Minimum concentrations below laboratory detection limits

The Total Iron data collected for the Flat Products East No.1 Drain shows a significant increase compared to the historical dry weather data (historical mean 1.3 mg/L, mean this study 3.0 mg/L). The standard deviation (6.2 mg/L) for the wet weather data set is also relatively large when compared to the mean. The maximum Total Iron result of 61.1 mg/L is above the current licence limit of 20 mg/L.

pH (units)	Mean Historical¹ dry weather result	Mean wet weather result (this study)	No. of Wet Weather Samples	Max. Recorded Historical¹ data	Maximum recorded this study	Current Wet Weather license limit
Main Drain	8.1 (0.2*)	7.9 (0.2*)	264	8.9	8.8	9.0^2
Iron Making East Drain	8.3 (0.3*)	8.0 (0.2*)	120	9.3	8.6	9.0^2
Flat Products East No.1 Drain	8.1 (0.3*)	8.0 (0.3*)	216	10.4	8.7	9.0^2
North Gate Drain	7.7 (0.3*)	7.6 (0.4*)	262	8.5	9.0	9.5

Table 3.3 pH Data Summary Table for PKSW Drains

* Standard Deviation
¹ Between Dec '96 and Mar '05
² Current Absolute Dry Weather Licence Limit

Table 3.3 presents a data summary for pH at PKSW drains included in this study. A comparison between the mean historical data and wet weather pH data shows there is no significant change in pH with wet weather for any of the drains. The North Gate Drain currently is the only licensed drain at PKSW which has a wet weather pH licence limit; the Main Drain, the Ironmaking East Drain, and the Flat Products East No.1 Drain do not, and will not be considered when calculating confidence limits in Section 3.3. The maximum pHs for samples collected as part of this study were below the current licence limits at all drains. It must be noted that all of the wet weather pH data collected for this study occurred whilst a large flow of salt water was present in the drains. Recent process changes have seen gradual reductions in the volume of salt water in the North Gate Drain with eventual goal of complete removal. This could have implications for pH at the North Gate Drain, as a loss in salinity will reduce the buffering capacity of the discharge water. This could lead to an increased risk of significant pH changes at the North Gate Drain during wet weather. It is recommended that wet weather pH sampling continue in conjunction with the salt water reductions.

3.2.3 Hydrographs and Pollutographs

Figures 3.24 – 3.27 show a typical hydrograph and pollutograph for each drain. The shape of each hydrograph and rate of discharge depends largely on a number of factors including the volume and intensity of the rainfall, and the major land usage within a catchment. Rainfall events with high volume and high intensity rainfall falling on catchments with large proportions of sealed impervious surfaces will result in hydrographs with a sharp rising limb and peak flow rate well above the 'normal' process discharge. As mentioned previously in Section 2.2.2 (i, iv), all hydrographs and pollutographs generated as part of monitoring for this study are presented in Appendices A-D.

Please see print copy for Figure 3.24

Figure 3.24 North Gate Drain Hydrograph and Pollutograph

These pollutographs show that generally the concentrations of pollutants in the initial period of stormwater runoff are substantially higher than during the later periods, indicating that a first flush has occurred and is consistent with previous studies on urban catchments (Deletic and Maksumovic, 1998; Gupta and Saul, 1996).

Please see print copy for Figure 3.25

Figure 3.25 Main Drain Hydrograph and Pollutograph

Please see print copy for Figure 3.26

Figure 3.26 Ironmaking East Drain Hydrograph and Pollutograph

Please see print copy for Figure 3.27

Figure 3.27 Flat Products East No.1 Drain Hydrograph and Pollutograph

3.2.4 Particle Identification

As mentioned previously in Section 2.5, light microscopy was used for particle identification of the particulate material retained in the TSS analysis of water samples. Table 3.4 presents a summary of the results from the light microscopy analysis. ‘Major’ material identified by light microscopy accounts for greater than 10% of the particulates, ‘minor’ material between 3% and 10%, and ‘trace’ accounts for less than 3%.

Drain	Major Material[1]	Minor Material[2]	Trace Material[3]
Main Drain	Coal	Coal, Fe prills	Kish, metallic Fe, coke, slag, hematite
Iron Making East Drain	Hematite	Coke, slag, silica	Limestone, sinter
Flat Products East No.1 Drain	Fe prills, others[4]	Hematite, metaillics, Fe oxyhydroxides, others[4]	Kish, slag, coke
North Gate Drain	Hematite, slag, others[4]	Slag, organics, kish	Organics, metallics, others[4]

Table 3.4 Particle Identification for PKSW Drains

[1] Major Material >10%
[2] Minor Material 3-10%
[3] Trace Material <3%
[4] Others denotes material which could not be identified by light microscopy

Results of the light microscopy analysis of particulate from the North Gate Drain identified hematite, slag and others as the major material present as TSS. Minor material also included slag, as well as kish and organics. Trace material was found to be organics, metallics and others. These findings are consistent with the land usage and associated activities within the North Gate Drain catchment: historically slag was used as landfill in northern areas of the PKSW; and hematite and kish can be attributed to wind borne dust from the iron and steel scrap storage, and iron ore stockpiles in adjacent areas (Flat Products East No.1 Drain and Ironmaking East Drain, see Figure 1.6). Results presented in Sections 3.2.1 and 3.2.2 show that TSS and iron concentrations are not elevated during wet weather. Potential stormwater capture and reuse may be a viable option at the North Gate Drain as results from this study show the water quality during wet weather is not different to the historical dry weather data. As mentioned previously, this study was undertaken whilst a large salt water flow existed on the drain and it is recommended that further studies be undertaken inline with the removal of the salt water.

Coal was identified as the major material (up to 90% in some cases) in the Main Drain TSS particulate; it was also seen as minor material in some samples along with iron prills. Trace material found in the Main Drain consisted of kish, metallic iron, coke, slag and hematite. The Main Drain catchment includes the Coke Ovens Retention Basin (CORB) as mentioned in Section 1.2.1.2 and the Main Drain is in close proximity to a coal handling and coal stockpile areas. Mobilisation of material in these areas is the most likely sources of coal during wet weather. Results presented in Section 3.2 indicate TSS in an obvious area of concern in the PKSW Main Drain. Given the current situation, the capture and reuse of stormwater from the Main Drain is not environmentally or economically viable. The elevated TSS concentrations in

Main Drain should be further investigated, the point source of coal found in the particulate be identified, and engineering controls implemented as appropriate.

Major material in particulates from the Ironmaking East Drain was identified as hematite. Minor material also included hematite, along with coke, slag and silica. Trace material contained limestone and sinter. As detailed in Section 1.2.1.3, the industrial activities within the Ironmaking East Drain Catchment include an iron ore unloading berth, iron ore stockpiles and associated raw materials handling and a sinter plant. All these activities are a potential source of iron ore (hematite), and all most likely contribute to the elevated TSS and iron concentrations seen at the Ironmaking East Drain during wet weather (see Section 3.2). Further investigations into the catchment hydrology, point source identification of hematite particulate and engineering controls would help reduce TSS and iron concentrations in the Ironmaking East Drain and it is recommended these steps be undertaken.

Iron prills and others were identified as the major material found in the TSS particulates at the Flat Products East No.1 Drain. Minor material consisted of hematite, metallics, other iron oxyhydroxides and others, whist the trace material was found to be kish slag and coke. The Flat Products East No. 1 Drain is located just to the south of the No.2 Products Loading berth (see Figure 1.6) and, as detailed in Section 1.2.1.4, the catchment for this drain contains BSL's large scrap steel area. Runoff from this scrap steel area is the most likely source of iron prills and elevated iron concentrations discussed in Sections 3.2.1 and 3.2.2. Further investigations to confirm this point source of contaminants found in the Flat Products East No.1 Drain should be undertaken, and engineering controls be implemented to improve the stormwater discharge quality.

3.2.5 Current Pollution Control Strategies

A number of pollution control strategies are currently employed by BSL to minimise the potential environmental impact of any stormwater discharge.

- Within the North Gate Drain catchment the current strategy includes, road and street sweeping for dust, particulate, and debris collection.

- Iron ore stockpiles within the Ironmaking East Drain catchment are wet down and reclaimed as part of routine operations for dust suppression, and roads and paved areas are swept and wet to minimise dust and wind borne particulate matter in this area.

- Current strategies within the Flat Products East No.1 Drain are focussed on dust suppression of the scrap steel storage areas and the same methods are used as for the North Gate Drain and Ironmaking East Drains.

- Within the Main Drain catchment, coal stockpiles are wet down and reclaimed to minimise and suppress dust, and roads are wet down and swept for dust suppression. Within the coal handling areas of the Main Drain catchment, stormwater retention basins exist and the CORB is used as a water capture and reuse facility: however, the management of this system needs improvement. Inadequate maintenance of the stormwater retention basins has meant they operate inefficiently in times of rainfall, and the stormwater captured in the CORB contains high concentrations of suspended solids and is often unsuitable for reuse. Furthermore elevated suspended solid concentrations in the CORB impact directly as a source of TSS in the Main Drain during wet weather (see Section 1.2.1.2).

Overall, these control strategies tend to minimise dust (and hence air quality problems), but they often do not stop particulates getting into the drainage system and thus adding to the load during storm events. Greater protection is required for drains from washing down activities if the stormwater suspended solids and particulate iron load are to be reduced.

3.3 CONFIDENCE LIMITS AS WET WEATHER LIMITS

This section will present the calculated confidence limits for parameters measured at each drain, leading to recommendations on wet weather licence limits based on these confidence limits and data presented in Section 3.1. The confidence limits are represented graphically with each graph including mean and maximum concentration recorded during monitoring for this study, and a 50,80,90,95 and 99% confidence limit calculated as detailed in Section 2.2.1. Recommendations will be made based on the 95% Confidence Limits (95% CL). The 95% CL can be statistically explained as: If a sample is taken for water quality analysis from a licensed drain at PKSW during wet weather, then there is a 95% chance the measured concentration will be below the 95% confidence limit. The 95% CL was selected as an appropriate level of confidence given the combination of a number of factors: current water quality sampling (for L6092) is every 8 days; there are only approximately 20 days per year where rainfall is greater than 10 mm (see Section 1.1.2); and pollutant concentration limits imposed on licensed drains whilst achievable, must be stringent enough to drive improved environmental performance. If current water sampling requirements for L6092 compliance purposes are changed or modified in any way, wet weather licence limits recommended in this study will need to be re-considered.

3.3.1 North Gate Drain Confidence Limits

Figure 3.28 shows the calculated confidence limits for the North Gate Drain TSS concentrations. Clearly all calculated confidence limits are well under the current wet weather licence limit of 200 mg/L. The mean wet weather concentration of 21 mg/L has a relatively small standard deviation (as mentioned in section 2.2.1). The current dry weather TSS licence limit is 50 mg/L. Based on the results of this study, it is recommended that the wet weather licence limit for TSS at the North Gate Drain be reduced to 60 mg/L (95 % CL). This limit has been determined by consideration of factors such as: current sampling frequency, number of wet days per year and, current licence limits and increasing environmental performance. The selection of 95% CL as wet weather licence limits is discussed further in Sections 3.3.5 and 3.3.6.

Figure 3.29 shows the calculated confidence limits for the North Gate Drain Total Iron concentrations. The 95% CL of 3.7 mg/L is below the current wet weather and absolute licence limit of 5.0 mg/L. As mentioned in Section 3.2.2, none of the samples collected for this study exceeded the current licence limit concentration for Total Iron at the North Gate Drain. Based on the results of this study it is recommended that the wet weather licence limit for Total Iron at the PKSW North Gate Drain be reduced to 4.0 mg/L.

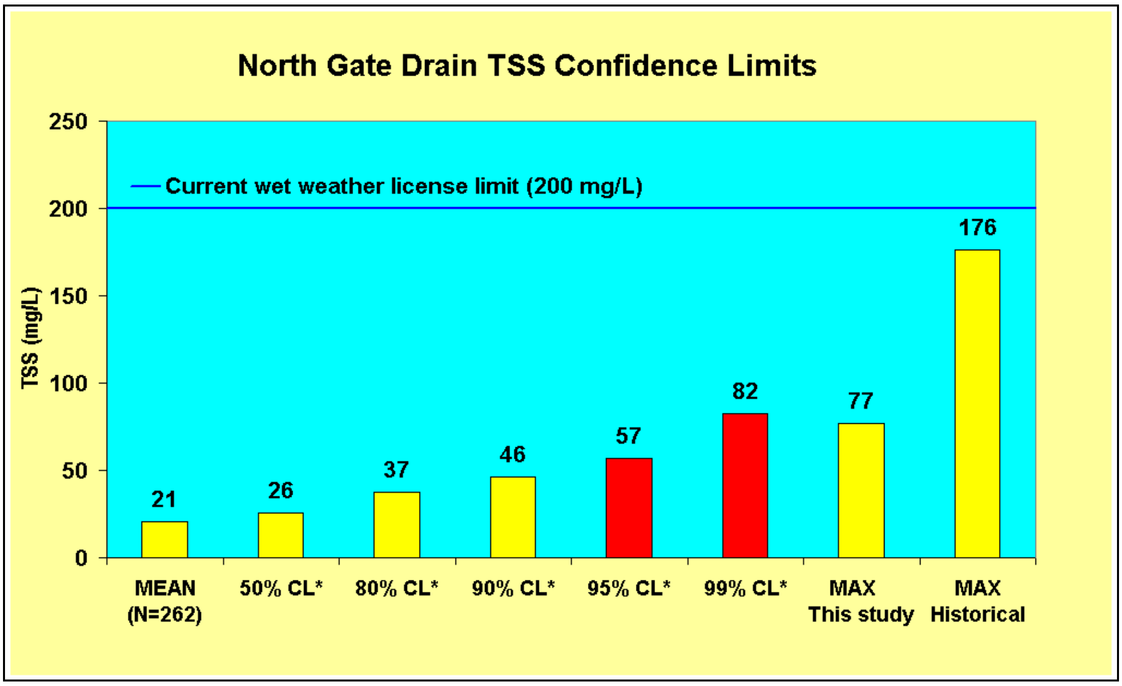


Figure 3.28 Calculated TSS Confidence Limits – North Gate Drain

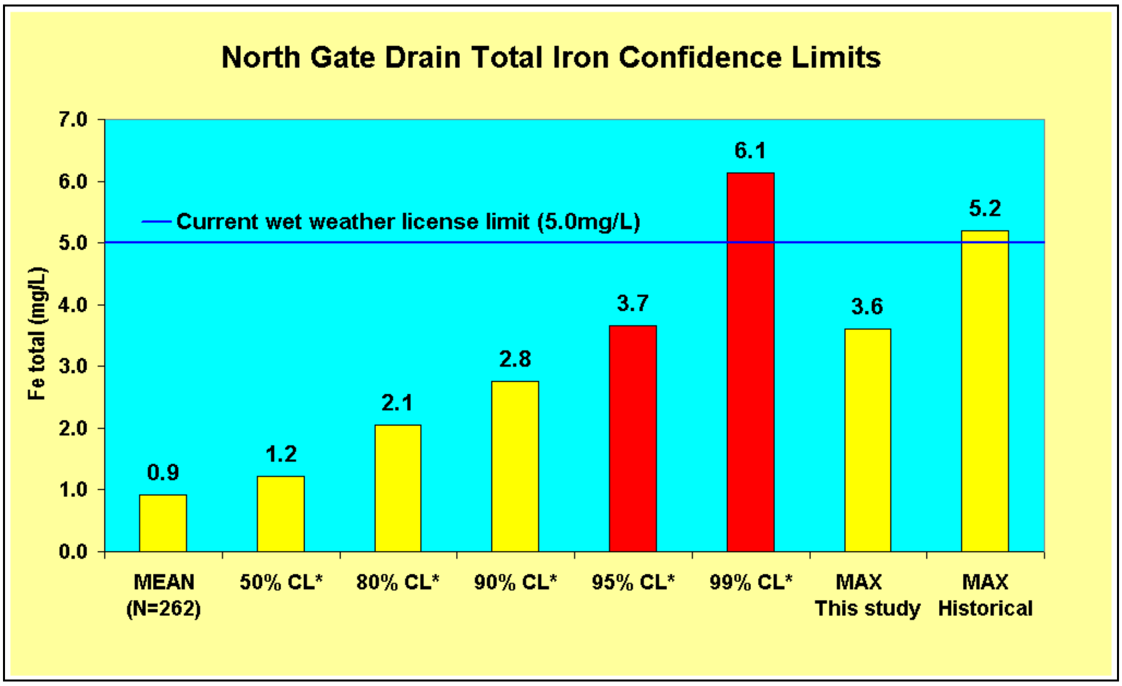


Figure 3.29 Calculated Total Iron Confidence Limits – North Gate Drain

Figure 3.30 shows the calculated confidence limits for the North Gate Drain pH. Both the upper 95% CL (8.5) and 99% CL (8.8) are below the current wet weather licence limit (9.5). However, as mentioned previously in Section 3.2.2, these confidence limits were based on samples collected whilst a large salt water flow existed on the drain. Potential significant pH changes during wet weather would have been buffered to some extent by the increased salinity on this drain. It is recommended that the current wet weather pH limit of 9.5 remains at the North Gate Drain, and further wet weather pH monitoring recommence once further salt water reductions have been made.

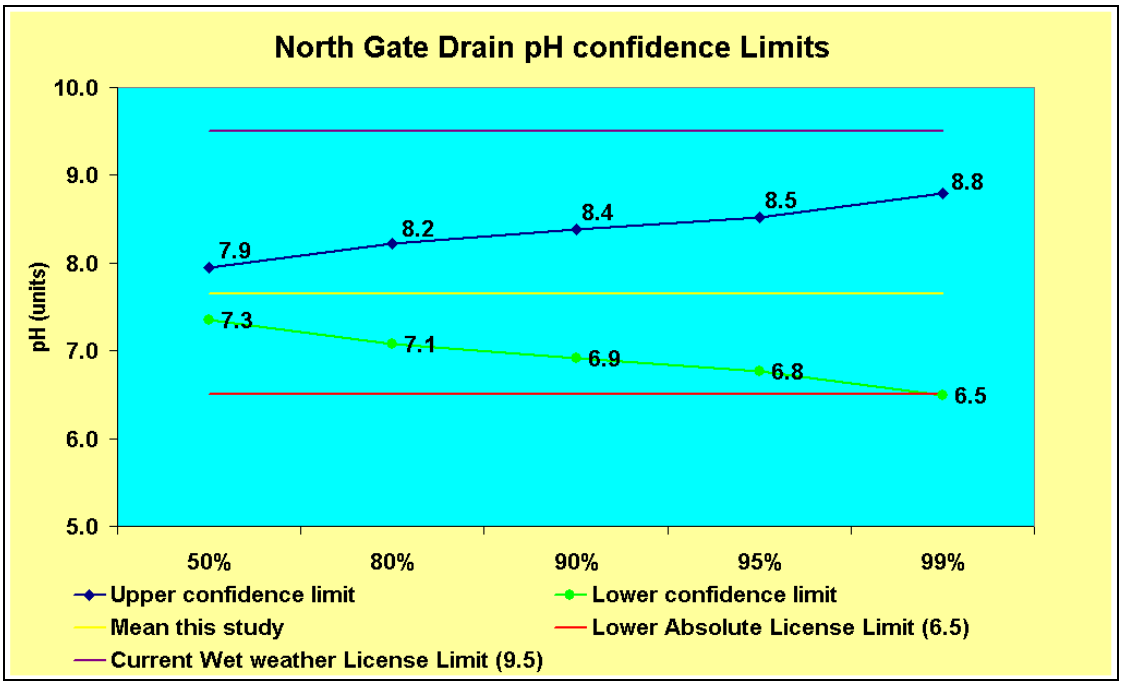


Figure 3.30 Calculated pH Confidence Limits – North Gate Drain

3.3.2 Main Drain Confidence Limits

Calculated confidence limits for the Main Drain TSS concentrations are shown in Figure 3.31. The 95 and 99% CL's are well above the current wet weather licence limit of 200 mg/L. The calculated confidence limits and data summary presented in Section 3.2.2 clearly identify a TSS issue in the Main Drain during wet weather. Based on the results of this study, it is recommended that the Main Drain wet weather licence limit is increased to 400 mg/L as an interim, until further monitoring of TSS during wet weather is undertaken, including more extensive catchment monitoring and point source identification.

Figure 3.32 shows the calculated Total Iron concentration confidence limits for the Main Drain, based on the data collected for this study. The minimal historical dry weather data available suggests Iron is not of concern at the Main Drain, but as mentioned in Section 3.2.2, the wet weather data collected for this study and calculated confidence limits presented in Figure 3.32 suggest there is a source of Iron within the Main Drain catchment, mobilised by wet weather conditions. Currently there are no licence limits for Total Iron concentrations in the Main Drain. A number of other PKSW licensed drains have a dry weather Total Iron limit of 5 mg/L and a wet weather Total Iron concentration limit of 20 mg/L. It is recommended these numbers be adopted as interim limits and an investigation into the source of Total Iron in the Main Drain during wet weather be commenced in conjunction with TSS as mentioned above.

