Analysis of Wet & Dry Weather Bacterial Concentrations within Kranji & Marina Catchments, Singapore

By

Genevieve Edine Ho

B.S.E Civil Engineering
University of Michigan, Ann Arbor 2009

Submitted to the Department of Civil and Environmental Engineering
in Partial Fulfillment of the Requirements for the Degree of

Master of Engineering in Civil and Environmental Engineering

at the

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Signature of Author ______________________________
Genevieve Edine Ho
Department of Civil and Environmental Engineering
May 12, 2011

Certified by ______________________________
Peter Shanahan
Senior Lecturer of Civil and Environmental Engineering
Thesis Supervisor

Accepted by ______________________________
Heidi M. Nepf
Chair, Departmental Committee for Graduate Students

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ABSTRACT

The Singaporean government's Public Utilities Board aims to open Kranji and Marina Reservoirs to the public for recreational use. Thus, the water bodies have to be safe from fecal contamination in order to protect the people's health during water-contact activities. Under the Singapore-MIT Alliance for Research and Technology (SMART) program, faculty and students from Nanyang Technological University and MIT have worked together to conduct bacteriological studies at both Kranji and Marina catchments and their reservoirs. Storm water, especially from urban landscapes, contains elevated concentrations of total coliform, *E. coli*, and enterococci bacteria. The goal of this study was to review, classify, and evaluate wet- and dry-weather bacteria samples dating back to 2005 with a focus on grab-samples collected by Nshimyimana (2010) in 2009 and samples collected during January 2011 field work at Choa Chu Kang Crescent, Bras Basah, and Verde. These bacteriological samples were collected from high density residential (HDR), low density residential, forested, and commercial areas.

Evaluation of the relationship between concentration and flow showed a linear increase in bacteria concentrations with flow in storm water from mixed forested and HDR areas, a pattern that is consistent with nonpoint source runoff, while commercial areas exhibited peak concentrations during low and high, but not intermediate, flows indicating contributions from both nonpoint and point sources. Likely point sources are sanitary sewer leakage due to aging infrastructure in the commercial area. All measured concentrations exceeded Singapore and USEPA's recommended bacterial levels for recreational water. Hence, more wet-weather sampling is recommended in order to collect data on bacterial concentrations so that more robust statistical analyses can be performed in future studies. The elevated bacterial concentrations during wet weather from this study indicate that extra precaution should be taken to manage discharge of storm water into receiving waters before they are made accessible to the public.

Thesis Supervisor: Peter Shanahan
Title: Senior Lecturer of Civil and Environmental Engineering

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Only those who risk going too far can possibly find out how far one can go.

T. S. Eliot

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Chapter 1: Introduction

This chapter was prepared collaboratively with Ryan Bossis and Yangyue Zhang.

1.1 Singapore Background

Singapore is located at the southern tip of Malaysia, and is 137 kilometers north of the equator. The total area of the entire country spans approximately 710 km^2 (Granger, 2010) and the country's current population is estimated to be around five million with a growth of 1% per annum (Nshimyimana, 2010). Singapore's free market economy has enjoyed almost uninterrupted growth since 1965, when it won its independence. The city-state has one of the highest per capital GDPs in the world ($45,000) with a standard of living comparable to North America and Western Europe. Among all the industries, the tourism industry is the best developed in that it generated $12.8 billion in receipts from a record of 9.7 million visitors in 2009.

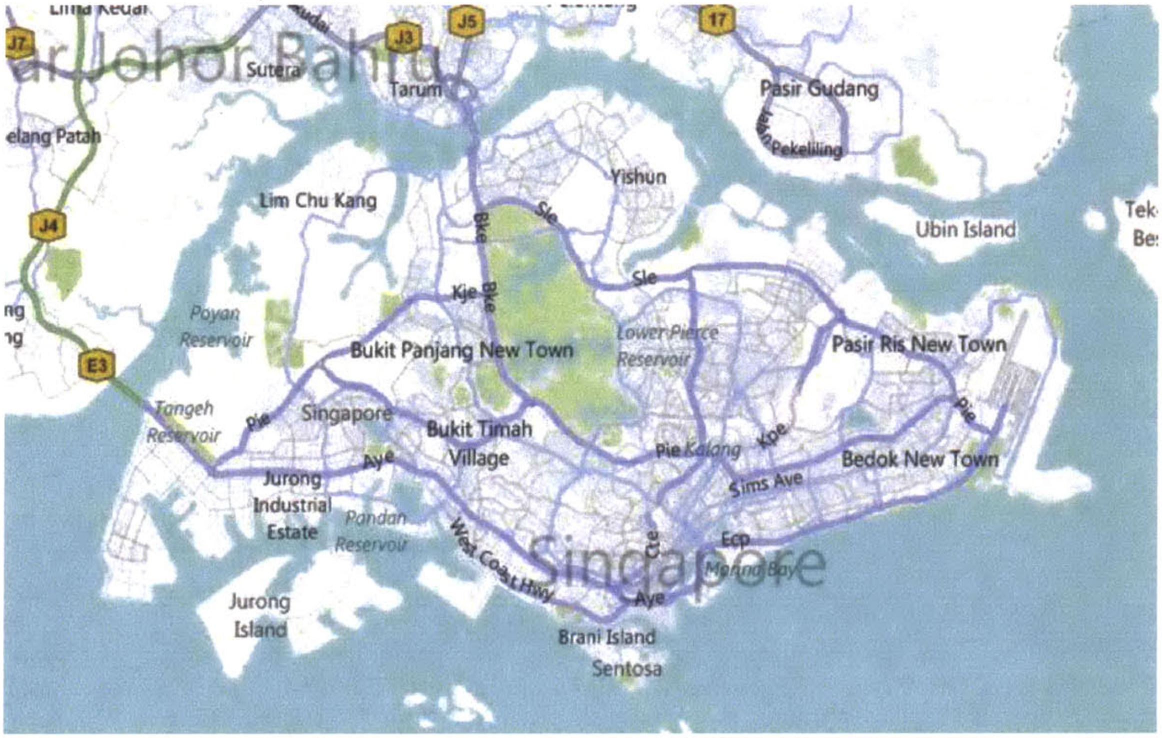


Figure 1.1: Map of Singapore (Bing.com, 2011)

The climate in the Southeast Asian region is typically humid, rainy and tropical with two main monsoon seasons from December to March and June to September, and inter-monsoon periods in between typically characterized by heavy thunderstorms in the afternoons. Singapore receives around 2400 mm of rainfall a year, which is above the global average of 1050 mm per year. However, lack of land and thus limited catchment area to collect rainwater, coupled with the high evaporation rates in the country, have caused Singapore to be classified as a water-scarce country. On the United Nations' list of country's fresh water availability, Singapore ranks 170 out of 190 (Tan *et al.*, 2009).

1.2 Water Issues and Water Management

1.2.1 Singapore's Water Supply – The Four National Taps

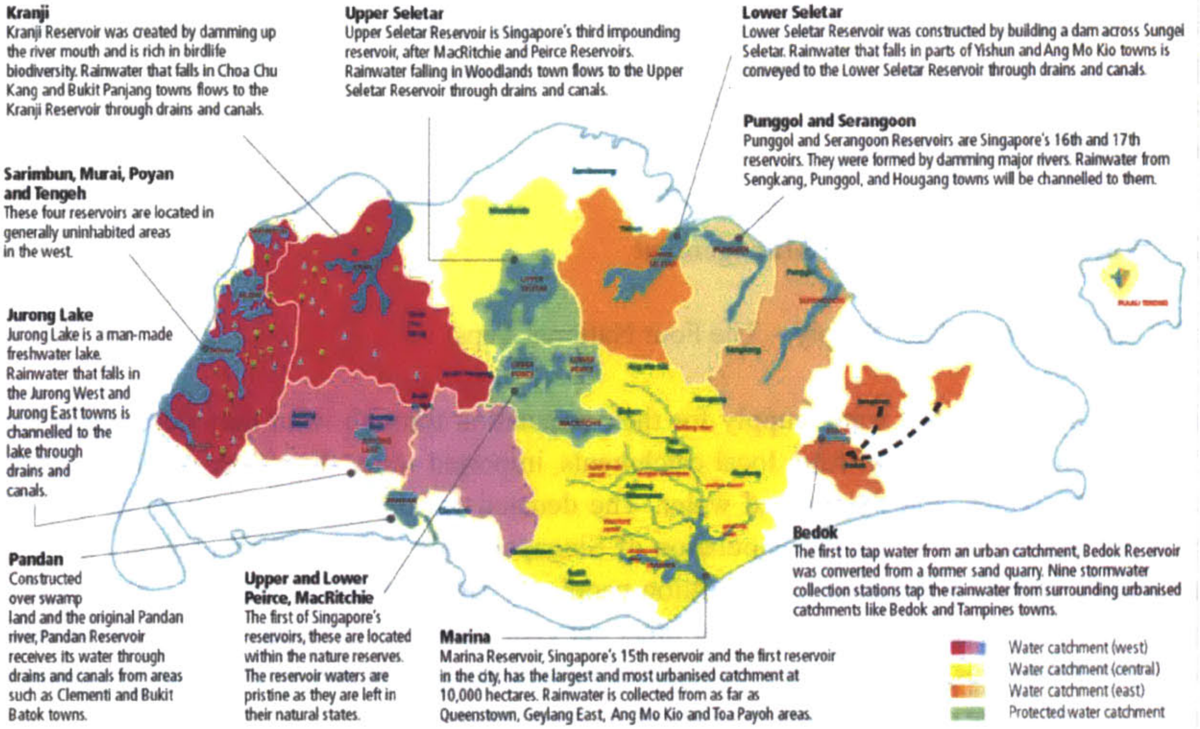
Singapore has developed water supply for their population through what they describe as their "Four National Taps": water from local catchments, imported water from their neighbor country Malaysia, NEWater, and desalinated water. The demand for domestic water was 75 liters per capita per day in 1965 when the population of Singapore was at 1.9 million (Tan *et al.*, 2009). Singapore's current population is 5.1 million people (S. Department of Statistics, 2011) and the current domestic water demand is at 154 liters per capita per day (Ministry of the Environment and Water Resources, 2011). With the projected population growth and an increasing demand for water per capita, the country is planning ahead to meet future needs.

Singapore does not have natural aquifers or lakes. The country draws water from 17 constructed reservoirs with storage water collected using a comprehensive network of drains, canals, rivers, and stormwater collection ponds. These catchments form Singapore's 1st National Tap (PUB, 2010). Figure 1.2 shows the 17 reservoirs (Pulau Tekong in the upper right corner is also a reservoir) (PUB, 2011).

The 2nd National Tap is imported water from Johor, Malaysia. Under a 1961 and revised 1962 Water Agreement with Malaysia, Singapore has the full and exclusive right and liberty to draw off, take, impound, and use all (raw) water from the Johor River up to a maximum of 250 million gallons per day with a payment of 3 cents per 1000 gallons (PUB, 2010). The 1961 and 1962 Agreements will expire in 2011 and 2061 respectively. Singapore is planning for self sufficiency when the Water Agreements to import water from Malaysia expire in 2011 and 2061.

NEWater, the 3rd National Tap, is reclaimed municipal wastewater treated using advanced membrane technologies and supplies 30% of Singapore's total water demand. There are currently five NEWater plants—Bedok (online in 2003), Kranji (2003), Seletar (2004), Ulu Pandan (2007), and Changi (2010) (PUB, 2010).

Singapore's 4th National Tap was turned online in September 2005 in the form of the SingSpring Desalination Plant in Tuas. The plant produces 30 million gallons of water per day using reverse osmosis (PUB, 2010).



Kranji
Kranji Reservoir was created by damming up the river mouth and is rich in birdlife biodiversity. Rainwater that falls in Choa Chu Kang and Bukit Panjang towns flows to the Kranji Reservoir through drains and canals.

Upper Seletar
Upper Seletar Reservoir is Singapore's third impounding reservoir, after MacRitchie and Peirce Reservoirs. Rainwater falling in Woodlands town flows to the Upper Seletar Reservoir through drains and canals.

Lower Seletar
Lower Seletar Reservoir was constructed by building a dam across Sungei Seletar. Rainwater that falls in parts of Yishun and Ang Mo Kio towns is conveyed to the Lower Seletar Reservoir through drains and canals.

Punggol and Serangoon
Punggol and Serangoon Reservoirs are Singapore's 16th and 17th reservoirs. They were formed by damming major rivers. Rainwater from Sengkang, Punggol, and Hougang towns will be channelled to them.

Sarimbun, Murai, Poyan and Tengeh
These four reservoirs are located in generally uninhabited areas in the west.

Jurong Lake
Jurong Lake is a man-made freshwater lake. Rainwater that falls in the Jurong West and Jurong East towns is channelled to the lake through drains and canals.

Pandan
Constructed over swamp land and the original Pandan river, Pandan Reservoir receives its water through drains and canals from areas such as Clementi and Bukit Batok towns.

Upper and Lower Peirce, MacRitchie
The first of Singapore's reservoirs, these are located within the nature reserves. The reservoir waters are pristine as they are left in their natural states.

Marina
Marina Reservoir, Singapore's 15th reservoir and the first reservoir in the city, has the largest and most urbanised catchment at 10,000 hectares. Rainwater is collected from as far as Queenstown, Geylang East, Ang Mo Kio and Toa Payoh areas.

Bedok
The first to tap water from an urban catchment, Bedok Reservoir was converted from a former sand quarry. Nine stormwater collection stations tap the rainwater from surrounding urbanised catchments like Bedok and Tampines towns.

Figure 1.2: Singapore's 17 Reservoirs

1.2.2 Current Campaign – Active, Beautiful, Clean Waters Programme

Via the Active, Beautiful, Clean Waters (ABC Waters) Programme, Singapore's Public Utilities Board (PUB) aims to transform the drains, canals, and reservoirs within the country into beautiful and vibrant streams, rivers, and lakes. The program's main objectives are to (1) transform water bodies into lifestyle attractions for the public in addition to functioning as collection, storage, and drainage systems; (2) involve People-Public-Private (3P) resources in developing water bodies into community spaces while at the same time maintaining water quality; (3) play the role of the umbrella program that connects all water management initiatives within the country; and (4) integrate water conservation into the community's lifestyle (PUB, 2008). PUB aims to transform two thirds of the country into a massive water catchment by the year 2011 (PUB, 2010).

PUB developed a Masterplan to identifying potential water catchment projects across the country. These projects would be implemented in phases over the span of ten to fifteen years with the first five-year plan being from 2007 to 2011. PUB divided the map of Singapore into three "watersheds": the Western, Eastern and Central Catchments, with respective themes and projects. The goal is to provide a suitable water management system to capture freshwater and additionally provide the public with water recreational activities.

1.3 Kranji and Marina Reservoirs

Kranji and Marina Reservoirs are two of the many reservoirs in Singapore being opened to the public under the ABC Waters Programme. Figure 1.2 shows both catchments relative to one another in size and distance. Kranji Catchment covers an area of 6,100 hectares whereas Marina Catchment covers an area of approximately 10,000 hectares.

1.3.1 Development of Kranji Reservoir

Kranji Catchment is a largely rural and underdeveloped area and has some of the most important nature areas in Singapore. Figure 1.3 shows the breakdown of water catchments in the Western Catchment, with Kranji Reservoir included in the figure at the northern corner and Figure 1.4 shows the Western Catchment's location within Singapore.

Kranji Reservoir is a drinking water reservoir in the northwest region of Singapore and is managed by Singapore Public Utilities Board (PUB). Kranji Reservoir has three main tributaries, Sungei Kangkar, Sungei Tengah, and Sungei Peng Siang. The reservoir, despite its strength in natural beauty, open space availability, and ecological uniqueness, has low visitor rates due to lack of transportation, poor access, and relatively isolated areas at the reservoir. Due to the availability of large undeveloped land however, Kranji Reservoir had high recreational potential among other reservoirs in the Western Catchment (Tan *et al.*, 2009). Under the 2003 Masterplan, the Urban Redevelopment Authority (URA) of Singapore proposes to develop a tropical wetlands experience for the public around the Kranji freshwater marshes (PUB, 2003).

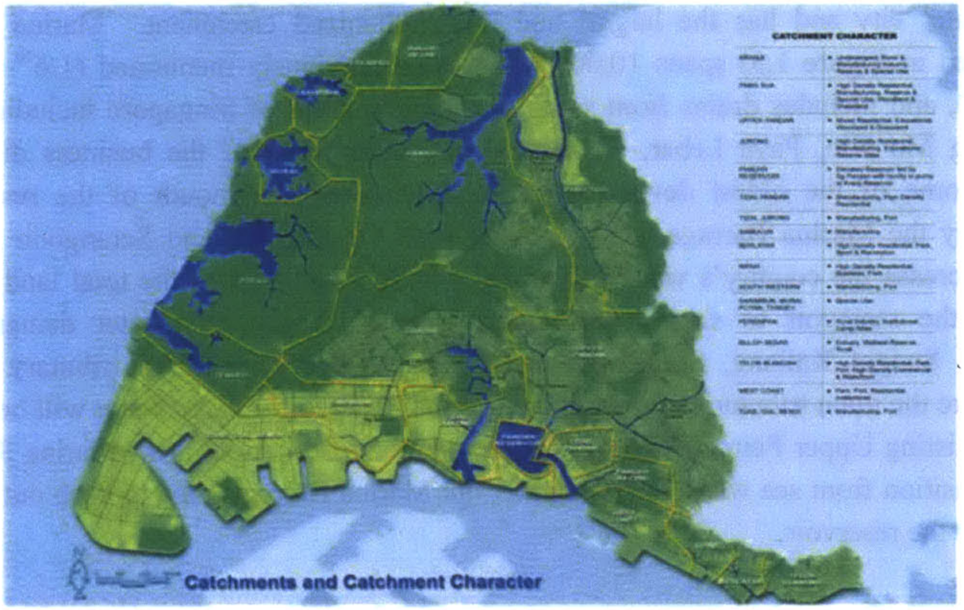


Figure 1.3: Western Catchment with Kranji Reservoir included (PUB, 2007)

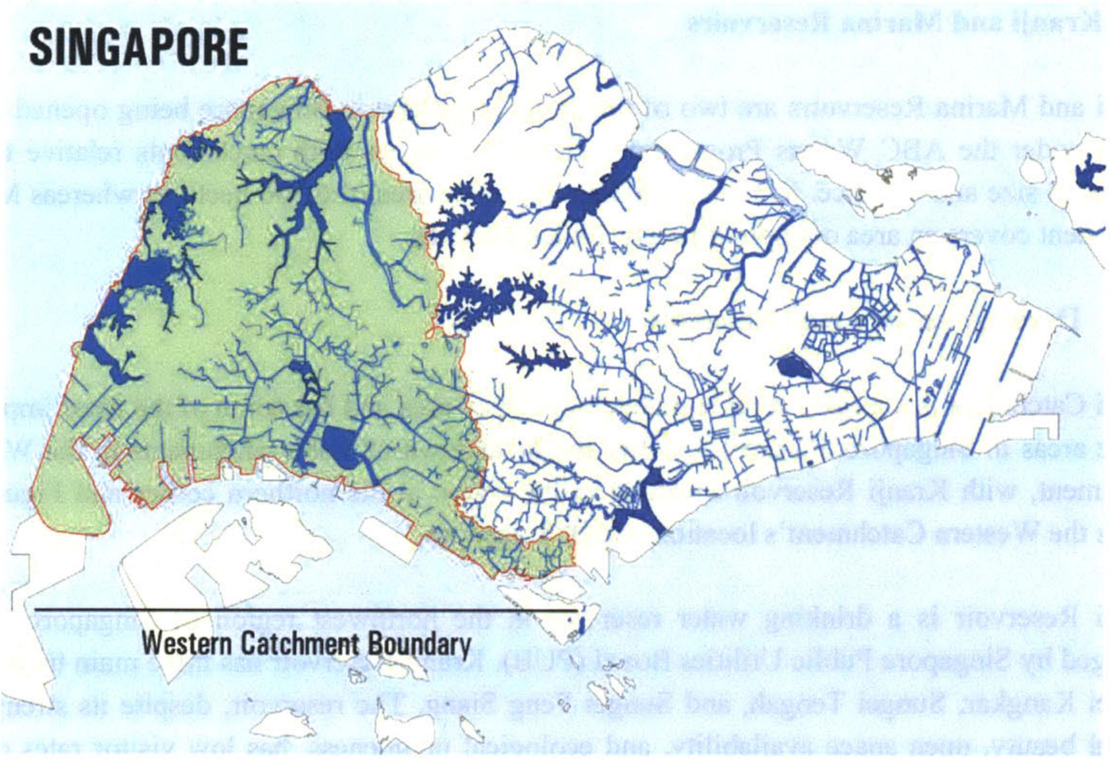


Figure 1.4: Location of Western Catchment within Singapore (APWA, 2010)

1.3.2 Marina Reservoir

Marina Reservoir was formed in 2008 and is Singapore's 15th reservoir. It is the first reservoir in the center city and has the largest and most urbanized catchment. Marina Catchment (highlighted in Figure 1.5) spans 10,000 hectares as previously mentioned (1/6th the area of Singapore), and includes drains from some of the main areas of Singapore including Orchard Road, Ang Mo Kio, Paya Lebar, Alexandra, and other parts of the business district. This includes some of the oldest developments in Singapore. The mouth of the reservoir was dammed by the Marina Barrage and combined with the Punggol and Serangoon Reservoirs, aims to increase the country's water catchment area to two thirds of the total land area. PUB estimates the reservoir to supply more than 10% of Singapore's water demand. Sungei Singapore, Sungei Kallang, Sungei Geylang, and Rochor Channel (a tributary of Sungei Kallang) are the main tributaries flowing into Marina Reservoir. Excess water will be channeled into the existing Upper Peirce Reservoir for storage purposes. As of now, Marina Reservoir is still in transition from sea water to fresh water but Marina Barrage aims to keep out all the salt water from the reservoir.

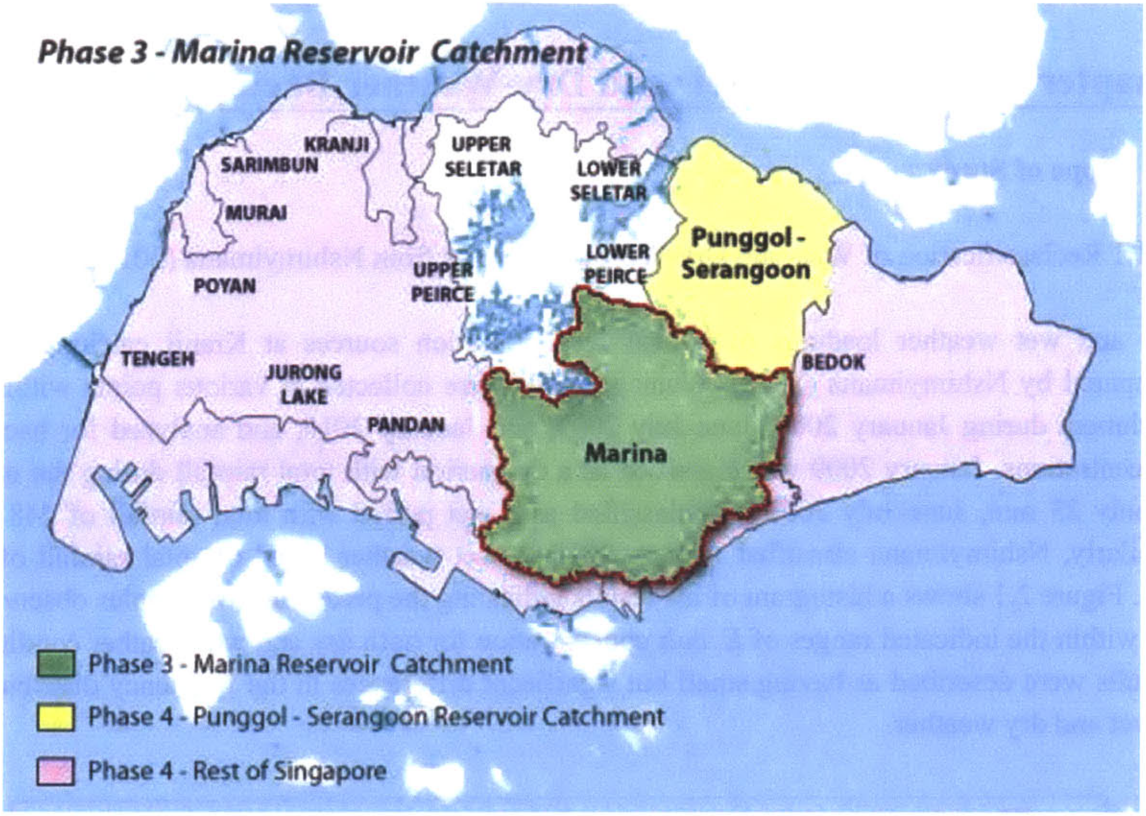


Figure 1.5: Location of Marina Catchment within Singapore (PUB, 2010)

Chapter 2: Analysis of Wet- and Dry-Weather Bacterial Loadings

2.1 Scope of Study

2.1.1 Reclassification of Wet- and Dry-Weather Samples from Nshimyimana (2010)

Dry and wet weather loadings of human fecal pollution sources at Kranji catchment were compared by Nshimyimana (2010). Water samples were collected at various points within the catchment during January 2009, June-July 2009, and January 2010, and analyzed for bacterial concentrations. January 2009 was classified as a dry period with total rainfall during the month of only 23 mm, June-July 2009 was classified as a wet period with total rainfall of 248 mm. Similarly, Nshimyimana classified January 2010 as wet weather based on total rainfall of 729 mm. Figure 2.1 shows a histogram of his results indicating the percentage of samples observed to fall within the indicated ranges of *E. coli* concentration for both dry and wet weather conditions. Results were described as having small but significant differences in the frequency distributions of wet and dry weather.

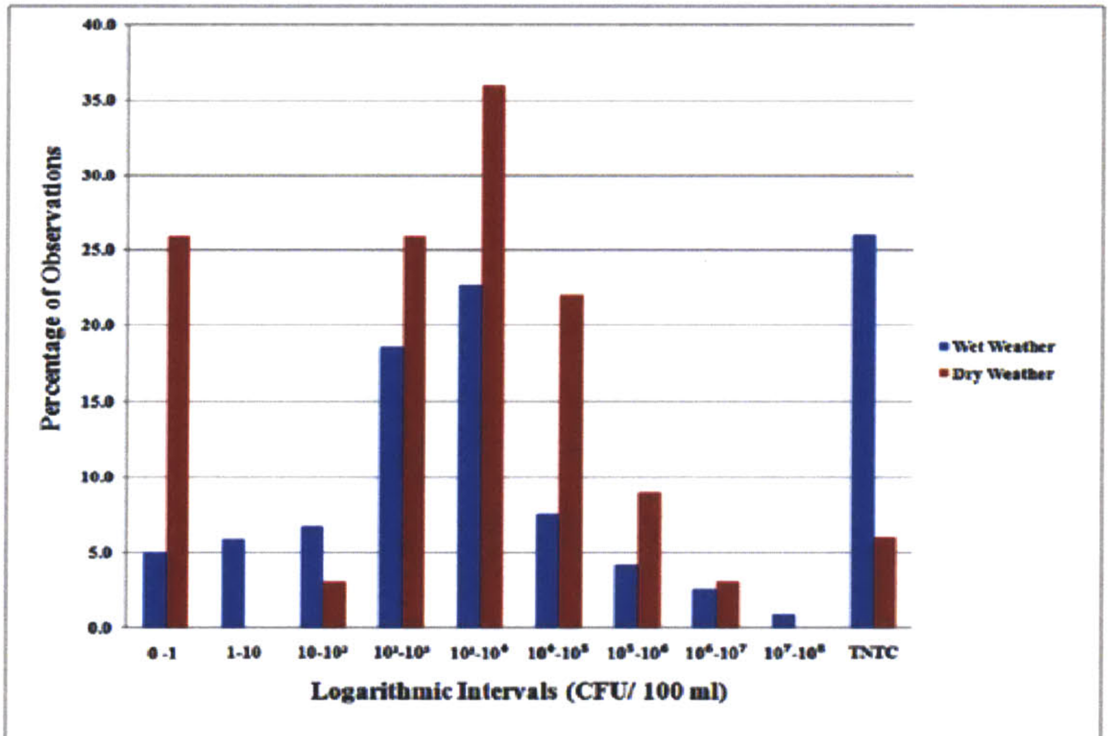


Figure 6.2 Comparison of Frequency Percentages of All E. coli Data Recorded under Dry (January 2009) and Wet Weather (July 2009 and January 2010)

Figure 2.1: Results of Percentage Observations of Wet- and Dry-Weather E. coli Loadings (Nshimyimana, 2010)

Figure 2.2 shows rainfall recorded at different sampling stations during January and June-July 2009 and January 2010 in millimeters of rain while Figure 2.3 shows the amount of rainfall in January 2009. Rainfall during January 2009 was measured only at the KC2 (Pang-Siang 1) monitoring station since that was the only station in operation at that time whereas by June-July 2009 and January 2010, KC1, KC2 (Pang Siang, Pang Siang-1), KC3, KC4 (Tengah), KC6 (Kangkar), and KC7 (Pang Sua-2) stations went into operation and rainfall could therefore be measured (Nshimyimana, 2010). Rainfall was recorded at five-minute intervals throughout the year in units of millimeters. Flow velocity in meters per second and water surface levels in meters were also recorded by loggers in adjacent drainage channels.