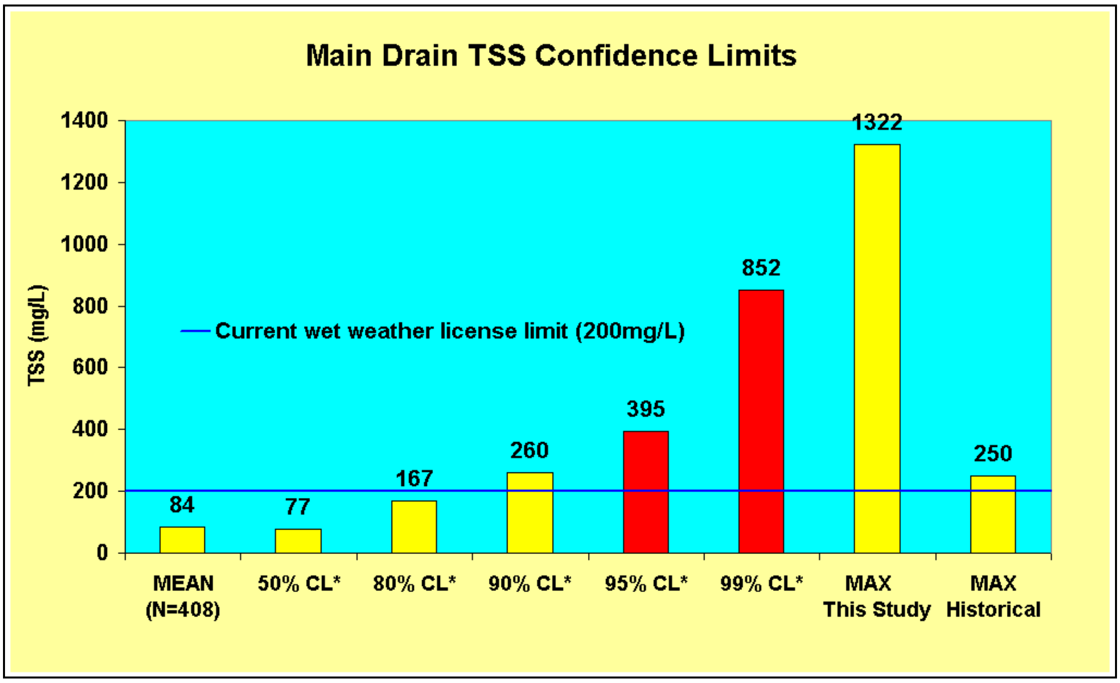


Figure 3.31 Calculated TSS Confidence Limits – Main Drain

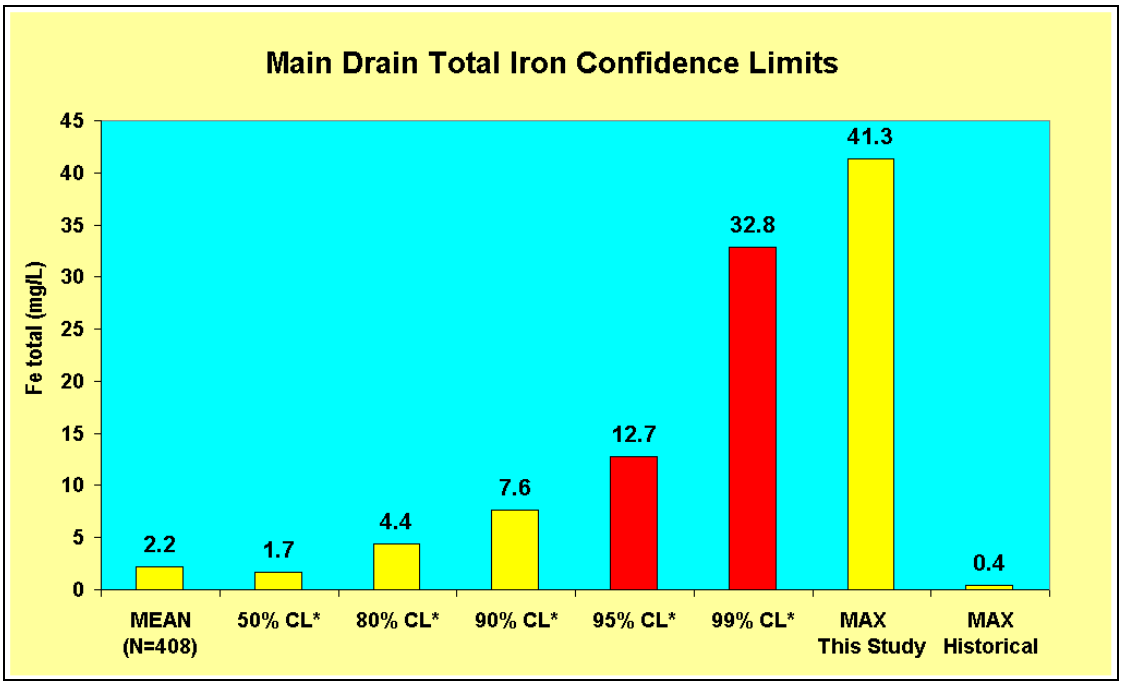


Figure 3.32 Calculated Total Iron Confidence Limits – Main Drain

3.3.3 Ironmaking East Drain Confidence Limits

Calculated confidence limits for the Ironmaking East Drain TSS concentrations are shown in Figure 3.33. Both the maximum recorded values for this study and the historical data are well above the current wet weather licence limit. The 95% CL of 132 mg/L is below the current wet weather licence limit of 200 mg/L. The current dry weather licence limit is 100 mg/L. Data presented in Section 3.2.2 shows the historical dry weather data and the wet weather data are clearly different, and a wet weather licence limit for TSS concentrations at the Ironmaking East Drain cannot be avoided. Based on the results of this study it is recommended that the wet weather licence limit for TSS at the Ironmaking East Drain be reduced to 130 mg/L.

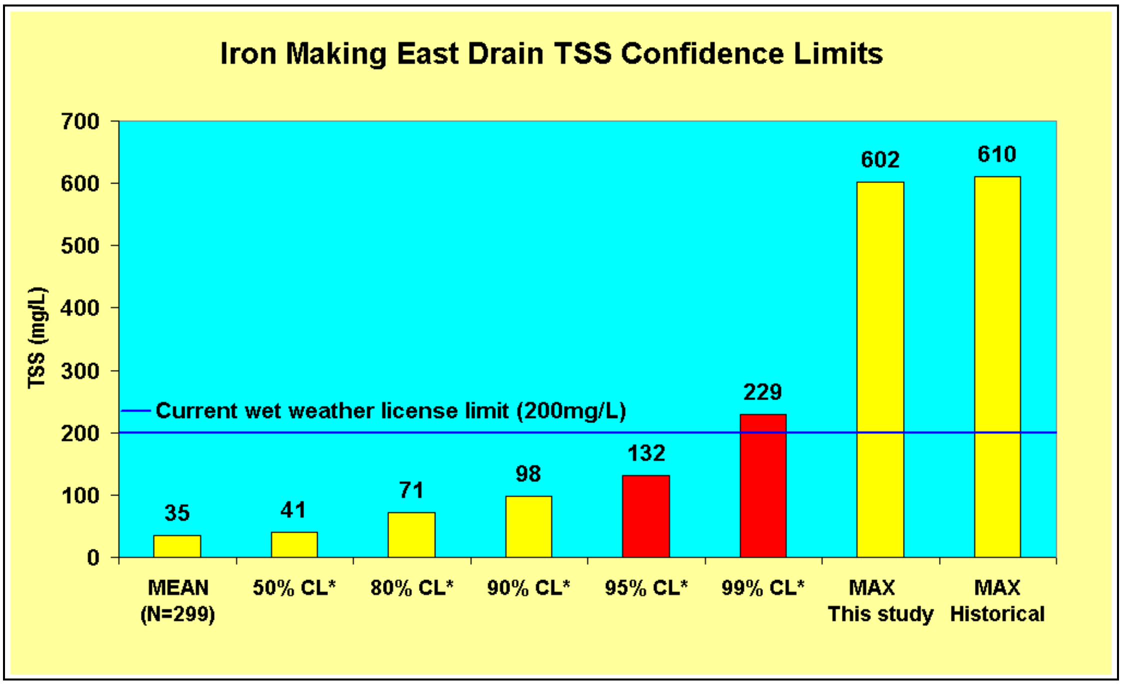


Figure 3.33 Calculated TSS Confidence Limits – Ironmaking East Drain

Total Iron concentration confidence limits for the Ironmaking East Drain are shown in Figure 3.34. Whilst the wet weather license limit (20 mg/L) is very close to the 95% CL (22.5 mg/L), based on the results of this study, it is currently considered inadequate. It is recommended that the wet weather licence limit for Total Iron at the Ironmaking East Drain be increased to 25 mg/L.

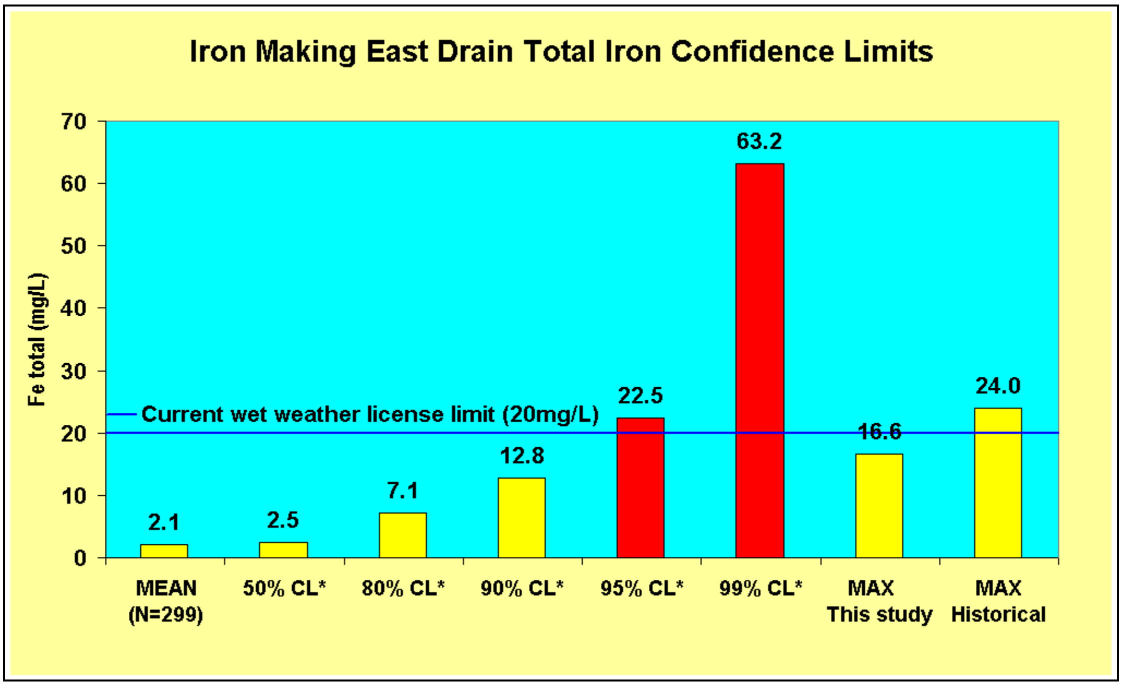


Figure 3.34 Calculated Total Iron Confidence Limits – Ironmaking East Drain

3.3.4 Flat Products East No.1 Drain Confidence Limits

Figure 3.35 shows the calculated confidence limits for the Flat Products East No.1 Drain TSS concentrations. The current wet weather licence limit of 200 mg/L is very close to the 95% CL of 201 mg/L. The current absolute (dry weather) licence limit is 70 mg/L. The data presented in Section 3.2.2 shows the historical dry weather data and wet weather data are different (historical dry weather – mean 12.5 mg/L standard deviation 13.2 mg/L, this study – mean 40.4 mg/L standard deviation 49.9 mg/L) and clearly a wet weather licence limit is required. Based on the results of this study, and considering the 95% CL, it is recommended that the wet weather licence limit for Flat Product East No.1 Drain TSS concentrations remains at 200 mg/L.

Confidence limits for the Flat Products East No.1 Drain Total Iron concentrations appear in Figure 3.36. The calculated 95% CL (34.5 mg/L) is above the current wet weather licence limit of 20 mg/L. The current absolute dry weather licence limit is 10 mg/L. The confidence limits presented in Figure 3.36 and data shown in Section 3.2.2 clearly show that a wet weather licence limit for Total Iron concentrations in the Flat Products East No.1 Drain is unavoidable, and is currently inadequate (at 95% CL). The two data sets (historical dry weather and this study) are clearly different (historical dry weather – mean 1.3 mg/L standard deviation 1.7 mg/L, this study – mean 3.0 mg/L standard deviation 6.2 mg/L). Based on the results of this study it is recommended that the wet weather licence limit for Total Iron concentrations at the Flat Products East No.1 Drain be increased to 35 mg/L.

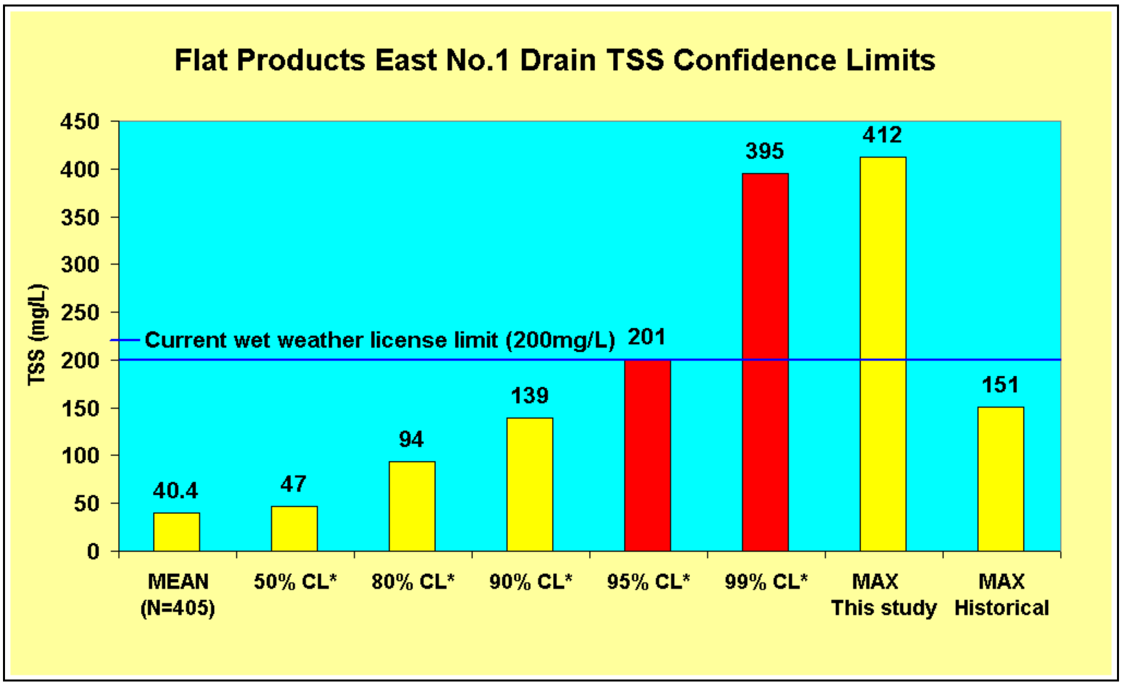


Figure 3.35 Calculated TSS Confidence Limits – Flat Products East No.1 Drain

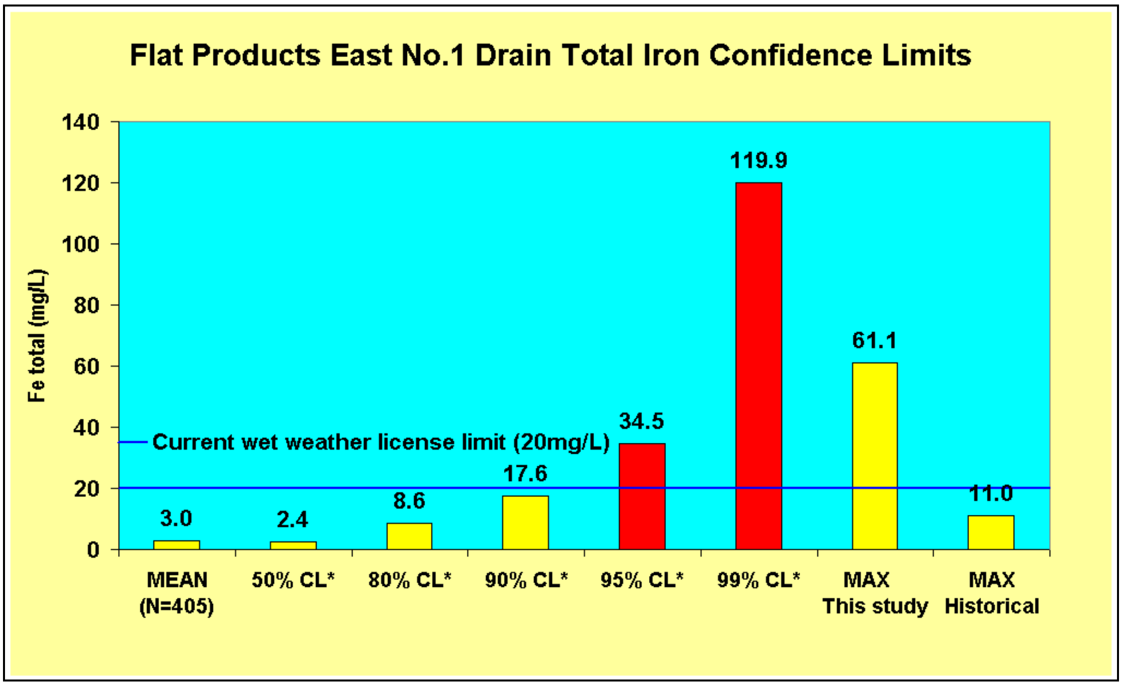


Figure 3.36 Calculated Total Iron Confidence Limits – Flat Products East No.1 Drain

3.3.5 Wet Weather Licence Limit Summary

This study has enabled the collection of wet weather data on licensed drains at PKSW that was previously unavailable. The data collected was compared to historical dry weather discharge water quality, and clearly for the drains included in this study separate wet and dry weather limits cannot be avoided as historical dry weather and wet weather water quality is significantly different (Sections 3.2.1 and 3.2.2). Areas where there are contaminant issues during wet weather have been identified (e.g., the Main Drain TSS) as well as areas where there are no current drain issues during wet weather (the North Gate Drain). An intensive sampling program has allowed for the collection of a diverse data set, identifying contaminant concentrations found in the first flush of a storm event. Included in this data set is a 1 in 5 year rainfall event. On this basis, and giving consideration to the current sampling frequency requirements, the 95% CL has been selected and as a result a number of revisions to wet weather licence limits are recommended. A full list of all recommendations for wet weather license limits on drains at PKSW appears in Table 3.5.

This study, whilst detailed and specific, is limited, as only four licensed drains at PKSW have been monitored for water quality during wet weather. The remaining 8 licensed drains each have different catchment sizes, land usage, process flow rates and salinities, limiting any extrapolation from the results and recommendations presented here. Furthermore, these catchments each contain different plant and activities and may contain storage for a range of different products used in the steelmaking process (i.e., raw material stockpiles, scrap steel, wastes, etc.) all contributing to the quality of any stormwater discharge. The continuance of wet weather licence limits for licensed discharge points not included in this study is recommended.

3.3.6 Application of Wet Weather Licence Limits

Recommendations for revised wet weather licence limits are made on the basis that current L6092 sampling frequency requirements remain at one grab sample every 8 days. If sampling frequency requirements for compliance purposes are changed or modified in any way, wet weather licence limits recommended in this report will need be re-considered. The recommendations made for wet weather licence limits in this study were based on the 95% CL. This confidence level was selected given the fact that: current water quality sampling requirements (for L6092) are one grab sample every 8 days; there are only approximately 20 days per year where rainfall is greater than 10 mm (i.e., the chances of sampling at the start of a major, high intensity rainfall event are slim); and pollutant concentrations limits whilst achievable, should also drive increased environmental performance.

Recommendations - Wet Weather License Limits for Drains at PKSW	
North Gate Drain	
Recommendation 1	The wet weather license limit for TSS at the North Gate Drain is reduced to 60 mg/L.
Recommendation 2	The wet weather license limit for Total Iron at the North Gate Drain is reduced to 4.0 mg/L.
Recommendation 3	The wet weather license limit of 9.5 for pH remains at the North Gate Drain, and further pH wet weather monitoring re-commence once further salt water reductions are made.
Main Drain	
Recommendation 4	Increasing the Main Drain TSS wet weather license limit to 400mg/L as an interim, until further monitoring and investigation of Main Drain TSS during wet weather is undertaken.
Recommendation 5	Setting Total Iron License Limits for the Main Drain of 5 mg/L for dry weather and 20 mg/L for wet weather and further investigation of Main Drain Total Iron during wet weather be commenced.
Ironmaking East Drain	
Recommendation 6	The wet weather license limit for the Ironmaking East Drain TSS is reduced to 130 mg/L.
Recommendation 7	Wet weather license limit for the Ironmaking East Drain Total Iron be increased to 25 mg/L
Flat Products East No.1 Drain	
Recommendation 8	Wet weather license limit for the Flat Products East No.1 Drain TSS remains at 200 mg/L.
Recommendation 9	The wet weather license limit for the Flat Products East No.1 Drain Total Iron be increased to 35 mg/L.
Application of Wet Weather Licence Limits	
Recommendation 10	Water quality limits do not apply for samples taken within 24 hours of a rainfall event that exceeds (in duration and/or intensity) a 1 in 5 year rainfall event.

Table 3.5 Recommendations - Wet Weather License Limits for Drains at PKSW

Along with the implementation of recommendations for wet weather licence limits made in this study, a decision needs to be made as to the size (storm recurrence interval) of rainfall event that will be effectively managed on the PKSW site. Wet weather licence limits for discharge drains at PKSW, will not apply, if the rainfall event (intensity and volume) exceeds the set limit. It is recommended that this limit (storm recurrence interval) be set at a 1 in 5 year storm event. Justification for this recommendation is that stormwater discharge quality data collected for this study includes one such storm event, occurring on the 4th and 5th of April 2004 where >250 mm of rainfall fell on the PKSW site. Appendix E shows a rainfall intensity and storm recurrence interval table for Port Kembla.

The next chapter presents the overall conclusions and recommendations for further research.

4 CONCLUDING SUMMARY AND RECOMMENDATIONS

This study looked at the hydrological and stormwater discharge quality characteristics of four licensed drains at the PKSW. The objectives of this study as outlined in Section 1 were achieved, and the conclusions drawn from the results and resulting recommendations are detailed in this section.

4.1 HYDROLOGICAL CONCLUSIONS

As the hydrological component of this study progressed it was clear there were two distinct types of catchments encountered: One which has relatively small surface area and consists almost entirely of sealed, impervious surfaces, exhibiting 'flashy' hydrographs, fast response to rainfall, negligible water losses and discharge not affected by API; the other which has a much larger surface area, and large portions of the catchment consisting of grassed areas, and surfaces pervious to moisture, these catchments had hydrographs with slow receding recession curves, large water losses and stormwater discharge which is affected by the moisture state of the ground (API).

The Flat Products East No.1 Drain and Iron Making East Drain both have relatively small catchment areas (204,073 and 182,222 m^2 respectively), with the major land usage within these catchments being sealed impervious surfaces such as roads, buildings, carparks and heavy industrial areas. The hydrographs for these two drains are very similar, both having a fast response to rainfall where peak discharge was within 15 minutes of peak rainfall intensity. The hydrographs also displayed very steep rising limbs and recession curves, with 'baseline' (process) flow returning within 30 minutes after the rain event in most cases. These features are typical of 'Urban' catchments as described in Section 1.1.3.

Linear relationships between rainfall and discharge volume for these two drains showed good correlation coefficients and these could be used to estimate discharge volumes for future rainfall events where the rainfall is known.

The fraction of total rainfall volume (falling on the catchment) that is discharged as runoff through the drain is very high for both the small catchment drains (0.96 for the Flat Products East No.1 and 0.82 for the Iron Making East Drain). This high fraction as discharge volume is due to the nature of the catchment where infiltration and percolation losses are negligible, and the most likely water loss is due to evaporation only.

The Flat Product East No.1 Drain and Iron Making East Drain did not show a relationship between Antecedent Precipitation Index (API) and discharge volume. It can be concluded that antecedent rainfall and moisture condition of the catchment does not affect the discharge volume for these two drains.

The Main Drain and North Gate Drain both have catchments that cover relatively large (by industrial standards) areas (3,312,500 and 983,100 m^2 respectively). Land usages within these two catchments include large portions, which are grassed, unsealed and pervious. The hydrographs for these drains are not dissimilar, both having very slow receding recession curves. ‘Baseline’ or process flow does not return for hours, even days after the rainfall event has ceased. There are differences however; the North Gate Drain showed a fast response to rainfall and the Main Drain response was delayed. These differences could be due to the sealed areas of the North Gate Drain catchment being close to the discharge point, and the fact that Main Drain is approximately 3 times larger. This will need further investigation to clarify.

The linear relationships between rainfall and discharge volume were not as good as the Flat Products East No.1 and Iron Making East Drain. However, the plots could still be used to estimate the discharge volumes for future rainfall events.

The fraction of total rainfall volume discharged as runoff for the Main Drain was much lower than the Flat Products East No.1 Drain and Iron Making East Drains. This value of 0.58 indicates there are large water losses via infiltration and percolation into the unsealed areas of the catchment. The fraction of total rainfall volume for the North Gate Drain was determined to be 4.I. This is impossible and this anomaly is almost certainly due to overestimations of flow rate as discussed in Section 3.1.1.3.

Both the Main Drain and North Gate Drain showed systematic increases of discharge volume with an increase in Antecedent Rainfall index. This indicates preceding rainfall events and the moisture state of these catchments does have an effect on the discharge volumes resulting from stormwater runoff.

4.2 WATER QUALITY CONCLUSIONS

The intensive water quality sampling program, undertaken in this study allowed for the collection of a diverse wet weather data set not collated before. The collected data was compared to historical dry weather water quality, and this study demonstrated that stormwater discharge quality in drains at PKSW contains elevated concentrations of pollutants (Section 3.2). This study identified areas where there are contaminant issues during wet weather, e.g., Main Drain Total Suspended Solid concentrations, which reached as high as 1322 mg/L (Section 3.2.2) and Flat Products East No.1 Drain Total Iron, peaking at 61.1 mg/L during the first flush. This study also found areas where there are no current drain issues during wet weather (the North Gate Drain).
Confidence limits were calculated and compared to current wet weather licence limits and in some cases the current wet weather licence limits are inadequate. Recommendations were made for the revision of wet weather licence limits using the 95% CL as a basis and a full list appears in Table 3.5.

Monitoring of pH at all specified drains in this study did not identify any significant pH changes during wet weather and no evidence of elevated pH in stormwater runoff was identified. However further monitoring will be required at North Gate Drain after the removal of saltwater.
Light microscopy identified the major particulate material found in the TSS for each drain, and this information was used to identify the potential point sources of the pollutants within each catchment. The Main Drain discharge was identified as containing significant concentrations of coal during wet weather (Section 3.2 and Table 3.4), most likely due to the close proximity of the drain to coal stockpiles and the CORB. This is an obvious area of concern and it is recommended that a separate, focussed investigation be commenced on this issue.

This study, whilst specific and extensive, is limited to only four licensed discharge points at PKSW. Extrapolating the findings of this report to remaining licensed discharge points is not recommended due to vast differences between catchments across the PKSW site, including their size, land usage, plant, associated equipment, activities and salinity.

4.3 RECOMMENDATIONS FOR FURTHER STUDIES

The anomaly found with discharge volumes at the North Gate Drain needs to be rectified. The inaccuracies seen are almost certainly due to overestimations of discharge rate by MHL. It has been mentioned that the height measurement determining flow, is not ideal for such a large weir as the one seen at the North Gate Drain. The weir is very wide and any small error in height measurement is greatly magnified in the flow calculation (pers. comm., Greg Smith, 2004). In addition to this overgrown reeds on the downstream side of the weir could be creating a ‘back pressure’ effect, raising the height of the level recorder during times of rainfall. It is recommended that the MHL discharge measuring equipment be recalibrated and the weir regauged before further stormwater studies are carried out at this site.

Further studies being undertaken will benefit from the installation of more rainfall gauges across BlueScope Steel’s Port Kembla site. This would help eliminate errors induced due to local rainfall variation.

It is recommended that this study be reinvestigated in 5 years, to determine if the findings and recommendations made in this report are still suitable for the process conditions and catchment characteristics at the time.

This study was limited to only four licensed drains at the PKSW. To evaluate the impact of stormwater across the rest of the PKSW site, it is recommended that a similar study be conducted on the 9 remaining licensed drains.

The results from this study show that pH does not vary with stormwater discharge. At present a number of licensed drains at PKSW include a saltwater flow, increasing salinity and potentially buffering significant pH changes. Planned process changes involve the removal of salt water from the North Gate Drain and it is recommended that pH monitoring during wet weather be recommenced inline with salt water reductions.

Water quality results show that of the drains included in this study, TSS at the Main Drain is the biggest issue. The major material present in TSS was found to be coal. It is recommended that priority and immediate focus be placed on elimination of elevated TSS concentrations in the Main Drain during wet weather.

5 REFERENCES

ANZECC/ARMCANZ. (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Barbosa, A.E and Hvitved-Jacobsen, T (1999). Highway Runoff and Potential for Removal of Heavy Metals in an Infiltration Pond in Portugal. *Science of the Total Env.*, **235**:151-159.

Bertrand-Krajewski, J.L., Chebbo, G., and Saget, A (1998). Distribution of Pollutant Mass vs. Volume in Stormwater Discharges and the First Flush Phenomenon. *Wat. Res.*, **32**:2341:2356.

BlueScope Steel Limited (BSL) 2005. Unpublished Water Quality Data from Licensed Drains at Port Kembla Steelworks. BlueScope Steel Environment Department, Port Kembla, New South Wales.

Brezonick, P.L. and Stadelmann, T.H (2002). Analysis and Predictive Models of Stormwater Runoff Volumes, Loads and Pollutant Concentrations from Watersheds in the Twin Cities Metropolitan Area, Minnesota, USA. *Wat. Res.*, **36**:1743-1757.

Chow, T.V., Maidment, D.R., Mays, L.W, (1988). *Applied Hydrology.* McGraw-Hill, New York.

Clarkson, D.J., (1995). *Allans Creek Hydrological Study.* B Env Sc Honours Thesis, University of Wollongong, New South Wales.

Deletic, A and Maksumovic, C.T (1998). Evaluation of Water Quality Factors in Storm Runoff from Paved Areas. *Env. Eng.*, **124**:869-879.

Department of Environment and Conservation (DEC) (2004). *Approved Methods for the Sampling and Analysis of Water Pollutants in New South Wales.* New South Wales Environment Protection Authority.

Department of Environment and Consevation (DEC) (2005). *Environment Protection Licence 6092*. New South Wales Environment Protection Authority.

Forbes Rigby (1999). *Stormwater Management Plan Wollongong Coastal Catchment.* Forbes Rigby Ltd. Wollongong, New South Wales

Green, B. (2005). Unpublished Rainfall Data for Port Kembla Steelworks. Microsoft Excel Spreadsheet, Environment Department BlueScope Steel, Port Kembla.

Gupta, K and Saul, A.J (1996). Specific Relationships for the First Flush Load in Combined Sewer Flows. *Wat. Res.*, **30**:1244-1252.

Hanson, A. (1982). *Water Pollution Studies in Port Kembla Harbour*. BE thesis, University of Wollongong. New South Wales.

Hatch Engineering (2003). 26 Atchison Street Wollongong, NSW Australia 2500. Telephone +61 2 42247222.

He, Z. (1995). *A historical analysis of the Marine Environment of Port Kembla Harbour Water Quality, Sediment Quality and Aquatic Organisms.* Honours Master of Environmental Science. University of Wollongong. New South Wales.

He, Z. and Morrison, R.J. (2001). Changes in the Marine Environment of Port Kembla Harbour, NSW, Australia, 1975-1995: A Review*. Marine Pollution Bulletin*, **42**:193-201.

Manly Hydraulics Laboratory (2005). **http://www.mhl.nsw.gov.au/fl2fax/bhpk00491.html,** 'Manly Hydraulics Laboratory Data'.

Bureau of Meteorology (2005). **http://www.bom.gov.auT,** 'Bureau of Meteorology Homepage'.

Lee, J.H and Bang, K.W (2000). Characterisation of Urban Stormwater Runoff. *Wat. Res.*, **34**:1773-1780.

Lee, J.H., Bang, K.W., Ketchum, J.S. and Choe, M.J. (2002). First Flush Analysis of Urban Stormwater. *Science of the Total Env.*, **293**:163-175.

Mitchell, V.G., Mein, R.G. and McMahon, T.A (2001). Modelling the Urban Water Cycle. *Environmental Modelling and Software*, **16**:615-629.

Nanson, G.C. and Reinsfelds, I. (2001). 'Torrents of Terror': the August 1998 Storm and the Magnitude, Frequency and Impact of Major Floods in the Illawarra Region of New South Wales. *Australian Geographical Studies,* **39**:335-352.

New South Wales Department of Information Technology and Management. (2000) 9029-25 Wollongong Topographic and Orthophoto Map 1:25 000.

Pitcher, S.K., Slade, R.T.C and Ward, N.I (2004) Heavy Metal Removal from Motorway Stormwater Using Zeolites. *Science of the Total Env.* **197**:35-40

PKPC. (1995). *Port Kembla Harbour Guidelines*. Port Kembla Port Corporation, Port Kembla, NSW.

Sansalone, J.J., Buchberger, S.G and Al-Abed, S.R (1996). Fractionation of Heavy Metals in Pavement Runoff. *Science of the Total Env.*, **189**:371-378.

Sansalone, J.J., Buchberger, S.G and Al-Abed, S.R (1998). Physical Characterisitcs of Urban Roadway Solids Transported During Rain Events. *Env. Eng.*, **124**:427-440.

Shaw, E.M., (1983). *Hydrology in Practice.* Van Nostrand Rheinhold (UK) Co. Ltd. Berkshire. England.

SPCC. (1977). *Water Pollution and its control in Port Kembla Harbour.* State Pollution Control Commission, Sydney, NSW

Taebi, A. and Droste, R.L (2004) Pollution Loads in Urban Runoff and Sanitary Wastewater. *Science of the Total Env.*, **327**:175-184.

Urban Land Institute (ULI) (1979). *Residential Stormwater Management.* Urban Land Institute, Washington, D.C., United States of America.

Van Buren, M.A., Watt, W.E. and Marsalek, J (1997). Application of the Log-Normal and Normal Distributions to Stormwater Quality Parameters. *Wat. Res.*, **31**:95-104

Walker, D.J and Hurl, S (2002). The Reduction of Heavy Metals in a Stormwater Wetland. *Ecological Eng.*, **18**:407-414.

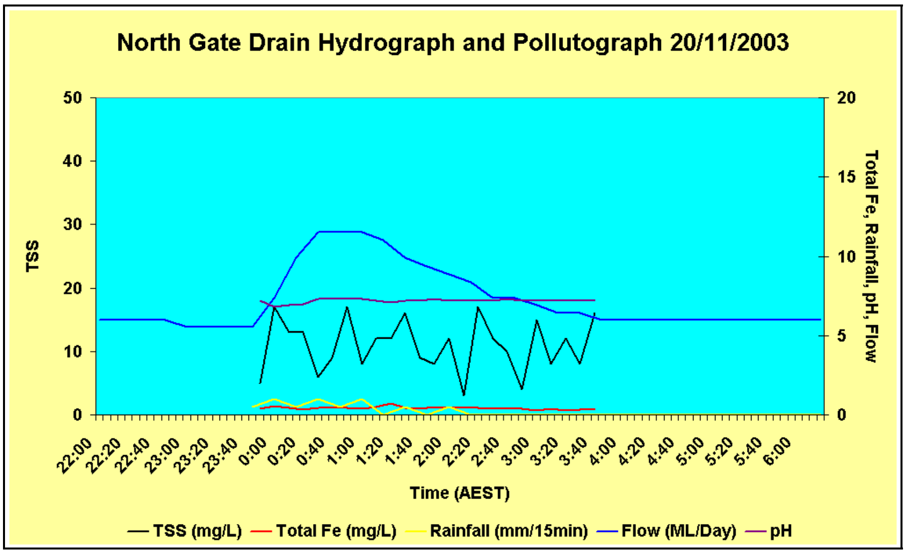
Wanielista, M.P and Yousef, Y.A (1993). *Stormwater Management*. John Wiley and Sons, Inc. New York, United States of America.

Ward, A.D and Elliot, W.J, (1995). *Environmental Hydrology*. CRC Press Inc. Florida. USA.

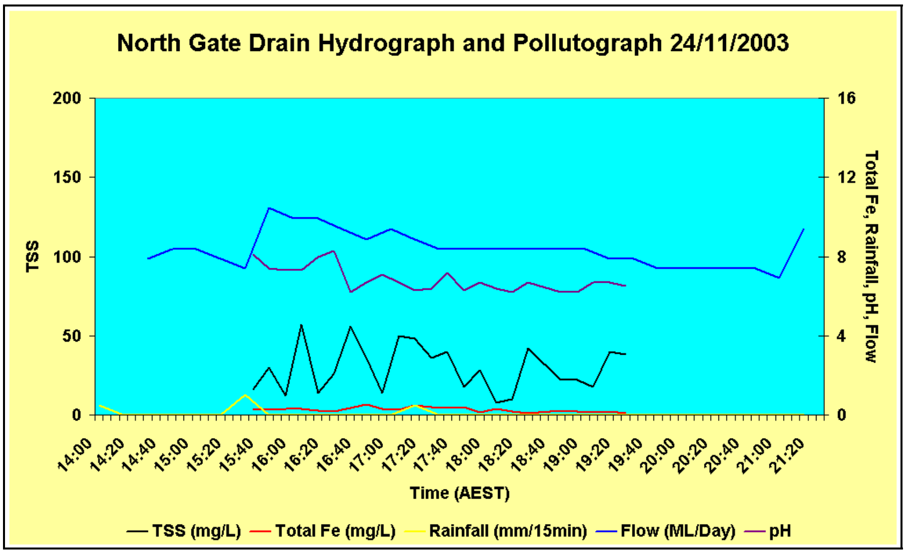
Warner, R.F. (1976). Water and Man in the City; Modification to Hydrologic and Geomorphic Systems. *Geography Bulletin,* **8**:74-84.

Appendices

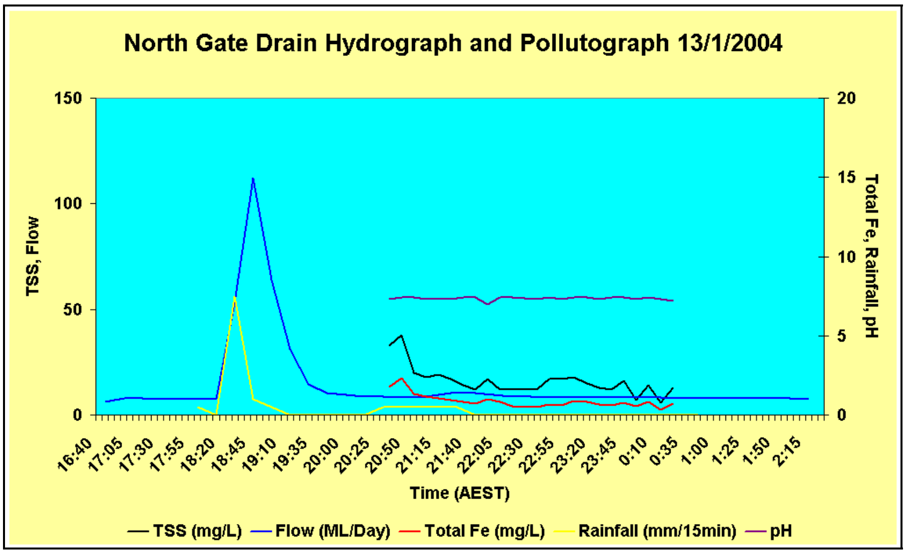
Appendix A. HYDROGRAPHS AND POLLUTOGRAPHS – NORTH GATE



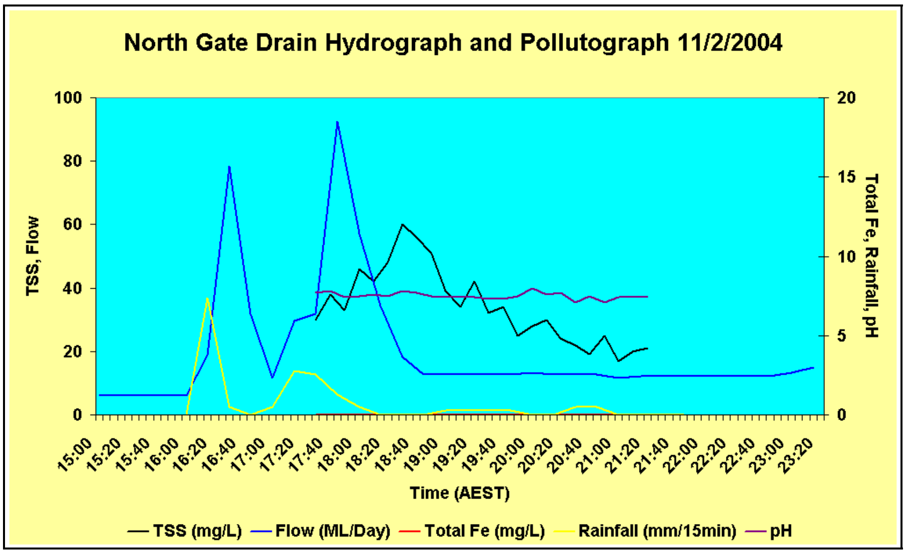
Rainfall Event Information	
Date	20/11/2003
Total Rainfall (mm)	5.5
Duration	2 hrs 15 min
Max Intensity (mm/hr)	4
Ave. Intensity (mm/hr)	2.5
1st Sample Taken	23:50
Duration of sampling	4hrs
TSS max. (mg/L)	17
Fe max. (mg/L)	0.72
pH max.	7.3



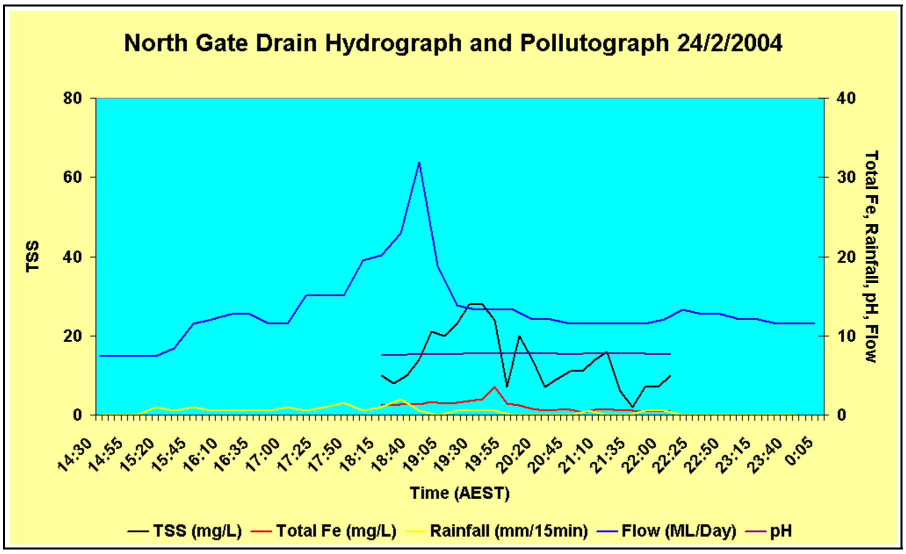
Rainfall Event Information	
Date	24/11/2003
Total Rainfall (mm)	2
Duration	3 hrs 15 min
Max Intensity (mm/hr)	4
Ave. Intensity (mm/hr)	<1
1st Sample Taken	15:35
Duration of sampling	4hrs
TSS max. (mg/L)	57
Fe max. (mg/L)	0.54
pH max.	8.3