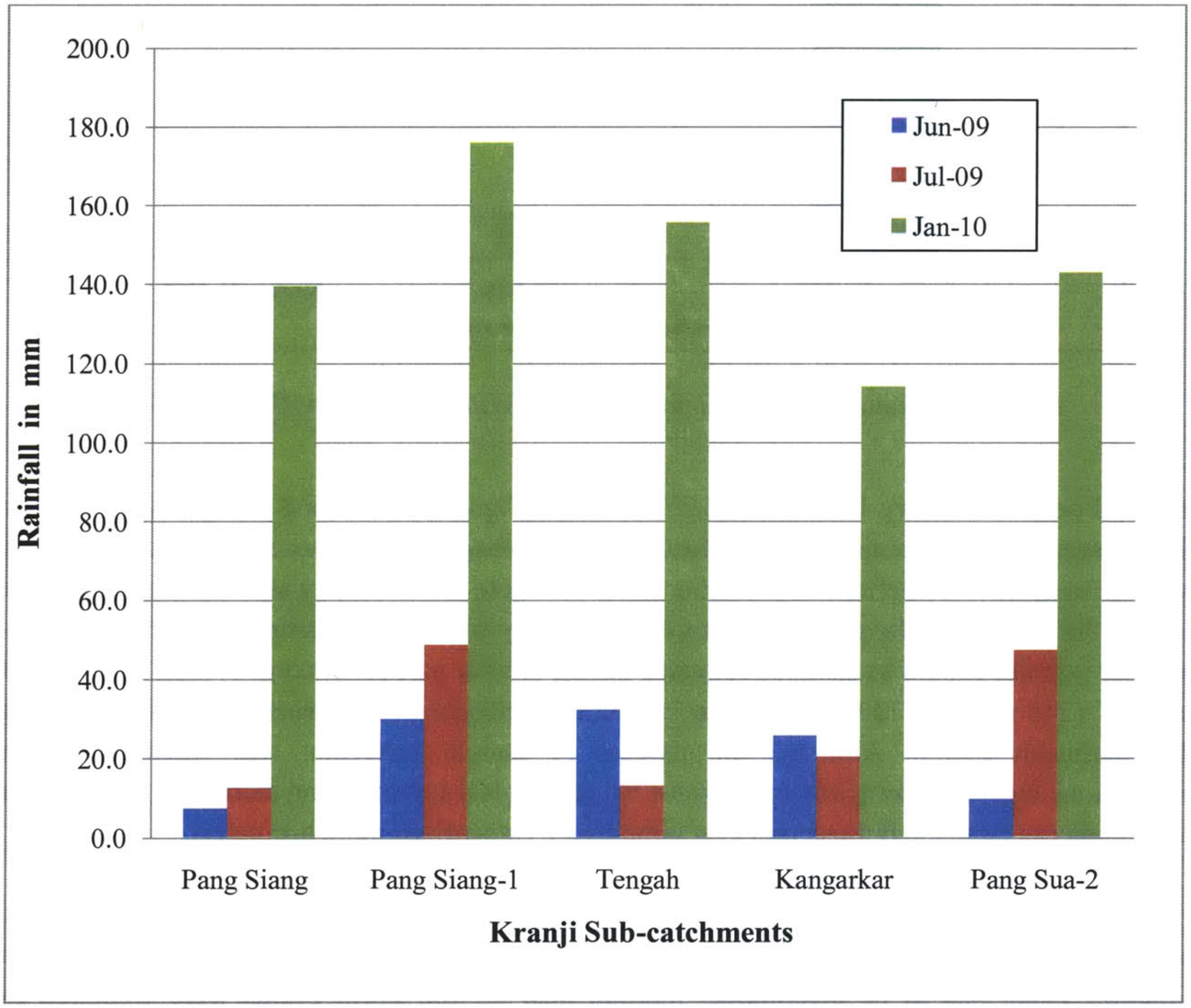


Figure 2.2: January 2009, June-July 2009, and January 2010 Rainfall (mm) for various Sub-catchments within Kranji (NTU, 2010) (NR = not recorded)

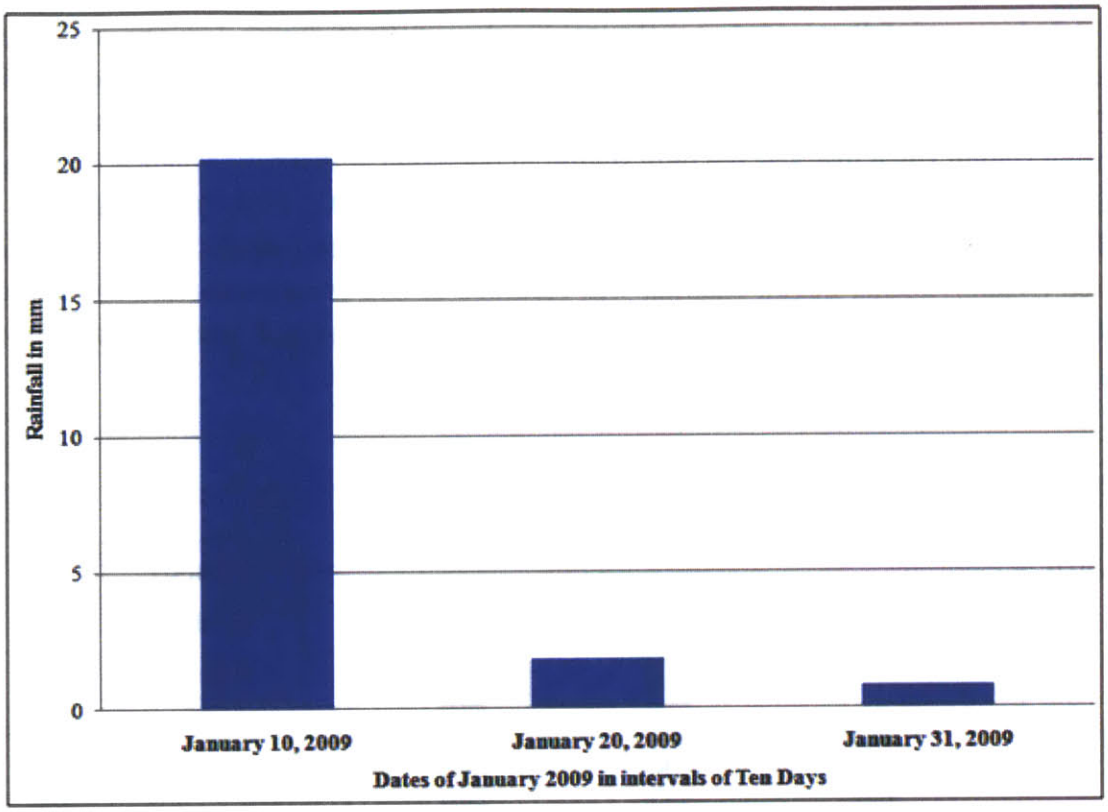


Figure 2.3: *January 2009 Rainfall (mm) for Kranji Catchment (NTU, 2009)*

It rained only on January 10th, 20th and 31st in 2009 (Figure 2.3) at Pang Siang-1 and based on field observations, no samples were collected at Pang Siang-1 during those dates. Hence, the dry weather samples were definite dry weather samples. There is uncertainty as to whether or not the June to July 2009 and January 2010 samples were truly wet weather samples. In actuality, wet-weather samples should be samples collected during or after particular storm events. Using "total rainfall" (248 mm and 729 mm) was an inaccurate representation of weather conditions during that particular month. Although the process of sample collection was extensive, better conclusions regarding comparisons between bacteriological levels during storm and dry weather conditions can be made if those previous samples are categorized more accurately.

Hence, this study firstly aims to reclassify the wet- and dry-weather bacterial samples presented by Nshimyimana (2010). In order to reclassify the samples, rainfall intensities and discharge per sampling event had to be determined. Rainfall data for the storm events were compiled by SysEng (S) Pte. Ltd. and Greenspan Pte. Ltd. which are both based in Singapore. Rainfall intensity in millimeters is continuously being recorded at different rain gauging stations (represented by the red circles and black crosses in Figure 2.4) located in Kranji Catchment in Singapore. The rain amount is recorded at 1-minute, 5-minute and 10-minute intervals. Discharges during storm events were obtained from measurements recorded in the field and the peak flow was identified for each sampling event (i.e. from flow values from start of sampling to end of sampling only). Windows Technical Release 55 (WinTR-55) was used to find peak discharges at stations at which field measurements were not available. The methodology for this determination is described in Chapter 5.

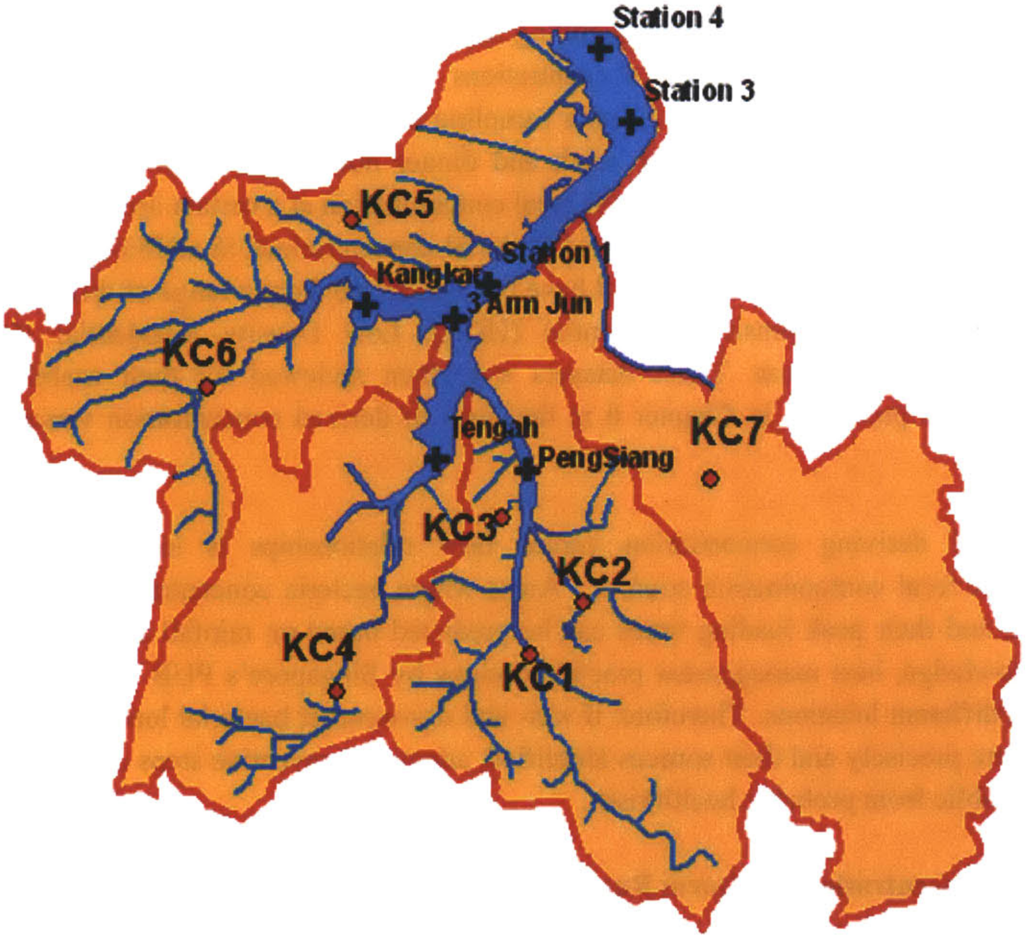


Figure 2.4: NTU Catchment and Reservoir Gauging Stations (NTU, 2008)

2.1.2 Identifying Bacteriological Levels in Storm Runoff

This study secondly intends to identify typical bacteriological levels in storm runoff in Kranji Catchment and in the commercial section of Marina Catchment for different land uses based on analysis of sampling data collected from 2006 to 2011. Both wet- and dry-weather bacterial concentrations were compiled from previous and current studies conducted by students from the Massachusetts Institute of Technology (MIT) and Nanyang Technological University (NTU). Specifically, information was gathered from the final project report *Water Quality Monitoring, Modelling and Management for Kranji Catchment/Reservoir System – Phases 1 and 2* submitted by the Division of Environmental and Water Resources Engineering of the School of Civil and

Environmental Engineering at NTU to PUB (NTU, 2008), *Bacteriological Studies for Kranji Catchment* by Lee Li Jun of NTU (Lee, 2009), *Evaluating Human Fecal Contamination Sources in Kranji Reservoir Catchment, Singapore* by Jean Pierre Nshimyimana of MIT (Nshimyimana, 2010), and data collected in January 2011 at Choa Chu Kang Crescent, Verde, and Bras Basah. Chapter 3 discusses the datasets for wet- and dry-weather sampling events from 2005 to 2010.

The objective of the wet- and dry-weather sampling conducted in 2011 (described in Chapter 4) was to obtain 12-hour series of bacterial concentrations from selected land use types draining into Kranji and Marina Reservoirs. This 12-hour sampling captured the fluxes of bacteria due to human activities such as cooking during lunch and dinner hours, as well as laundry in the mornings. It provides a better representation of fecal contamination at a certain area compared to results from grab sampling. This new dataset of bacterial concentrations in addition to previous years' datasets of bacterial concentrations will have been collected from a range of different land use types including High Density Residential (HDR), Low Density Residential (LDR), Commercial, and Forested areas. Those datasets were then reviewed for their usability for analysis. Results are presented in Chapter 6 in the form of derived concentration versus flow relationships.

The objective of deriving concentration versus flow relationships is to provide better representation of fecal contamination sources. Areas where bacteria concentrations are higher can be located and their peak loading times can be predicted based on rainfall and flow levels. With such knowledge, best management practice designs by Singapore's PUB could be better catered to suit different locations. Therefore, if wet- and dry-weather bacterial loadings could be reclassified more precisely and their sources identified, adequate preventive steps could be taken to protect the public from probable health risks.

2.2 Bacterial Concentrations in Storm Runoff

This section was written in collaboration with Yangyue Zhang.

Previous studies have shown elevated indicator bacteria concentrations in storm runoff from urban areas and in streams. Based on microbial analysis, Overcash and Davidson (1980) found that densities of indicator microorganisms in storm runoff were usually tenfold higher than densities in urban streams and were close to densities found in raw sewage. There is proof of increased health effects to individuals swimming near storm-water outfalls in Santa Monica Bay, California, and of elevated indicator bacteria concentrations in shellfish waters after storm events (Hathaway *et al.*, 2010). Infections of the skin, eyes, ears, nose, and throat may result from contact with the water during such recreational activities as bathing, water skiing, boating, and fishing (Thomann and Mueller, 1987). This is because common modes of transmission of pathogens are through ingestion of contaminated water and food, and exposure to infected persons or animals. In the event that the runoff is redistributed to surface waters in use by the public as could be done at Kranji and Marina Reservoirs, health risks to the public have to be taken into consideration. Reservoirs may be closed permanently or intermittently during rainfall conditions when high concentrations of pathogenic bacteria are discharged from urban runoff and combined sewer overflows.

It is therefore important to identify concentration levels of bacteria being discharged into receiving waters. Measurement approaches for bacteria in water include analysis for (a) indicator bacterial groups that reflect the potential presence of pathogens, (b) the pathogenic bacteria directly, (c) viruses, and (d) intestinal parasites. Of these, indicator bacteria are the most commonly used and are discussed further in Section 2.3.

2.3 Indicator Microorganisms

This section was written in collaboration with Yangyue Zhang.

Indicator microorganisms are used to indicate the presence of pathogenic microorganisms or fecal contamination. The ideal indicator organism can be described as (1) being usable for different types of water sample environments but has no elevated growth rates whilst in water, (2) being present whenever pathogens are present and therefore have densities with direct relationships to degree of fecal pollution, (3) having survival times that are reasonably longer than the survival times of pathogens being detected, and (4) being commonly found in the intestines of warm-blooded animals (Maier *et al.*, 2009). Indicator microorganisms are not necessarily pathogenic but are found more often than not in parallel quantities to the amount of fecal contamination (which contains pathogenic microorganisms) due to their presence in the intestines and therefore feces of mammals.

While the use of bacterial indictors to measure water quality is widespread, no universal agreement exists to indicate the most favorable indicator microorganism to be used. Presently, the most commonly measured bacterial indicators include total coliforms and *E. coli*. Total coliforms were first to be used in studies with a threshold of 2,300 CFU/100mL as an indicator for detectable swimming-associated health effects based on observations in an epidemiology study conducted by the United States Public Health Service (Dufour, 2001 as cited by Noble *et al.*, 2003). Following the use of total coliforms, *E. coli* (a subset of the fecal coliform group) was established as the preferred indicator and its threshold was based on a series of epidemiological studies carried out in sewage-impacted recreational waters (Cabelli *et al.*, 1982; Dufour, 1984). These studies demonstrated that that the concentration of *E. coli* correlated better with water-contact-related illnesses in comparison with total coliforms. *E. coli* is a good indicator in fresh water and is generally absent in unpolluted waters. More recently, enterococci has been introduced as another indicator of fecal contamination. Enterococci is more persistent in water and sediments compared to coliforms (Sobsey, 2007).

However, the applicability of *E. coli* as an indicator organism in tropical climates has been doubted (Lopez-Torres, 1987; Hazen, 1988) due to its growth in soils and waters in such climates, and its poor survival in high salinity water, which might give low predictability of health risks (Sobsey, 2007). Singapore is a tropical country with abundant rainfall throughout the year. Hence, the efficiency of using *E. coli* as an indicator in this region might decrease.

In August 2008, Singapore's National Environment Agency (NEA) adopted new water quality guidelines for recreational water based on studies dating back to 2005 conducted by members of NEA, PUB, the National Water Agency, National University of Singapore, and NTU. These new guidelines apply to whole-body water contact activities which are also known as primary contact activities. Enterococcus was stated to be the better indicator of gastrointestinal and respiratory illnesses but *E. coli* is still used alongside as a water quality indicator in most bacterial studies in Singapore (Dixon *et al.*, 2009; Kerigan and Yeager 2009; Granger 2010; Nshimyimana 2010) since there is no adequate amount of evidence to show that E. coli has failed to identify the sources of fecal contamination. The 2008 NEA guidelines state that for recreational and fresh water bodies, Enterococcus counts should be less than or equal to 200 CFU/100mL water 95% of the time (NEA, 2008). The USEPA guidelines state 126 CFU/100mL for *E. coli* concentrations and 33 CFU/100mL for enterococci (USEPA, 2003).

2.4 Point and Nonpoint Sources of Bacterial Loading

Bacterial pollution stems from two main groups; natural and man-made (Novotny and Chesters, 1981). These can be further categorized into point sources or nonpoint (diffuse) sources. Point source pollution enters water bodies via identifiable locations and are easily measured or quantified. Their impact can usually be evaluated directly. Major sources include effluent from solid waste disposal sites, sewage treatment plants (STPs), or industrial sources. The flow of point sources into surface water is steady, with relatively constant quality in which variability ranges less than one order of magnitude. Point sources cause higher impact during dry (low-flow) periods. Other parameters of interest besides bacterial loadings associated with point sources include biological oxygen demand (BOD), dissolved oxygen (DO) content, nutrients, and suspended solids.

Nonpoint source pollution usually enters surface waters due to meteorological events (Novotny and Chesters, 1981). Their exact source is hard to identify as the pollution accumulates over a large land area and is later transported overland before being discharged into surface waters. Flow of nonpoint sources is highly dynamic in random intermittent intervals with variability ranging at several orders of magnitude. Nonpoint sources cause most severe impacts during or following storm events. Examples of nonpoint sources include land erosion, residues from agricultural chemicals, or weathering of minerals. Their loading to surface water is a response of drainage area to a storm event which usually has limited duration; from a fraction of an hour to two days. The magnitude of nonpoint sources depends on rain volume, intensity, quality, duration of previous dry period and others. Parameters of interest besides bacterial loadings include amount of sediments, nutrients, toxic substances, DO concentrations and pH.

2.5 Defining a Storm Event

According to Hathaway *et al.* (2010), a storm event is defined as "any rainfall event which produces runoff in excess of base flow." Base flow or base runoff is defined by the United States Geological Survey (USGS) as sustained or fair weather runoff, composed largely of groundwater effluent (Langbein and Iseri, 2008). Stream flows mostly consist of both groundwater discharge and land surface runoff (Schilling, 2010). Direct runoff and base runoff recede at different rates. Direct runoff recession curves and base runoff recession curves are usually drawn to aid in depicting the decreasing rate of runoff following a period of rain. For the purpose of this study, samples collected in January of 2011 are considered storm samples if collected during rainfall based on field observations. For samples collected in previous years, rainfall and discharge values are obtained and are plotted with concentration as a secondary y axis against time, to find an indication of where the samples lie during the storm.

Chapter 3: Previous Wet and Dry Weather Sampling Events

Total coliform, *E. coli*, and enterococci bacteria samples had been collected during both storm and dry weather in prior studies. Samples were collected in 2005 and 2006 using an autosampler by a team formed by the Division of Environmental and Water Resources Engineering at NTU (NTU, 2008). Lee Li Jun from the School of Civil and Environmental Engineering at NTU carried out 18-hour sampling events in January and February of 2009 (Lee, 2009). Lastly, Jean Pierre Nshimyimana from the Massachusetts Institute of Technology collected grab samples during the months of January 2009 and June and July 2009 (Nshimyimana, 2010). Another team of MIT students collected grab samples in January of 2010 (Foley *et al.*, 2010).

The rainfall amount over time, time of sample collection, and discharge at the point of sampling for each sampling event was reviewed to identify the usability of each dataset for the analysis of wet and dry-weather bacterial concentrations. The dataset was considered usable if the following were available: (1) the 24-hour rainfall amount over time at regular time intervals at the sampling location, and/or (2) gauging record of the 24-hour discharge at the point of sampling, and most importantly (3) the time at which samples were collected. These parameters were required so that distributions of concentration and rainfall or discharge over time and of concentration versus discharge could be plotted in order to identify typical bacteriological levels in storm runoff in Kranji Catchment and parts of Marina Catchment in addition to reclassifying Nshimyimana's (2010) previous wet- and dry-weather bacteria samples.

3.1 November 2005 to February 2006 Sampling

Storm runoff was sampled under the Phase I and II Water Quality Monitoring, Modeling and Management for Kranji Catchment/Reservoir System Project by the Division of Environmental and Water Resources Engineering at NTU for PUB (NTU, 2008). Samples were collected at KC1 (Bricklands Road) and KC2 (Choa Chu Kang Walk) using ISCO 6712 autosamplers during the months of June 2005 to November 2006 and October 2006 to August 2007 respectively. The autosamplers were set to be triggered when water levels in the drains rose to above base flow and collected 24 one-liter samples at a time interval of 10 minutes. Rainfall, water flow levels, and water velocity were logged at 5-minute intervals. The samples were analyzed for *E. coli* and enterococci concentrations and results are shown in Table 3.1 and Table 3.2 below.

Table 3.1: E. coli Density (MPN/100ml) for Gauging Stations KC1 and KC2

	Bottle Analyzed							
KC1	#3	#6	#9	#12	#15	#18	#21	#24
Time Sampled	4:55:00 AM	5:25:00 AM	5:55:00 AM	6:25:00 AM	6:55:00 AM	7:25:00 AM	7:55:00 AM	8:25:00 AM
23-Nov-05	64,900	68,700	38,700	64,900	41,000	>242,000	43,500	17,300
Time Sampled	-	-	-	-	-	-	-	-
18-Jan-06	4,500	5,500	5,800	4,400	5,300	2,400	4,100	7,900
KC2	#1	#4	#7	#10	#13	#16	#19	#22
Time Sampled	-	-	-	-	-	-	-	-
10-Dec-05	3,100	1,300	4,200	3,900	3,900	1,500	850	4,500
Time Sampled	-	-	-	-	-	-	-	-
25-Feb-06	740	3,600	2,500	2,700	4,600	7,900	16,700	7,500

Table 3.2: Enterococci Density (MPN/100ml) for Gauging Stations KC1 and KC2

	Bottle Analyzed							
KC1	#3	#6	#9	#12	#15	#18	#21	#24
Time Sampled	4:55:00 AM	5:25:00 AM	5:55:00 AM	6:25:00 AM	6:55:00 AM	7:25:00 AM	7:55:00 AM	8:25:00 AM
23-Nov-05	45690	34410	24810	27230	16070	19890	10390	6630
Time Sampled	-	-	-	-	-	-	-	-
18-Jan-06	4780	7820	5200	6050	4570	3450	4410	7890
KC2	#3	#6	#9	#12	#15	#18	#21	#24
Time Sampled	-	-	-	-	-	-	-	-
10-Dec-05	>24196	>24196	>241960	141360	>24196	>24196	>241960	>241960
Time Sampled	-	-	-	-	-	-	-	-
25-Feb-06	32700	5200	12200	28500	18900	20900	14600	12000

Unfortunately, time-of-sampling information for the 10th of December 2005, 18th of January 2006, and 25th of February 2006 was not provided by the contractor hired for the work. Therefore in the future, if sampling times could be obtained for the other events in this series, further analysis on wet- and dry-weather bacterial concentrations could be carried out since this series of data collected via autosampler shows a good distribution of bacterial loadings over time. Dry weather sampling data were available (Table D-1 and D-2 in Appendix D) from this series of sampling but unfortunately without the sample collection times, the *E. coli* and enterococci concentrations could not be included in this analysis.

3.2 January & February 2009 18-Hour Water Sampling

Lee Li Jun (2009) collected first-flush storm-event samples at CP2 with the Isco 6712 Full-size Portable Autosampler (Teledyne Isco, Inc., Lincoln, NB) set to collect at 10-minute intervals and triggered to start collecting samples when water levels rose above 0.25 m. CP2 covers Peng Siang sub-catchment and is located at Choa Chu Kang Walk. The Peng Siang sub-catchment covers an area of 1300 ha and is 62% undeveloped area, 32% residential area, and 6% agricultural area. Lee chose the site because previous studies (Tay *et al.*, 2008) had shown that CP2 had the highest bacteria level count. Analysis of samples collected during dry weather shows both *E. coli* and enterococci bacterial concentration peaks at around 12:00 pm whereas results from the wet weather samples showed first-flush effects and higher total coliform and *E. coli* concentrations. Lee also concluded that this meant nonpoint source pollution was of importance at KC2.

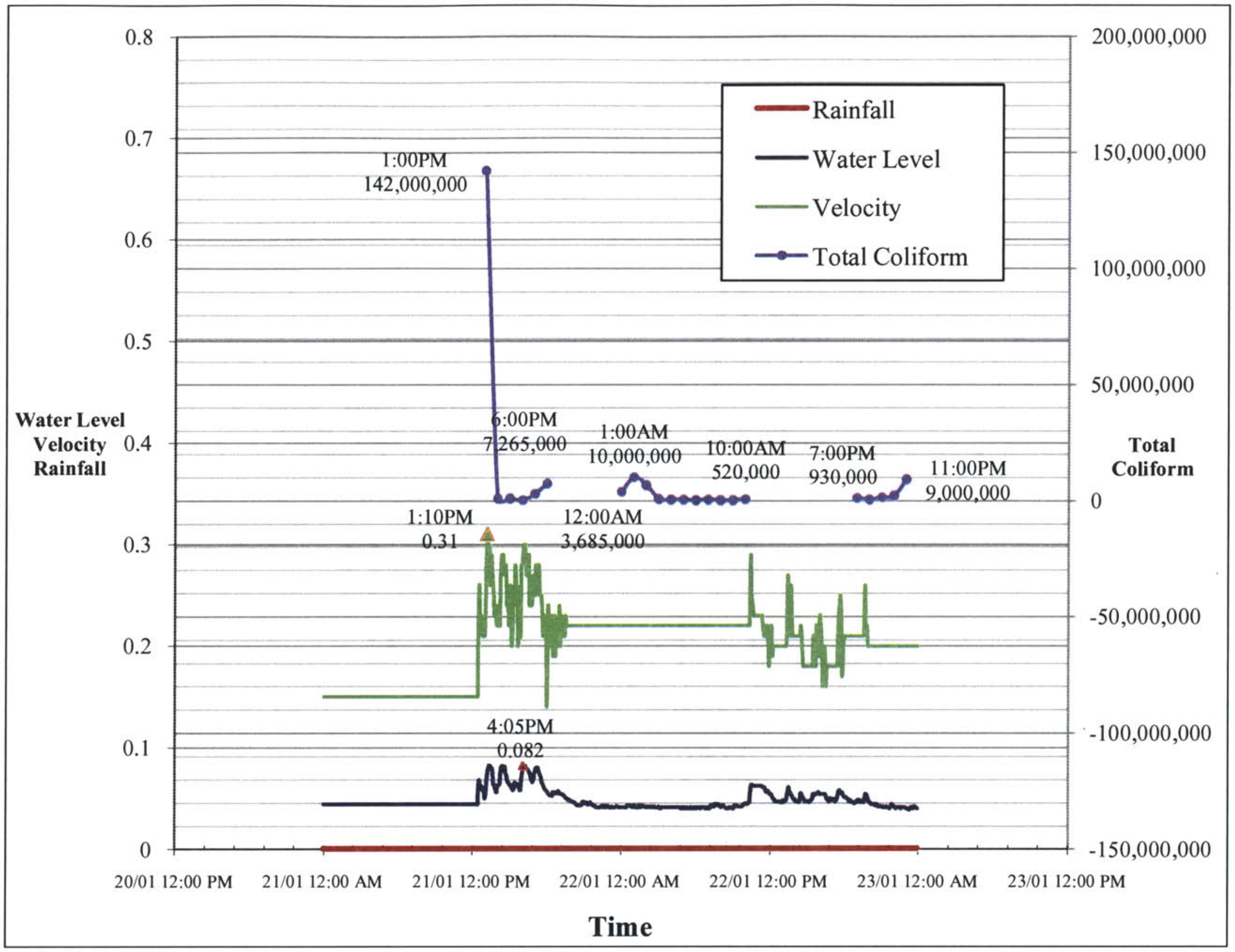


Figure 3.1: Averaged Total Coliform for 18 hour Dry Weather Sampling during 21 & 22 Jan 2009 (Lee, 2009)

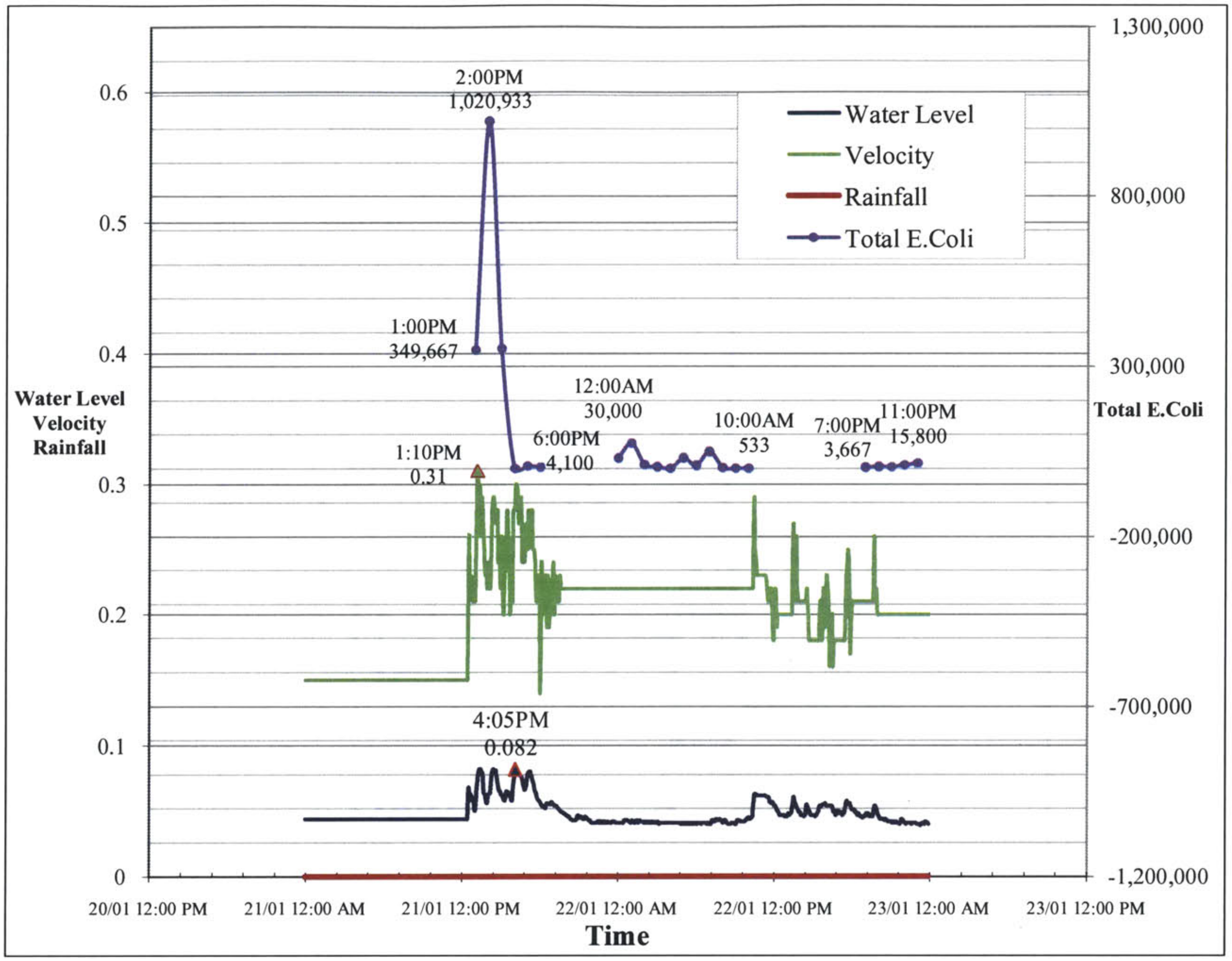


Figure 3.2: Averaged E. coli for 18 hour Dry Weather Sampling during 21 & 22 Jan 2009 (Lee, 2009)

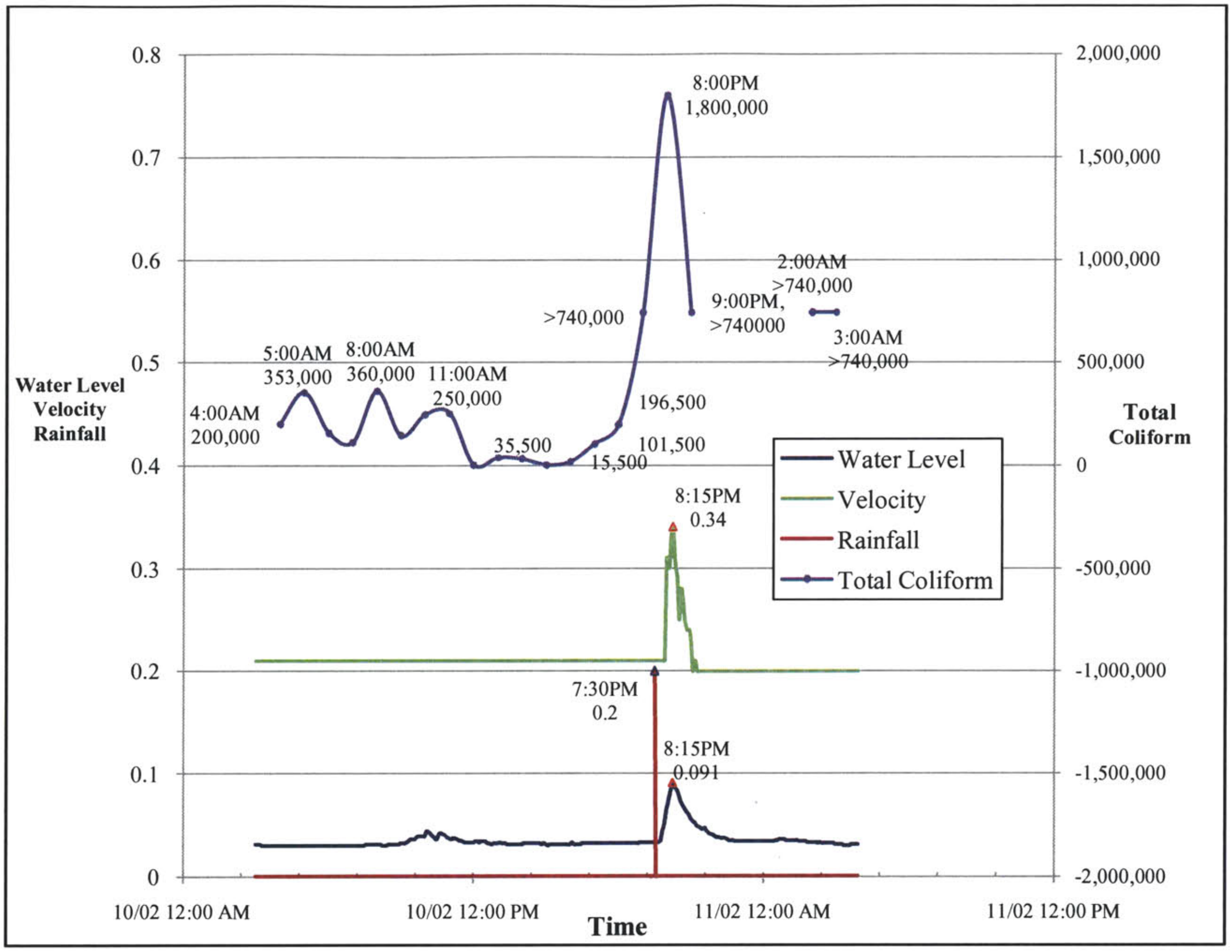


Figure 3.3: Averaged Total Coliform for 18 hour Wet Weather Sampling during 10 & 11 Feb 2009 (Lee, 2009)

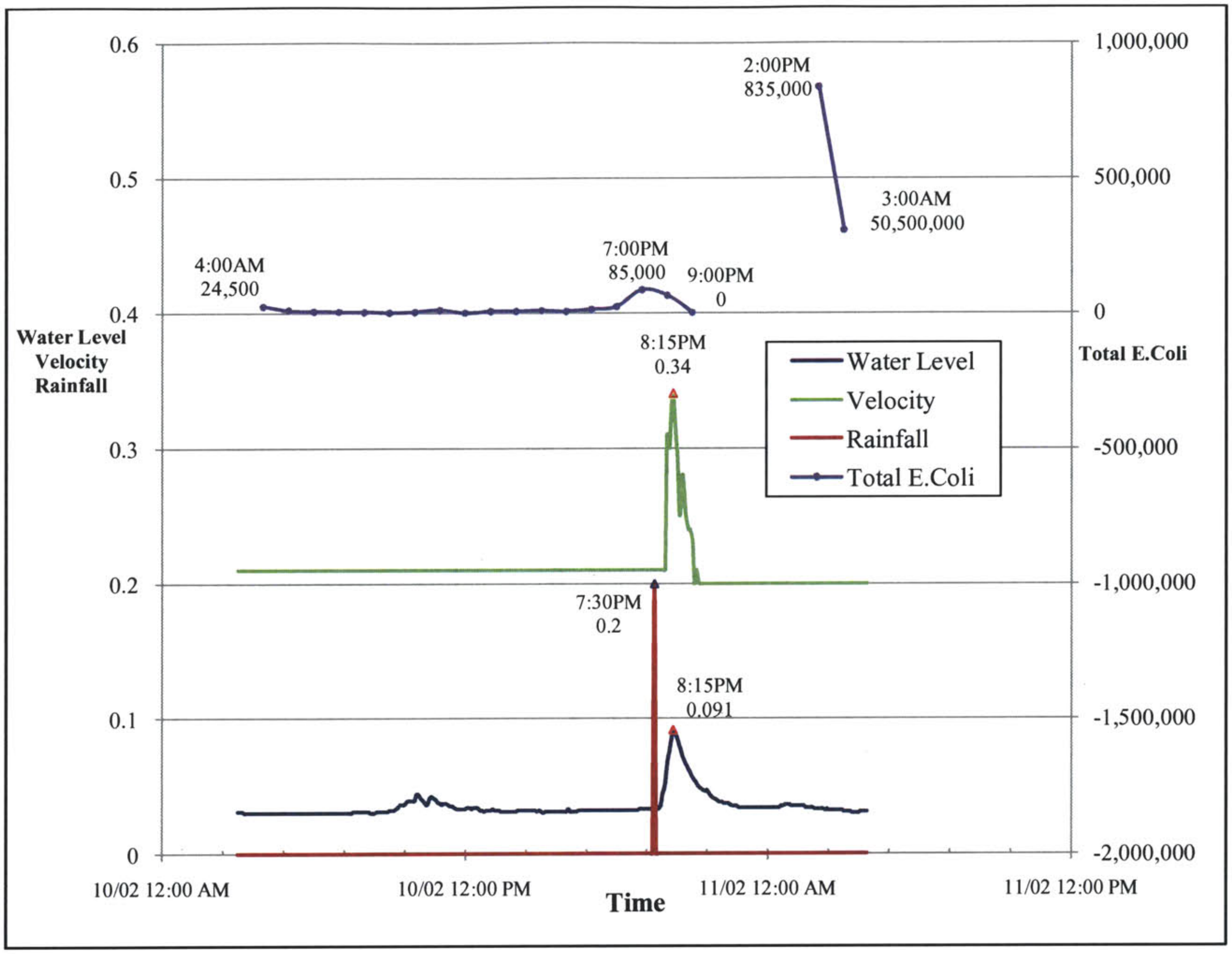


Figure 3.4: Averaged E. coli for 18 hour Wet Weather Sampling during 10 & 11 Feb 2009 (Lee, 2009)

3.3 July 2009 Grab Sampling

Grab samples were collected by Jean Pierre Nshimyimana in July of 2009 (Nshimyimana, 2010). Runoff samples were collected on 7th and 9th of July 2009 from KC7, 15th of July 2009 at KC1, KC2, KC3, KC5 and KC6, and 22nd of July 2009 from KC6. During the 2009 samplings, new name codes were given to the sampling locations within the sub-catchments. The new labels are shown in Table 3.3. Bacterial concentrations were obtained from Jean Pierre and from Eveline Ekklesia. Rainfall data from KC1, KC2, KC6 and KC7 was obtained from databases provided by SysEng (S) Pte. Ltd. and Greenspan Pte. Ltd.. Although bacterial concentration data were available for KC3 and KC5, rainfall data was not available as NTU did not have permission from PUB to access the monitoring stations. Hence, those concentration values were not taken into account for this report.

Table 3.3: New Names for 2009 Sampling

Sub-catchment	2008 NTU Sites	2009 Sampling Locations
Peng Siang	KC1	PB01
Peng Siang	KC2	PS01
Tengah	KC3	TH01
Neo Tiew	KC5	NT01, NT02
Kangkar	KC6	KK01,KK05, KK06
Pang Sua	KC7	PU02, PU03, PU04, PU05, PU06, PU07, PU09, PU09, PU10, PU11

Nshimyimana's raw data for January, June-July 2009 and January 2010 from his *Kranji Catchment Singapore Field Data Sheet* was acquired and reviewed. Samples collected in January 2009 were confirmed to be dry-weather samples because all of them were collected outside of storm events. Sampling events in July 2009 were highlighted and reevaluated to ascertain if they fell into the storm sampling category based on field observations written in the notes and also on rainfall data. Several of the sampling events were carried out during rainfall events and others were collected before, after, or close to rainfall events. Unfortunately, sampling times for June 2009 and January 2010 samples were not available in the field data sheet. Hence, those sets of bacterial samples could not be evaluated. Figures 3.5 to 3.10 show the sampling events which were possible wet-weather data.

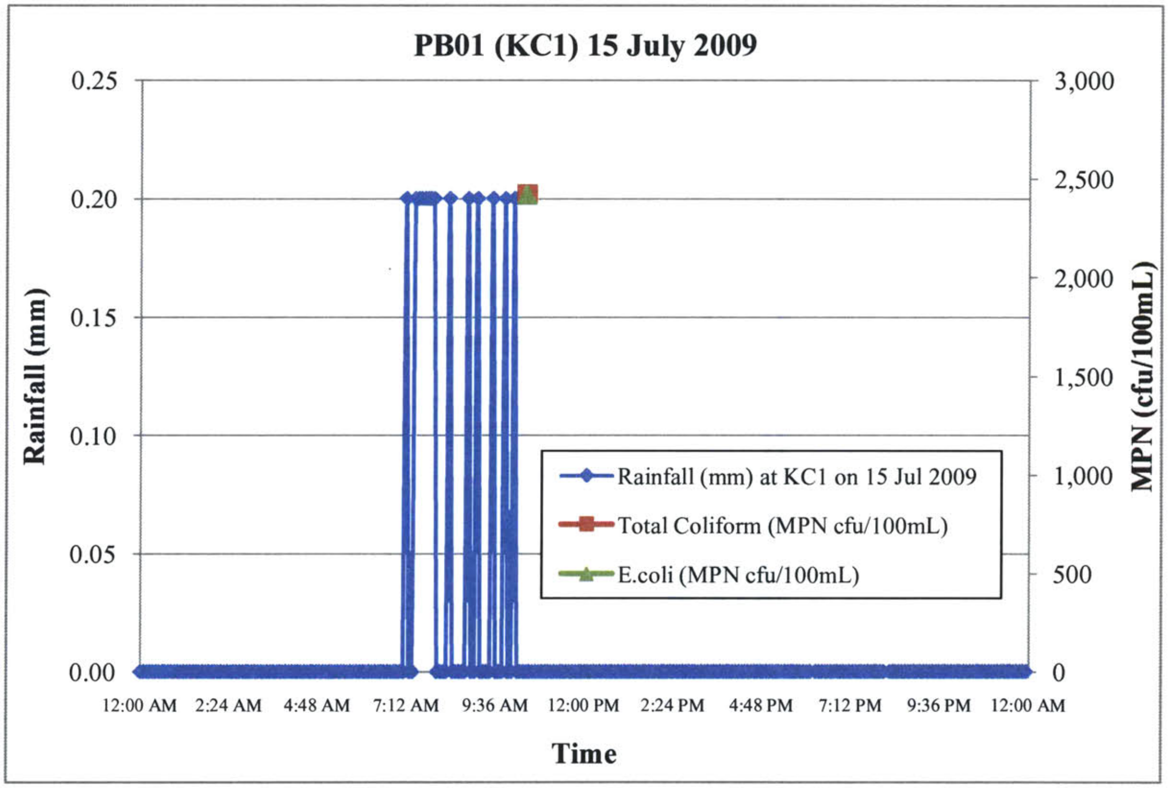


Figure 3.5: 15th July 2009 Sampling Event at PB01 (KC1)

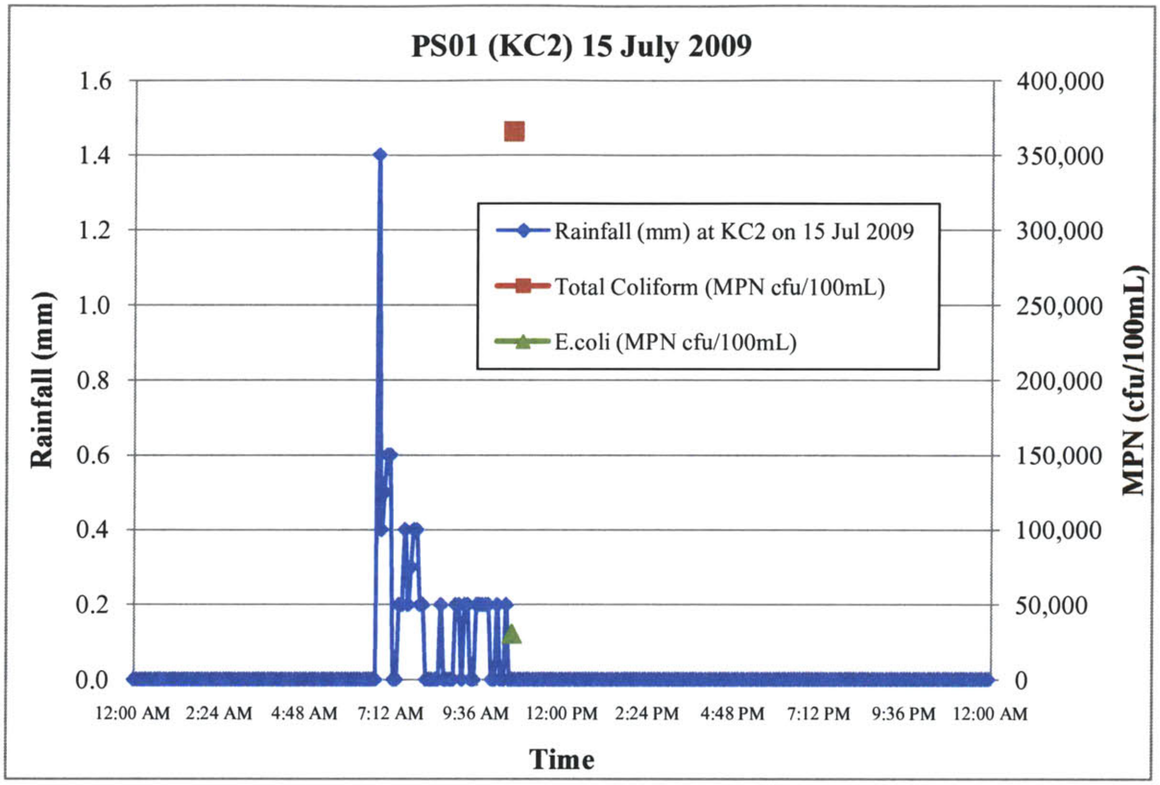


Figure 3.6: 15th July 2009 Sampling Event at PS01 (KC2)

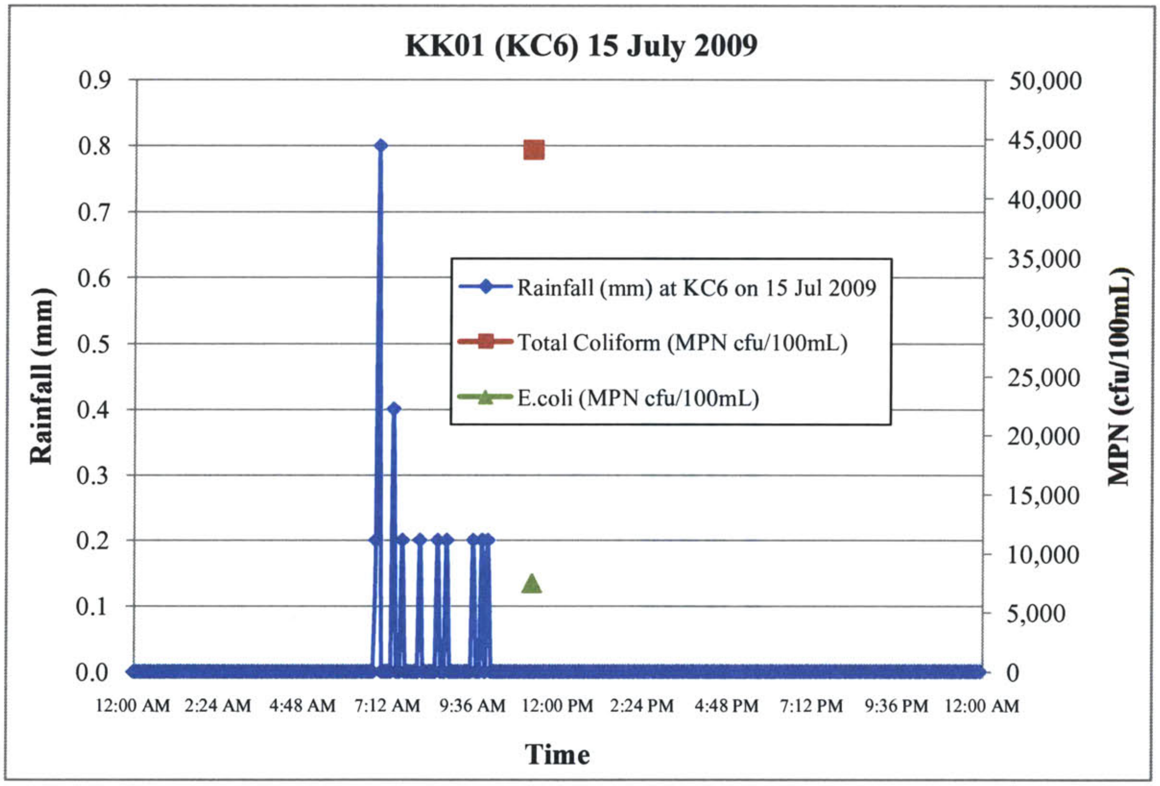


Figure 3.7: 15th July 2009 Sampling Event at KK01 (KC6)

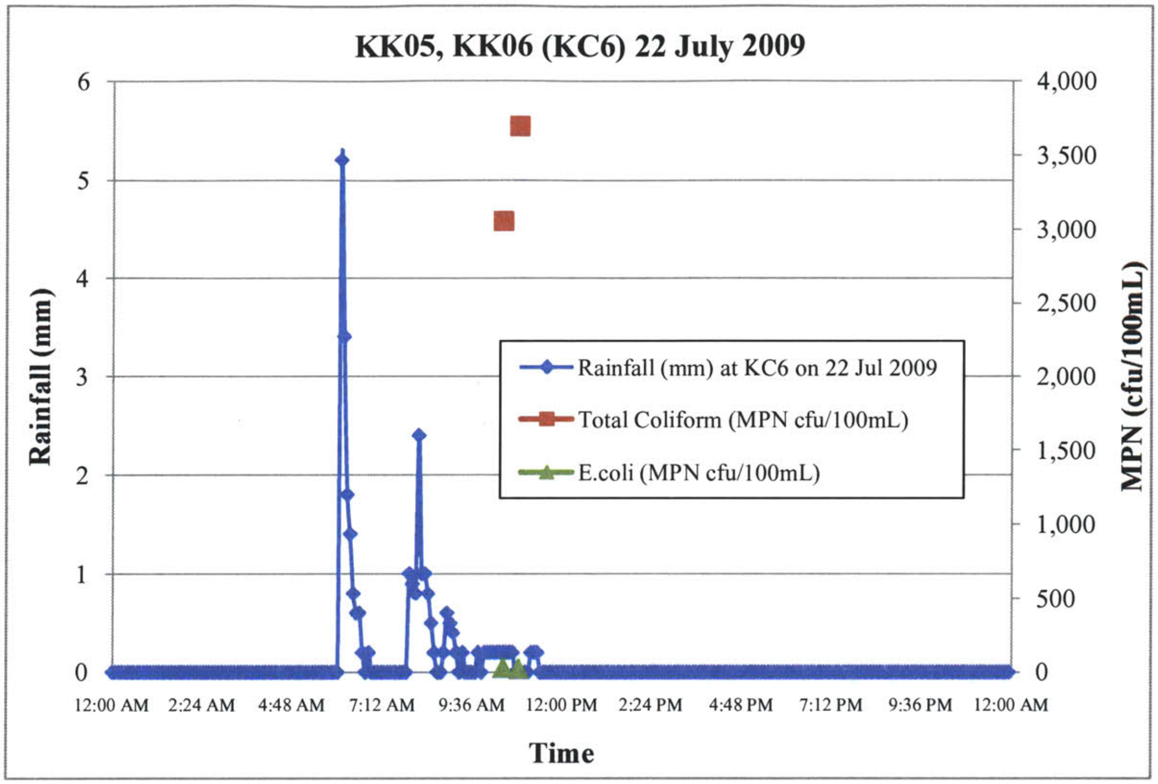


Figure 3.8: 22nd July 2009 Sampling Event at KK05 and KK06 (KC6)

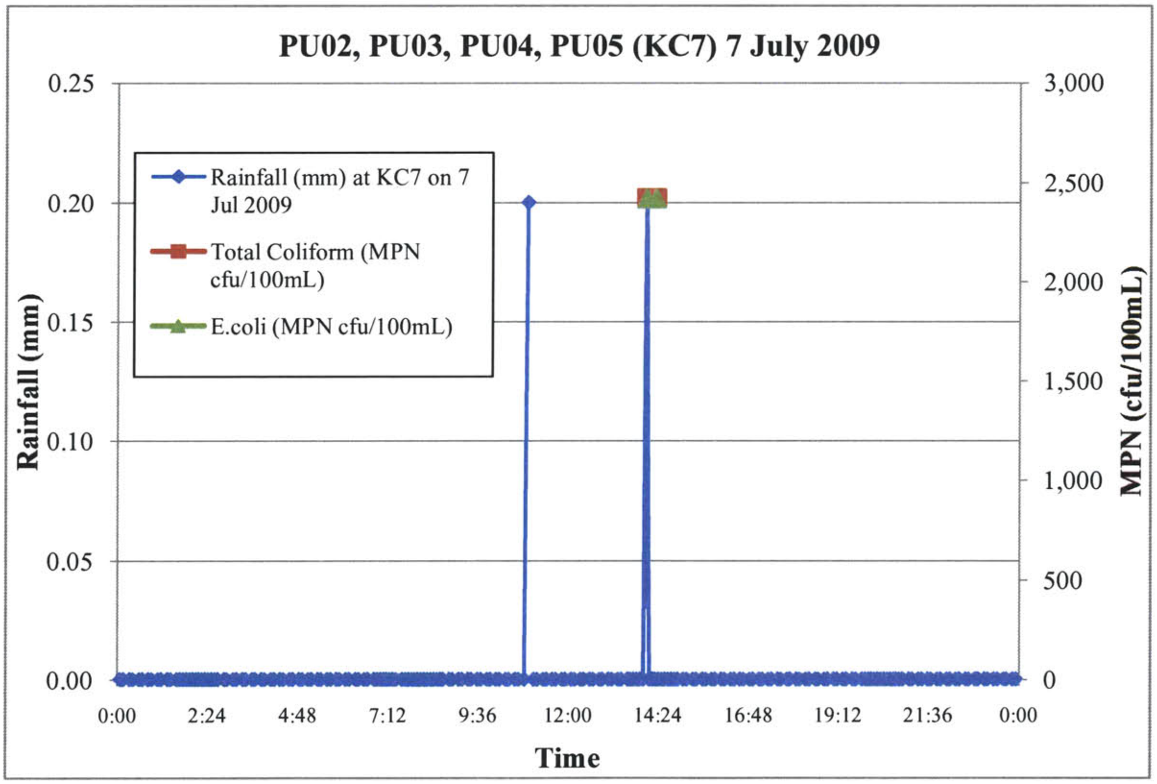


Figure 3.9: 7th July 2009 Sampling Event at PU02, PU03, PU04, PU05 (KC7)

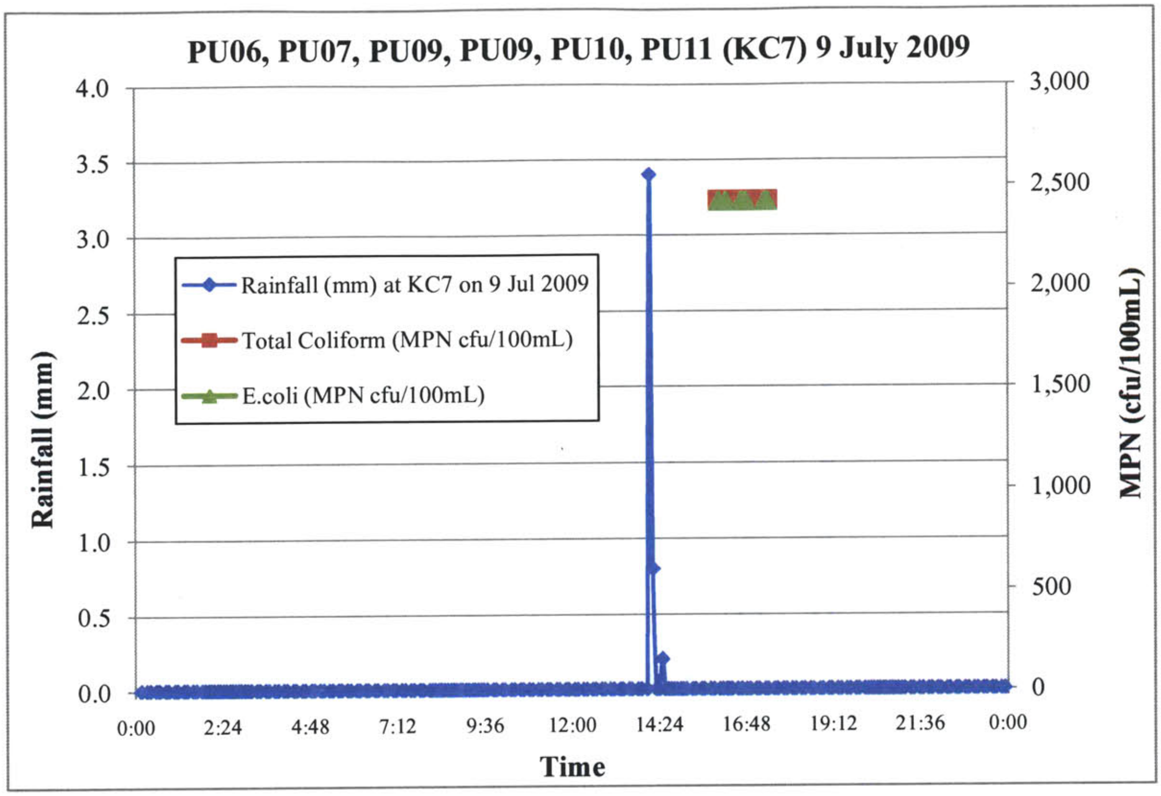


Figure 3.10: 9th July 2009 Sampling Event at PU06, PU07, PU09, PU10, PU11 (KC7)

Chapter 4: January 2011 Field Work

January 2011 field work was planned by Eveline Ekklesia and carried out by Ryan Bossis, Genevieve Ho, and Yangyue Zhang. Three sampling locations were pre-selected for the field work. Manual sampling by the students took place from 4th January 2011 to 18th January 2011 and lasted from 8:00 am to 7:00 pm whereas an autosampler was configured to detect discharge levels and automatically start collecting samples during the storm event on 8th February 2011.