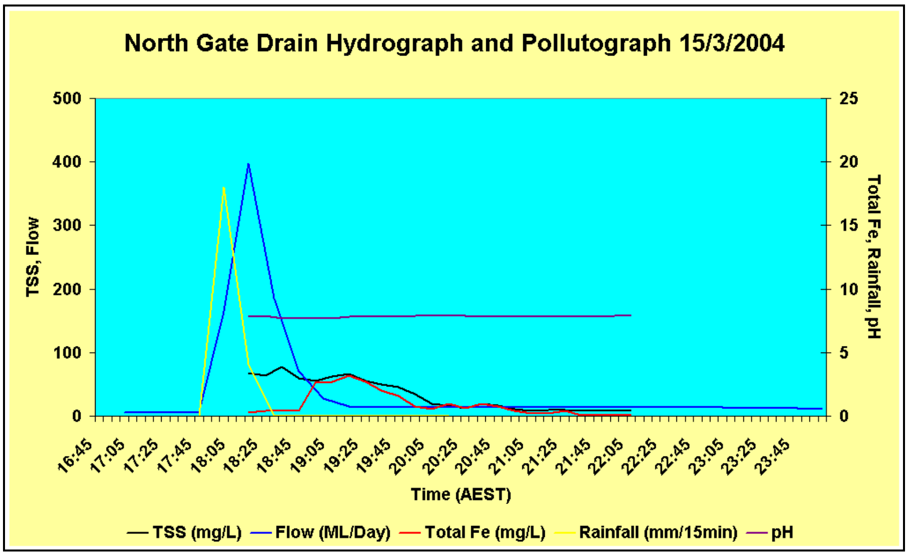
Rainfall Event Information	
Date	13/01/2004
Total Rainfall (mm)	12
Duration	3 hrs 30 min
Max Intensity (mm/hr)	30
Ave. Intensity (mm/hr)	3.5
1st Sample Taken	20:35
Duration of sampling	4hrs
TSS max. (mg/L)	38
Fe max. (mg/L)	2.3
pH max.	7.4



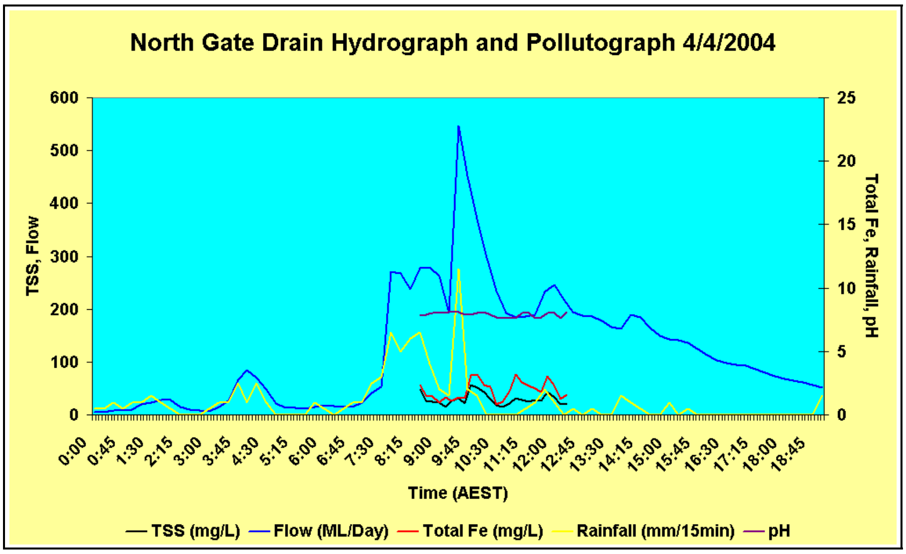
Rainfall Event Information	
Date	11/02/2004
Total Rainfall (mm)	17.5
Duration	4 hrs 30 min
Max Intensity (mm/hr)	29.5
Ave. Intensity (mm/hr)	4
1st Sample Taken	17:30
Duration of sampling	4hrs
TSS max. (mg/L)	60
Fe max. (mg/L)	[NT]
pH max.	8.0



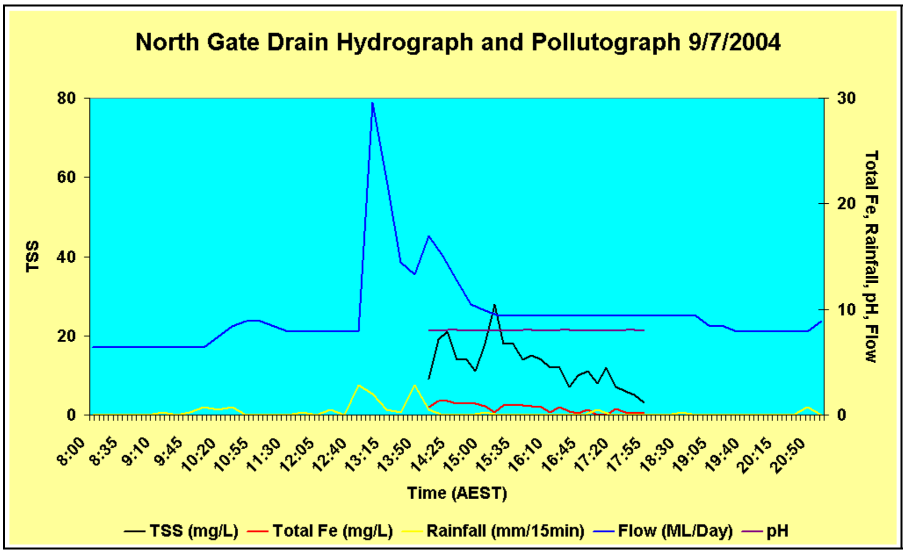
Rainfall Event Information	
Date	24/02/2004
Total Rainfall (mm)	15.5
Duration	6 hrs 45 min
Max Intensity (mm/hr)	8
Ave. Intensity (mm/hr)	2.5
1st Sample Taken	18:15
Duration of sampling	4hrs
TSS max. (mg/L)	28
Fe max. (mg/L)	3.6
pH max.	7.9



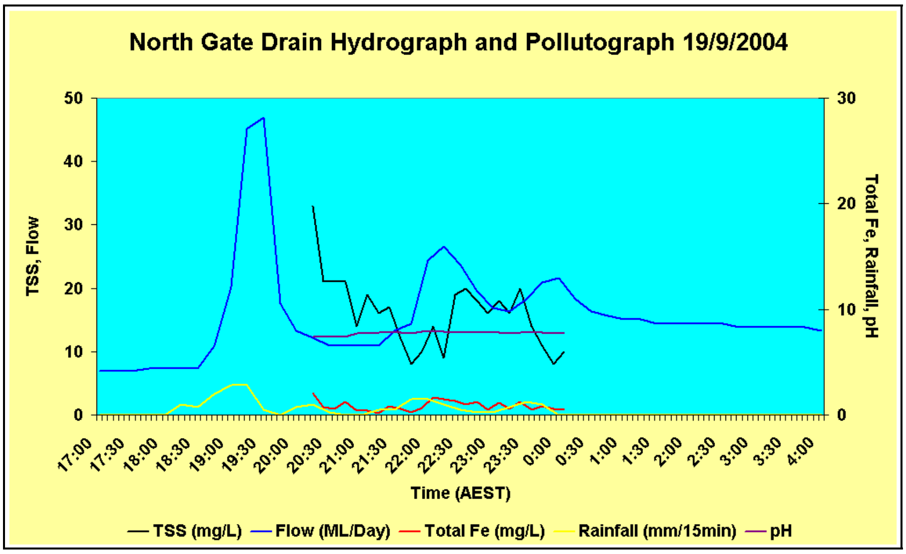
Rainfall Event Information	
Date	15/03/2004
Total Rainfall (mm)	22
Duration	0 hrs 30 min
Max Intensity (mm/hr)	72
Ave. Intensity (mm/hr)	44
1st Sample Taken	18:15
Duration of sampling	4hrs
TSS max. (mg/L)	77
Fe max. (mg/L)	3.2
pH max.	7.9



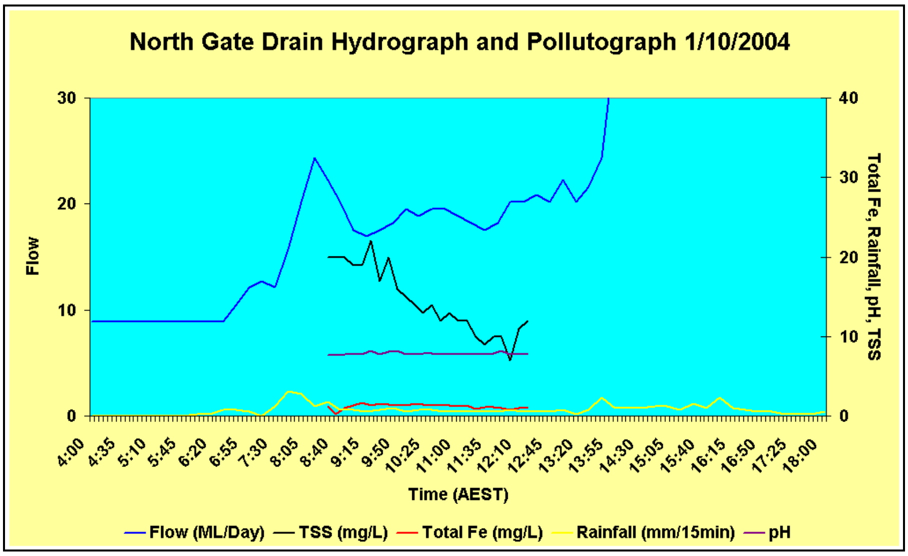
Rainfall Event Information	
Date	4/04/2004
Total Rainfall (mm)	84.5
Duration	5 hrs 30 min
Max Intensity (mm/hr)	46
Ave. Intensity (mm/hr)	15.5
1st Sample Taken	08:30
Duration of sampling	4hrs
TSS max. (mg/L)	56
Fe max. (mg/L)	3.22
pH max.	8.2



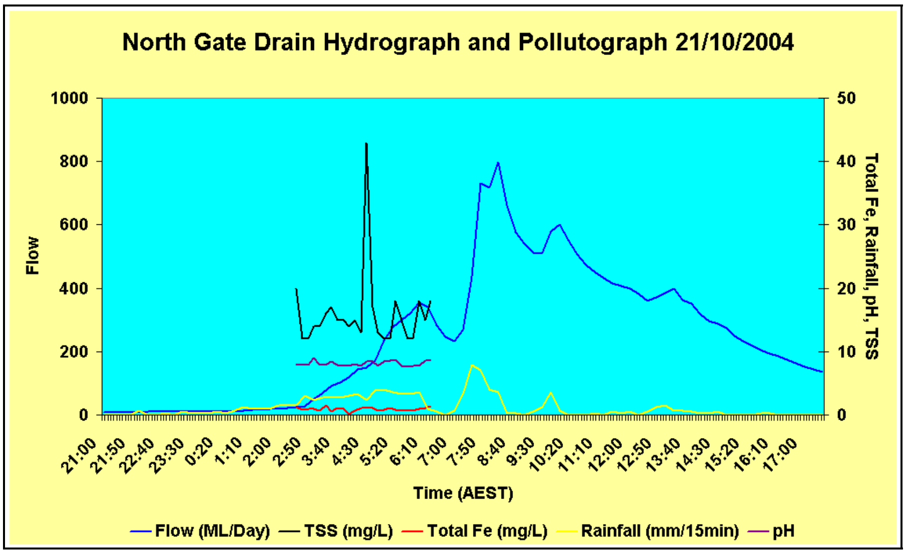
Rainfall Event Information	
Date	9/07/2004
Total Rainfall (mm)	14
Duration	9 hrs 15 min
Max Intensity (mm/hr)	11
Ave. Intensity (mm/hr)	1.5
1st Sample Taken	14:00
Duration of sampling	4hrs
TSS max. (mg/L)	28
Fe max. (mg/L)	1.33
pH max.	8.1



Rainfall Event Information	
Date	19/09/2004
Total Rainfall (mm)	21
Duration	5 hrs 30 min
Max Intensity (mm/hr)	11
Ave. Intensity (mm/hr)	4
1st Sample Taken	20:15
Duration of sampling	4hrs
TSS max. (mg/L)	33
Fe max. (mg/L)	2.08
pH max.	8.0

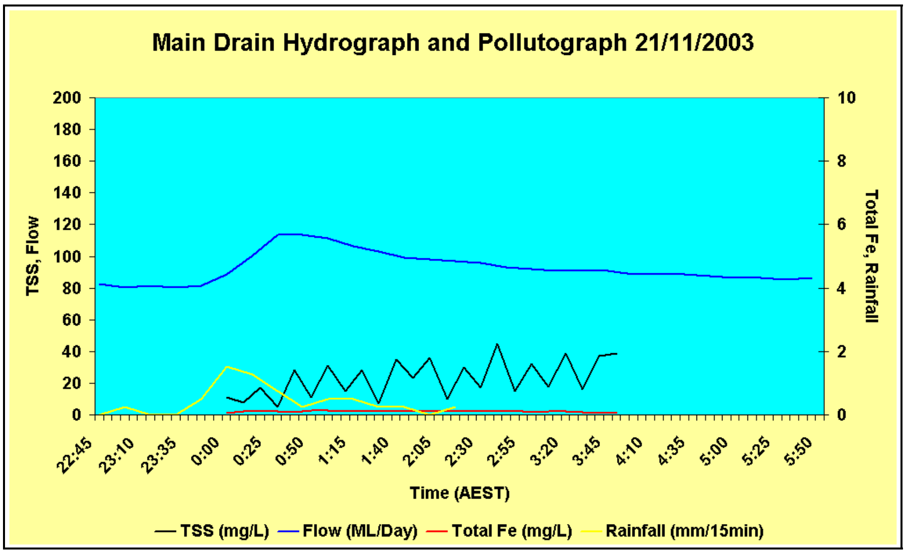


Rainfall Event Information	
Date	1/10/2004
Total Rainfall (mm)	22.5
Duration	12 hrs
Max Intensity (mm/hr)	12
Ave. Intensity (mm/hr)	2
1st Sample Taken	08:30
Duration of sampling	4hrs
TSS max. (mg/L)	22
Fe max. (mg/L)	1.63
pH max.	8.2

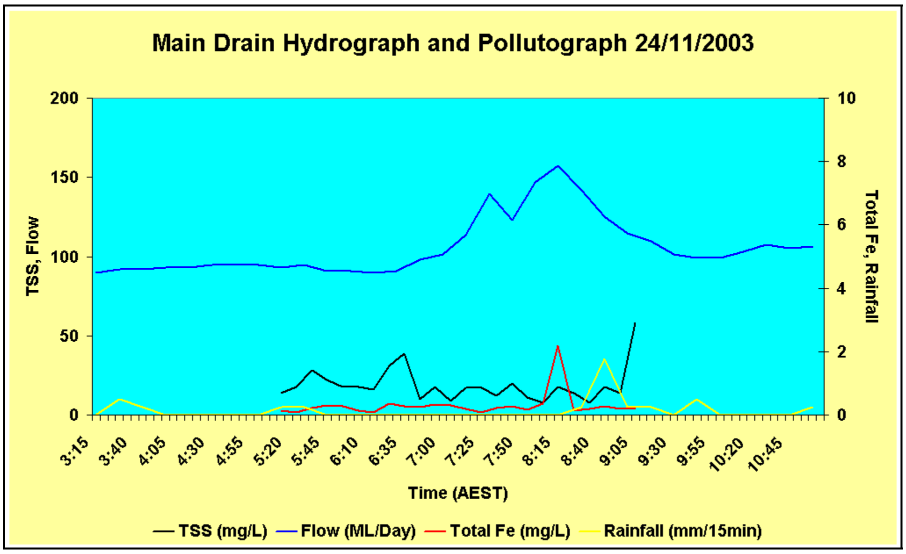


Rainfall Event Information	
Date	21/10/2004
Total Rainfall (mm)	100
Duration	15 hrs 15 min
Max Intensity (mm/hr)	31.5
Ave. Intensity (mm/hr)	6.5
1st Sample Taken	02:30
Duration of sampling	4hrs
TSS max. (mg/L)	43
Fe max. (mg/L)	1.53
pH max.	9.0

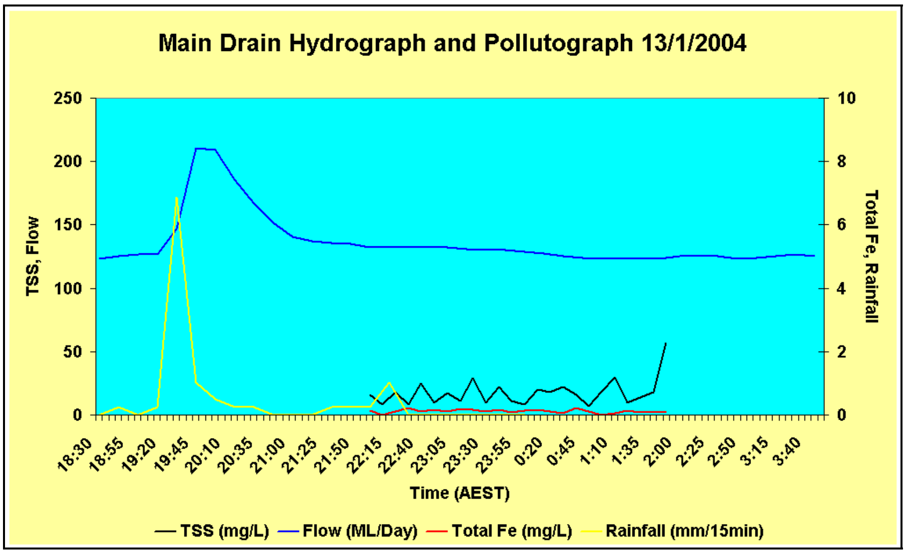
Appendix B. HYDROGRAPHS AND POLLUTOGRAPHS – MAIN DRAIN



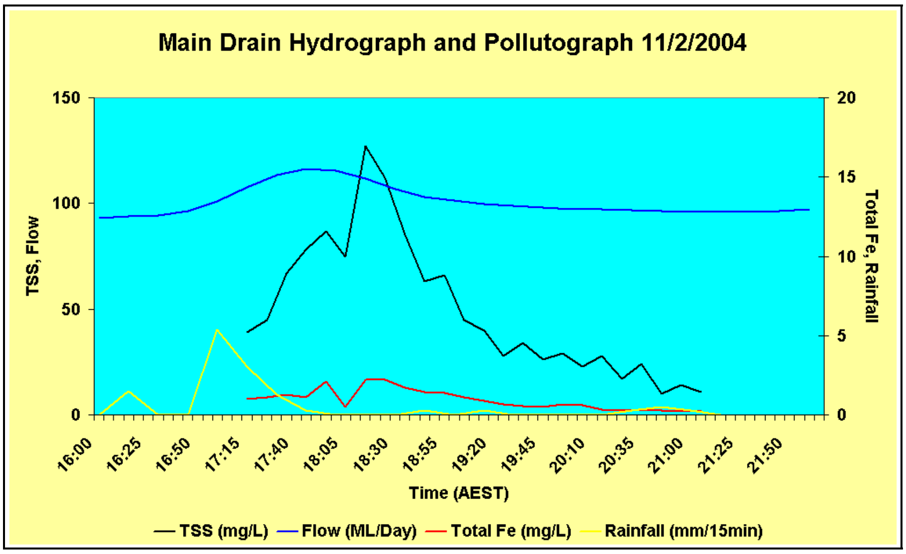
Rainfall Event Information	
Date	21/11/2003
Total Rainfall (mm)	6.5
Duration	3 hrs 15 min
Max Intensity (mm/hr)	6
Ave. Intensity (mm/hr)	2
1st Sample Taken	00:00
Duration of sampling	4 hrs
TSS max. (mg/L)	45
Fe max. (mg/L)	0.14



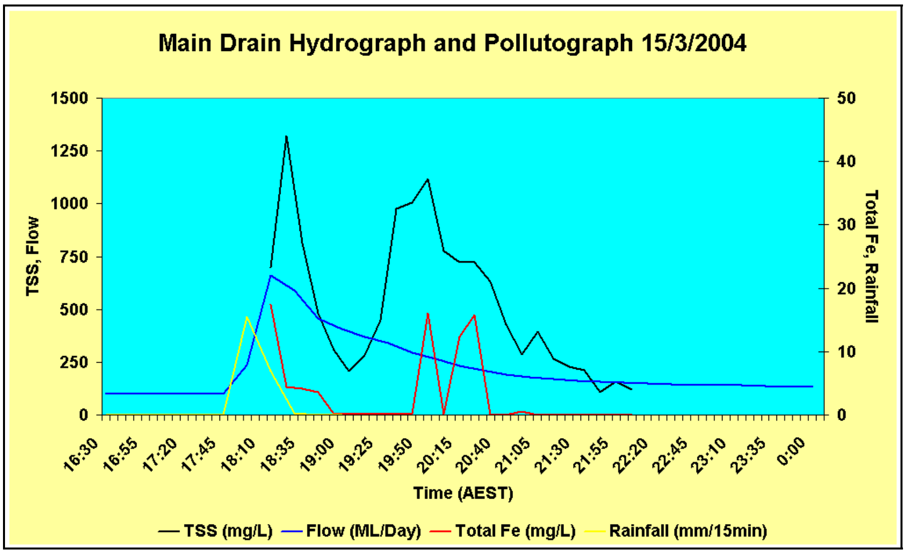
Rainfall Event Information	
Date	24/11/2003
Total Rainfall (mm)	4.5
Duration	6 hrs 15 min
Max Intensity (mm/hr)	7
Ave. Intensity (mm/hr)	<1
1st Sample Taken	05:15
Duration of sampling	4 hrs
TSS max. (mg/L)	58
Fe max. (mg/L)	2.18



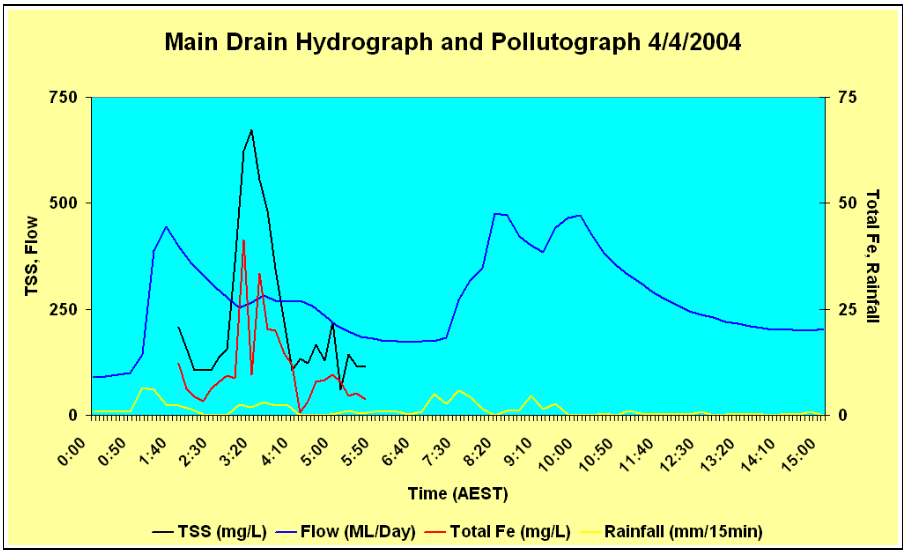
Rainfall Event Information	
Date	13/01/2004
Total Rainfall (mm)	11
Duration	3 hrs 30 min
Max Intensity (mm/hr)	27.5
Ave. Intensity (mm/hr)	3
1st Sample Taken	22:00
Duration of sampling	4 hrs
TSS max. (mg/L)	57
Fe max. (mg/L)	0.22