4.1 Sampling Locations

Sampling locations were selected by Eveline Ekklesia. They were selected to be representative of high-density residential (HDR) areas, also known as Housing Development Board (HDB) areas, low-density residential (LDR) areas, and commercial areas. Factors considered when choosing the sites included total area covered, percentage of land usage being represented, and dry weather flow level to meet sample volume requirements.

The first selected site was Choa Chu Kang (CCK) Crescent (N 1°24'4.8" E 103°45'34.2") which is the outlet point for drainage from an overall area of 37 hectares, and is 84% HDR (Figure 4.1). The name code for CCK Crescent was KC whereby K stood for Kranji and C stood for CCK Crescent. HDR areas at CCK Crescent consisted of high-rise flats and several grocery stores. The specific sampling site was a covered drain that flowed into the canal and is shown in Figure 4.2.

The second site was Verde (N 1°23'29.9" E 103°45'9.7"), shown in Figures 4.3 and 4.4, which drains an overall area of approximately 7 hectares and is 76% LDR. The name code for Verde samples was KV. Verde's neighborhood consisted of landed houses such as terrace houses and semi-detached houses. The sampling site was the outlet point of drainage discharging into the same canal as CCK Crescent.

The last site (Figures 4.5 through 4.7) was Bras Basah (N 1°18'13", E 103°51'12") which drains an area of 16 hectares and is 65% commercial area. More specifically, the location was surrounded by Hindu and Buddhist temples, an art gallery, a shopping complex, several eateries, office buildings, parking garages, and hotels. Bras Basah is located at Singapore's Historic District and is also densely populated. Bras Basah samples were coded MB, with M standing for the Marina Catchment.

CCK Crescent and Verde are both in Kranji Catchment and are within the catchment drained by gauging station KC7 whereas Bras Basah is located in Marina Catchment and is in the area tributary to gauging station MC11.

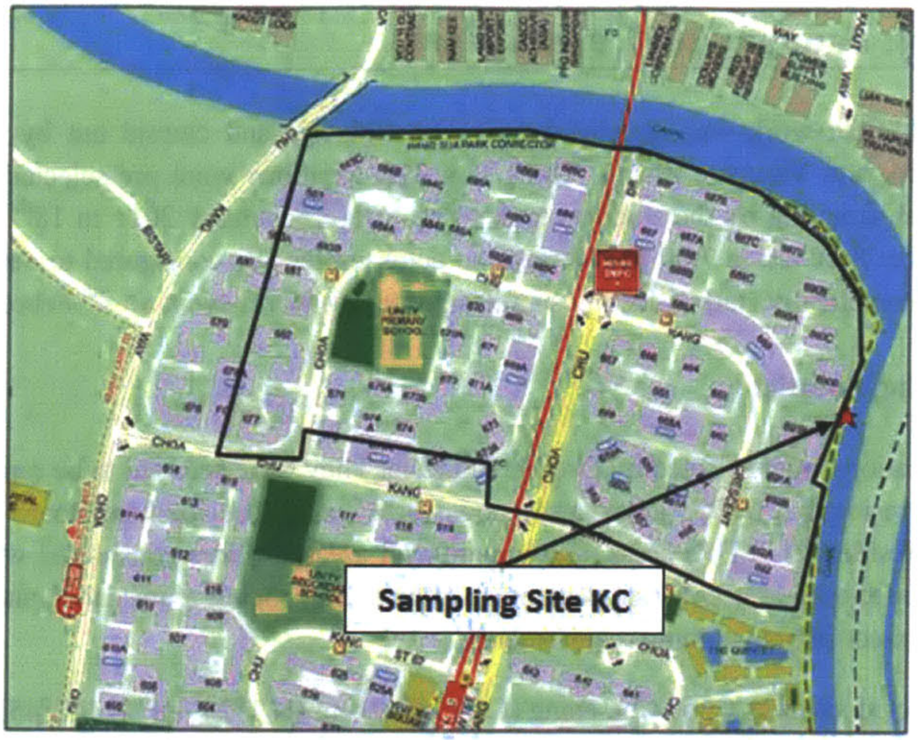


Figure 4.1: Catchment Area of Choa Chu Kang Crescent (Streetdirectory, 2010)

Figure 4.2: Author Conducting Field Sampling and View of High Density Residential Properties at Choa Chu Kang Crescent (Photographs by Eveline Ekklesia and Ryan Bossis)

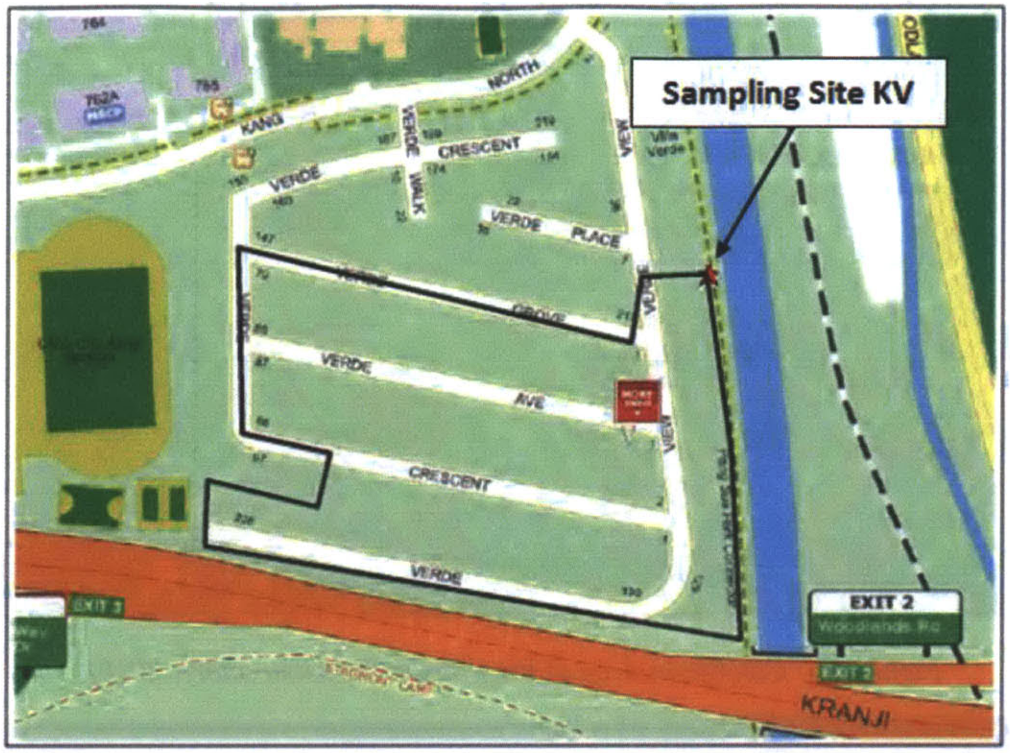


Figure 4.3: Catchment Area of Verde (Streetdirectory, 2010)

Figure 4.4: MIT Student Conducting Field Sampling and Image of Low Density Residential Properties at Verde (Photographs by Eveline Ekklesia and Ryan Bossis)

Figure 4.5: Catchment Area of Bras Basah (Streetdirectory, 2010)

Figure 4.6: NTU and MIT Students Sampling at Bras Basah and Drain Sampled

Figure 4.7: Bras Basah Commercial Area

4.2 Collection of Dry Weather Samples

Dry weather samples were collected every hour on site. Samples were collected using an adjustable Nasco Sampling Pole for Whirl-Pak® bags and a sterile Nasco 500-mL Whirl-Pak® bag (Nasco, Fort Atkinson, WI). The Whirl-Pak® bag was fixed to the pole using a retainer ring and the pole could be extended from six to 12 feet as needed. Two 100-mL and one 50-mL Whirk-Pak® thio-bags (all sterile) were filled for every sampling time and stored in an ice box to be sent to the laboratory for analysis. Bags were labeled with location names, day of sampling, and time of sampling. Sterile gloves were used throughout the sampling process. Conductivity, salinity, and pH were measured with a YSI meter and recorded. Samples were collected at CCK Crescent on the 4th and 19th of January 2011, at Verde on 6th and 12th January 2011, and at Bras Basah on 10th and 18th January 2011.

4.3 Wet Weather Sampling

The most reliable kind of sampling is usually carried out manually with the requirement that field personnel understand the methods and are on time with the sampling (Wanielista and Yousef, 1993). However, storm events are hard to predict in the Singaporean climate. Although thunderstorms are usually predicted in the afternoons, they are typically very scattered. Therefore, autosamplers are sometimes used for convenience and are set to collect samples when the water level rises to a certain level. In the event of wet weather at Bras Basah on the 10th of January 2011, samples were collected every 20 minutes or 30 minutes by MIT students depending on intensity of rainfall. Wet weather samples were collected using the Nasco Sampling Pole. The Isco Model 3700 Sampler (Teledyne Isco, Inc., Lincoln, NB) was used to collect wet weather samples at Verde on 8th February 2011. The autosampler was triggered to collect samples when water levels reached 5.5cm at a time interval of 10 minutes. Rainfall and water level values were obtained from the EnVault website based on the Isco Model 3230 Flow Meter (Teledyne Isco, Inc., Lincoln, NB).

4.4 Colilert® and Enterolert™ Systems

The Colilert® and Enterolert™ systems (IDEXX Laboratories, Inc., Westbrook, ME) were used for the Most Probable Number (MPN) test to detect total coliforms and *E. coli*, and enterococci. The Colilert® reagent consists of salts, nitrogen, carbon and indicator-nutrients which are specific for total coliforms and *E. coli*. Total coliforms metabolize the indicator-nutrient orthonitrophenyl-â-d-galacto-pyranoside (ONPG) thus turning the sample yellow whereas *E. coli* metabolizes 4-methyllumbelliferyl-â-d-glucuronide (MUG) which enables the sample to fluoresce (Aquatic Life, Ltd., 2000). Enterolert™ contains the nutrient indicator 4-methyl-umbelliferyl β-D-glucoside which fluoresces when it is metabolized by enterococci with their β-glucosidase enzyme.

4.5 Laboratory Analysis

The ideal time for sample analysis to start is within six hours of collection (Mitchell and Stapp, 1995). At the lab, each sample was diluted to 1:1, 1:100 and 1:10000. This was done by measuring 100 mL of the sample using a graduated glass cylinder into a 250-mL glass bottle, pipetting 1 mL using an Eppendorf Research Pipette® (Eppendorf AG, Hamburg, Germany) and adding it to 99mL of deionized (DI) water (18 megOhm) into a second 250-mL bottle for the 1:100 dilution, then pipetting 1 mL of the 1:100 mixture into a third 250-mL bottle and adding 99 mL of DI water to obtain the 1:10000 dilution. Sampling runs were conducted twice per location and for samples collected on the second day of field data collection, dilutions were carried out to omit the 1:1 dilution and replace it with the 1:10 dilution based on observations from first sampling results.

These steps were carried out for each of two duplicate 100 mL samples; the first 100-mL batch was tested for total coliform and *E. coli* concentration while the second 100-mL batch was tested for enterococci concentration. After dilutions were carried out, Colilert® and Enterolert™ reagents were added respectively and mixed until the reagents had dissolved into the solution. Then, the mixtures were poured into IDEXX Quanti-Tray®/2000 trays and sealed with the IDEXX Quanti-Tray® Sealer (IDEXX Laboratories, Inc., Westbrook, ME). The sealer distributes the sample mix evenly into wells in the Quanti-Tray®. The Quanti-Trays® were labeled with the sample name, dilution factor, time of incubation, and time of analysis. The trays to be analyzed for total coliform and *E. coli* concentrations were placed in the incubator at 35±0.5 °C whereas trays analyzed for enterococci were incubated at 41±0.5 °C for 24 to 28 hours.

After the appropriate time had passed, the trays were taken out of the incubators and results were noted down. Each Quanti-Tray® has 49 large wells and 48 small wells. Yellow wells as seen in Figure 4.8 indicate positive results for total coliform bacteria, while fluorescent wells under a 6-watt, 365-nm ultraviolet light (within 5 inches of sample) shown in Figure 4.9 indicate positive results for *E. coli* (Colilert®) and enterococci (Enterolert™). The numbers of positive wells were recorded and the most probable number (MPN) of total coliform, *E. coli* and enterococci was determined by referring to the MPN table provided by IDEXX with the Quanti-Trays®. The system uses a Poisson distribution statistical model and has 95% confidence limit.

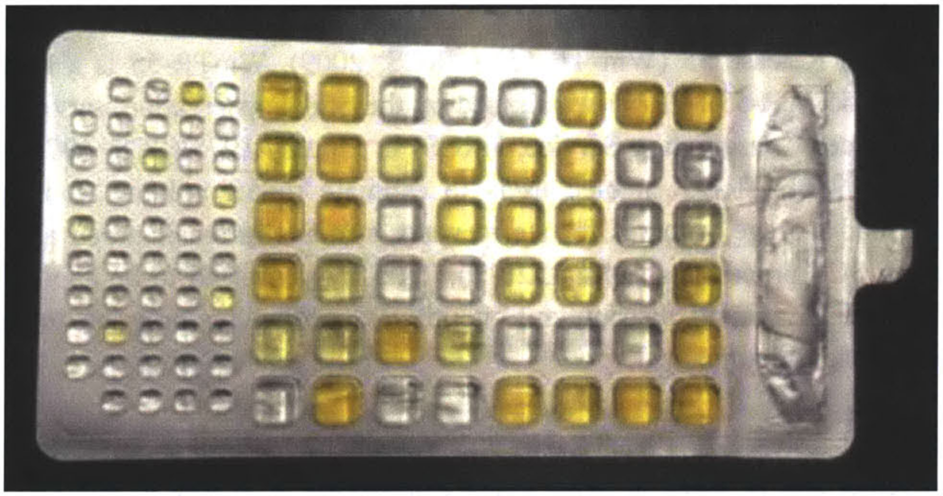


Figure 4.8: Yellow Wells Indicating Positive Results for Total Coliform

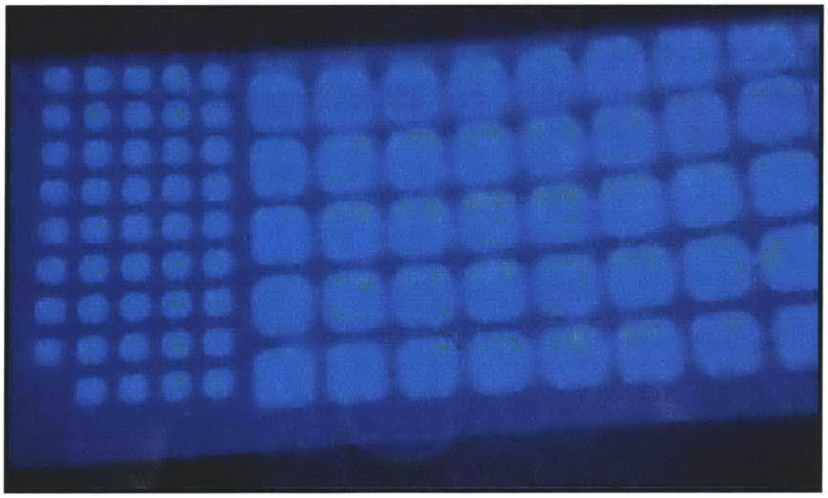


Figure 4.9: Fluorescent Wells Indicating Positive Results for Enterococci

Chapter 5: Peak Runoff Estimation using WinTR-55

5.1 Windows Technical Release 55 (WinTR-55)

Concurrent measurements of channel flow were not available for Jean-Pierre Nshimyimana's (2010) grab samples at KC1, KC2, KC6 and KC7 in 2009 and thus an estimate of flow had to be obtained. This set of data was the only set whereby discharge (Q) values were not readily available. The storm runoff peak values (Q_p) and time to peak (T_p) were calculated using Windows Technical Release 55 (Win TR-55) (NRCS, 2009). WinTR-55 is a modification of Technical Release 55 (TR-55). TR-55 was issued by the Soil Conservation Service (SCS—now the Natural Resources Conservation Service, NRCS) in January 1975 (SCS, 1975) and updated in 1986 (NRCS, 1986). TR-55 enabled users to estimate runoff volume from storms, peak discharge rates, and storage volumes for storm water systems in small urban and agricultural watersheds using SCS procedures (NRCS, 2010). TR-55 was created to be applicable for SCS Type I, IA, II, and III rainfall distributions. It utilizes a computer program to perform SCS procedure computations automatically.

Windows Technical Release 20 (WinTR-20) was introduced in 1998 to model storm events at the watershed scale, and to assist in flood event evaluations. It is able to analyze both current watershed conditions and alternates to current conditions. WinTR-55 was introduced the same year as WinTR-20. Changes made to the program included an upgrade of source code to Microsoft® Visual Basic® 6.0, a revision in data input to replace usage of generalized tables and graphs with a hydrograph computational routine, and the development of a Windows® interface and output post-processor (NRCS, 2009). The program uses WinTR-20 (Version 1.11)'s computational routine to generate, route, and add hydrographs. A schematic of WinTR-55's system is shown in Figure 5.1.

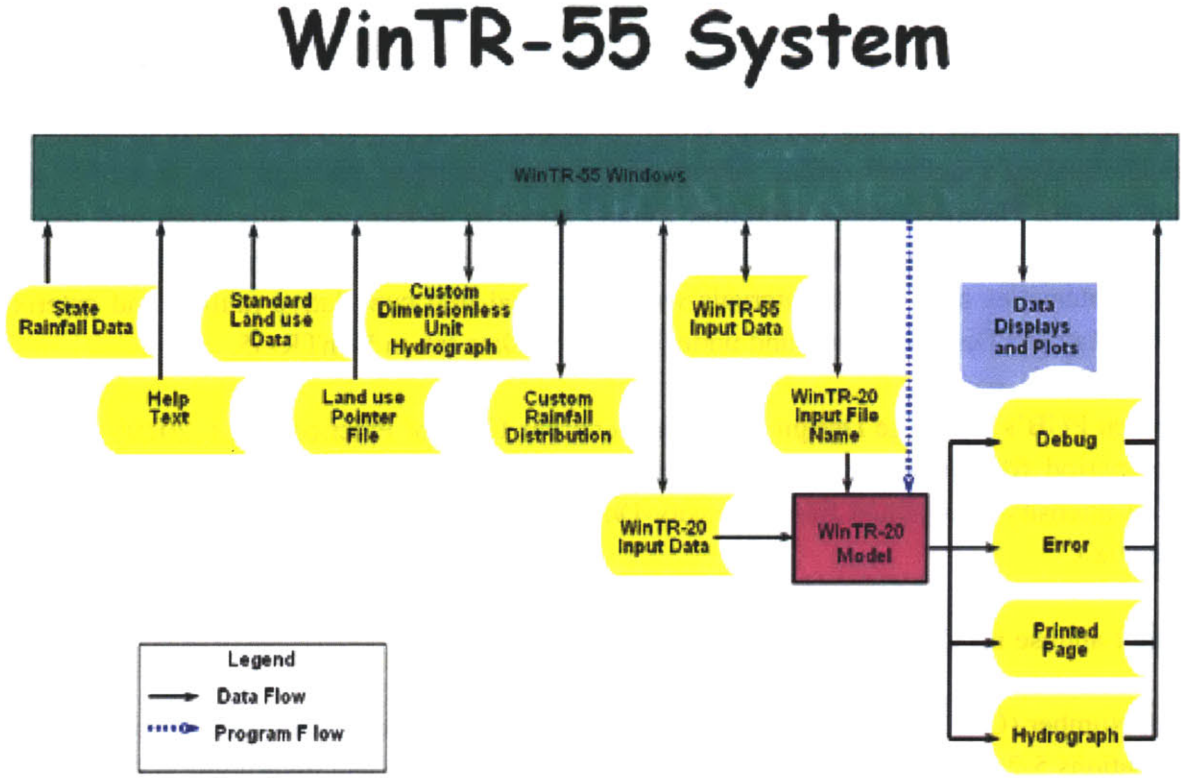


Figure 5.1: WinTR-55 System Schematic (NRCS, 2009)

5.2 Using WinTR-55

WinTR-55 uses the SCS Runoff Curve Number (CN) method to estimate runoff. The equations used to estimate runoff are:

$$Q = \frac{(P-I_a)^2}{(P-I_a)+S} \qquad \text{Equation 5-1}$$

$$I_a = 2S \qquad \text{Equation 5-2}$$

$$S = \frac{1000}{CN} - 10 \qquad \text{Equation 5-3}$$

where Q is the runoff, P refers to rainfall, I_a is the initial abstraction, S refers to the potential maximum retention after runoff begins, and CN refers to the curve number. Required input into WinTR-55 therefore includes (1) rainfall distribution, (2) drainage area, (3) CN values, and (4) the basin time of concentration (T_c).

5.2.1 Rainfall Distribution, P

Rainfall values used in this analysis were obtained from Prof. Chua Hock Chye of NTU who was provided the data by SysEng (S) Pte. Ltd. in Singapore. Recent rainfall data could be accessed through SysEng's updated online server, and from Greenspan Pte. Ltd. but most of rainfall events during Nshimyimana's sampling rounds occurred before 24th July 2009 and were not accessible via the servers. Hence, they had to be acquired directly from SysEng (S) Pte, Ltd. The rainfall intensities at 5-minute intervals were converted into cumulative rainfall and entered as Custom Rainfall Distributions found under the GlobalData tab in WinTR-55.

Based on PUB's Drainage Design and Considerations Code of Practice (PUB, 2010), the design return period for Singapore's outlet drains and secondary drainage facilities is 5 years. The rainfall intensity is obtained from Intensity-Duration-Frequency curves shown in Figure C-6 in Appendix C.

5.2.2 Landuse for CN Values using ArcGIS

Curve Number (CN) values are required in order to determine the initial abstraction (I_a) as shown in Equations 5-2 and 5-3. These CN values are based on land use and hydrologic soil types.

To obtain land usage and area covered information, ArcGIS geographic information system software (Environmental Systems Research Institute, Inc., Redlands, CA) was used. Previously created files were obtained from Erika Granger. A DEM shapefile was available whereby both drainage and topography had been incorporated. This ensures that the flow of water is not dependent only upon streams, but also upon the drainage system in the region. Previous drainage and land use files (Figure 5.2) were also available.

The Fill, Flow Direction and Flow Accumulation tools within the Hydrology section of Spatial Analyst found in ArcToolbox were used to generate respective layers. The Fill tool removes imperfections in the data by filling in sinks of surface rasters. The Flow Direction tool creates a raster showing flow direction in the form of colors and numbers from the least steep to steepest downslope cell. The Flow Accumulation tool then creates a raster of accumulated flow into each cell. Using the Raster Calculator, streams could be generated by selecting the Flow Accumulation raster and selecting it to be larger than a self selected number. New shapefiles were created in ArcCatalog and based on the existing gauging stations (in this case KC1, KC2, KC6 and KC7), they were edited using Editor whereby polylines were drawn where the gauging stations were situated. After changing the shapefile into a raster, the Watershed Tool could be used to generate land area covered based on water flowing into each gauging station. This can be seen in Figure 5.3. Once this was done, the Clip tool under the Extraction section in Analysis Tools was used to clip the land use layer onto the generated watersheds.

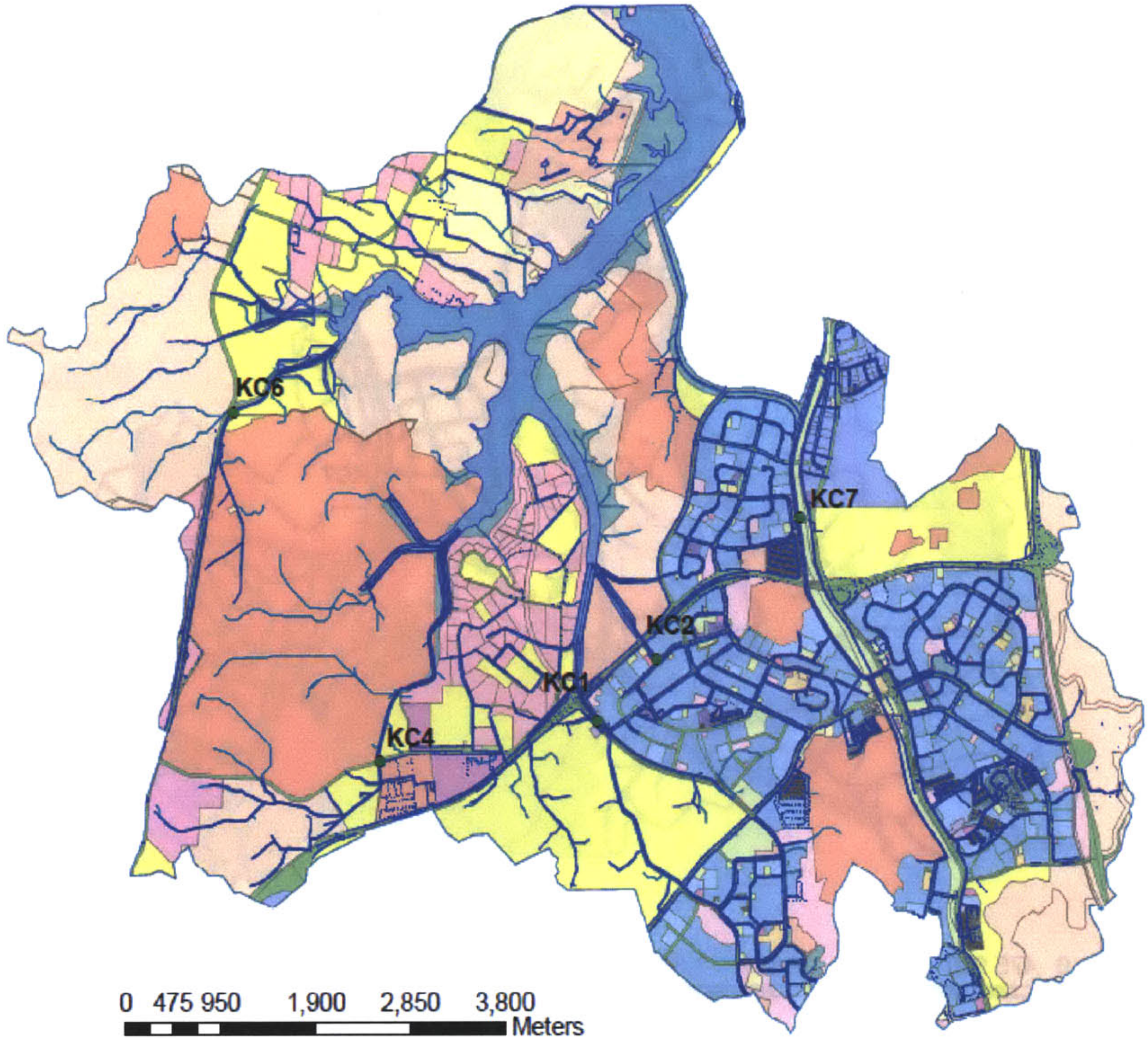


Figure 5.2: Land Use GIS Data and Gauging Stations
(Different Colors Indicate Different Land Uses)

Based on Attribute Tables for each layer, the land areas were obtained and soil types from Erika Granger were looked up to determine Hydrologic Soil Groups. These were then entered as Land Use Details in WinTR-55 which generates the CN numbers. After the layers were clipped to the subcatchment boundaries, summed areas in square kilometers by land use for each subcatchment could be extracted by viewing the Attribute Table.

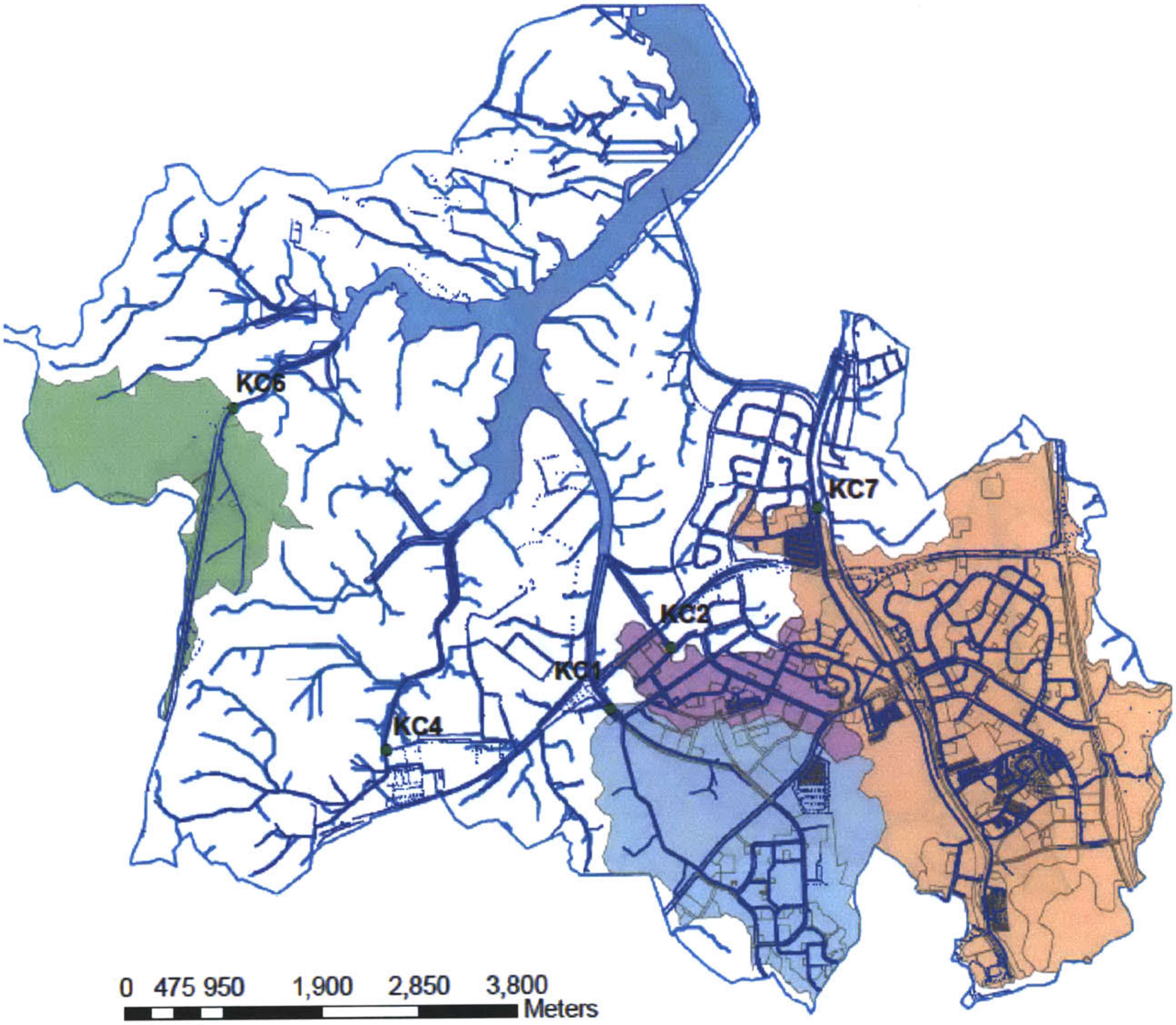


Figure 5.3: Land Area Upstream of Gauging Stations KC1, KC2, KC6, and KC7

5.2.3 Time of Concentration, T_c

The time of concentration, T_c is the time required for a drop of water to travel from the edge of the watershed to the point of collection. To obtain this value for WinTR-55, the T_c path was determined using ArcGIS.

The time of concentration is the sum of travel times (T_t). Travel times are the ratio of flow length to flow velocity and as described in the WinTR-55 manual, is calculated using the equation:

$$T_t = \frac{L}{3600V}$$ *Equation 5-4*

where T_t = travel time (hours), L = flow length (m), V = average velocity (m/s), and 3600 is the conversion from seconds to hours.

The time of concentration then is:

$$T_c = \sum T_t \qquad \textit{Equation 5-5}$$

For the first 300 feet (~0.09 km), the flow is considered to be sheet flow or overland flow. The time of travel for overland flow (sheet flow) was found using a nomograph from Goldman *et al.* (1986, page 4.20). This was done for KC2 and KC7 only and the information required includes the distance travelled by overland flow, land-surface slope, and the rational method runoff coefficient (represented by the symbol C). The C values chosen were 0.15 and 0.20. Times of travel in minutes are read off the nomograph. A topography map provided by NTU was available and accessible via ArcGIS (Figure 5.4), thus slopes could be calculated and then using Figure 5.5 (from NCRS, 1986), corresponding V can be obtained.

After overland flow, the flow becomes shallow concentrated flow. For shallow concentrated flow, V is also obtained from Figure 5.5 and T_t is calculated using Equation 5-4. Once shallow concentrated flow collects in channels, it becomes open-channel flow. For open-channel flow, Manning's equation is used to find the average velocity. Manning's equation is:

$$V = \frac{k}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \qquad \textit{Equation 5-6}$$

whereby k = 1.00 (SI units), n is Manning's roughness coefficient for open-channel flow, R refers to the hydraulic radius (m), and S is the slope of the hydraulic grade line (m/m). R is calculated by dividing the cross sectional area of the channel by its wetted perimeter. Channel dimensions were provided by NTU and are shown in Appendix C. Roughness coefficients for the drains at KC1, KC2, KC6, and KC7 were provided by NTU and can be found in Appendix C as well.

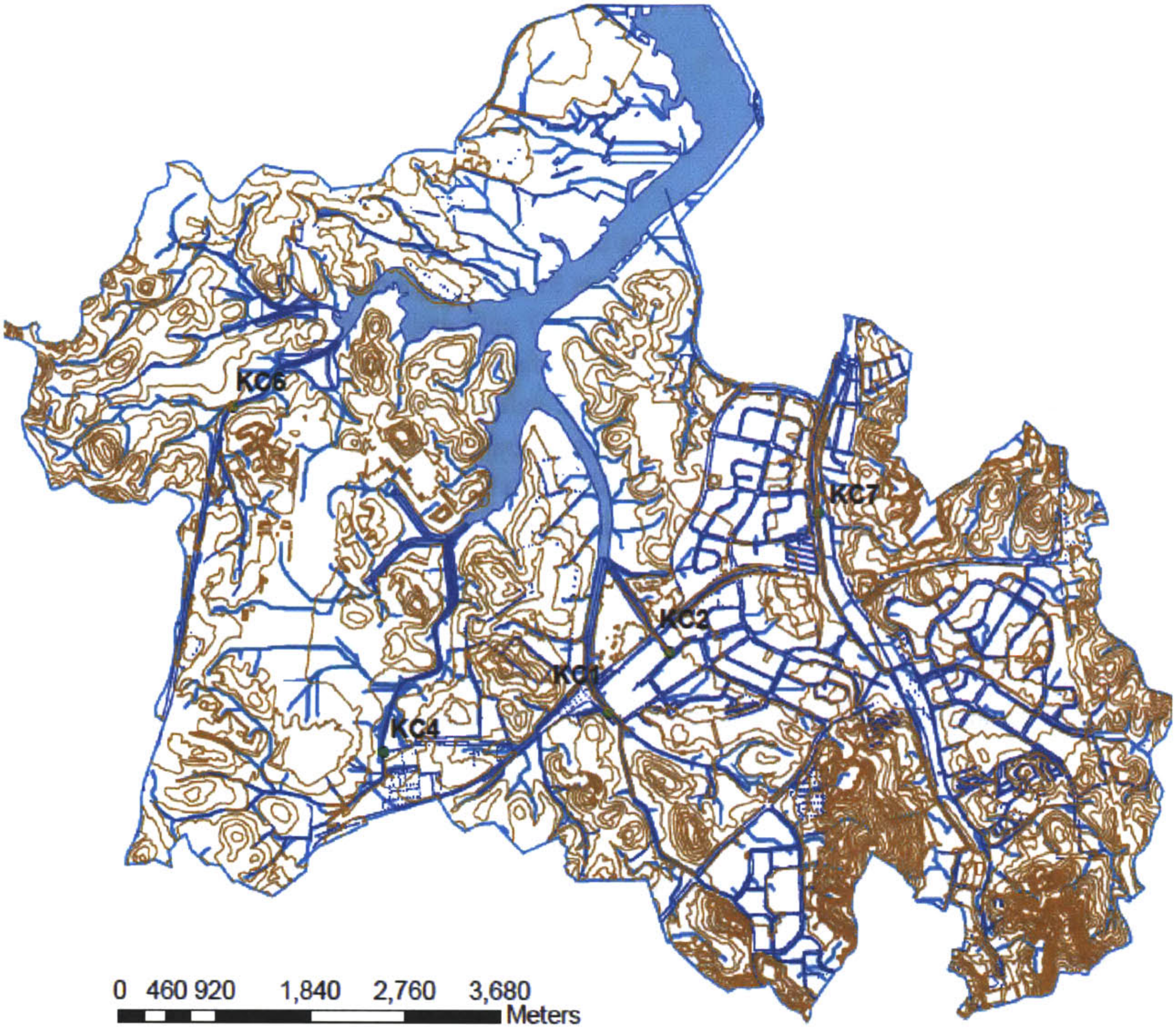


Figure 5.4: Topographic Map of Kranji Catchment (contour interval = 5 m)

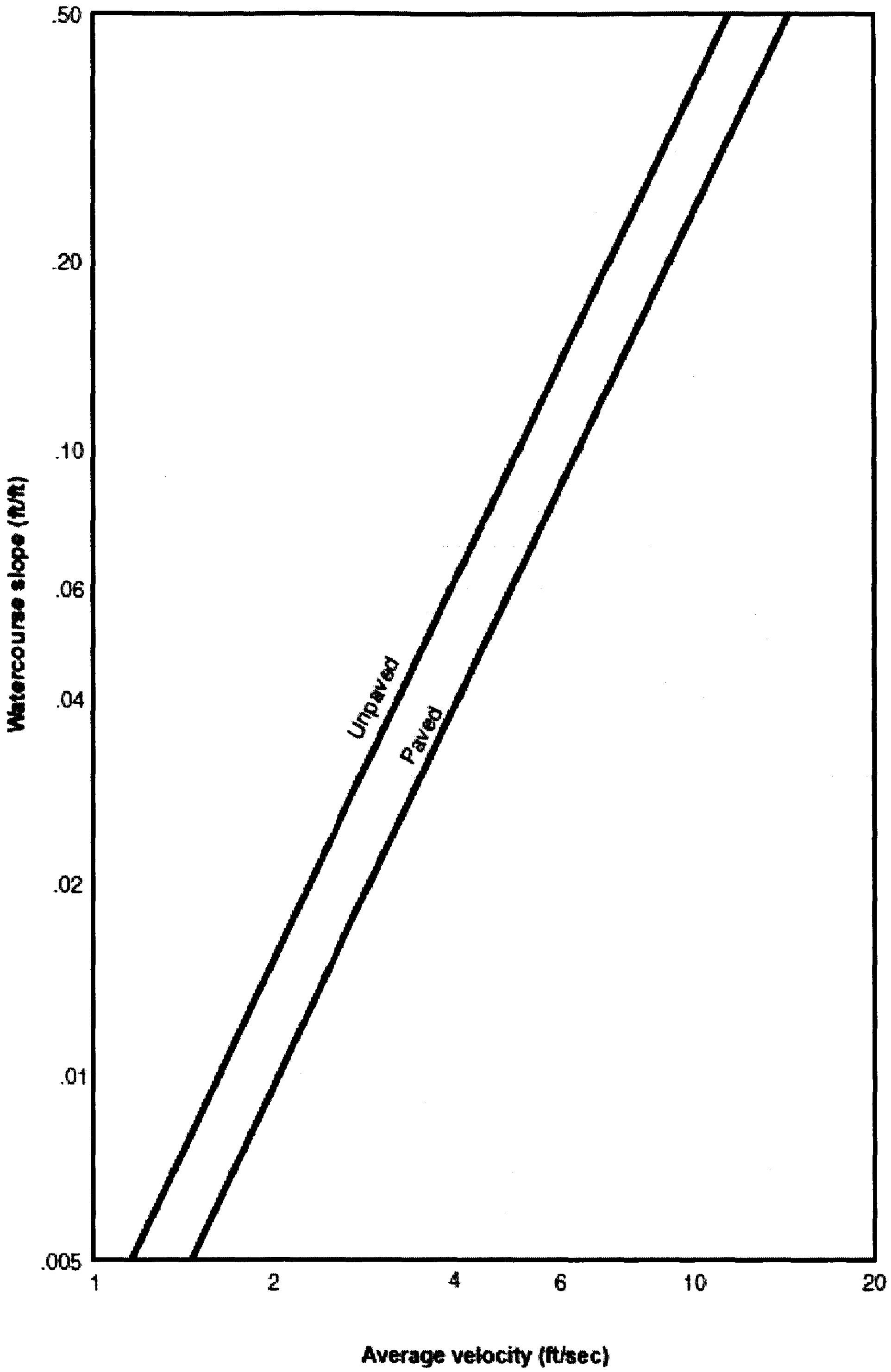


Figure 5.5: Average Velocities for Estimating Time of Travel for Shallow Concentrated Flow (NRCS, 1986)

5.2.4 Q_p and T_p using WinTR-55

The Q_p and T_p values are computed by WinTR-55 and are shown in Table 5.1. There were two storm events each for the KC6 and KC7 stations, hence they were labeled $KC6_{(1)}$, $KC6_{(2)}$, $KC7_{(1)}$, and $KC7_{(2)}$ for the first and second storm event. Of the six storm events sampled by Nshimyimana (2010), only two events could be analyzed for wet weather bacterial loading conditions based on results from WinTR-55. These were for KC2 and $KC6_{(2)}$ with total rainfall intensities of 8.4 mm and 22.7 mm shown in Table 5.1. The other four events could not be analyzed because the total amount of rainfall during those events fell below the initial abstraction threshold of WinTR-55 and no flow was predicted to occur.

Table 5.1: Total Rainfall, Q_p and T_p of Storm Events

Station	**Total Rainfall (mm)**	**Q_p (m^3/s)**	**T_p (hr)**
KC1	2.8	-	-
KC2	8.4	0.07	10.53
$KC6_{(1)}$	2.8	-	-
$KC6_{(2)}$	22.7	1.20	8.63
$KC7_{(1)}$	0.4	-	-
$KC7_{(2)}$	4.4	-	-

Chapter 6: Data Analysis

After wet weather samples had been determined and sorted, they were then analyzed statistically to find the multiple correlations between wet weather conditions, land use, and bacterial loading. Out of the eight sampling events selected from Nshimyimana's data set hypothesized as wet weather sampling events, only one could be considered as a truly wet weather event (KC2, 15 July 2009) but only one is known for certain to be truly dry weather data. This truly dry weather data was the sampling event carried out on the 22nd of July 2009 at KC6 which is the grassed-over land cover area. Samples were found to have been collected before rainfall (based on discharge over time plots) and are excluded from the analysis. A summary of results is shown in Table 6.1 showing the six storm events that were analyzed, the two events that could not be analyzed because we had no access to the rain gages (KC3 and KC5), and the final two events that could be reclassified as samples collected during wet weather and dry weather conditions.

Table 6.1: Summary of Results (N/A = not available)

Station	Dates	2009 Sampling Locations	Total Rainfall (mm)	Q_p (m^3/s)	Comments
KC1	15-Jul-09	PB01	2.8	-	Flow was too low
KC2	15-Jul-09	PS01	8.4	0.07	Wet-weather sample
KC3	15-Jul-09	TH01	N/A	N/A	No rain intensity ava ilable
KC5	15-Jul-09	NT01, NT02	N/A	N/A	No rain intensity available
KC6 $_{(1)}$	15-Jul-09	KK01	2.8	-	Flow was too low
KC6 $_{(2)}$	22-Jul-09	KK05, KK06	22.7	1.2	Dry-weather sample
KC7 $_{(1)}$	7-Jul-09	PU02, PU03, PU04, PU05	0.4	-	Flow was too low
KC7 $_{(2)}$	9-Jul-09	PU06, PU07, PU09, PU09, PU10, PU11	4.4	-	Flow was too low

6.1 Effect of Land Use

The land use breakdown represented by the monitoring stations is shown in Table 6.2 (Chua *et al.*, 2010). Different land uses present different bacterial loadings mainly due to the percentage of point and nonpoint sources in those different land uses. This previously obtained information will be used to analyze bacterial loadings into the catchment during wet and dry-weather conditions.

Table 6.2: Percentage Distribution of Land Use (Chua et al., 2010)

Station	Name	HDR	LDR	Forest	Comm.	Transp.
KC1	Bricklands	36	-	50	-	-
KC2	CCK Ave.	68	-	17	-	-
KC7	Verde	-	76.4	-	-	-
MC11	Bras Basah	-	-	-	65	30.9

Notes:

1. HDR = High Density Residential
2. LDR = Low Density Residential
3. Comm = Commercial
4. Transp = Transportation
5. HDR percentage is shown as 32.6% for KC1 and 70.3% for KC2 by NTU (2008)

The graphs in this chapter show total coliform, *E. coli*, and enterococci concentrations for Forest & HDR, HDR, HDR (JP), Commercial, and LDR land uses. Forest & HDR represents the land use at KC1 where storm samples were analyzed for *E. coli* and enterococci concentrations by NTU (2008). HDR and HDR (JP) are the major land uses at KC2. HDR refers to land use at KC2 where total coliform and *E. coli* concentrations were analyzed by Lee (2009) whereas HDR (JP) refers to concentrations from Nshimyimana (2010). Land use at MC11 is mostly commercial and samples were collected 10th January 2011 whereas land use at KC7 was mostly LDR and were collected on 8th February 2011 by NTU and MIT students.

6.2 Event Mean Concentrations

The event mean concentration (EMC) represents the flow-weighted concentration of bacterial loadings for each storm event. The equation to calculate EMC is:

$$EMC = \frac{\Sigma(Q \times C)}{\Sigma Q} \qquad \textit{Equation 6-1}$$

where Q refers to discharge and C refers to bacteria concentration. Figure 6.1 plots EMC values against land use for the sampling events analyzed. The symbol NS is used to represent samples that were “not sampled”. The log-normal graph in Figure 6.2 was plotted to show clearer comparisons which could not be seen from Figure 6.1, such as the lower EMC values in the forested & HDR, commercial, and LDR areas. Figure 6.3 shows the same values found in Figure 6.1 without total coliform. EMC values for enterococci were higher compared to *E. coli* EMC values, with the exception of enterococci EMC levels at Bras Basah, which is a commercial area with suspected inflow from leaking sanitary sewers.

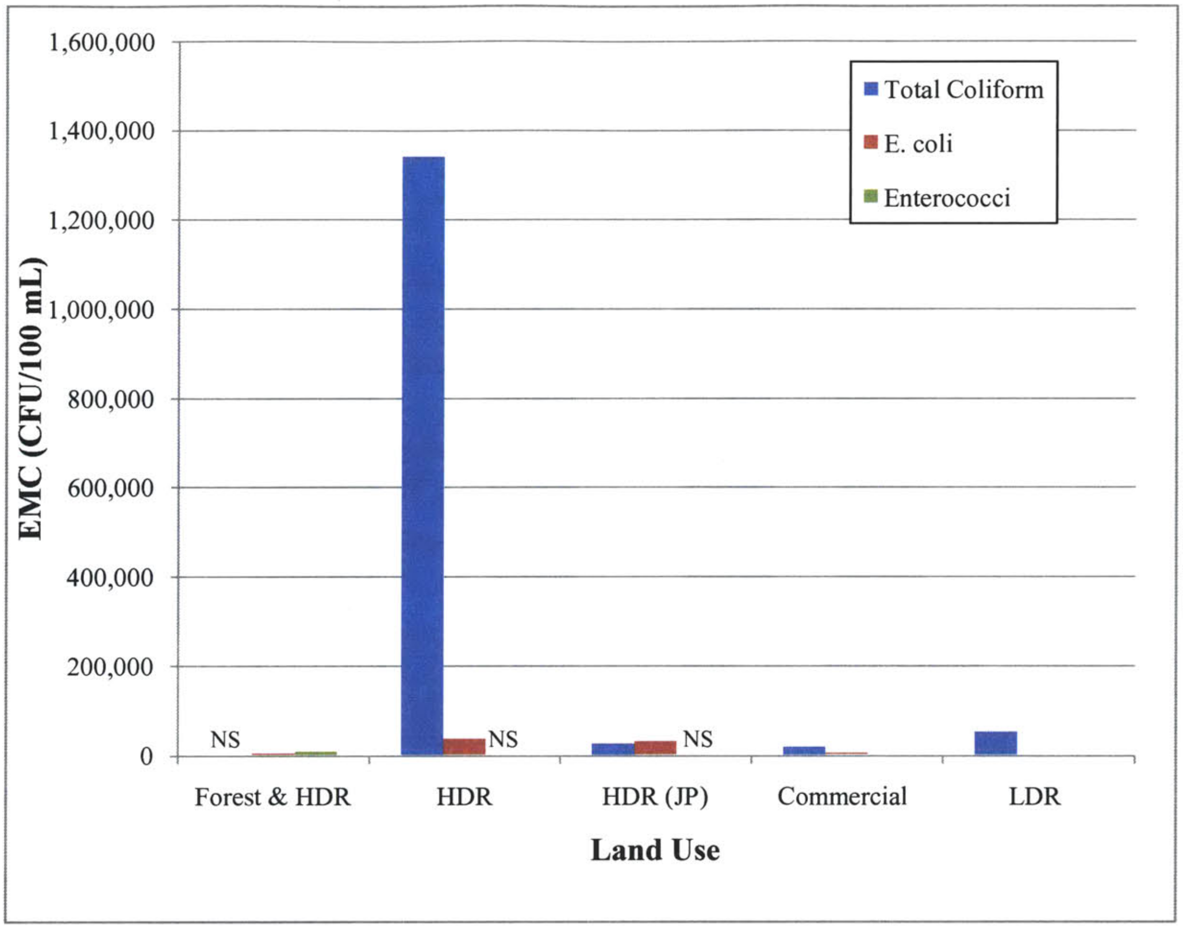


Figure 6.1: Event Mean Concentrations for Different Land Uses (NS = not sampled)

The accuracy of the EMC increases with an increasing number of sampling events. For the purposes of this report, finding the EMC might not serve as a proper representation of bacterial concentrations because there are a limited number of storm samples available. The number of samples collected during the storm event at HDR was only two whereas only one sample was collected during the HDR (JP) storm event. Additionally, the EMC values shown in Figures 6.1 through 6.3 conflict with results from existing literature. The estimated levels of fecal coliform in raw sewage ranges from 10^6-10^7 whereas for enterococci it ranges from 10^4-10^5 (Maier *et al.*, 2009) indicating that fecal coliform levels are typically higher than that of enterococci. Results in Figure 6.3 show that at forest & HDR and LDR land uses, EMC values for *E. coli* are lower than those of enterococci (5,000 vs. 9,000 for forest & HDR and 1,600 vs. 2,100 for LDR) thus conflicting with existing literature. If more field sampling could be conducted in future studies, more bacterial concentration values can be recorded and another analysis can be carried out to calculate new EMC values.

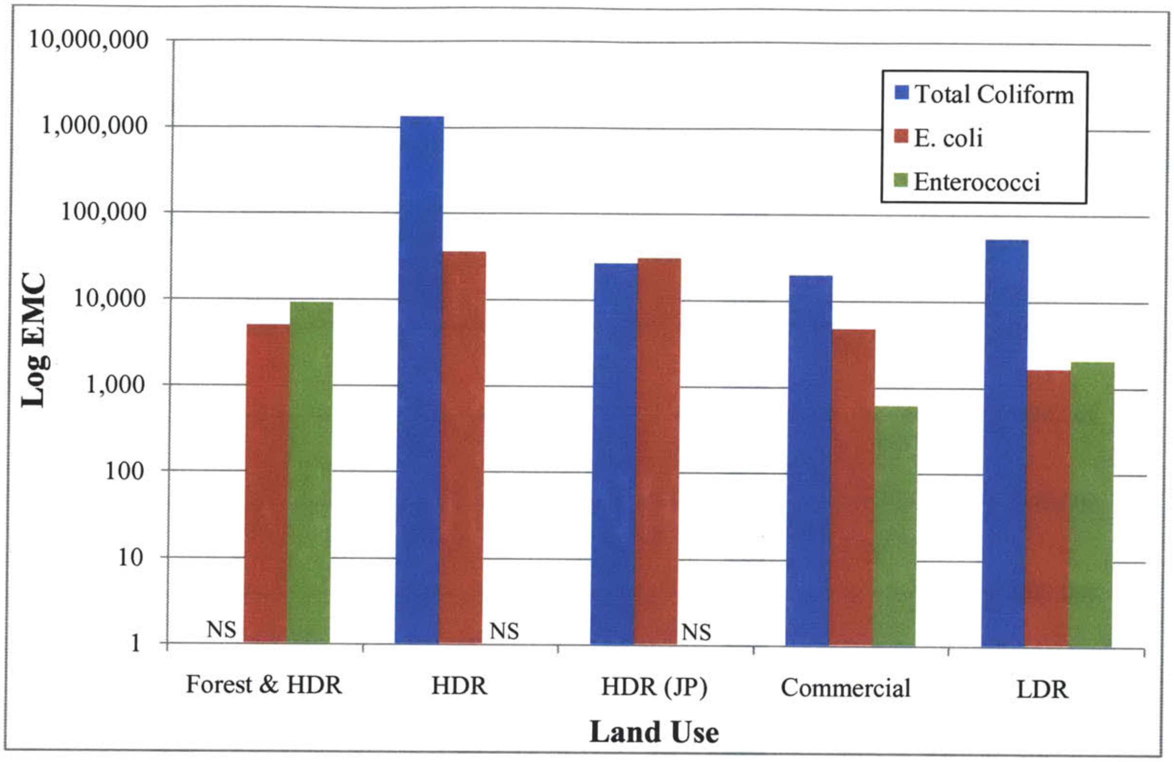


Figure 6.2: Log-normal Bar Graphs of Event Mean Concentrations for Various Land Uses (NS = not sampled)

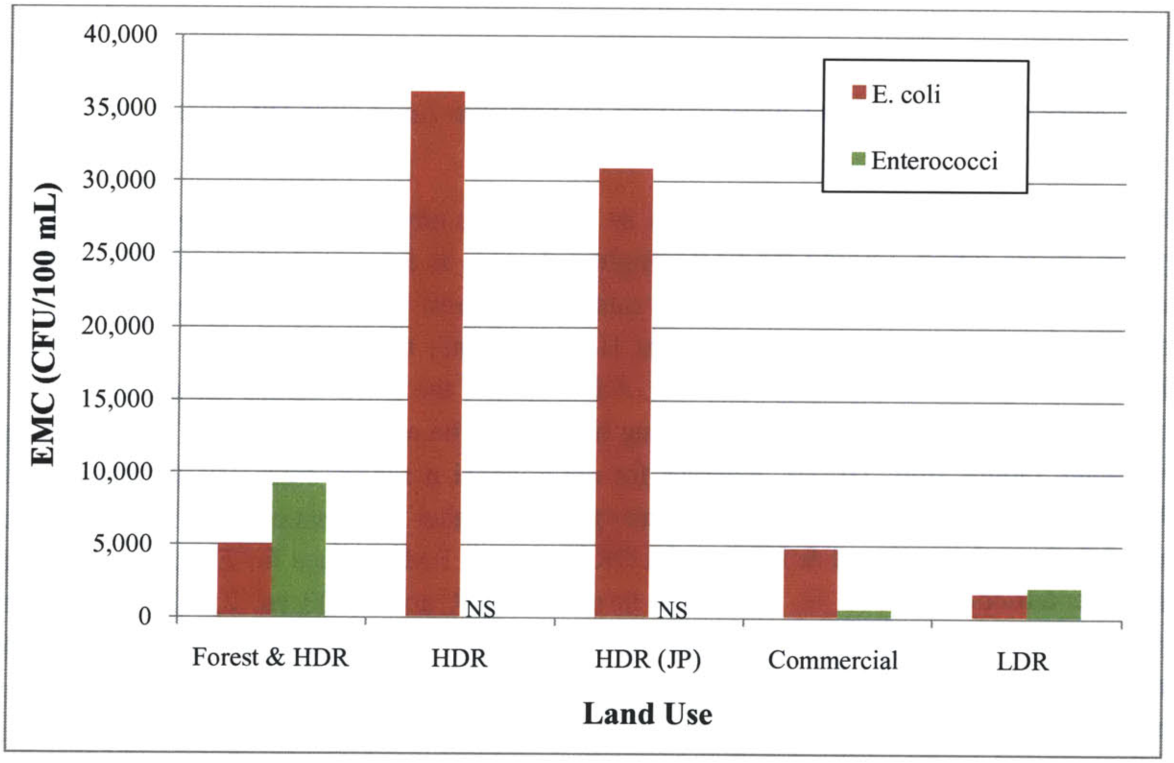


Figure 6.3: Event Mean Concentrations for E. coli and Enterococci for Various Land Uses (NS = not sampled)

6.3 Concentration vs Q/Q_p

The C vs Q/Q_p graphs show correlations between degree of wetness (represented by the symbol Q/Q_p) and bacterial concentration (represented by the symbol, C). Graphs were plotted for wet weather C values for total coliform, *E. coli* and enterococci versus Q/Q_p. Concentration values are in units of CFU/100 mL. Both concentration and flow were measured over time for storm events at KC1, KC2, KC7 (Verde), and MC11 (Bras Basah) representing forest and HDR, HDR, LDR and commercial land uses respectively, and are shown in Figures 6.4a through 6.6a.