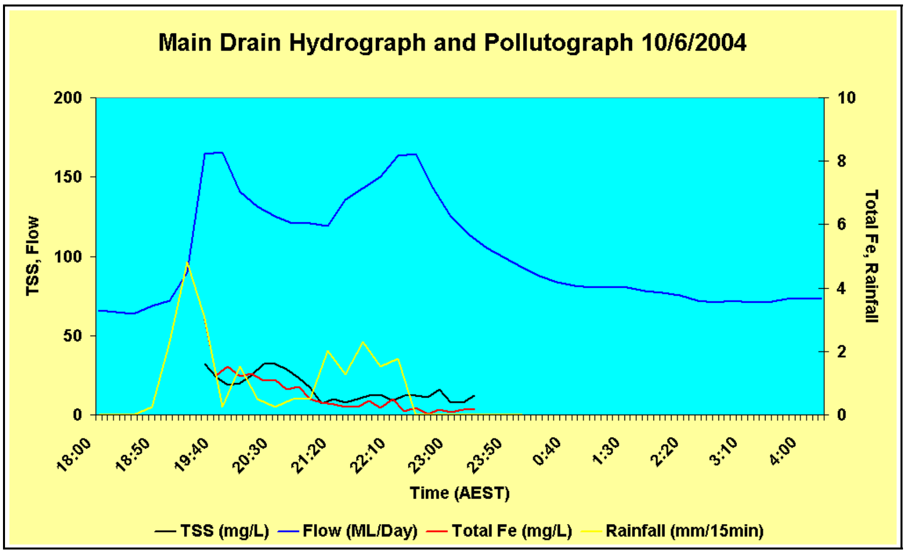
Rainfall Event Information	
Date	11/02/2004
Total Rainfall (mm)	13
Duration	4 hrs 45 min
Max Intensity (mm/hr)	21.5
Ave. Intensity (mm/hr)	2.5
1st Sample Taken	17:15
Duration of sampling	4 hrs
TSS max. (mg/L)	127
Fe max. (mg/L)	2.21



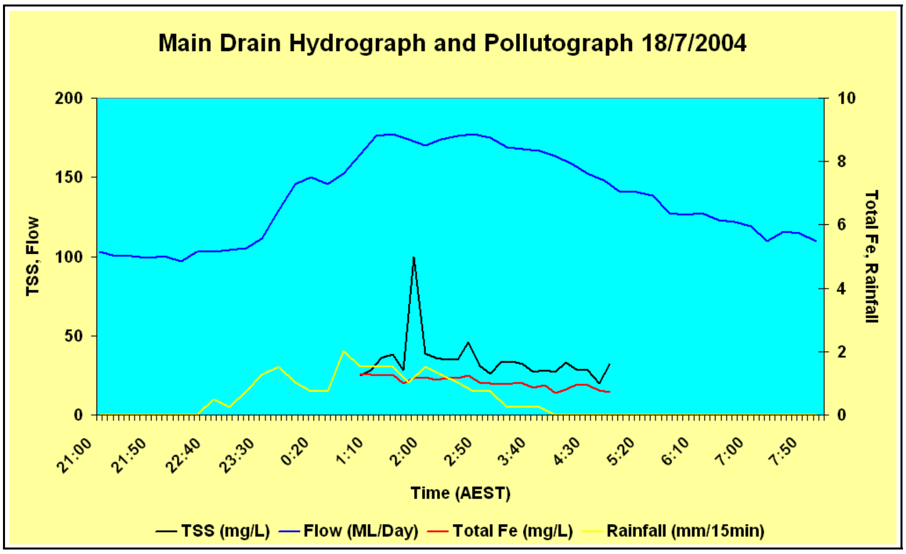
Rainfall Event Information	
Date	15/03/2004
Total Rainfall (mm)	22.5
Duration	0 hrs 45 min
Max Intensity (mm/hr)	62
Ave. Intensity (mm/hr)	30
1st Sample Taken	18:15
Duration of sampling	4 hrs
TSS max. (mg/L)	1322
Fe max. (mg/L)	17.5



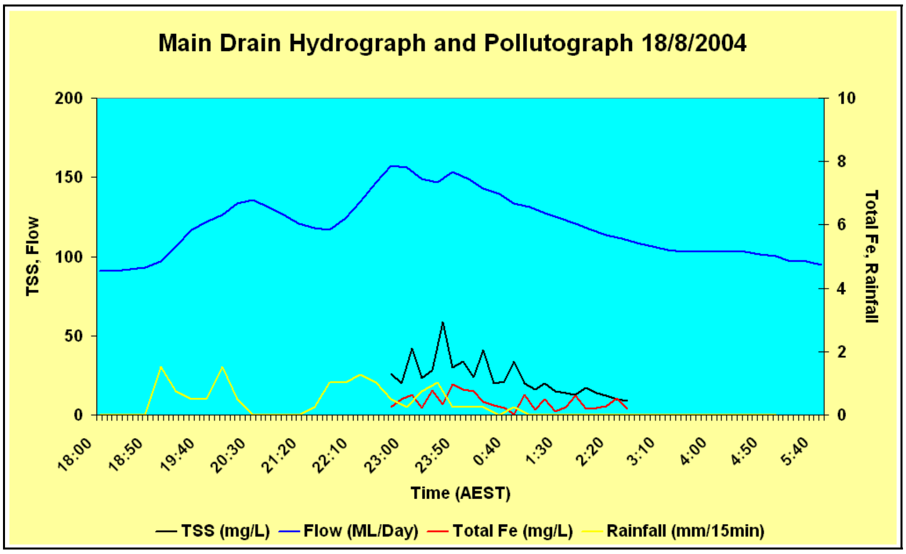
Rainfall Event Information	
Date	4/04/2004
Total Rainfall (mm)	78
Duration	15 hrs
Max Intensity (mm/hr)	25.5
Ave. Intensity (mm/hr)	5
1st Sample Taken	01:45
Duration of sampling	4 hrs
TSS max. (mg/L)	674
Fe max. (mg/L)	41.3



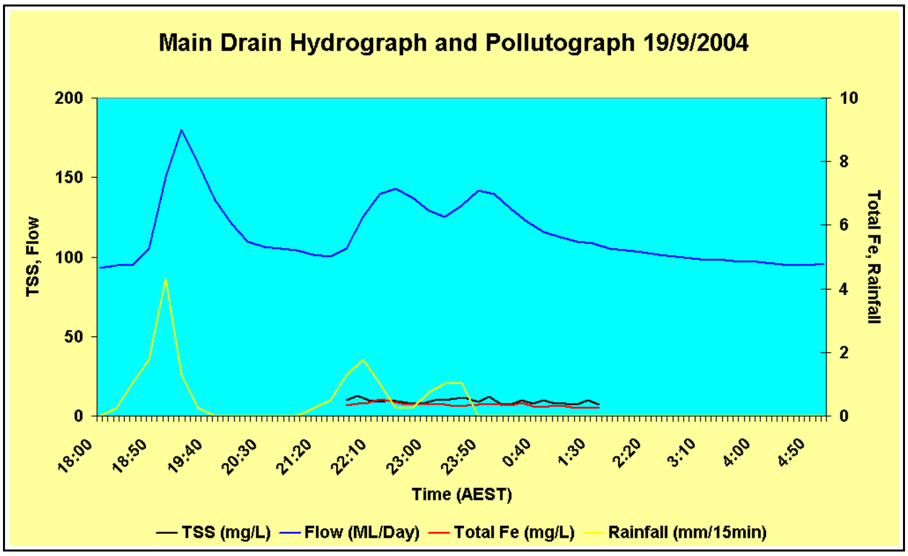
Rainfall Event Information	
Date	10/06/2004
Total Rainfall (mm)	23
Duration	3 hrs 30 min
Max Intensity (mm/hr)	19.5
Ave. Intensity (mm/hr)	6.5
1st Sample Taken	19:30
Duration of sampling	4 hrs
TSS max. (mg/L)	32
Fe max. (mg/L)	2.98



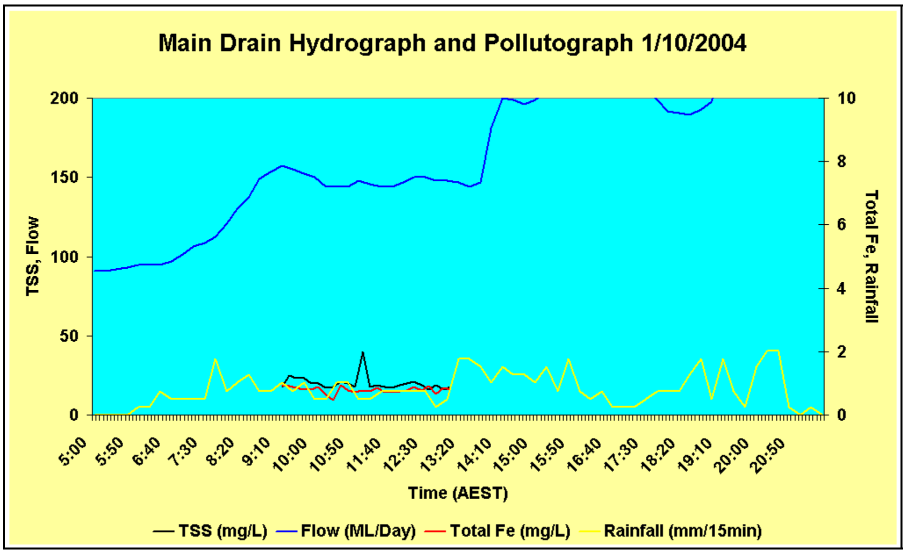
Rainfall Event Information	
Date	18/07/2004
Total Rainfall (mm)	20.5
Duration	5 hrs
Max Intensity (mm/hr)	8
Ave. Intensity (mm/hr)	4
1st Sample Taken	01:00
Duration of sampling	4 hrs
TSS max. (mg/L)	100
Fe max. (mg/L)	1.3



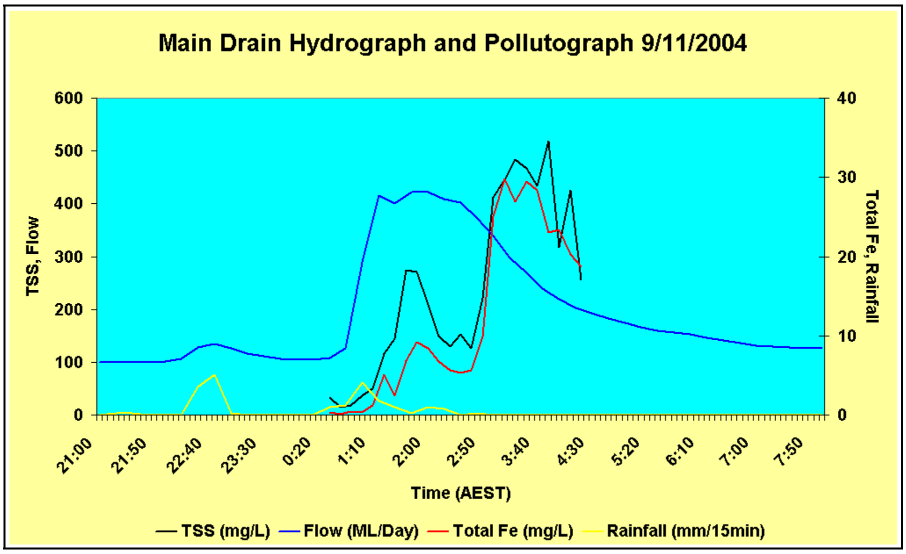
Rainfall Event Information	
Date	18/07/2004
Total Rainfall (mm)	20.5
Duration	5 hrs
Max Intensity (mm/hr)	8
Ave. Intensity (mm/hr)	4
1st Sample Taken	01:00
Duration of sampling	4 hrs
TSS max. (mg/L)	100
Fe max. (mg/L)	1.3



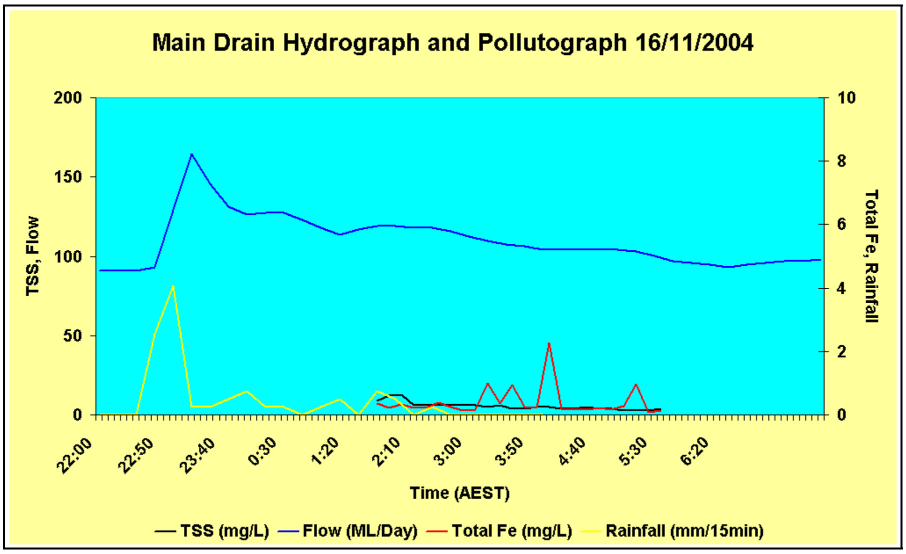
Rainfall Event Information	
Date	19/09/2004
Total Rainfall (mm)	17
Duration	5 hrs 15 min
Max Intensity (mm/hr)	17.5
Ave. Intensity (mm/hr)	3
1st Sample Taken	21:45
Duration of sampling	4 hrs
TSS max. (mg/L)	13
Fe max. (mg/L)	0.54



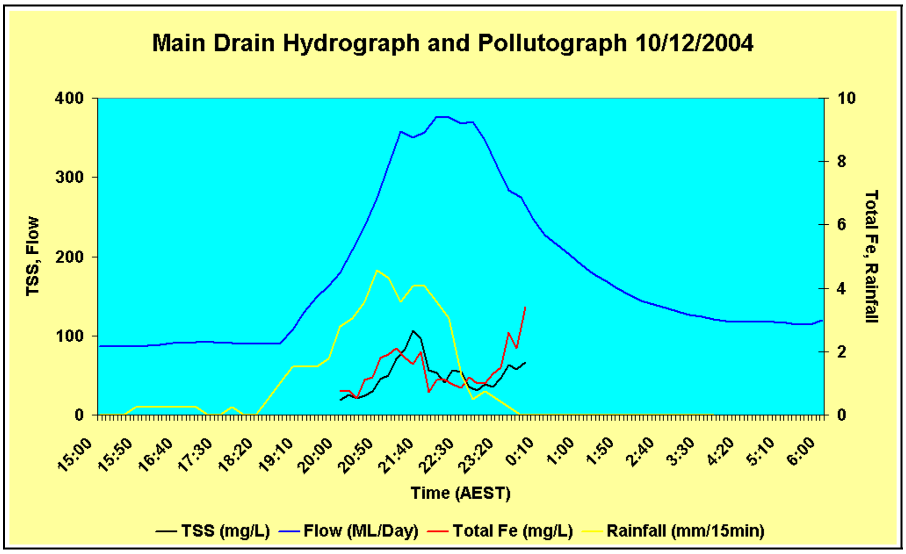
Rainfall Event Information	
Date	1/10/2004
Total Rainfall (mm)	62
Duration	19 hrs
Max Intensity (mm/hr)	10
Ave. Intensity (mm/hr)	3.5
1st Sample Taken	09:15
Duration of sampling	4 hrs
TSS max. (mg/L)	40
Fe max. (mg/L)	0.95



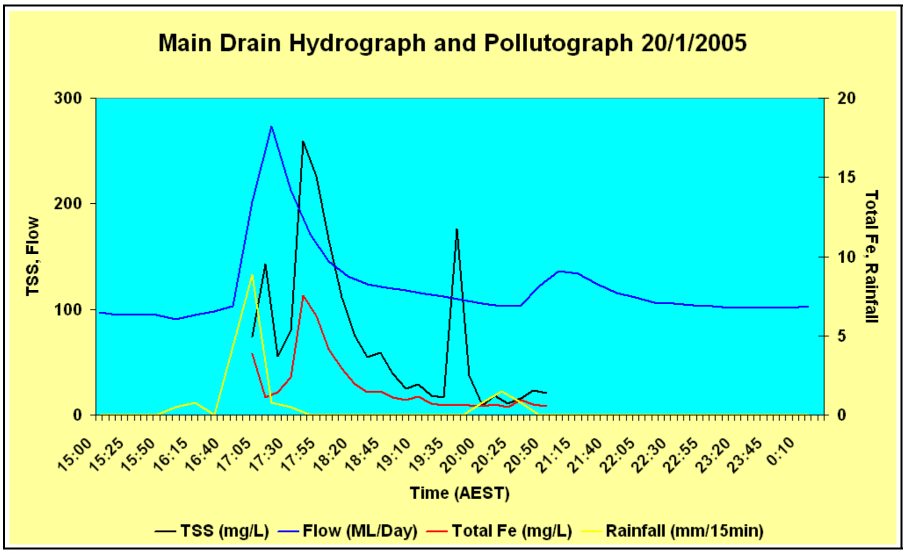
Rainfall Event Information	
Date	9/11/2004
Total Rainfall (mm)	21
Duration	4 hrs 15 min
Max Intensity (mm/hr)	20.5
Ave. Intensity (mm/hr)	5
1st Sample Taken	00:30
Duration of sampling	4 hrs
TSS max. (mg/L)	518
Fe max. (mg/L)	29.8



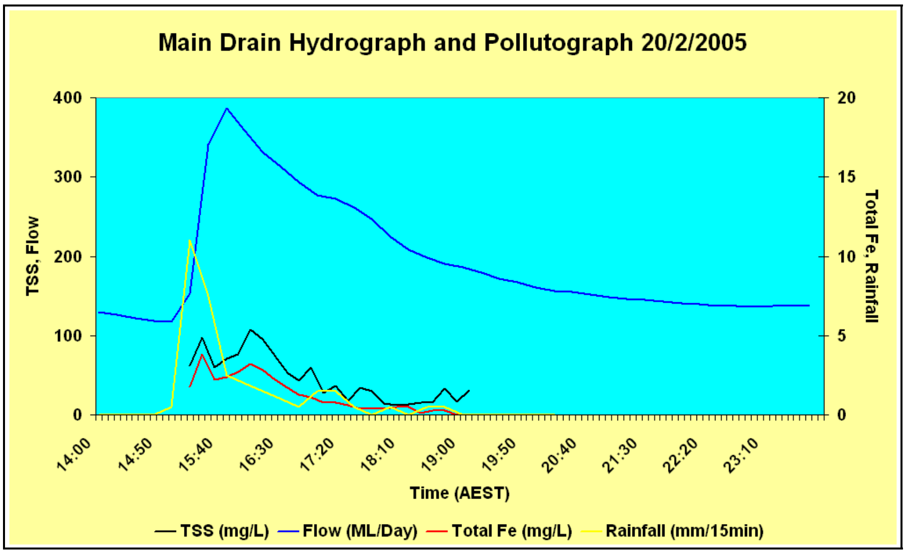
Rainfall Event Information	
Date	16/11/2004
Total Rainfall (mm)	11
Duration	3 hrs 45 min
Max Intensity (mm/hr)	16
Ave. Intensity (mm/hr)	3
1st Sample Taken	01:45
Duration of sampling	4 hrs
TSS max. (mg/L)	13
Fe max. (mg/L)	2.28



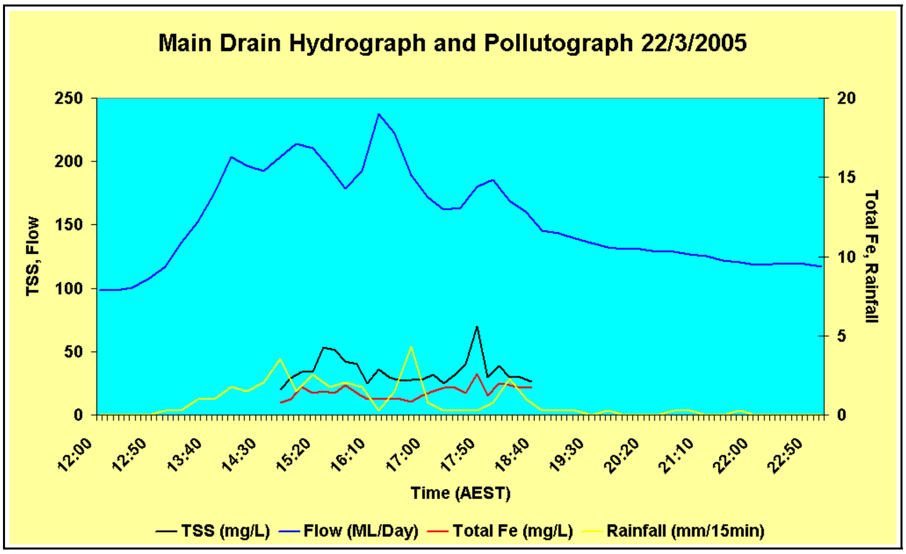
Rainfall Event Information	
Date	11/12/2004
Total Rainfall (mm)	49.5
Duration	6 hrs 45 min
Max Intensity (mm/hr)	18.5
Ave. Intensity (mm/hr)	7.5
1st Sample Taken	20:00
Duration of sampling	4 hrs
TSS max. (mg/L)	100
Fe max. (mg/L)	3.4



Rainfall Event Information	
Date	20/01/2005
Total Rainfall (mm)	19
Duration	1 hrs 45 min
Max Intensity (mm/hr)	35.5
Ave. Intensity (mm/hr)	11
1st Sample Taken	17:00
Duration of sampling	4 hrs
TSS max. (mg/L)	259
Fe max. (mg/L)	7.52

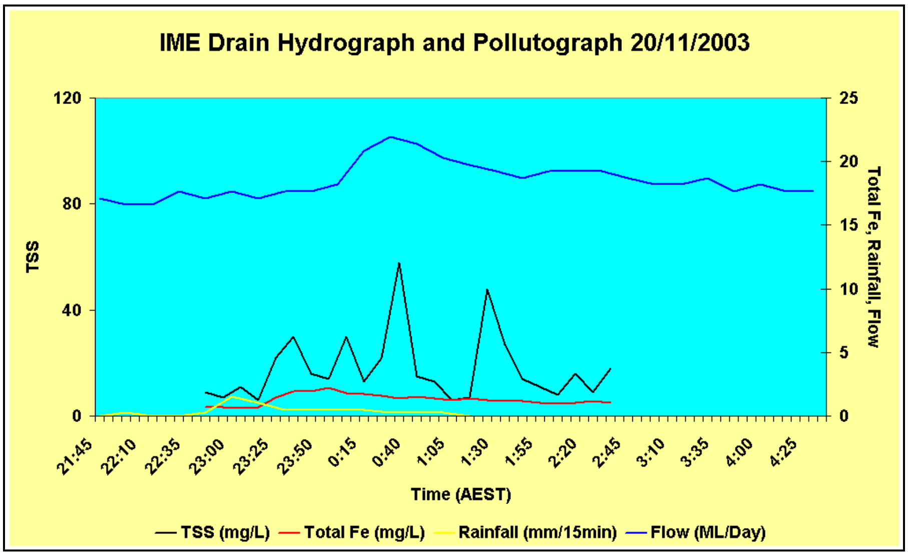


Rainfall Event Information	
Date	20/02/2005
Total Rainfall (mm)	31.5
Duration	3 hrs 45 min
Max Intensity (mm/hr)	44
Ave. Intensity (mm/hr)	8
1st Sample Taken	15:15
Duration of sampling	4 hrs
TSS max. (mg/L)	108
Fe max. (mg/L)	3.8

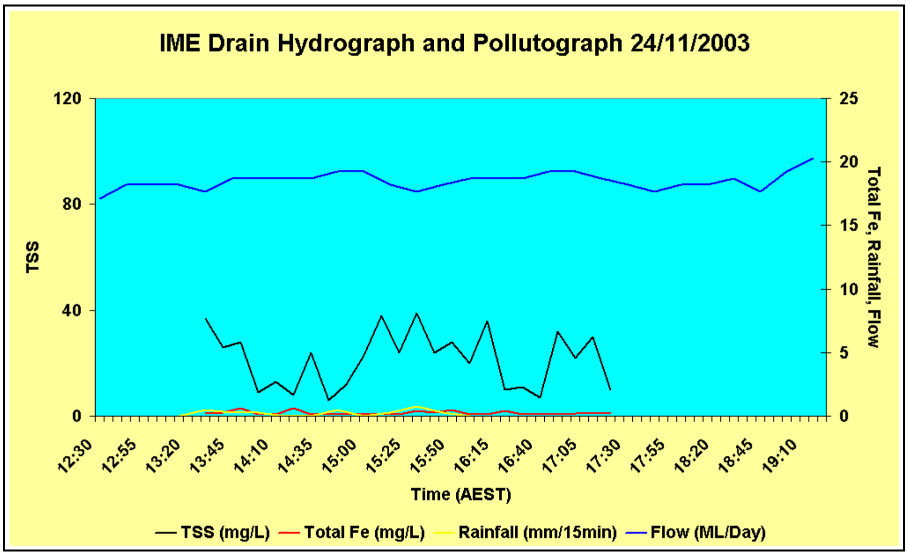


Rainfall Event Information	
Date	22/03/2005
Total Rainfall (mm)	34.5
Duration	8 hrs 45 min
Max Intensity (mm/hr)	17.5
Ave. Intensity (mm/hr)	4
1st Sample Taken	14:45
Duration of sampling	4 hrs
TSS max. (mg/L)	70
Fe max. (mg/L)	2.6

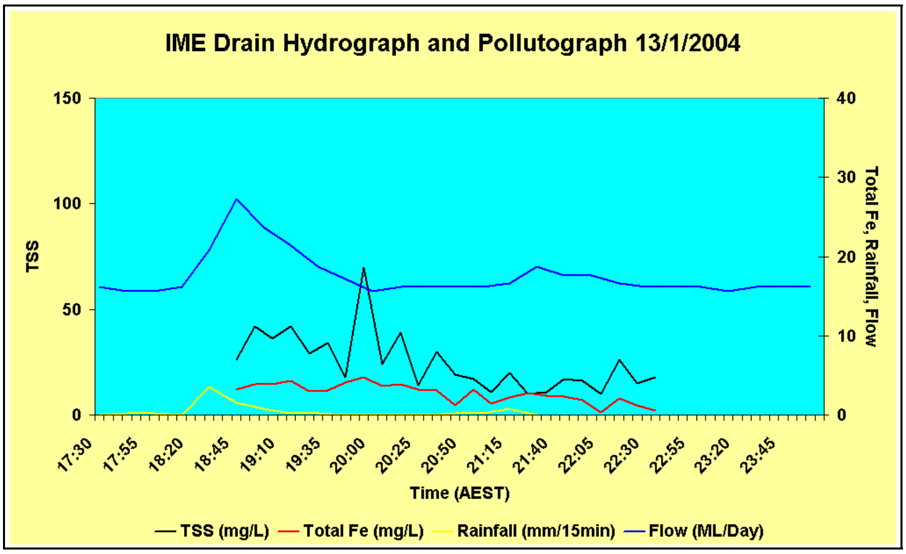
Appendix C. HYDROGRAPHS AND POLLUTOGRAPHS – IME DRAIN



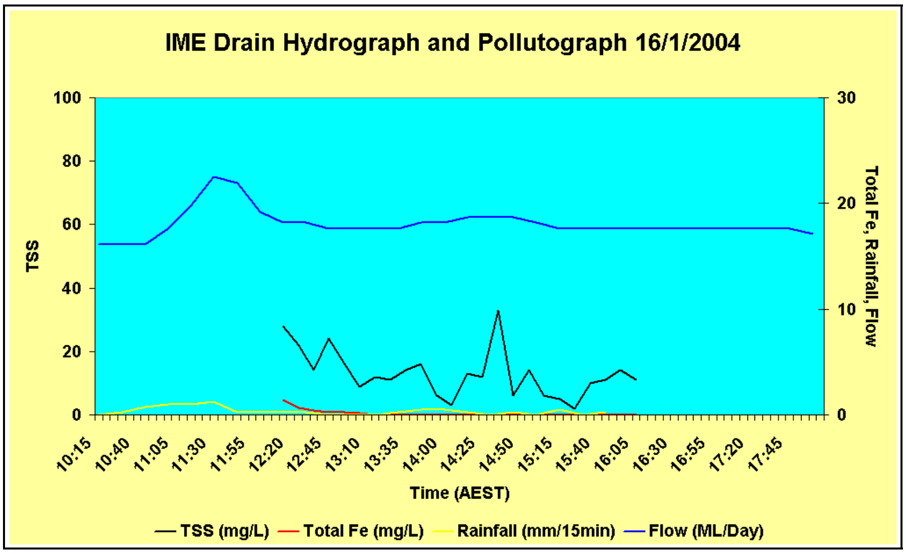
Rainfall Event Information	
Date	21/11/2003
Total Rainfall (mm)	6
Duration	3 hrs
Max Intensity (mm/hr)	6
Ave. Intensity (mm/hr)	2
1st Sample Taken	22:45
Duration of sampling	4hrs
TSS max. (mg/L)	58
Fe max. (mg/L)	2.22



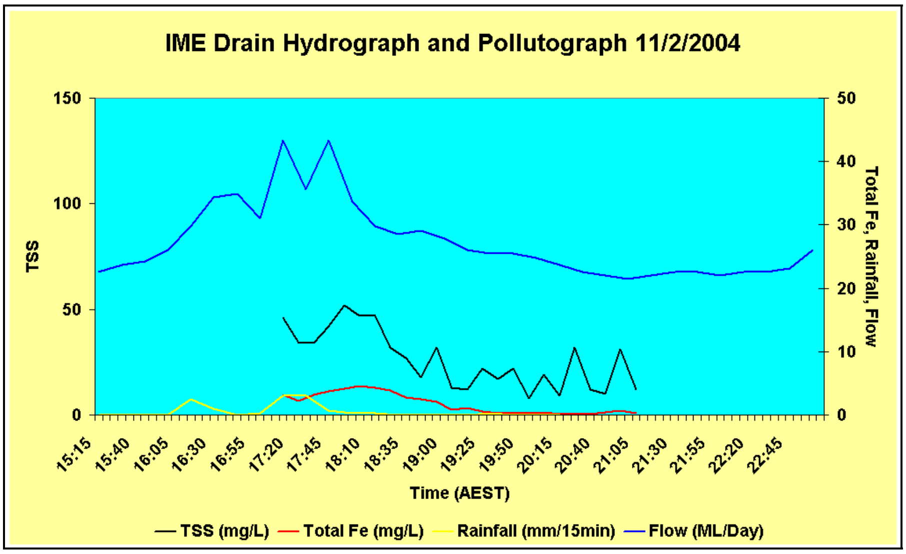
Rainfall Event Information	
Date	24/11/2003
Total Rainfall (mm)	3
Duration	2 hrs 15 min
Max Intensity (mm/hr)	3
Ave. Intensity (mm/hr)	1.5
1st Sample Taken	13:30
Duration of sampling	4hrs
TSS max. (mg/L)	39
Fe max. (mg/L)	0.64



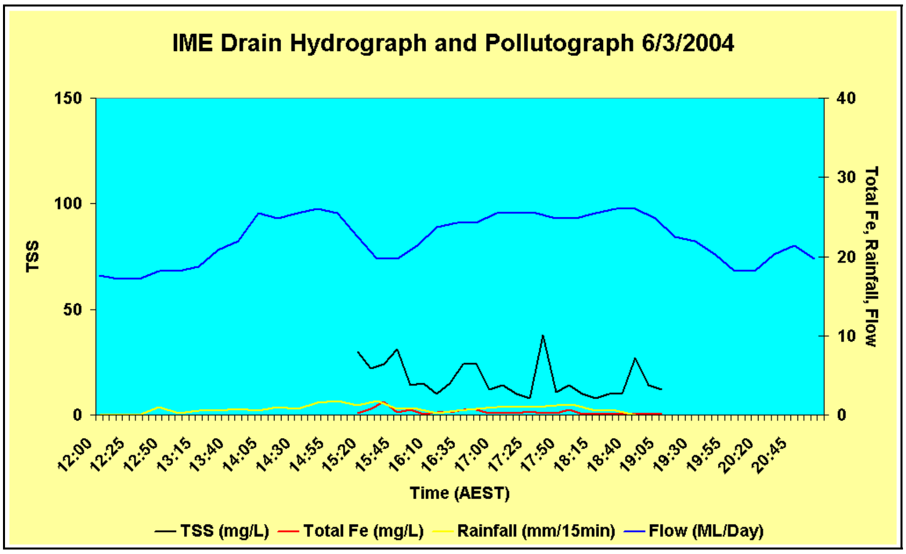
Rainfall Event Information	
Date	13/01/2004
Total Rainfall (mm)	8
Duration	3 hrs 30 min
Max Intensity (mm/hr)	14
Ave. Intensity (mm/hr)	2.5
1st Sample Taken	18:45
Duration of sampling	4hrs
TSS max. (mg/L)	70
Fe max. (mg/L)	4.75



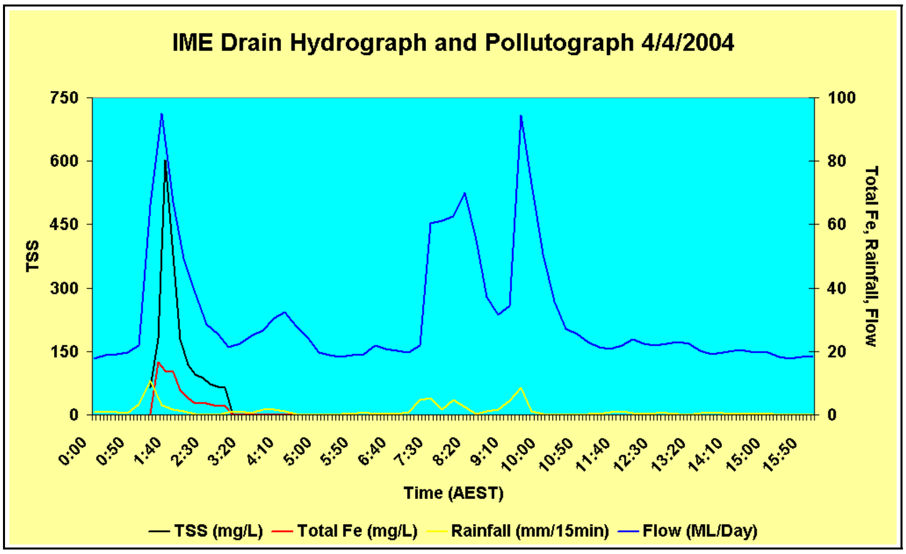
Rainfall Event Information	
Date	16/01/2004
Total Rainfall (mm)	8
Duration	5 hrs 15 min
Max Intensity (mm/hr)	5
Ave. Intensity (mm/hr)	1.5
1st Sample Taken	12:15
Duration of sampling	4hrs
TSS max. (mg/L)	33
Fe max. (mg/L)	1.39



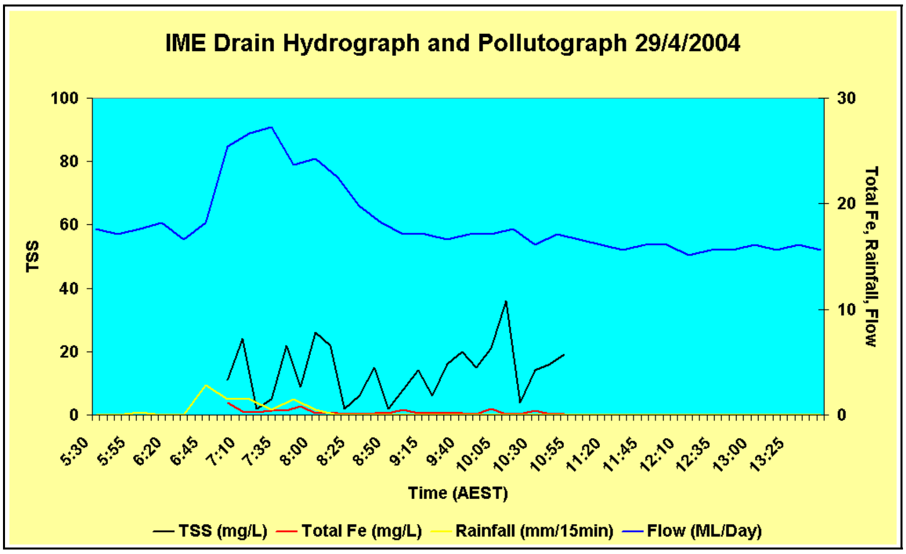
Rainfall Event Information	
Date	11/02/2004
Total Rainfall (mm)	11.5
Duration	3 hrs 15 min
Max Intensity (mm/hr)	12
Ave. Intensity (mm/hr)	3.5
1st Sample Taken	17:15
Duration of sampling	4hrs
TSS max. (mg/L)	52
Fe max. (mg/L)	4.53



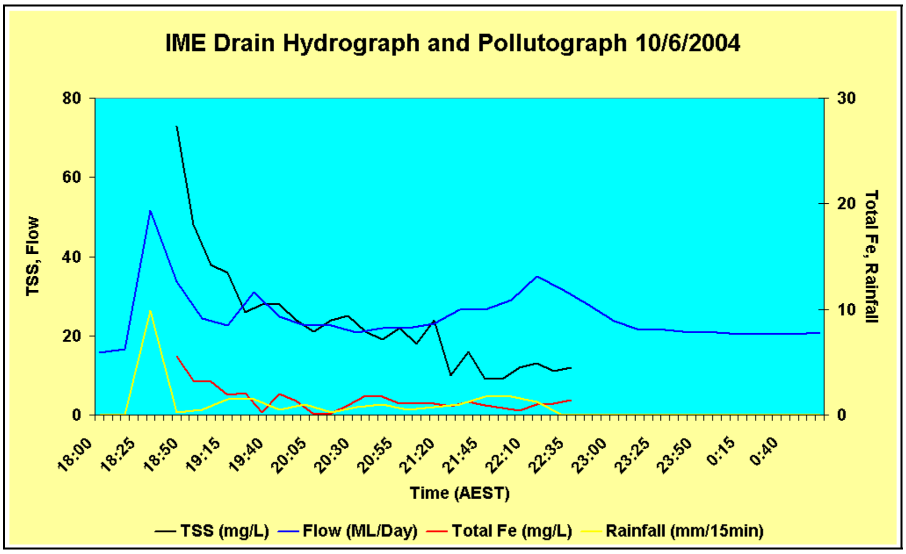
Rainfall Event Information	
Date	6/03/2004
Total Rainfall (mm)	24.5
Duration	10 hrs 30 min
Max Intensity (mm/hr)	7
Ave. Intensity (mm/hr)	2.5
1st Sample Taken	15:15
Duration of sampling	4hrs
TSS max. (mg/L)	38
Fe max. (mg/L)	1.63



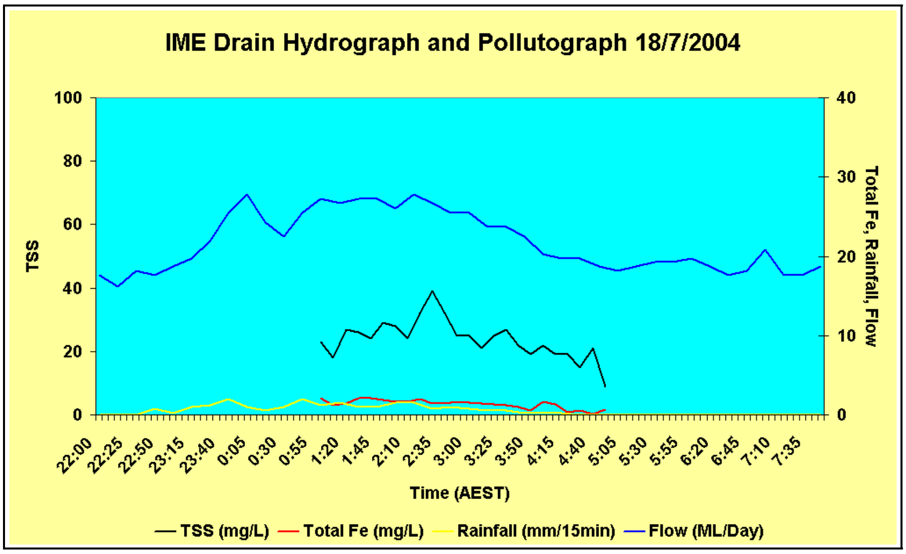
Rainfall Event Information	
Date	4/04/2004
Total Rainfall (mm)	76
Duration	15 hrs 15 min
Max Intensity (mm/hr)	43.5
Ave. Intensity (mm/hr)	5
1st Sample Taken	01:15
Duration of sampling	2 hrs
TSS max. (mg/L)	602
Fe max. (mg/L)	16.6



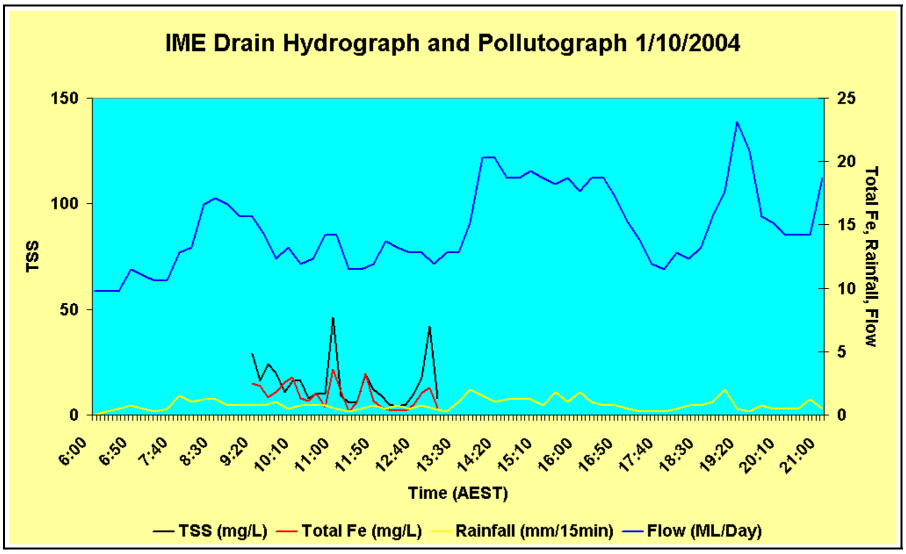
Rainfall Event Information	
Date	29/04/2004
Total Rainfall (mm)	15
Duration	3 hrs 45 min
Max Intensity (mm/hr)	15
Ave. Intensity (mm/hr)	4
1st Sample Taken	07:00
Duration of sampling	4 hrs
TSS max. (mg/L)	36
Fe max. (mg/L)	1.16