Q/Q_p values were used instead of discharge (represented by the symbol, Q) for two reasons. The first was to understand when, for different land uses, bacterial concentrations peaked and were more concentrated during the course of a storm. For example, based on Figure 6.4a, LDR (red square symbols) showed high total coliform concentrations at both low flow (Q/Q_p value of 0.006) and high flow (Q/Q_p value of 0.67). The second reason was to make the graphs more uniform and comparable since Q values varied widely from one storm event to another. The Q values for commercial (light blue circle symbols) varied from 0.01 m^3/s to 1.35 m^3/s whereas the Q values for LDR varied from 0.000002 m^3/s to 0.0006 m^3/s. Converting these to Q/Q_p ratios sets all those different Q ranges from different storm events to a fixed range from 0.0 to 1.0 and eliminates that variability.

Previous reports (Lee, 2009) have indicated that the HDR areas at KC2 (light green triangle symbols) had the highest bacterial loadings in Kranji Catchment. This can be seen by comparing in Figure 6.4a overall bacterial concentrations from HDR, forest & HDR, and LDR land use areas, which are all located within Kranji Catchment. Additionally, the commercial area (light blue circle symbols) which is located in Marina Catchment also showed high bacterial loadings (Figure 6.4a). Bacterial concentrations from point sources are usually higher than those of nonpoint sources (Novotny and Chesters, 1981). Discharge from the HDR housing areas can be considered as virtual point sources due to the fluctuations in volume of discharge over a day caused by daily activities such as washing clothes or cooking. Bras Basah is one of the oldest areas in Singapore and therefore the old age of the sewers in Bras Basah suggests that leaking sanitary sewers might be significant point sources of bacterial loadings to storm drains in the neighborhood. Discharge from this particular commercial area is also considered as a type of point source due to those leaky sanitary sewers.

Trendlines were fitted using Microsoft Excel to C vs Q/Q_p data for forest & HDR as well as LDR, and are shown in Figures 6.4b, 6.5b and 6.6b. Trendlines are used to show trends in existing data and forecasts of future data. The R^2 value ranges from 0.00 to 1.00 and indicates how closely estimated values on the trendline correspond to actual data. Trendlines were not fitted to data for HDR because there was an insufficient amount of sampling points available, and were also not fitted to data for the commercial land use area because Microsoft Excel could not detect a trendline for the series. The trendlines for LDR for all three figures showed a U-shaped pattern although it was less apparent in Figure 6.6b. The significance of the U-shaped curve is discussed in Section 6.4. Trendlines for the forest & HDR land use areas depicted a pattern of increasing concentration with increasing flow (Figures 6.5b and 6.6b) and fit with R^2 values of approximately 0.65..

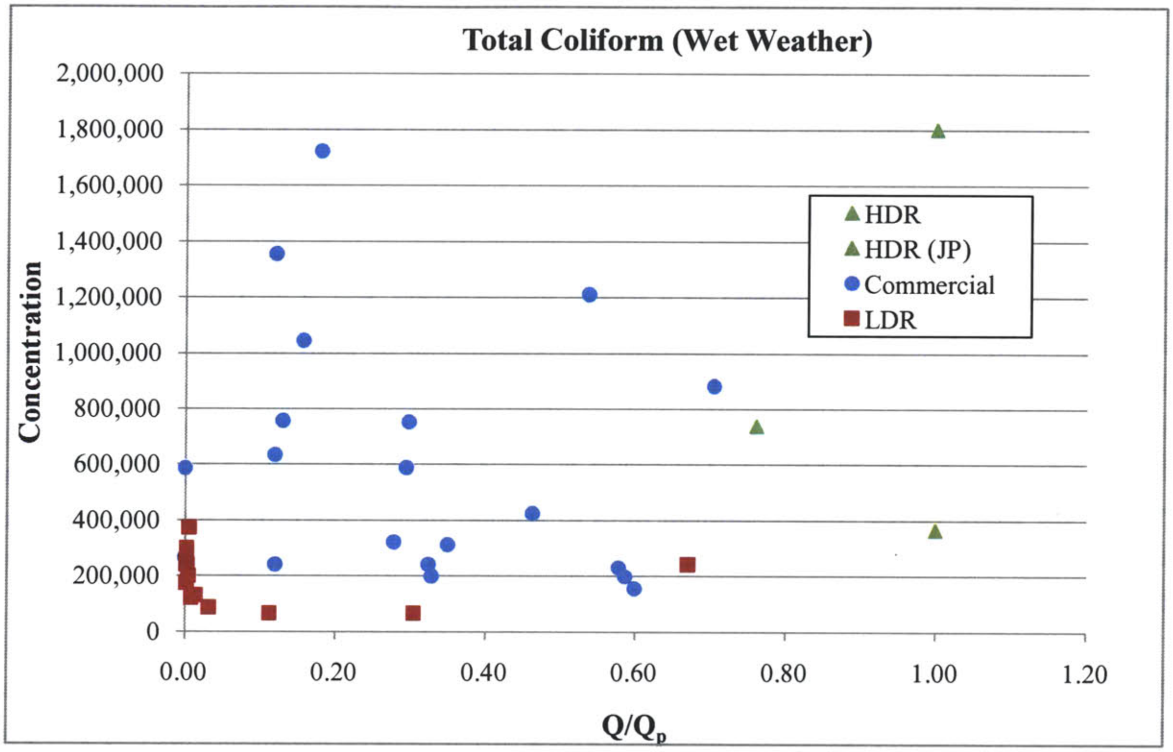


Figure 6.4a: 2006 – 2011 Wet Weather Total Coliform Concentration (CFU/100 mL) vs Q/Q_p

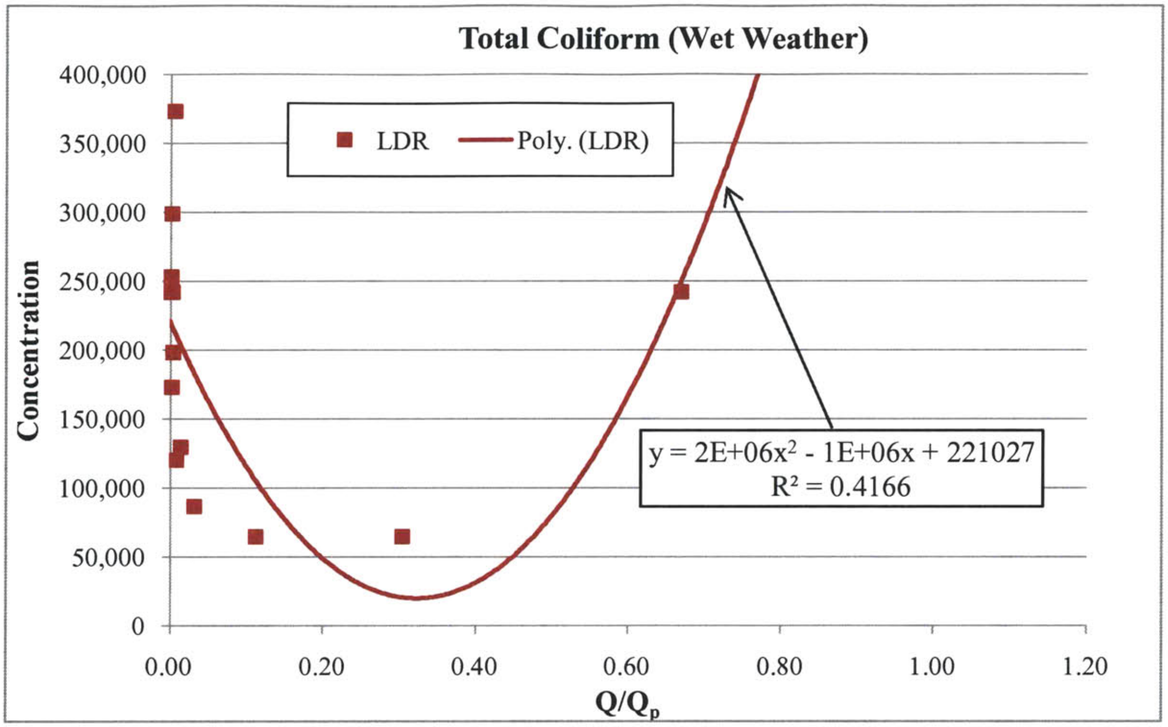


Figure 6.4b: Total Coliform Trendline for LDR Land Use

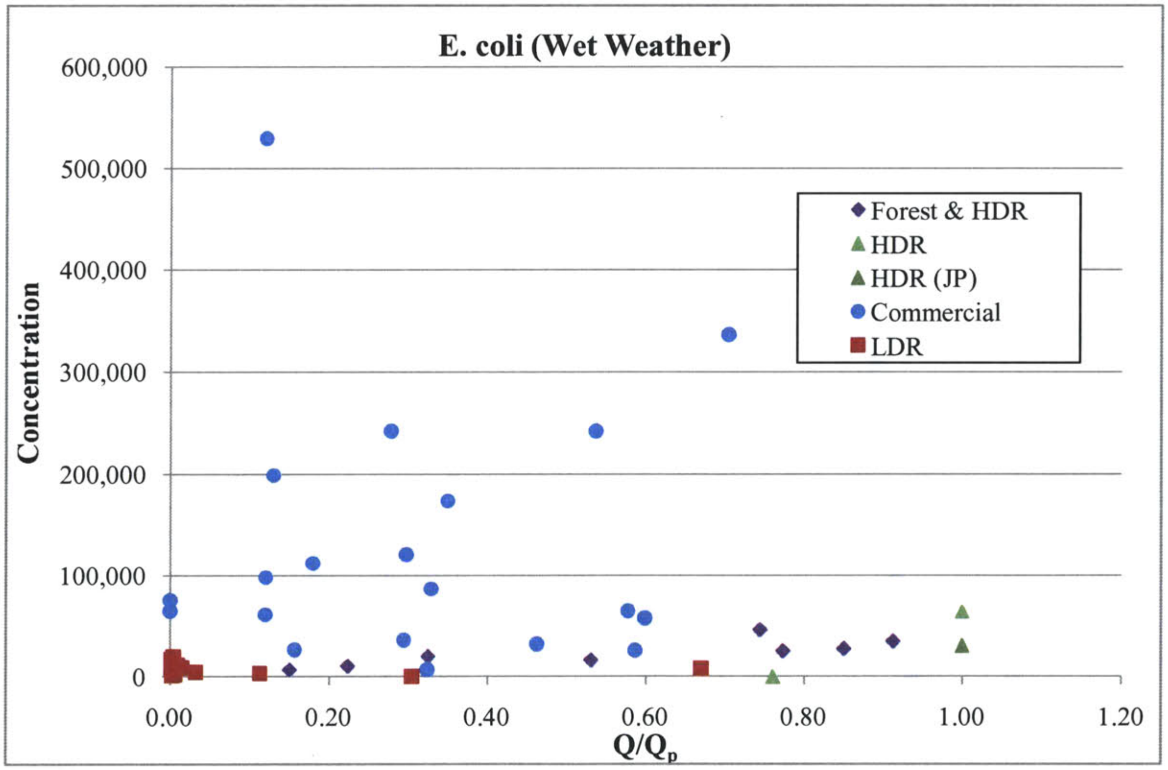


Figure 6.5a: 2006 - 2011 Wet Weather E. coli Concentration (CFU/mL) vs Q/Q_p

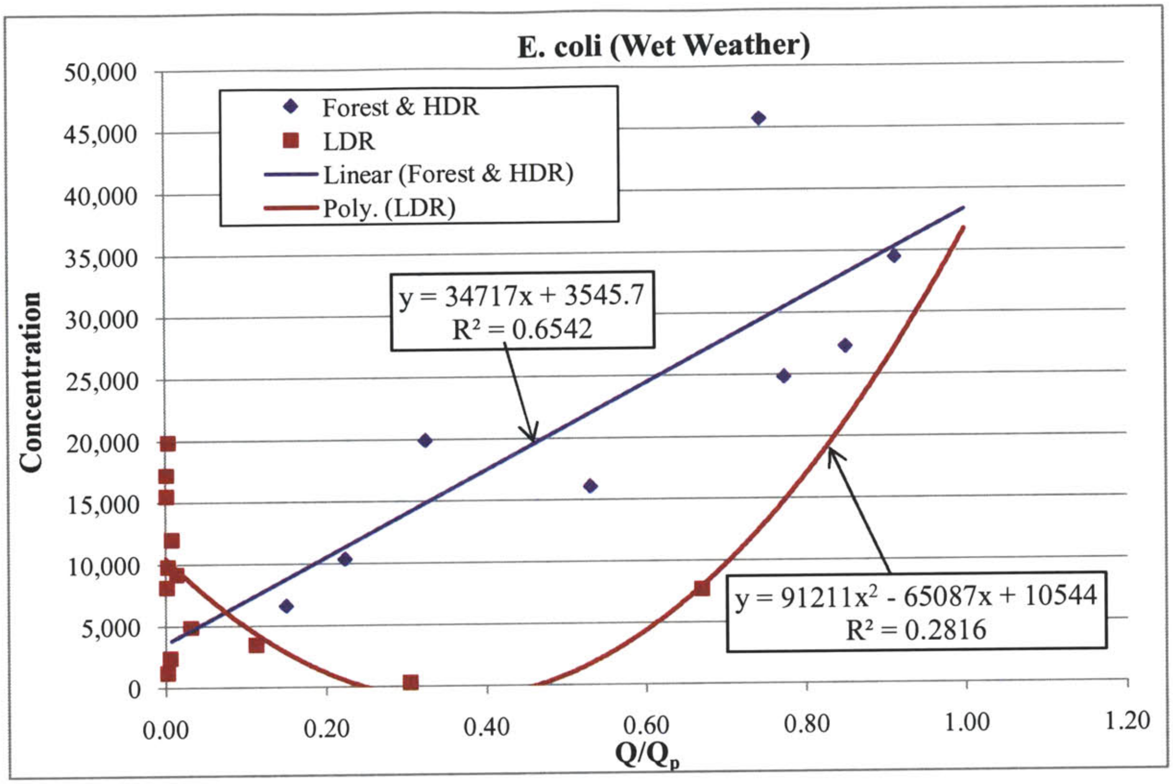


Figure 6.5b: E. coli Trendline for Forest & HDR and LDR Land Uses

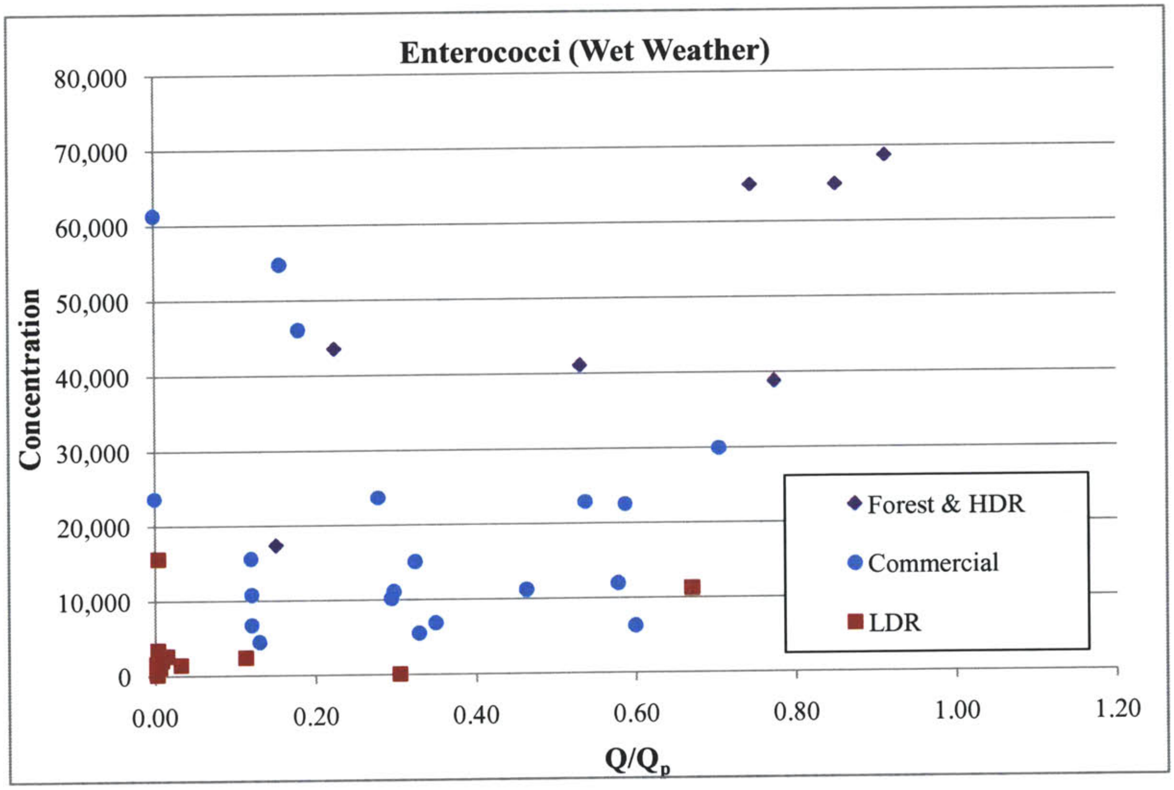


Figure 6.6a: Concentration of Enterococci (CFU/100 mL) versus Q/Q_p

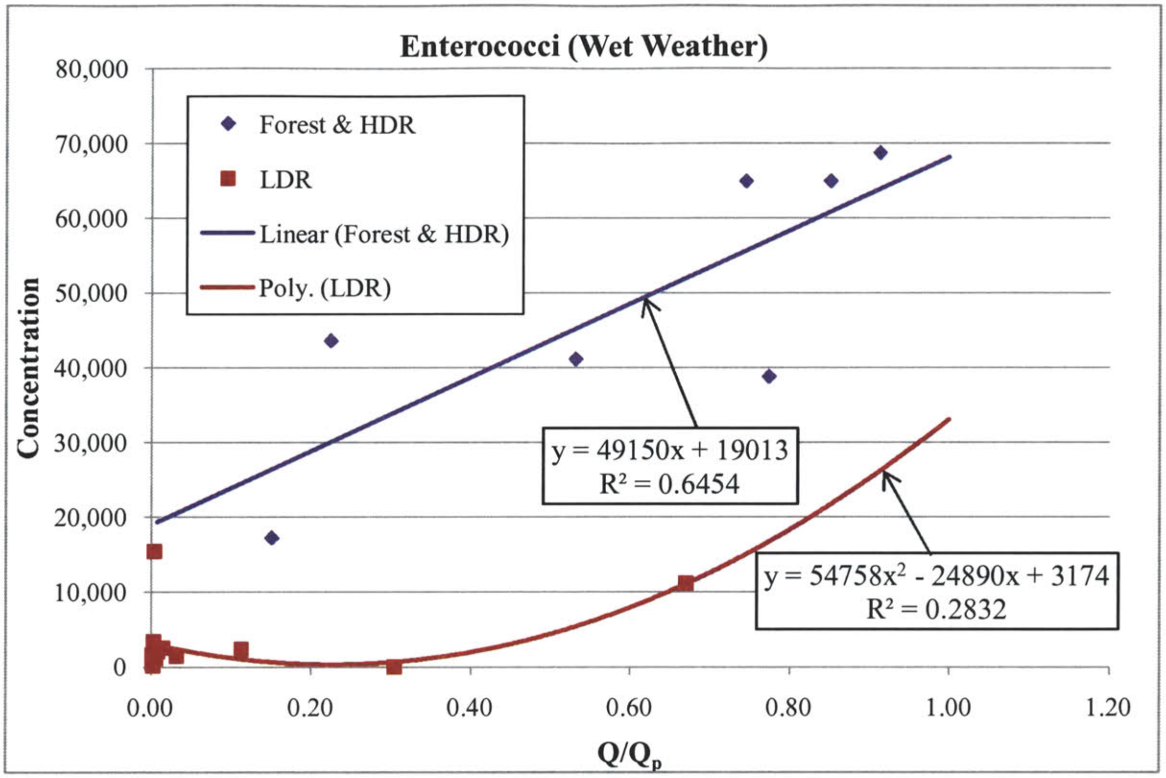


Figure 6.6b: Enterococci Trendline for Forest & HDR and LDR Land Uses

6.4 Log C vs Q/Q_p

The logarithm of concentration was plotted in Figures 6.7 through 6.9 since logarithmic plots provide concise summaries of highly variable bacterial concentration measurements—variability that can be observed over a short period of time. These plots enable variability of the data to be identified easily (Novotny and Olem, 1994).

From the logarithmic plots (Figure 6.8b), forest and HDR samples (purple diamond symbols) show increased concentration with increased flow. This type of concentration-vs.-flow trend is typically observed for nonpoint sources (NCWQR, 2005). Nonpoint sources contribute higher pollutant loads with higher flow as more of the load is being flushed out by the flow. Distributions for the commercial area (blue circular symbols in Figures 6.7 through 6.9) show that most of the bacterial concentrations are concentrated around lower flows. The old age of the sewers in the commercial area that was sampled suggests that leaking sanitary sewers might be significant point sources of bacterial loadings to storm drains in the neighborhood. Bacterial concentrations from point loadings that are constantly discharged will generally show higher levels during low flow since there is less water to dilute the loadings (Novotny and Chesters, 1981).

Samples for bacterial analysis were collected at the LDR site using the Isco Model 3700 Sampler (Teledyne Isco, Inc., Lincoln, NB) and are shown with square red symbols in Figures 6.7 through 6.9. Higher bacterial concentrations are observed both at low flows and at high flows, creating a U-shaped concentration vs. flow curve as shown by the trendlines in Figure 6.7b, 6.8b, and 6.9b. Areas with both point and nonpoint sources contributing to elevated pollutant concentrations usually give U-shaped graphs since point sources contribute elevated concentrations during low flow whereas nonpoint sources contribute elevated concentrations during higher flows (NCWQR, 2005).

Logarithmic graphs usually show this pattern more clearly compared to linear C vs Q/Q_p graphs and this can be seen by comparing the trendlines in Figures 6.4b-6.6b with those in Figures 6.7b-6.9b. R^2 values for trendlines fitted for the LDR U-curves in Figures 6.4b-6.6b ranged from 0.28 to 0.42 whereas trendlines in Figures 6.7b-6.9b were much better and ranged from 0.38 to 0.76. A R^2 value closer to 1.00 indicates a better fit.

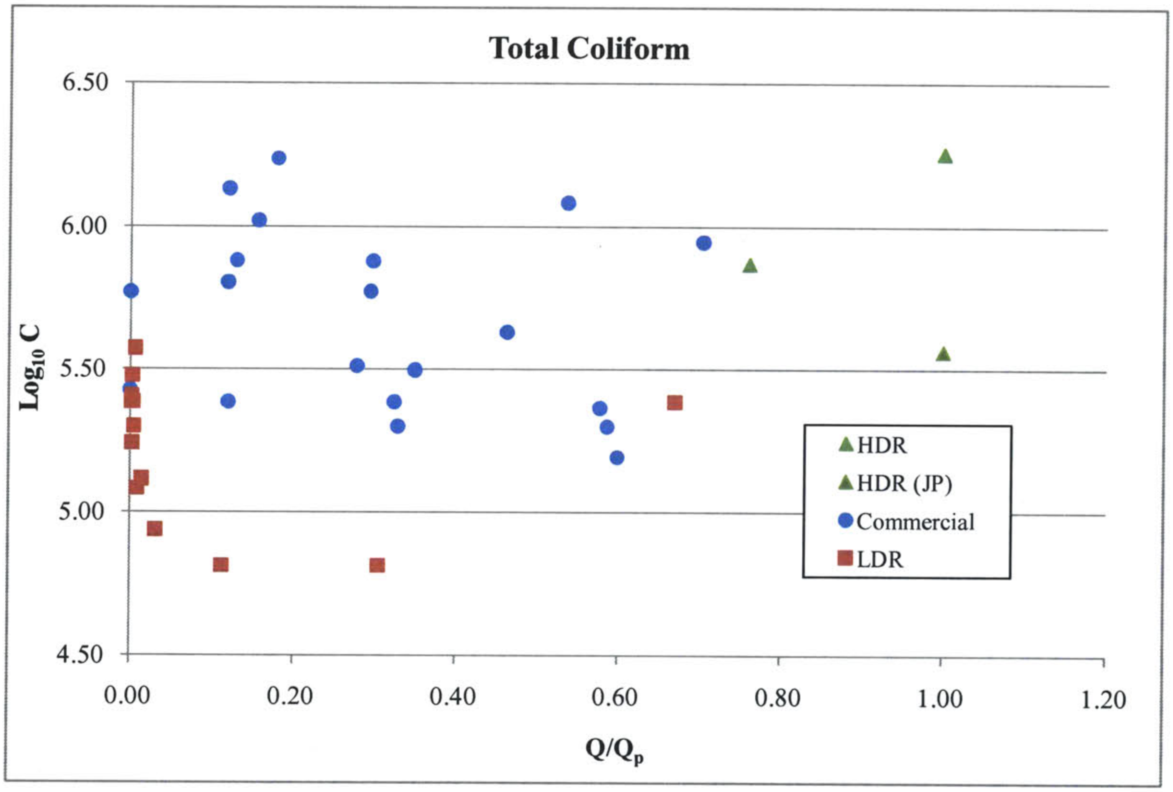


Figure 6.7a: Logarithm of Concentration of Total Coliform versus Q/Q_p

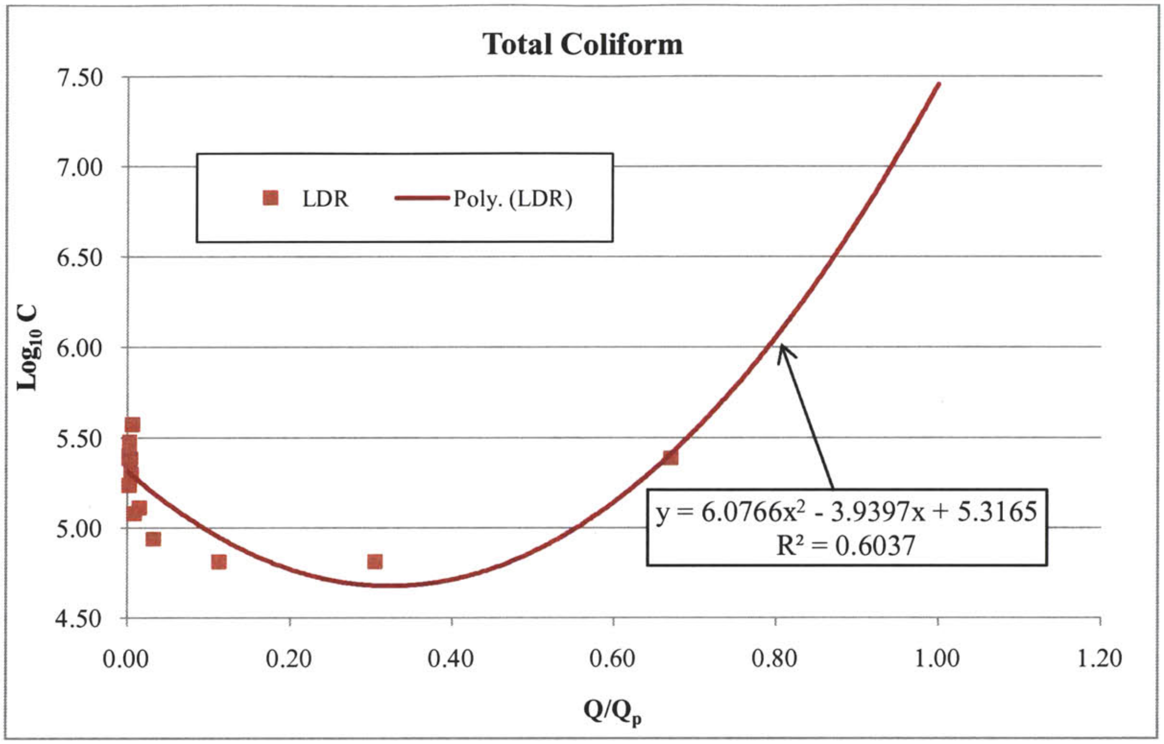


Figure 6.7b: Total Coliform Trendline for LDR Land Use (Note: in trendline formula, y = Loc$_{10}$C, x = Q/Q$_P$)