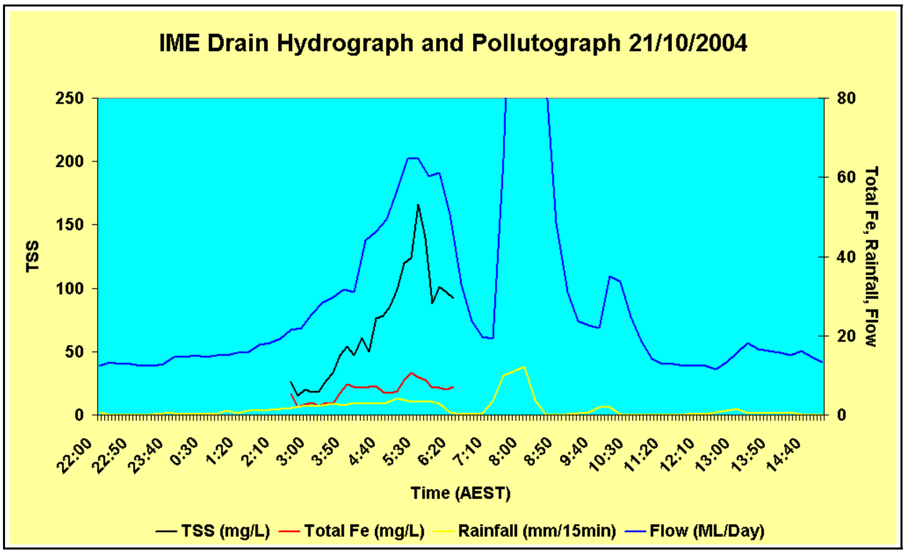
Rainfall Event Information	
Date	10/06/2004
Total Rainfall (mm)	24.5
Duration	3 hrs 45 min
Max Intensity (mm/hr)	39.5
Ave. Intensity (mm/hr)	6.5
1st Sample Taken	18:45
Duration of sampling	4 hrs
TSS max. (mg/L)	73
Fe max. (mg/L)	5.55



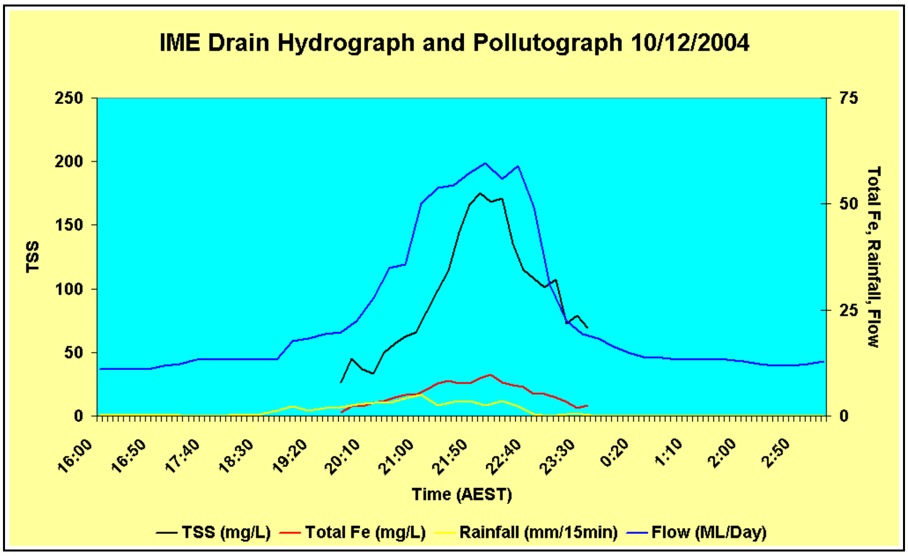
Rainfall Event Information	
Date	18/07/2004
Total Rainfall (mm)	22
Duration	5 hrs 30 min
Max Intensity (mm/hr)	8
Ave. Intensity (mm/hr)	4
1st Sample Taken	01:00
Duration of sampling	4 hrs
TSS max. (mg/L)	39
Fe max. (mg/L)	2.14



Rainfall Event Information	
Date	1/10/2004
Total Rainfall (mm)	48.5
Duration	14 hrs 45 min
Max Intensity (mm/hr)	8
Ave. Intensity (mm/hr)	3.5
1st Sample Taken	09:15
Duration of sampling	4 hrs
TSS max. (mg/L)	46
Fe max. (mg/L)	3.6

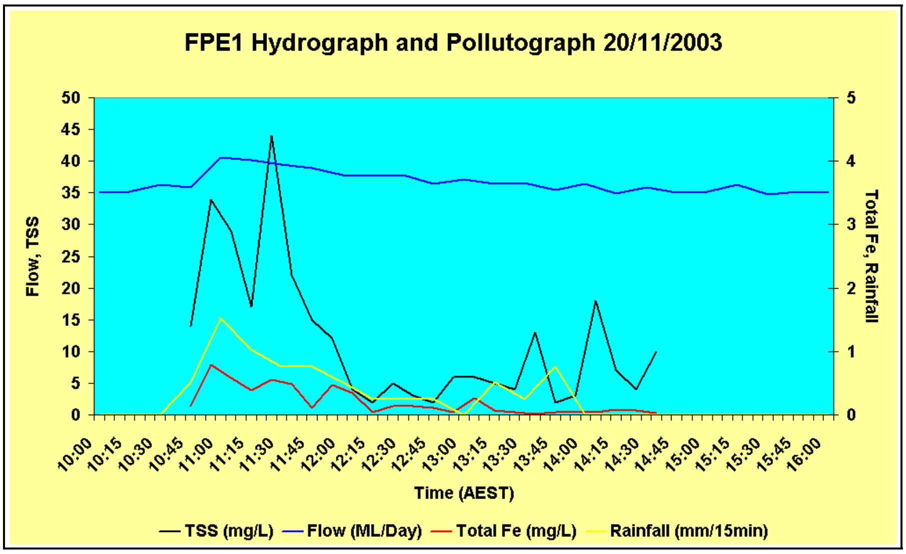


Rainfall Event Information	
Date	21/10/2004
Total Rainfall (mm)	109.5
Duration	16 hrs 30 min
Max Intensity (mm/hr)	49
Ave. Intensity (mm/hr)	6.5
1st Sample Taken	02:30
Duration of sampling	4 hrs
TSS max. (mg/L)	166
Fe max. (mg/L)	10.6

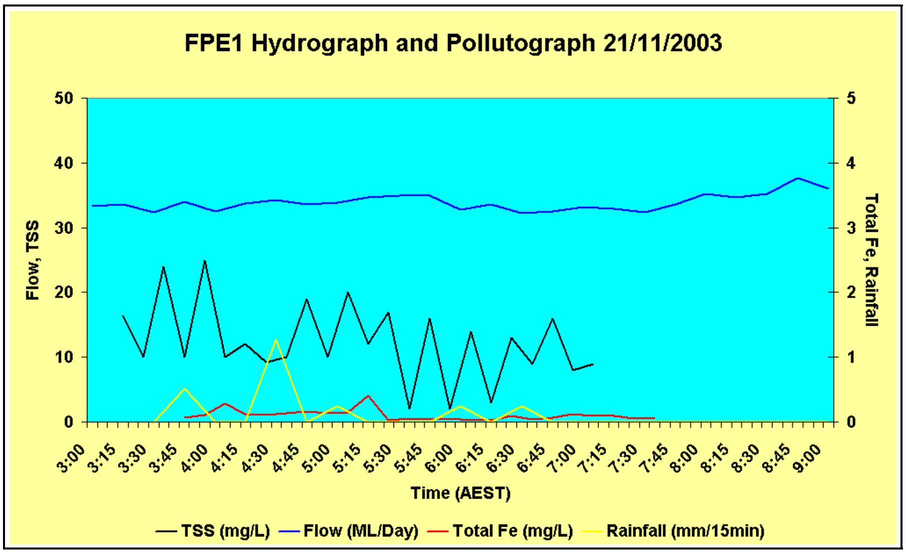


Rainfall Event Information	
Date	10/12/2004
Total Rainfall (mm)	49.5
Duration	8 hrs 30 min
Max Intensity (mm/hr)	20.5
Ave. Intensity (mm/hr)	6
1st Sample Taken	19:45
Duration of sampling	4 hrs
TSS max. (mg/L)	175
Fe max. (mg/L)	9.7

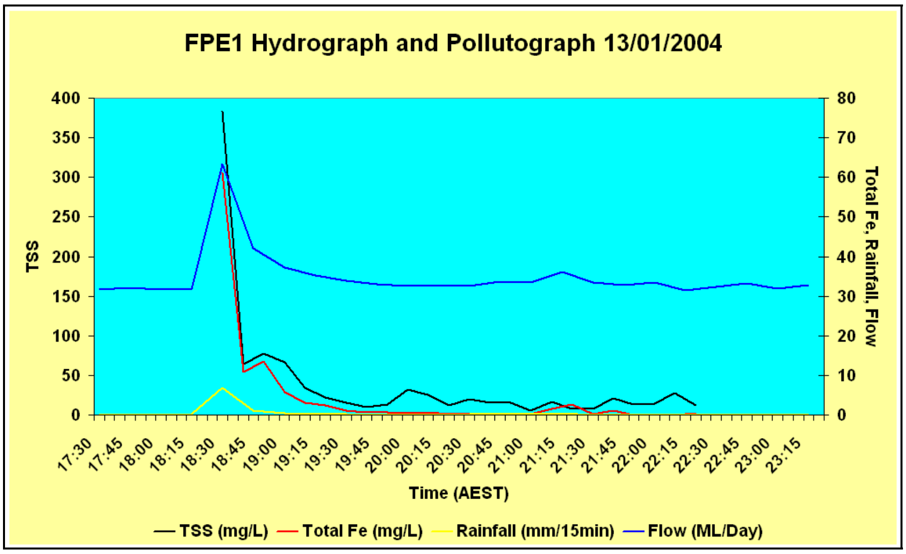
Appendix D. HYDROGRAPHS AND POLLUTOGRAPHS – FPE1 DRAIN



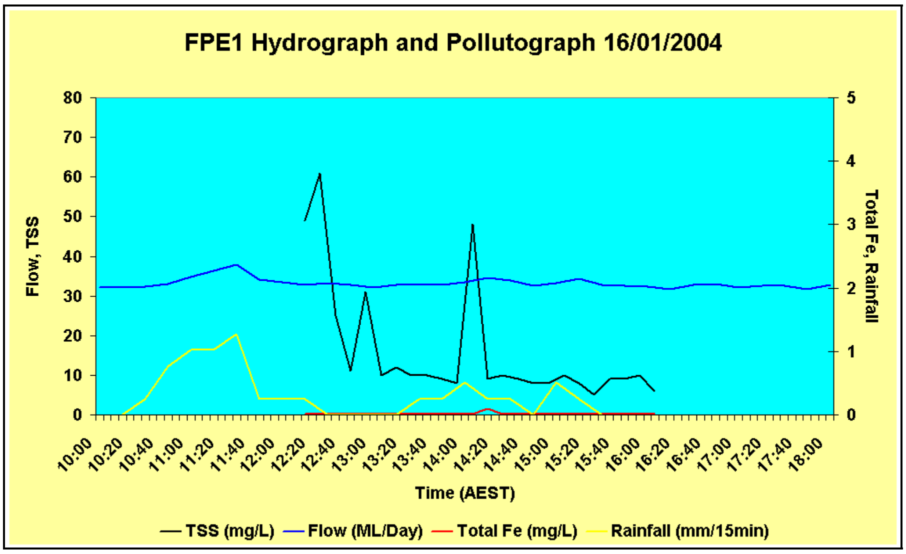
Rainfall Event Information	
Date	20/11/2003
Total Rainfall (mm)	7.5
Duration	3 hrs
Max Intensity (mm/hr)	6
Ave. Intensity (mm/hr)	2.5
1st Sample Taken	10:45
Duration of sampling	4hrs
TSS max. (mg/L)	44
Fe max. (mg/L)	0.79



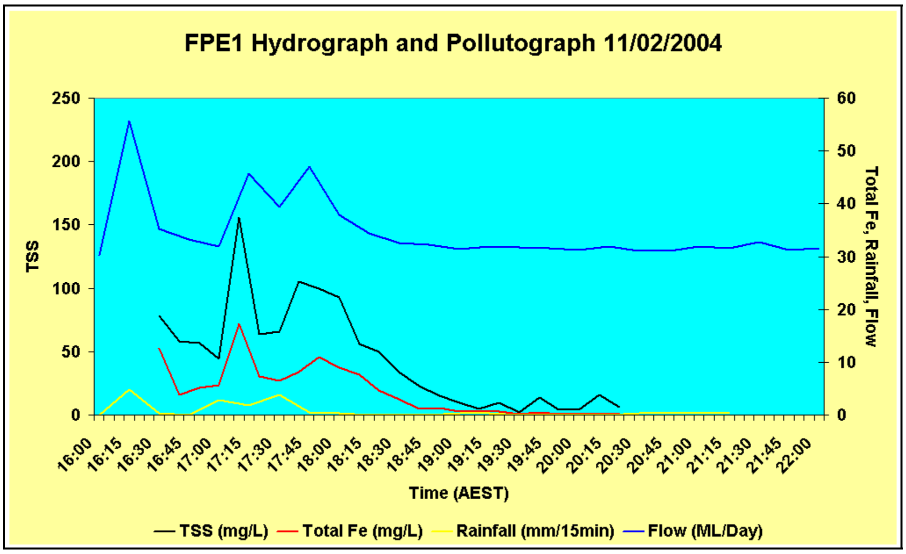
Rainfall Event Information	
Date	21/11/2003
Total Rainfall (mm)	2.5
Duration	2 hrs 45 min
Max Intensity (mm/hr)	5
Ave. Intensity (mm/hr)	<1
1st Sample Taken	3:45
Duration of sampling	4hrs
TSS max. (mg/L)	25
Fe max. (mg/L)	0.41



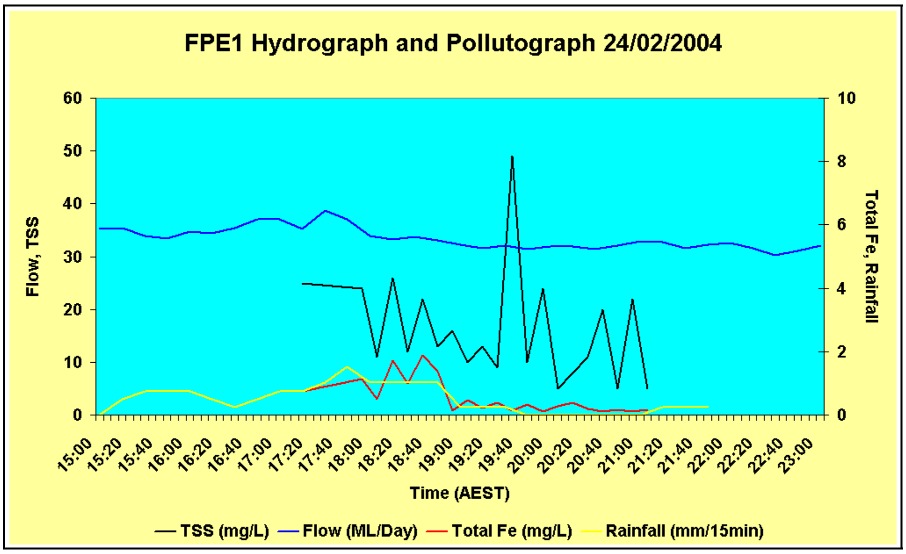
Rainfall Event Information	
Date	13/01/2004
Total Rainfall (mm)	10.5
Duration	3 hrs 30 min
Max Intensity (mm/hr)	27.5
Ave. Intensity (mm/hr)	3
1st Sample Taken	18:30
Duration of sampling	4hrs
TSS max. (mg/L)	383
Fe max. (mg/L)	61.1



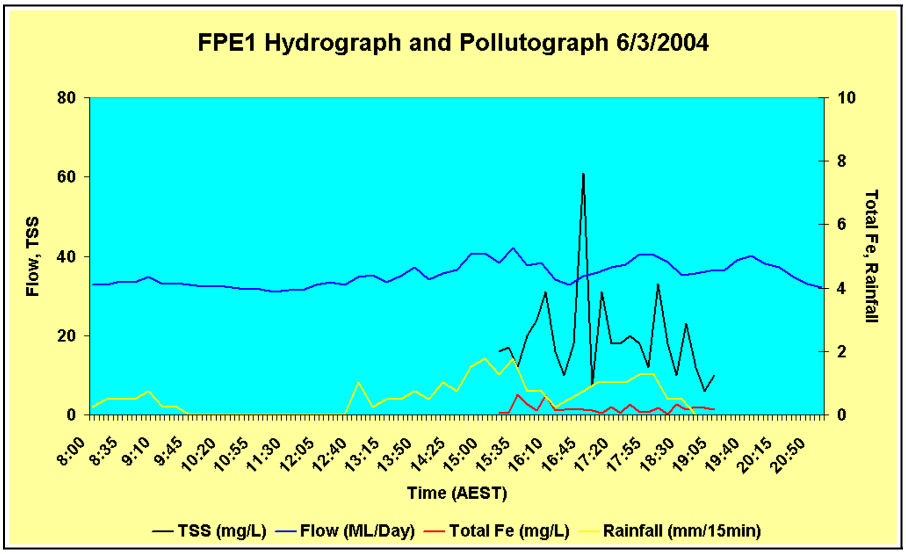
Rainfall Event Information	
Date	16/01/2004
Total Rainfall (mm)	7.5
Duration	4 hrs 45 min
Max Intensity (mm/hr)	5
Ave. Intensity (mm/hr)	1.5
1st Sample Taken	12:15
Duration of sampling	4hrs
TSS max. (mg/L)	61
Fe max. (mg/L)	0.10



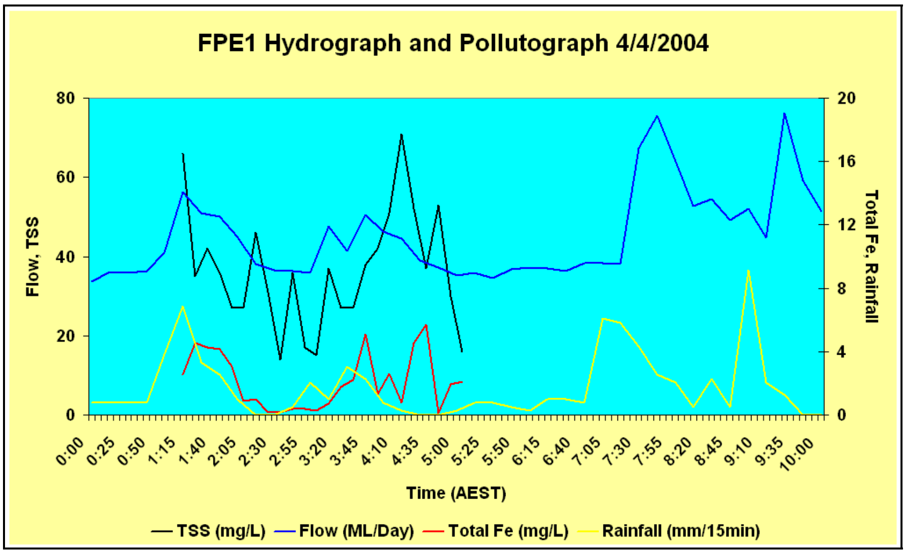
Rainfall Event Information	
Date	11/02/2004
Total Rainfall (mm)	15.5
Duration	5 hrs
Max Intensity (mm/hr)	19.5
Ave. Intensity (mm/hr)	3
1st Sample Taken	16:30
Duration of sampling	4hrs
TSS max. (mg/L)	156
Fe max. (mg/L)	17.3



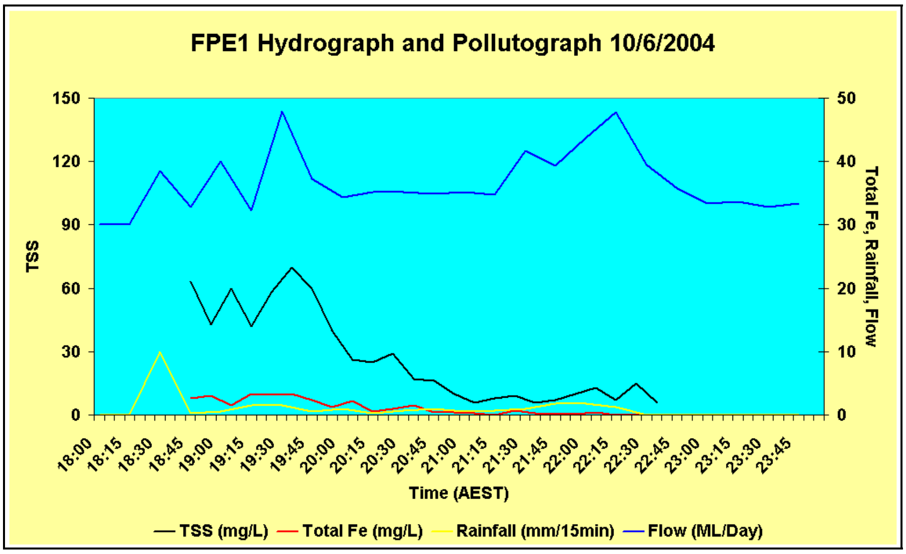
Rainfall Event Information	
Date	24/02/2004
Total Rainfall (mm)	13.5
Duration	6 hrs 30 min
Max Intensity (mm/hr)	6
Ave. Intensity (mm/hr)	2
1st Sample Taken	17:15
Duration of sampling	4hrs
TSS max. (mg/L)	49
Fe max. (mg/L)	1.89