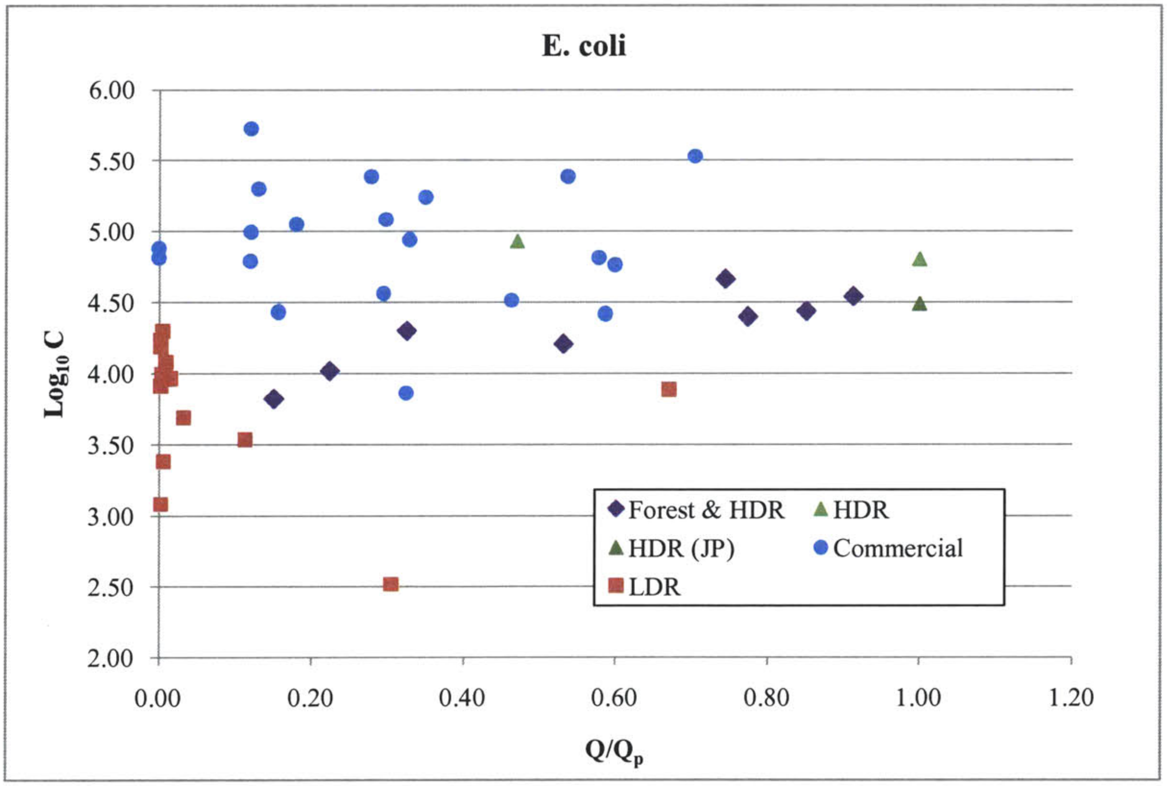


Figure 6.8a: Logarithm of Concentration of E. coli versus Q/Q$_p$

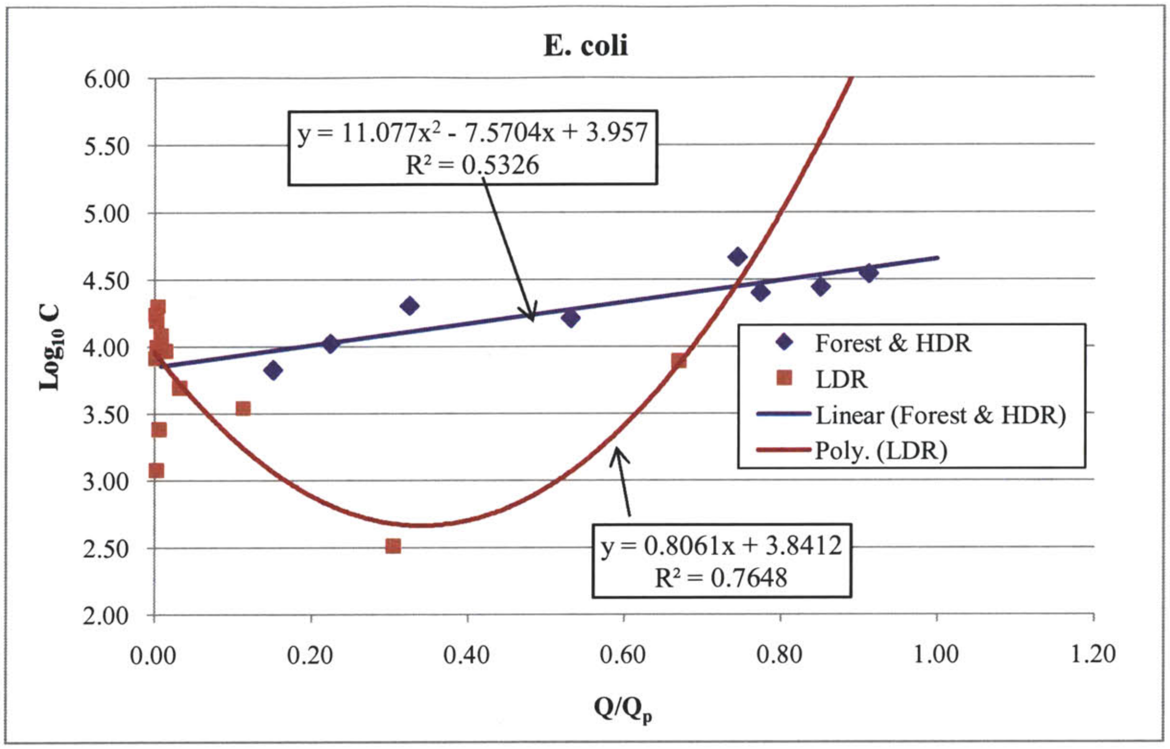


Figure 6.8b: E. coli Trendline for Forest & HDR and LDR Land Uses (Note: in trendline formula, $y = Loc_{10}C$, $x = Q/Q_P$)

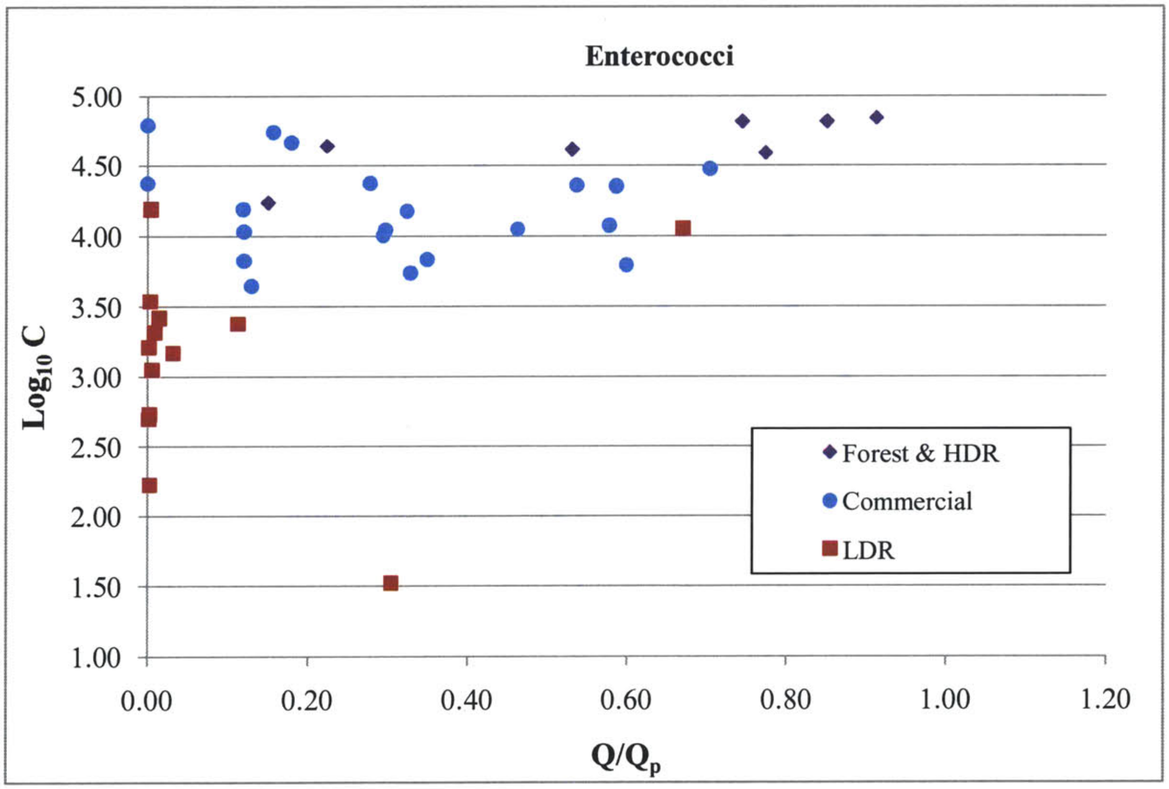


Figure 6.9a: Logarithm of Concentration of Enterococci versus Q/Q_p

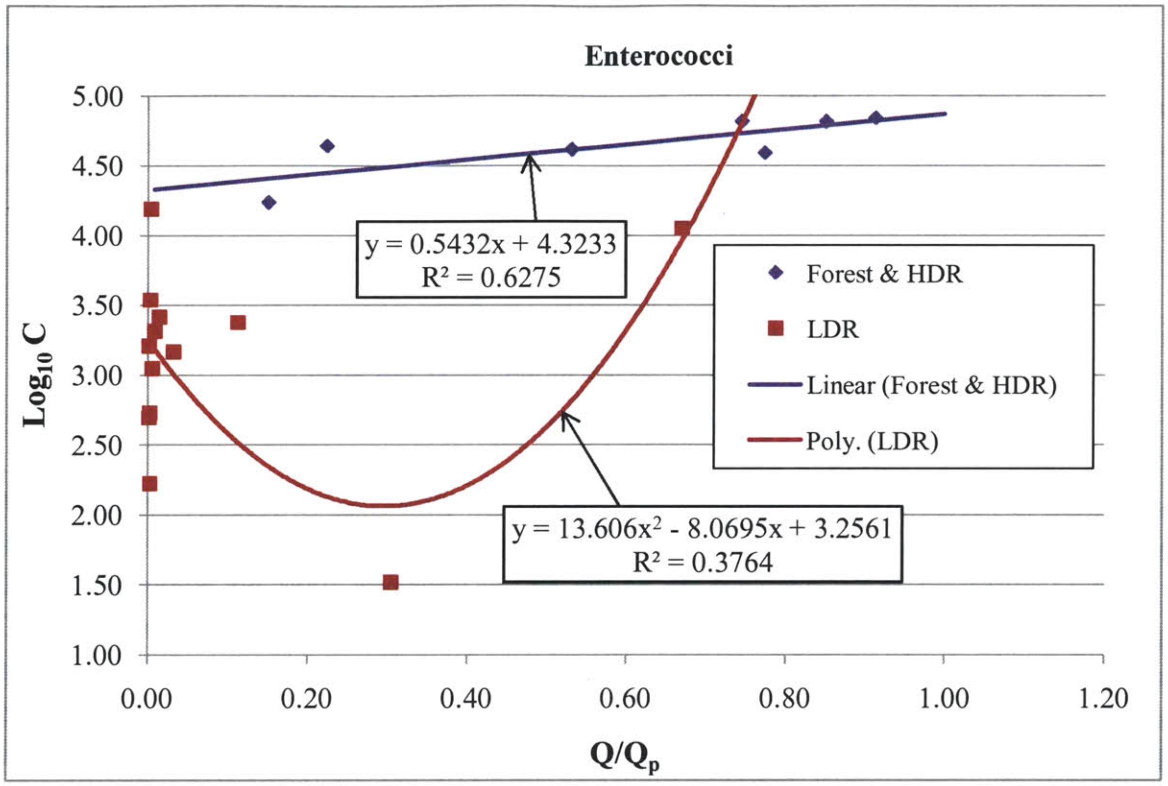


Figure 6.9b: Enterococci Trendline for Forest & HDR and LDR Land Uses (Note: in trendline formula, y = $Loc_{10}C$, x = Q/Q_P)

6.5 C/C_{dry} vs Q/Q_p

C/C_{dry} versus Q/Q_p graphs were also plotted for two reasons. First, only using C values does not show any form of comparison with C_{dry} conditions. Hence, the ratio of wet-weather concentration over dry-weather concentration (represented by the symbol C/C_{dry}) was used whereby C_{dry} values serve as the baseline ("typical" concentration without effects of rainfall) and C/C_{dry} serves as the relative departure from the baseline. Wet-weather bacterial concentrations are historically much higher than dry-weather bacterial concentrations and this comparison is an easy way to show what could be expected if a storm occurs. Secondly, similar to using Q/Q_p to eliminate variability from one storm event to another, the ratio of the instantaneous wet-weather bacterial concentration divided by a reference concentration measured during dry-weather (represented by symbol C/C_{dry}) was also used to eliminate variability between land uses. Bacterial concentrations vary systematically between land uses and were found, for example, to be consistently higher in the commercial land use area than at the LDR land use areas.

C_{dry} values were obtained from previous years' sampling data and matched with wet weather values. The dates on which dry-weather bacteria samples were collected are shown in Table 6.2. C_{dry} for the HDR land use sites were for samples collected by June (2009), as mentioned in Section 3.2, whereas C_{dry} for the commercial site were for samples collected by MIT students on

18th January 2011. All of those samples were selected because they had been collected and evaluated using similar methodology, or because the C_{dry} values were readily available. For example, both 10th February 2009 and 21 January 2009 samples had been collected by the same auto-sampler, at 1-hour time intervals, and were analyzed for total coliform and *E. coli*.

Table 6.3: Bacterial Sample Collection Dates for C and C_{dry}

Land Use	**C**	**C_{dry}**
HDR	10-Feb-09	21-Jan-09
HDR (JP)	15-Jul-09	21-Jan-09
Commercial	10-Jan-11	18-Jan-11

We also tried to ensure that corresponding dry weather samples (C_{dry} values) were collected from the site at the same time and location as the storm samples, meaning that if C was sampled under wet weather conditions at KC2 at 8:00 pm on the 10th of February 2009, we would look for C_{dry} sampled at KC2 at 8:00 pm at a date close to the 10th of February 2009 as the corresponding C_{dry}. However, those corresponding C_{dry} values were not always available since wet weather samples were collected every 20 minutes while dry weather samples were collected only once per hour. Without previous years' C_{dry} values to substitute, an average value of all C_{dry} values was used in replacement. Lack of a C_{dry} value collected under truly comparable conditions might contribute slight inaccuracies to the constructed C/C_{dry} ratios given changes in landscape over the years. For the case of the samples collected during storm events at the Forest & HDR and LDR land uses, no corresponding C_{dry} values were available so these land uses were omitted from the C/C_{dry} versus Q/Q_p graphs.

E. coli C/C_{dry} ratios were much larger than those of total coliform and enterococci. Concentrations of fecal coliform in untreated domestic wastewater ranging from low strength wastewater to high strength wastewater typically span the range 10^3-10^8 CFU/100 mL whereas concentrations of total coliform typically range from 10^6 to 10^{10} CFU/100 mL (Tchobanoglous *et al.*, 2003). The range of concentration for enterococci over low to high strength wastewater is not available but as indicated by Maier *et al.* (2009), the estimated level in raw sewage is generally 10^4-10^5 CFU/100 mL. This indicates that *E. coli* has concentrations that, despite being lower than total coliform, vary over a broader range than total coliform and than enterococci as well.

For enterococci the only C/C_{dry} values available were at the MC11 commercial area, as shown in Figure 6.12a. Wet-weather enterococci concentrations were higher than dry-weather concentrations (hence having high C/C_{dry} values) during low flows and high flows, at Q/Q_p values of 0.1 and 0.7 respectively. At mid-level flows, with Q/Q_p values of 0.3, the wet-weather enterococci concentrations were closer to the dry-weather enterococci concentrations. These fluctuations in bacterial concentrations at different flow levels show a U-shaped pattern (Figure 6.12b).

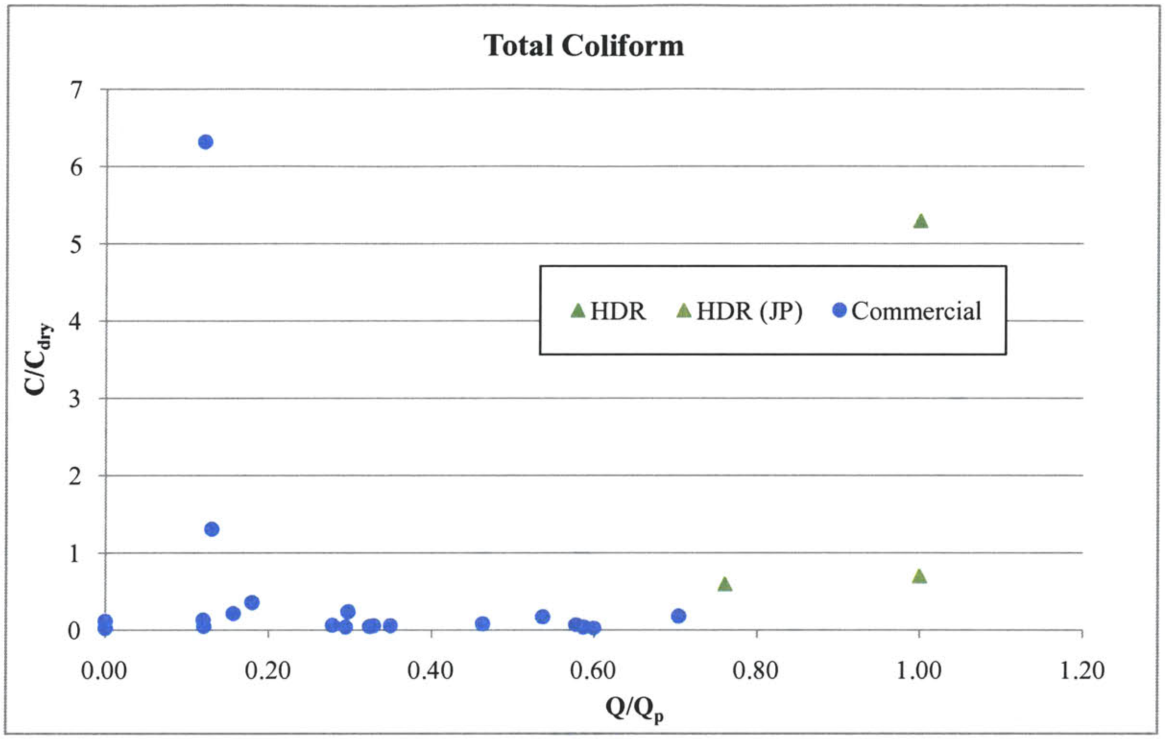


Figure 6.10: Total Coliform C/C_{dry} values versus Q/Q_p

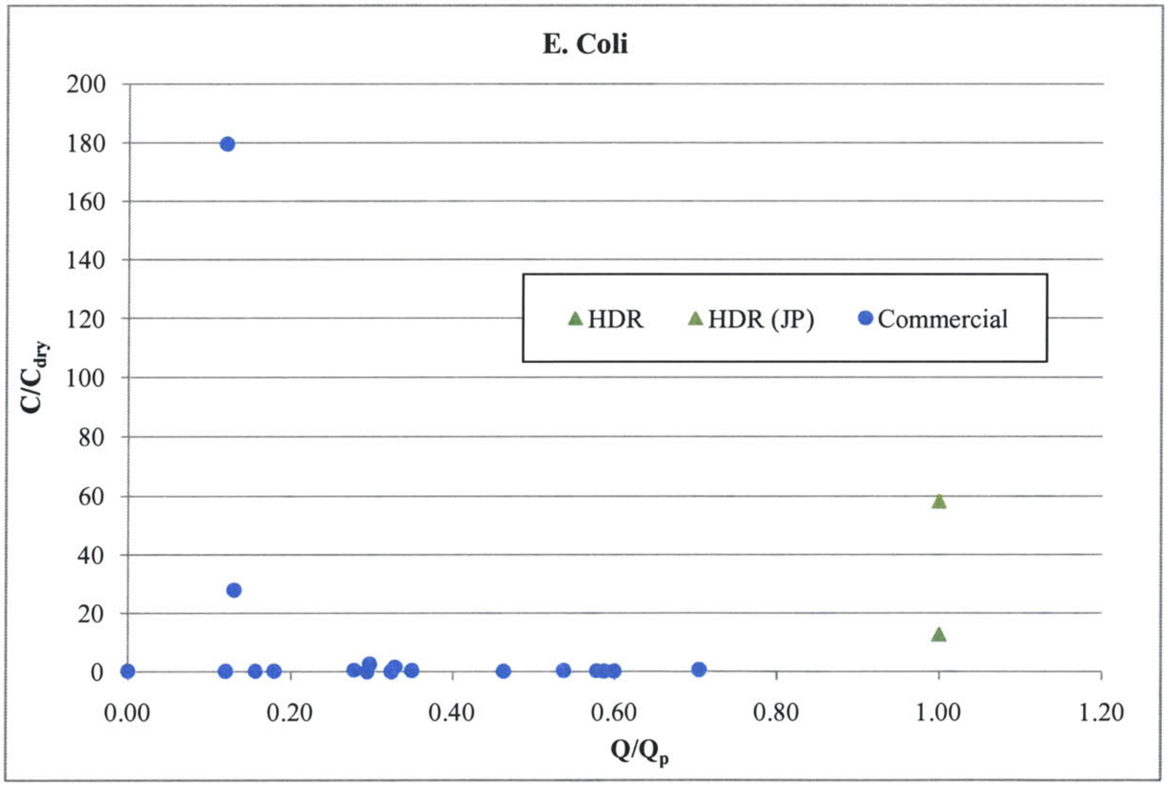


Figure 6.11: E. coli C/C_{dry} versus Q/Q_p

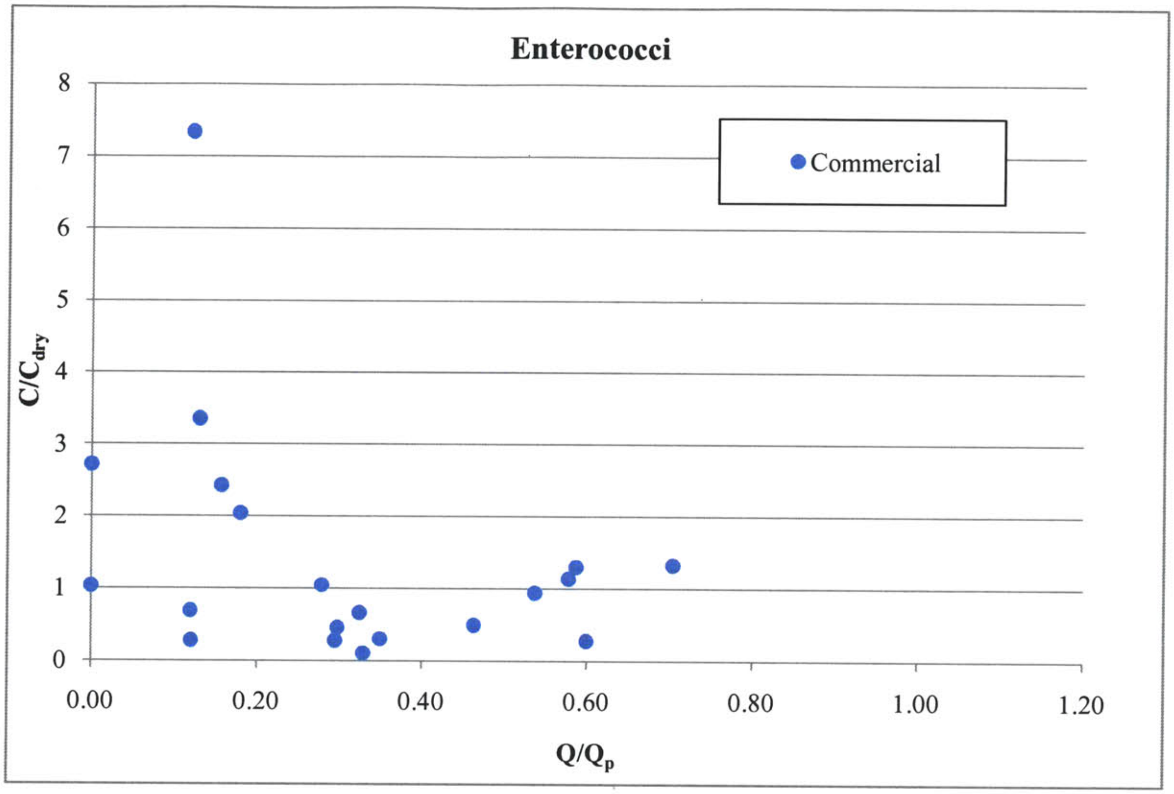


Figure 6.12a: Enterococci C/C_{dry} versus Q/Q_p

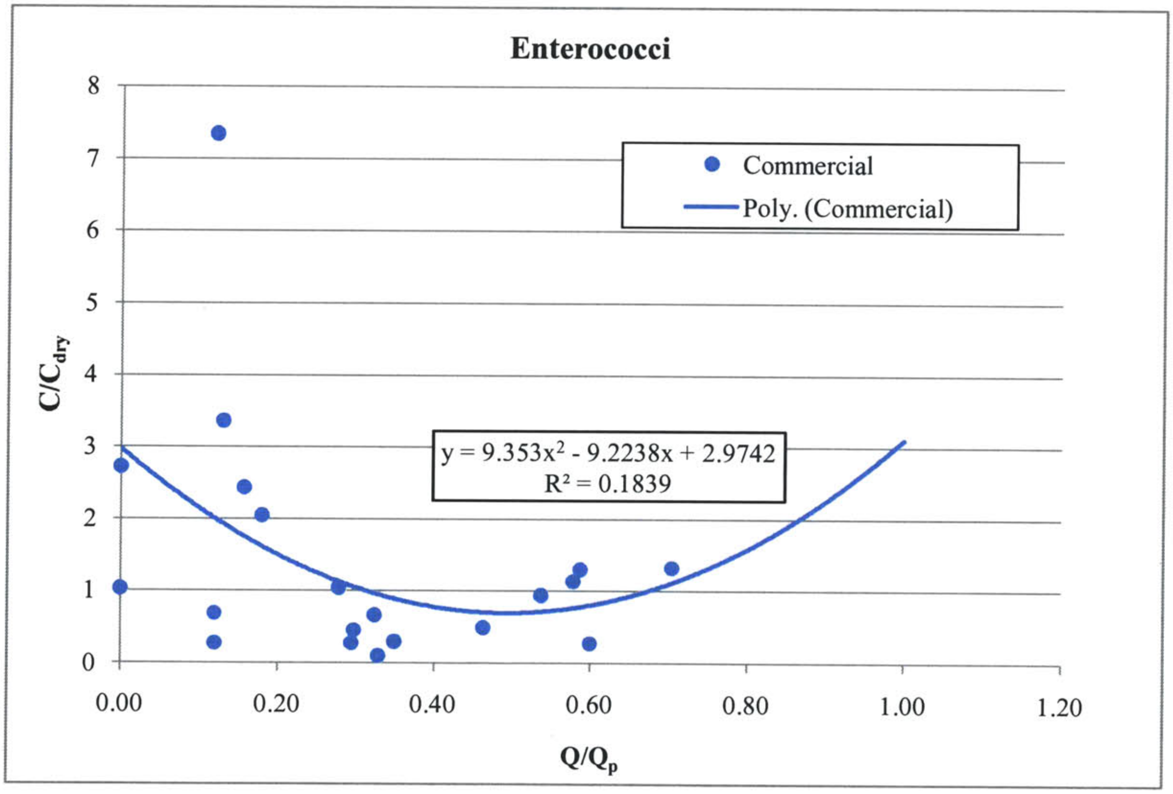


Figure 6.12b: Enterococci Trendline for Commercial Land Use

6.6 Log C vs Q/Q_{dry}

The ratio of wet-weather flow and dry-weather flow (represented by the symbol Q/Q_{dry}) was also considered besides Q/Q_p as an indicator of differences in flow during wet weather and dry weather and the effect of flow on bacterial concentrations if any. Most Q_{dry} values were obtained from previous dry weather flow information, as well as from SysEng (S) Pte. Ltd. and Greenspan Pte. Ltd.. Table 6.3 shows the dates on which Q and Q_{dry} were measured.