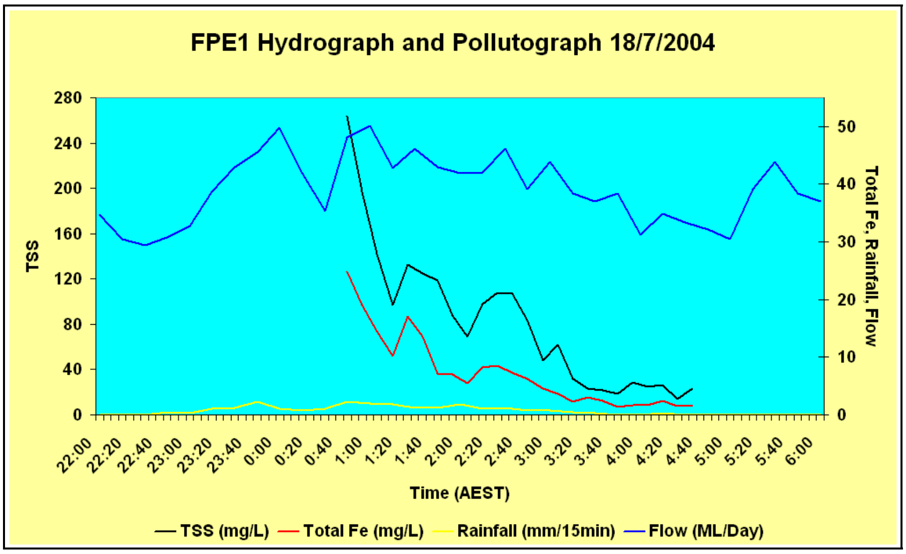
Rainfall Event Information	
Date	6/03/2004
Total Rainfall (mm)	24.5
Duration	10 hrs 30 min
Max Intensity (mm/hr)	7
Ave. Intensity (mm/hr)	2.5
1st Sample Taken	15:15
Duration of sampling	4hrs
TSS max. (mg/L)	61
Fe max. (mg/L)	0.63



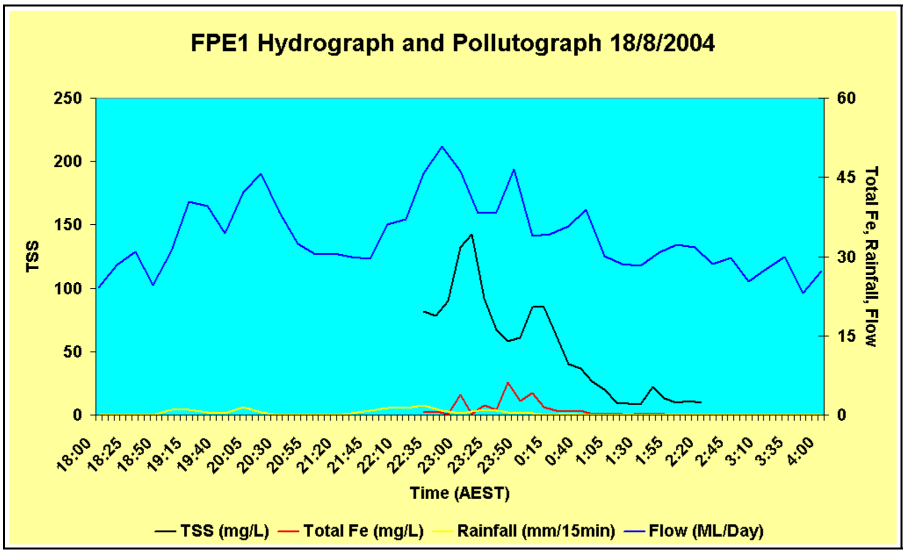
Rainfall Event Information	
Date	4/04/2004
Total Rainfall (mm)	72.5
Duration	9 hrs 45 min
Max Intensity (mm/hr)	36.5
Ave. Intensity (mm/hr)	8
1st Sample Taken	1:15
Duration of sampling	4hrs
TSS max. (mg/L)	71
Fe max. (mg/L)	5.71



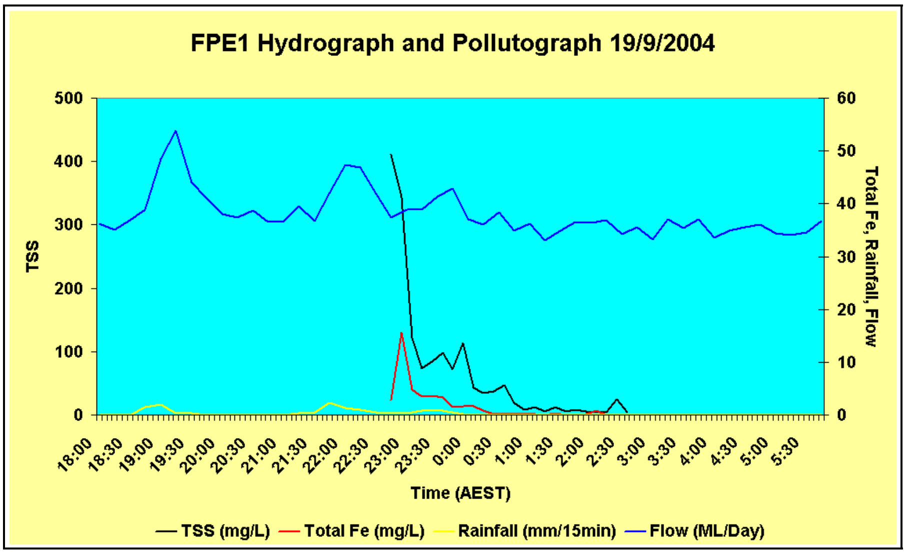
Rainfall Event Information	
Date	10/06/2004
Total Rainfall (mm)	24.5
Duration	3 hrs 45 min
Max Intensity (mm/hr)	39.5
Ave. Intensity (mm/hr)	6.5
1st Sample Taken	18:45
Duration of sampling	4hrs
TSS max. (mg/L)	70
Fe max. (mg/L)	3.32



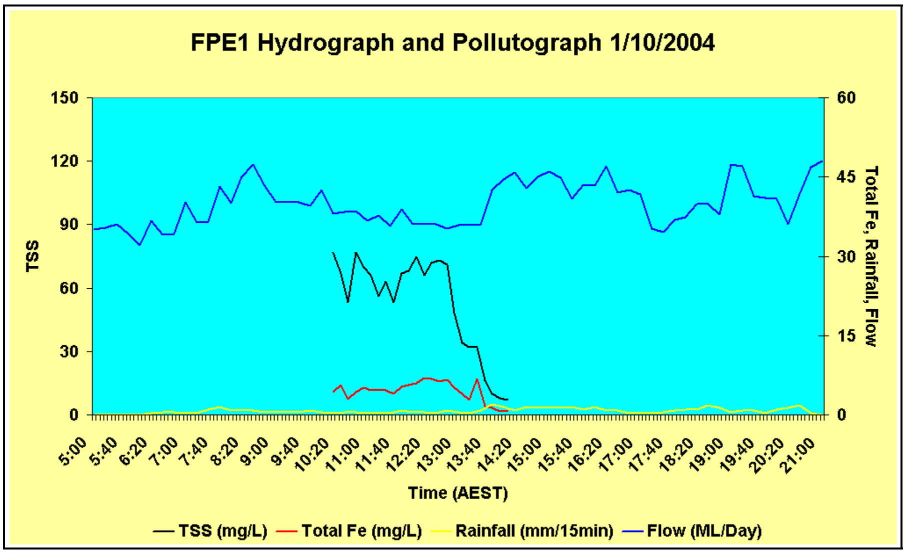
Rainfall Event Information	
Date	18/07/2004
Total Rainfall (mm)	23.5
Duration	5 hrs 45 min
Max Intensity (mm/hr)	9
Ave. Intensity (mm/hr)	4
1st Sample Taken	00:45
Duration of sampling	4hrs
TSS max. (mg/L)	264
Fe max. (mg/L)	24.8



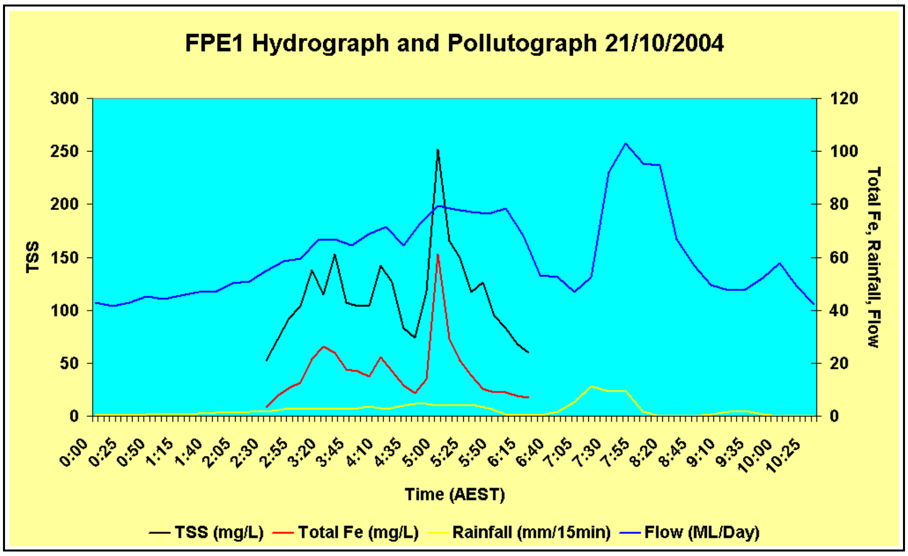
Rainfall Event Information	
Date	18/08/2004
Total Rainfall (mm)	13.5
Duration	5 hrs 30 min
Max Intensity (mm/hr)	7
Ave. Intensity (mm/hr)	2.5
1st Sample Taken	22:30
Duration of sampling	4hrs
TSS max. (mg/L)	143
Fe max. (mg/L)	6.22



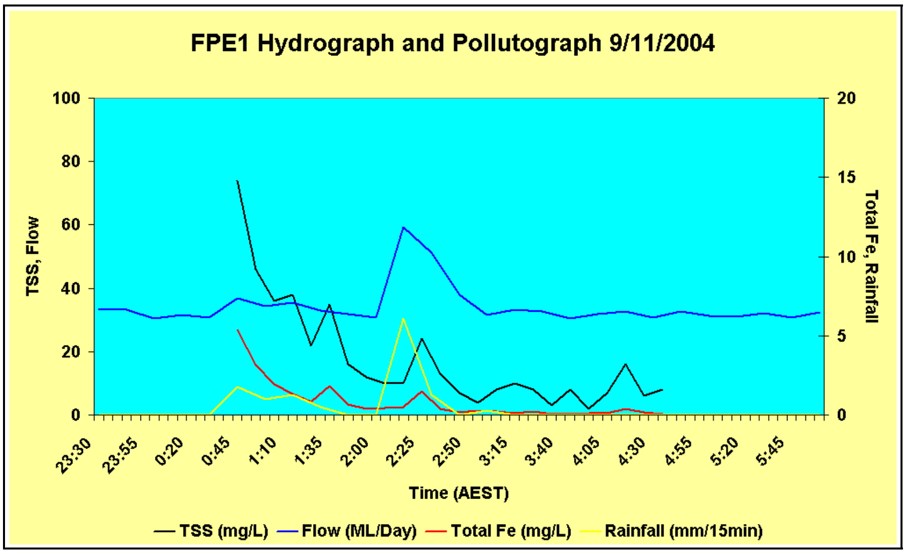
Rainfall Event Information	
Date	19/09/2004
Total Rainfall (mm)	12.5
Duration	5 hrs
Max Intensity (mm/hr)	9
Ave. Intensity (mm/hr)	2.5
1st Sample Taken	22:45
Duration of sampling	4hrs
TSS max. (mg/L)	412
Fe max. (mg/L)	15.7



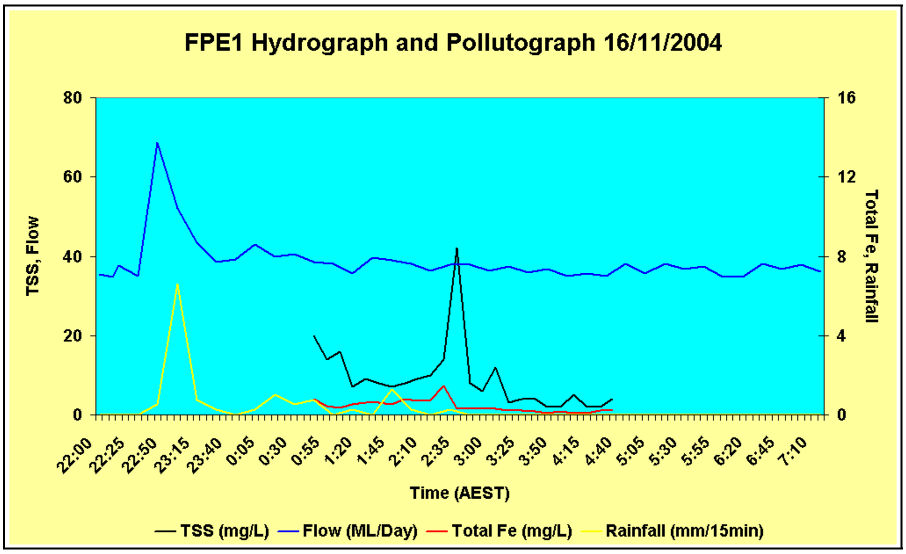
Rainfall Event Information	
Date	1/10/2004
Total Rainfall (mm)	45
Duration	14 hrs 30 min
Max Intensity (mm/hr)	8
Ave. Intensity (mm/hr)	3
1st Sample Taken	10:15
Duration of sampling	4hrs
TSS max. (mg/L)	77
Fe max. (mg/L)	7.0



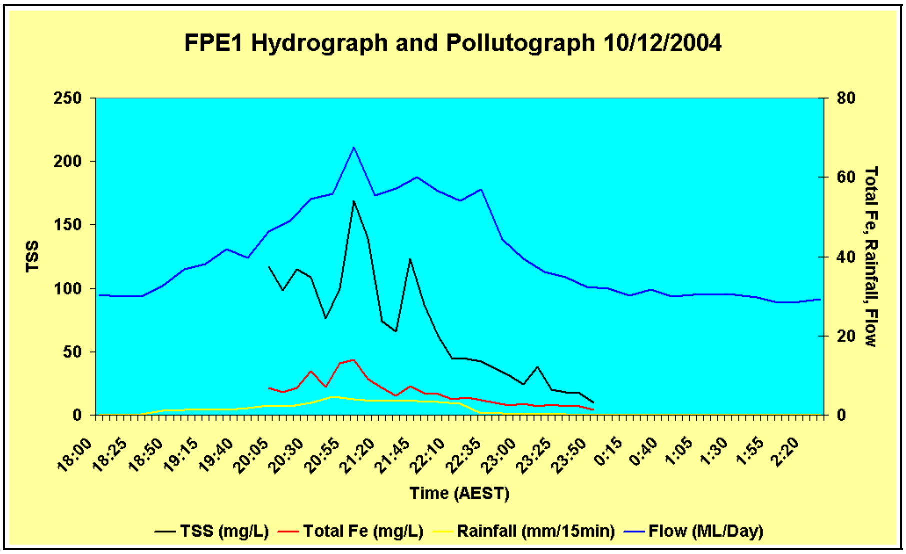
Rainfall Event Information	
Date	21/10/2004
Total Rainfall (mm)	100
Duration	10 hrs 30 min
Max Intensity (mm/hr)	44.5
Ave. Intensity (mm/hr)	9.5
1st Sample Taken	02:30
Duration of sampling	4hrs
TSS max. (mg/L)	252
Fe max. (mg/L)	61.1



Rainfall Event Information	
Date	9/11/2004
Total Rainfall (mm)	22
Duration	3 hrs 30 min
Max Intensity (mm/hr)	24.5
Ave. Intensity (mm/hr)	7
1st Sample Taken	00:45
Duration of sampling	4hrs
TSS max. (mg/L)	74
Fe max. (mg/L)	5.4



Rainfall Event Information	
Date	16/11/2004
Total Rainfall (mm)	12.5
Duration	3 hrs 45 min
Max Intensity (mm/hr)	26.5
Ave. Intensity (mm/hr)	3.5
1st Sample Taken	00:45
Duration of sampling	4hrs
TSS max. (mg/L)	42
Fe max. (mg/L)	1.45



Rainfall Event Information	
Date	10/12/2004
Total Rainfall (mm)	44
Duration	7 hrs 30 min
Max Intensity (mm/hr)	18.5
Ave. Intensity (mm/hr)	6
1st Sample Taken	20:00
Duration of sampling	4hrs
TSS max. (mg/L)	169
Fe max. (mg/L)	14.0

Appendix E. RAINFALL INTENSITY TABLE

Rainfall Intensity (mm/h) for PORT KEMBLA

Please see print copy for Appendix E

Appendix F. NORTH GATE DRAIN ANOVA TESTS

North Gate Drain - Single Factor ANOVA Tests

TSS

SUMMARY TSS

Groups	*Count*	*Sum*	*Average*	*Variance*
All Historical TSS Data	375	3463.5	9.236	134.4181
This Study TSS Data	262	5386	20.55725	191.6883

ANOVA TSS

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	19768.88	1	19768.88	125.1532	1.21E-26	3.856144
Within Groups	100303	635	157.9575			
Total	120071.9	636				

Total Fe

SUMMARY Total Fe

Groups	*Count*	*Sum*	*Average*	*Variance*
All Historical Total Fe Data	375	342.9845	0.914625	0.3747
This Study Total Fe Data	238	219.09	0.920546	0.459953

ANOVA Total Iron

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.005104	1	0.005104	0.012517	0.910955	3.856726
Within Groups	249.1467	611	0.407769			
Total	249.1518	612				

pH

SUMMARY pH

Groups	*Count*	*Sum*	*Average*	*Variance*
All Historical pH Data	375	2882	7.685333	0.083929
This Study pH Data	262	2003.5	7.646947	0.198362

ANOVA pH

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.227277	1	0.227277	1.735424	0.188195	3.856144
Within Groups	83.16189	635	0.130964			

N_0 (Null hypothesis) = mean historical data and data collected from this study are not significantly different at 95% confidence level.

Null hypothesis is rejected if the calculated F value (*F*) is ≥ critical F value (*F crit*).

Appendix G. MAIN DRAIN ANOVA TESTS

Main Drain - Single Factor ANOVA Tests

TSS

SUMMARY TSS

Groups	*Count*	*Sum*	*Average*	*Variance*
All Historical TSS Data	745	8197.5	11.00336	190.3148
This Study TSS Data	408	34087	83.54657	27541.39

ANOVA TSS

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1387333	1	1387333	140.6774	1.07E-30	3.84955
Within Groups	11350939	1151	9861.807			
Total	12738272	1152				

Total Fe

SUMMARY Total Fe

Groups	*Count*	*Sum*	*Average*	*Variance*
All Historical Total Fe Data	19	1.68	0.088421	0.010229
This Study Total Fe Data	408	895.4	2.194608	26.16587

ANOVA Total Iron

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	80.53407	1	80.53407	3.213893	0.073727	3.863434
Within Groups	10649.69	425	25.0581			
Total	10730.23	426				

pH

SUMMARY pH

Groups	*Count*	*Sum*	*Average*	*Variance*
All Historical pH Data	372	3008.1	8.08629	0.031698
This Study pH Data	264	2093.6	7.930303	0.042044

ANOVA pH

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.757234	1	3.757234	104.3966	8.63E-23	3.856172
Within Groups	22.81766	634	0.03599			
Total	26.57489	635				

N_0 (Null hypothesis) = mean historical data and data collected from this study are not significantly different at 95% confidence level.

Null hypothesis is rejected if the calculated F value (*F*) is ≥ critical F value (*F crit*).

Appendix H. IRONMAKING EAST DRAIN ANOVA TESTS

Ironmaking East Drain - Single Factor ANOVA Tests

TSS

SUMMARY TSS

Groups	*Count*	*Sum*	*Average*	*Variance*
All Historical TSS Data	742	9660	13.01887	574.393
This Study TSS Data	299	10597	35.44147	2666.898

ANOVA TSS

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	107151.1	1	107151.1	91.22706	8.86E-21	3.850431
Within Groups	1220361	1039	1174.553			
Total	1327512	1040				

Total Fe

SUMMARY Total Fe

Groups	*Count*	*Sum*	*Average*	*Variance*
All Historical Total Fe Data	371	393.187	1.059803	2.109977
This Study Total Fe Data	299	613.96	2.053378	6.647944

ANOVA Total Fe

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	163.4449	1	163.4449	39.53292	5.83E-10	3.855419
Within Groups	2761.779	668	4.1344			
Total	2925.224	669				

pH

SUMMARY pH

Groups	*Count*	*Sum*	*Average*	*Variance*
All Historical pH Data	371	3062.1	8.253639	0.077196
This Study pH Data	120	964.8	8.04	0.043261

ANOVA pH

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.138414	1	4.138414	60.03113	5.44E-14	3.860549
Within Groups	33.71059	489	0.068938			

N_0 (Null hypothesis) = mean historical data and data collected from this study are not significantly different at 95% confidence level.

Null hypothesis is rejected if the calculated F value (*F*) is ≥ critical F value (*F crit*).

Appendix I. FLAT PRODUCTS EAST NO.1 DRAIN ANOVA TESTS

Flat Products East No.1 Drain - Single Factor ANOVA Tests

TSS

SUMMARY TSS

Groups	*Count*	*Sum*	*Average*	*Variance*
All Historical TSS Data	376	4716	12.54255	173.2902
This Study TSS Data	405	16348.6	40.36691	2486.837

ANOVA TSS

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	150953.2	1	150953.2	109.9339	3.76E-24	3.853415
Within Groups	1069666	779	1373.127			
Total	1220619	780				

Total Fe

SUMMARY Total Fe

Groups	*Count*	*Sum*	*Average*	*Variance*
All Historical Total Fe Data	376	501.853	1.334715	2.729654
This Study Total Fe Data	405	1234.94	3.049235	38.46347

ANOVA Total Iron

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	573.1608	1	573.1608	26.95743	2.66E-07	3.853415
Within Groups	16562.86	779	21.2617			
Total	17136.02	780				

pH

SUMMARY pH

Groups	*Count*	*Sum*	*Average*	*Variance*
All Historical pH Data	376	3046	8.101064	0.106026
This Study pH Data	216	1721.1	7.968056	0.065533

ANOVA pH

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.427042	1	2.427042	26.59196	3.44E-07	3.857267
Within Groups	53.84916	590	0.09127			
Total	56.2762	591				

N_0 (Null hypothesis) = mean historical data and data collected from this study are not significantly different at 95% confidence level.

Null hypothesis is rejected if the calculated F value (*F*) is ≥ critical F value (*F crit*).