Table 6.4: Dates for Q and Q_{dry} Measurements

Station	**Q**	**Q_{dry}**
KC1	23-Nov-05	18-Jan-06
KC2	10-Feb-09	21-Jan-09
	15-Jul-09	21-Jan-09
KC7	8-Feb-11	9-Feb-11
MC11	10-Jan-11	18-Jan-11

As discussed by Dixon *et al.* (2009), January 2009 was an unusually dry month in Singapore and thus measured flows can be reliably taken as dry weather flow. Q_{dry} values for the commercial area (Bras Basah – MC11) were taken from measurements on 18th January 2011 whereas Q_{dry} values for LDR at Verde (KC7) were taken from measurements on 9th February 2011 because examination of the rainfall record showed both were dry-weather periods.

Log C was plotted against Q/Q_{dry} since log distributions were less spread out compared to C distributions as aforementioned in Section 6.4 and are thus an easier means to analyze patterns in different bacterial concentration distributions over the different land uses. Distributions for all three types of indicator bacteria showed similar patterns for all the different land uses: concentrations were more concentrated around lower Q/Q_{dry} ratios than around higher ratios. LDR land use bacterial concentrations (Figures 6.14 through 6.16) were the only ones with a large Q/Q_{dry} ratio, and thus large peak flow, and exhibited its highest concentrations at high flows. Forest & HDR distributions showed different patterns between *E. coli* and enterococci bacterial concentrations, as seen in Figures 6.15 and 6.16. *E. coli* concentrations were more spread out from lower to higher concentrations on the vertical axis whereas enterococci were more centered on a smaller range of values that were much lower than *E. coli* concentrations.

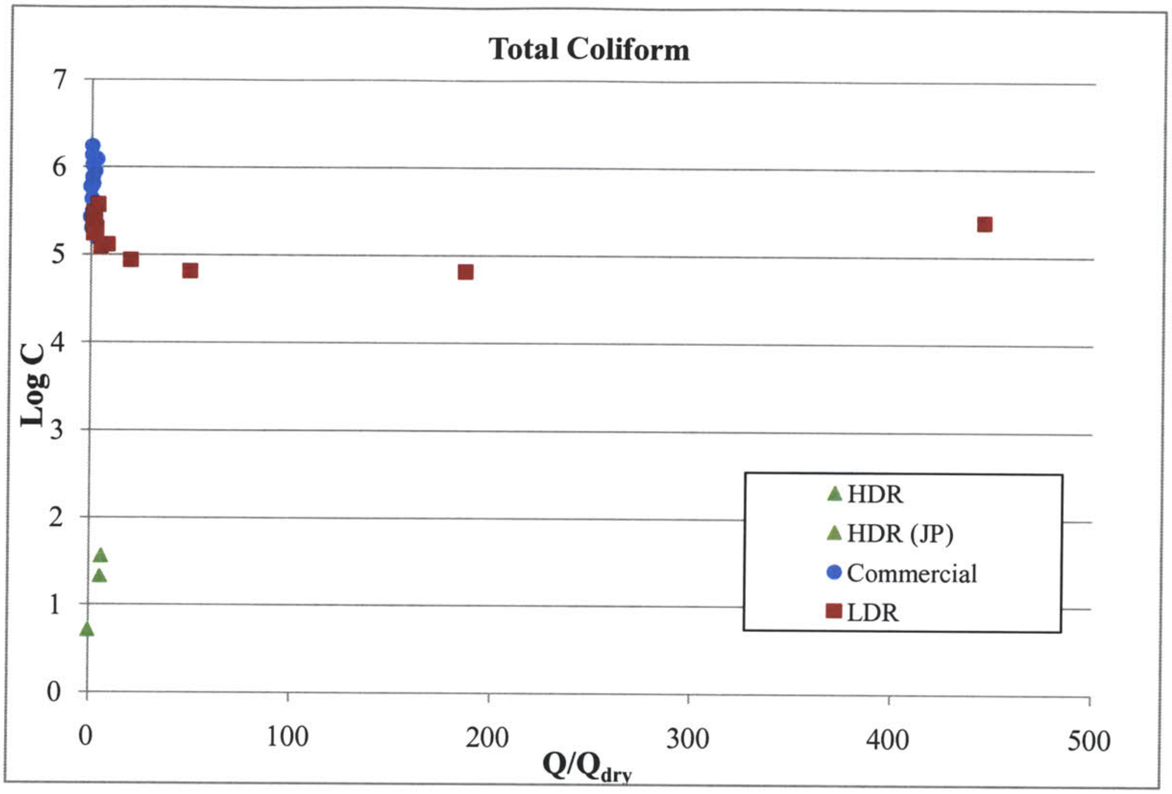


Figure 6.13: Log Total Coliform Concentration vs Q/Q_{dry}

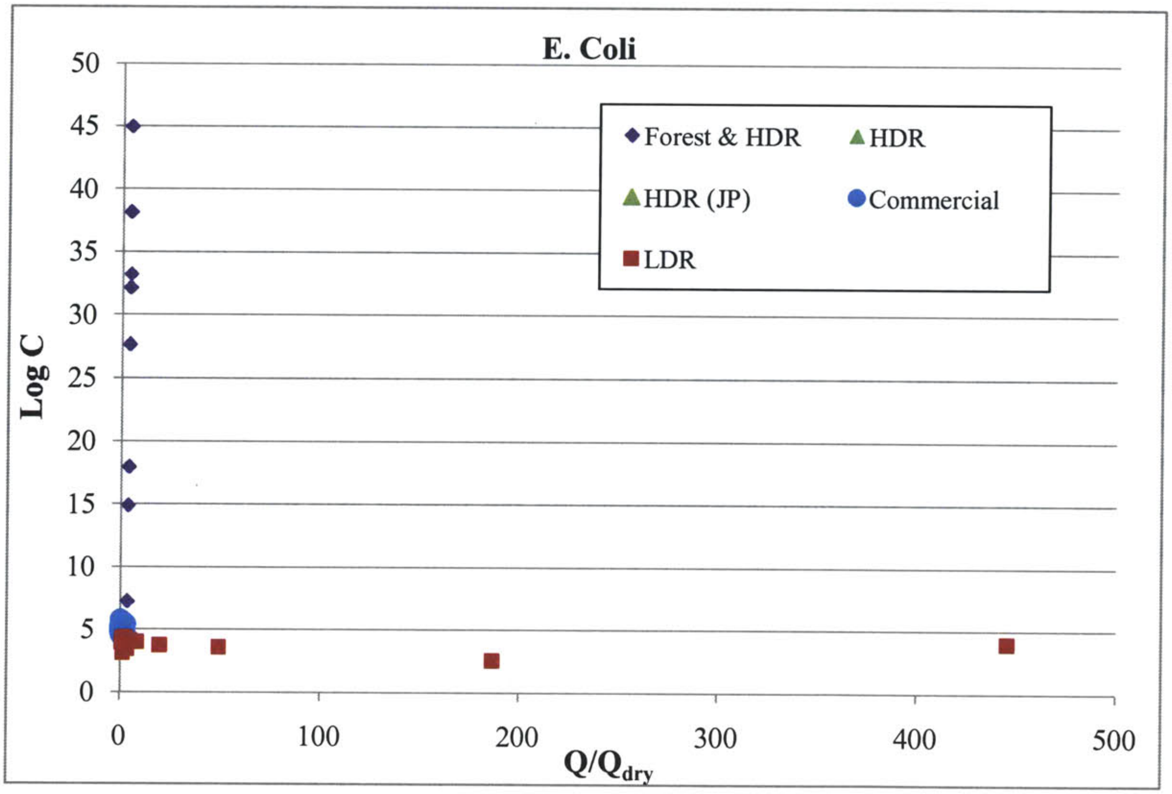


Figure 6.14: Log E. coli Concentration vs Q/Q_{dry}

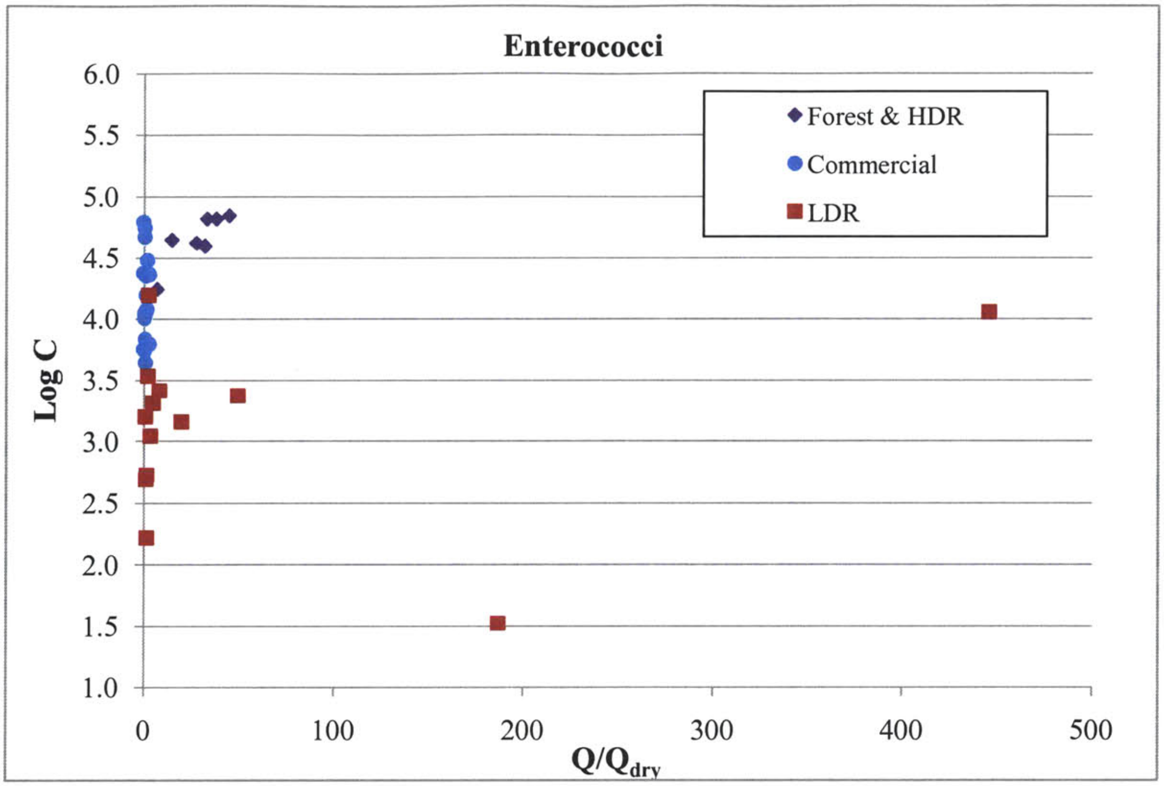


Figure 6.15: Log Enterococci Concentration vs Q/Q_{dry}

Chapter 7: Conclusions & Recommendations

7.1 Reclassification of Nshimyimana's (2010) Wet- and Dry-Weather Samples

Out of the six wet-weather datasets compiled from Nshimyimana's studies (2010), only two were able to be reclassified. These two were samples collected at KC2 and KC6 on the 15th of July 2009 and 22nd of July 2009 respectively. Bacterial samples collected at KC2 on the 15th of July were indeed storm samples, and was sampled at Q/Q_p of 1.00, indicating that the samples were collected during the peak flow of that particular storm event. When compared with flow and rainfall over time, it was discovered that KC6 samples fell outside of the storm event, and were reclassified as dry-weather samples.

The other four storm events that were sampled at KC1, KC6, and KC7 (two of the four were at KC7) could not be reclassified because the total amount of rainfall intensities fell below the initial abstraction threshold of WinTR-55 and hence no flow was predicted to occur.

7.2 Bacteriological Levels in Storm Runoff

USEPA's guideline for *E. coli* concentrations is 136 CFU/100 mL and 33 CFU/100 mL for enterococci. Singapore's 2008 NEA guidelines for enterococci is 200 CFU/100. All the wet-weather bacteria concentrations from storm water draining into Kranji and Marina Reservoirs from the various land use types exceed the guidelines with total coliform concentrations from high-density residential (HDR) areas ranging from 65,000 CFU/100 mL up to 1,800,000 CFU/100 mL (Figure 6.4a), *E. coli* concentrations from 300 CFU/100 mL to 530,000 CFU/100 mL (Figure 6.5a) and enterococci concentrations ranging from 170 CFU/100 mL to 70,000 CFU/100 mL (Figure 6.6a).

Based on Q vs C evaluations in Chapter 6, several noticeable trends were associated with the land use types, especially in concentration patterns from samples collected in November 2006 at KC1 (Forest & HDR) as well as during 2011 field sampling at Bras Basah (commercial area) and Verde (low-density residential (LDR) area).

Bacterial concentrations draining from Forest & HDR regions (shown as purple star symbols in Figures 6.5a through 6.9b) increased linearly with increasing flow when concentrations is plotted against Q/Q_p. Linear regression trendlines fitted using Microsoft Excel showed clear correlations with R^2 values ranging from 0.50 to 0.60. The forest & HDR region is considered a nonpoint source of bacteria. Hence, bacterial loads increase with flow as the higher flow flushes higher amounts of bacteria into receiving waters. Point sources are believed to be minimal in the HDR regions because sanitary sewers of recent construction service the entire area. Bacterial concentrations from LDR regions (red square symbols) peaked at low and high flows with lower concentrations at intermediate flows, thus showing U-shaped pattern curves when concentration was plotted against flow. R^2 values for these were approximately 0.65. U-shaped bacterial distributions are associated with regions where both point and nonpoint sources exist. During low flow, dry-weather sources produce limited flow, but very high loads, resulting in a high concentration. During wet weather, nonpoint source runoff contributes both flow and load, resulting in both a high flow and a high concentration.

Commercial land use consistently exhibited U-shaped C vs. Q curves with high bacterial concentrations during low and high flows. High concentrations during low flow are suspected to be due to leaky sewers in the area whereas high concentrations during high flow are caused by urban runoff from the largely impervious and densely populated area. This land is located in Bras Basah, one of the oldest commercial areas in Singapore's Historic District, which dates back to 1822. The aging infrastructure in the area has a high probability of having leaky sewers, which are point sources with high fecal coliform loads.

There was not a sufficient number of datasets for wet-weather and dry-weather concentrations to be analyzed statistically. Therefore, although several general trends were apparent (linear and U-shaped curves) and general contaminant levels are known, a conclusion cannot be made as to what parameters are best used to compare bacterial concentrations exhibited during different flow patterns from different land use types.

7.3 Recommendations

The main limitation to this study is the availability of data. Not enough rainfall intensity and flow information was readily available. Issues concerning contracted studies came in the way of obtaining required information for rainfall intensity before 22nd July 2009, and also for the KC3 and KC5 rain gage stations. Even when rainfall intensity values could be obtained from rain gages owned by SysEng(S) Pte. Ltd., the rainfall might not have been representative of the sampling site. The field sampling locations were not necessarily at or near to rain gage stations and additionally, Singapore's storms are typically highly localized thunderstorms. Hence, the rainfall intensity might have read 0.2 mm/minute at the rain gage but it could have actually been 0.5 mm/minute at the actual sampling location. Furthermore, gauging stations were sometimes not set to record flow levels. If rain gage stations closer to sampling locations with hydrologic records dating back to 2005 can be accessed in the future and more accurate rainfall conditions can be obtained, it is recommended that sampling events, especially those carried out by Nshimyimana (2010) at KC1, KC6, and KC7 (Section 3.3), be reevaluated.

Required information, especially for the November 2005 to February 2006 dataset (Section 3.1) was also not available. Part of that bacteriological study was conducted by contracted teams who were not NTU or MIT personnel from the current study team. Due to that reason, time of sampling was not known for several sampling events, which was a waste of good information. If those sampling times are discovered, future storm water bacteriological studies can incorporate this dataset, as it is quite a complete set of data from both wet and dry weather sampling events (with up to 24 samples collected per run using autosamplers).

The lack of consistency in bacterial sampling methods also posed as a limitation. Several samples were collected in January 2010 without records of sampling times. This meant that even though samples were available, we did not know when they were actually collected, and could not verify if they were collected during a storm or not.

Figure 6.1 in Chapter 6 shows that several studies focused on obtaining concentration levels for total coliform and *E. coli* whereas others focused on *E. coli* and enterococci levels. Hence, complete sets of bacterial concentration levels for all three microorganisms—total coliform, *E. coli* and enterococci—were not always available. Additionally, several samples were taken as grab samples and were not representative of the bacterial loadings in that area. Sampling conducted over longer periods of time better representation bacterial concentration fluxes over time and is recommended for future purposes.

A final recommendation is that more sampling events be carried out to collect samples during wet-weather conditions. Results certainly show elevated bacteriological conditions during storms, posing a threat to recreational water users of Kranji and Marina Reservoirs.

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Appendix A

2011 Field Sampling Results

Table A-1: Choa Chu Kang Crescent Day 1: 4th January 2011 (Dry-weather)

Sample Name	Time Sampled		Total Coliform (Yellow)									Most Representative Total Coliform (MPN/100 mL)	E. coli (Yellow and Fluorescent)									Most Representative E. coli (MPN/100 mL)	Enterococci (Fluorescent)									Most Representative Enterococci (MPN/100 mL)
Dilutions			1			100			10,000				1			100			10,000				1			100			10,000			
			L	S	MPN	L	S	MPN	L	S	MPN		L	S	MPN	L	S	MPN	L	S	MPN		L	S	MPN	L	S	MPN	L	S	MPN	
KC1B1			0	0	<1			-			-	<1	0	0	<1			-			-	<1	0	0	<1			-			-	<1
KC108	8:00	AM	49	48	>2,419.6	49	40	111,990	11	1	134,000	111,990	49	46	1,986	12	5	1,930	1	0	10,000	1,986	49	48	>2,419.6	15	1	1,870	0	0	<10,000	1,870
KC109	9:00	AM	49	48	>2,419.6	49	48	>241,960	19	2	259,000	259,000	49	44	1,553	12	0	1,350	0	0	<10,000	1,553	49	48	>2,419.6	31	1	4,790	1	0	10,000	4,790
KC110	10:00	AM	49	48	>2,419.6	49	47	241,960	21	1	279,000	241,960	49	42	1,300	13	2	1,710	1	0	10,000	1,300	49	48	>2,419.6	33	7	6,380	0	0	<10,000	6,380
KC111	11:00	AM	49	48	>2,419.6	49	47	241,960	17	2	228,000	241,960	49	47	2,420	21	1	2,790	0	0	<10,000	2,420	49	48	>2,419.6	38	6	7,940	0	0	<10,000	7,940
KC1B2			49	47	2,420			-			-	2,420	0	0	<1			-			-	<1	0	0	<1			-			-	<1
KC112	12:00	PM	49	48	>2,419.6	49	48	>241,960	48	11	1,860,000	1,860,000	49	48	>2,419.6	44	7	11,530	3	0	31,000	11,530	49	48	>2,419.6	32	11	6,820	1	0	10,000	6,820
KC113	1:00	PM	49	48	>2,419.6	49	48	>241,960	49	27	5,172,000	5,172,000	49	48	>2,419.6	28	2	4,260	0	0	<10,000	4,260	49	48	>2,419.6	38	4	7,490	1	0	10,000	7,490
KC114	2:00	PM	49	48	>2,419.6	49	48	>241,960	0	0	<10,000	>241,960	49	48	>2,419.6	35	1	5,860	0	0	<10,000	5,860	49	48	>2,419.6	32	6	5,910	0	0	<10,000	5,910
KC115	3:00	PM	49	48	>2,419.6	49	48	>241,960	24	6	402,000	402,000	49	48	>2,419.6	30	4	5,040	0	0	<10,000	5,040	49	48	>2,419.6	28	7	5,040	0	0	<10,000	5,040
KC116	4:00	PM	49	48	>2,419.6	49	44	155,310	10	0	110,000	155,310	49	48	>2,419.6	19	0	2,330	0	0	<10,000	2,330	49	48	>2,419.6	23	2	3,270	2	0	20,000	3,270
KC1B3			9	1	11			-			-	11	0	0	<1			-			-	<1	0	0	<1			-			-	<1
KC117	5:00	PM	49	48	>2,419.6	49	47	241,960	0	0	<10,000	241,960	49	48	>2,419.6	17	2	2,280	0	0	<10,000	2,280	49	48	>2,419.6	41	4	8,800	1	0	10,000	8,800
KC118	6:00	PM	49	48	>2,419.6	49	48	>241,960	20	2	275,000	275,000	49	48	>2,419.6	7	2	960	0	0	<10,000	960	49	48	>2,419.6	25	2	3,640	0	0	<10,000	3,640
KC119	7:00	PM	49	48	>2,419.6	49	48	>241,960	16	2	213,000	213,000	49	48	>2,419.6	30	6	5,370	1	0	10,000	5,370	49	48	>2,419.6	42	14	12,340	1	0	10,000	12,340

Error in lab. Possible reason is either 1mL or Colilert was forgotten to be added.

18 analytes were analysed by Setsco.

Table A-2: Choa Chu Kang Crescent Day 2: 19th January 2011 (Dry-weather)

Sample Name	Time Sampled	Total Coliform (Yellow)									Most Representative Total Coliform (MPN/100 mL)	E. coli (Yellow and Fluorescent)									Most Representative E. coli (MPN/100 mL)	Enterococci (Fluorescent)									Most Representative Enterococci (MPN/100 mL)
Dilutions		10			100			10,000				10			100			10,000				10			100			1,000			
		L	S	MPN	L	S	MPN	L	S	MPN		L	S	MPN	L	S	MPN	L	S	MPN		L	S	MPN	L	S	MPN	L	S	MPN	
KC2B1		0	0	<1			-			-	<1	0	0	<1			-			-	<1	0	0	<1			-			-	<1
KC211	11:00:00	49	48	>24,196	49	31	64,880	9	0	98,000	64,880	30	8	571	4	0	410	0	0	<10,000	571	12	1	146	0	0	<100	0	0	<1,000	146
KC212	12:00:00	49	48	>24,196	49	46	198,630	13	4	195,000	198,630	46	17	1,842	5	3	840	0	0	<10,000	1,842	44	11	1,296	11	2	1,450	0	0	<1,000	1,296
KC213	13:00:00	49	48	>24,196	49	46	198,630	15	0	175,000	198,630	48	19	2,603	7	1	850	1	0	10,000	2,603	47	13	1,785	15	1	1,870	0	0	<1,000	1,785
KC214	14:00:00	49	48	>24,196	49	48	>241,960	49	36	8,664,000	8,664,000	47	27	3,044	19	7	3,240	0	0	<10,000	3,044	49	30	6,131	40	9	9,590	7	1	8,500	6,131
KC215	15:00:00	49	48	>24,196	49	48	>241,960	34	7	670,000	670,000	43	11	1,211	7	1	850	0	0	<10,000	1,211	48	16	2,282	9	1	1,090	2	0	2,000	2,282
KC216	16:00:00	49	48	>24,196	49	48	>241,960	49	18	3,076,000	3,076,000	45	22	1,951	13	3	1,830	0	0	<10,000	1,951	49	27	5,172	25	4	3,930	3	0	3,100	5,172
KC217	17:00:00	49	48	>24,196	49	48	>241,960	43	6	1,050,000	1,050,000	48	15	2,187	20	4	3,010	0	0	<10,000	2,187	49	20	3,448	32	3	5,380	4	0	4,100	3,448
KC218	18:00:00	49	48	>24,196	49	48	>241,960	44	8	1,187,000	1,187,000	49	20	3,448	18	2	2,430	1	0	10,000	3,448	49	26	4,884	27	1	3,890	6	0	6,300	4,884
KC219	19:00:00	49	48	>24,196	49	48	>241,960	44	5	1,086,000	1,086,000	46	20	2,035	16	3	2,260	0	0	<10,000	2,035	49	42	12,997	36	6	7,170	3	0	3,100	7,170

Blank was done at dilution of 1

Table A-3: Bras Basah Day 1: 18^{th} January 2011 (Wet-Weather)

Sample Name	Time Sampled	Total Coliform (Yellow)									Most Representative Total Coliform (MPN/100 ml)	E. coli (Yellow and Fluorescent)									Most Representative E. coli (MPN/100 mL)	Enterococci (Fluorescent)									Most Representative Enterococci (MPN/100 mL)
Dilutions		1			100			10,000				1			100			10,000				1			100			10,000			
		L	S	MPN	L	S	MPN	L	S	MPN		L	S	MPN	L	S	MPN	L	S	MPN		L	S	MPN	L	S	MPN	L	S	MPN	
MB1B1		1	0	1			-			-	1	0	0	<1			-			-	<1	0	0	<1			-			-	<1
MB108		49	48	>2,419.6	49	48	>241,960	45	10	1,354,000	1,354,000	49	48	>2,419.6	49	48	>241,960	31	4	529,000	529,000	49	48	>2,419.6	42	9	10,760	3	0	31,000	10,760
MB109		49	48	>2,419.6	49	48	>241,960	36	8	759,000	759,000	49	48	>2,419.6	49	46	198,630	15	1	187,000	198,630	49	48	>2,419.6	28	3	4,410	1	0	10,000	4,410
MB110		49	48	>2,419.6	49	48	>241,960	7	2	96,000	96,000	49	48	>2,419.6	49	43	141,360	0	0	<10,000	141,360	49	48	>2,419.6	35	0	5,680	0	0	<10,000	5,680
MB111		49	48	>2,419.6	49	48	>241,960	15	2	199,000	199,000	49	48	>2,419.6	49	36	86,640	5	1	63,000	86,640	49	48	>2,419.6	33	2	5,480	1	0	10,000	5,480
MB112		49	48	>2,419.6	49	48	>241,960	37	6	754,000	754,000	49	48	>2,419.6	49	41	120,330	11	3	156,000	120,330	49	48	>2,419.6	42	10	11,060	0	0	<10,000	11,060
MB1B2		0	0	<1			-			-	<1	0	0	<1			-			-	<1	0	0	<1			-			-	<1
MB1-1237		49	48	>2,419.6	49	48	>241,960	48	9	1,722,000	1,722,000	49	48	>2,419.6	49	40	111,990	11	2	145,000	111,990	49	48	>2,419.6	49	25	46,110	8	0	86,000	46,110
MB1-1250		49	48	>2,419.6	49	47	241,960	17	1	216,000	241,960	49	48	>2,419.6	33	12	7,330	2	0	20,000	7,330	49	48	>2,419.6	47	8	15,000	4	1	52,000	15,000
MB113		49	48	>2,419.6	49	48	>241,960	18	1	231,000	231,000	49	48	>2,419.6	49	31	64,880	7	0	75,000	64,880	49	48	>2,419.6	41	15	11,910	0	0	<10,000	11,910
MB1-1320		49	48	>2,419.6	49	48	>241,960	30	9	588,000	588,000	49	48	>2,419.6	49	31	64,880	6	0	63,000	64,880	49	48	>2,419.6	49	30	51,310	2	0	20,000	61,310
MB1-1340		49	48	>2,419.6	49	48	>241,960	42	8	1,046,000	1,046,000	49	48	>2,419.6	47	24	27,000	1	0	10,000	27,000	49	48	>2,419.6	49	28	54,750	7	0	75,000	54,750
MB114		49	48	>2,419.6	49	48	>241,960	43	11	1,211,000	1,211,000	49	48	>2,419.6	49	47	241,960	15	0	175,000	241,960	49	48	>2,419.6	48	16	22,820	3	0	31,000	22,820
MB1-1420		49	48	>2,419.6	49	48	>241,960	36	2	637,000	637,000	49	48	>2,419.6	49	30	61,310	7	0	75,000	61,310	49	48	>2,419.6	47	9	15,530	3	0	31,000	15,530
MB1-1440		49	48	>2,419.6	49	48	>241,960	28	2	426,000	426,000	49	48	>2,419.6	49	19	32,550	7	0	75,000	32,550	49	48	>2,419.6	44	6	11,190	0	0	<10,000	11,190
MB115		49	48	>2,419.6	49	48	>241,960	32	6	591,000	591,000	49	48	>2,419.6	49	21	36,540	3	1	41,000	36,540	49	48	>2,419.6	40	11	10,120	0	0	<10,000	10,120
MB1-1530		49	48	>2,419.6	49	48	>241,960	23	1	313,000	313,000	49	48	>2,419.6	49	45	173,290	12	0	135,000	173,290	49	48	>2,419.6	38	1	6,840	2	0	20,000	6,840
MB116		49	48	>2,419.6	49	47	241,960	15	2	199,000	241,960	49	48	>2,419.6	49	38	98,040	10	1	121,000	98,040	49	48	>2,419.6	37	2	6,700	0	0	<10,000	6,700
MB1B3		2	1	3	-	-	-	-	-	-	3	2	1	3	-	-	-	-	-	-		0	0	<1	-	-	-	-	-	-	<1
MB1-1630		49	48	>2,419.6	49	44	155,310	18	0	218,000	155,310	49	48	>2,419.6	49	29	57,940	4	0	41,000	57,940	49	48	>2,419.6	35	3	6,240	2	0	20,000	6,240
MB117		49	48	>2,419.6	49	48	>241,960	17	5	266,000	266,000	49	48	>2,419.6	48	42	75,560	30	0	439,000	75,560	49	48	>2,419.6	49	13	23,590	3	0	31,000	23,590
MB1-1720		49	48	>2,419.6	49	48	>241,960	22	3	323,000	323,000	49	48	>2,419.6	49	47	241,960	4	0	41,000	241,960	49	48	>2,419.6	49	13	23,590	0	0	<10,000	23,590
MB1-1740		49	48	>2,419.6	49	48	>241,960	39	8	884,000	884,000	49	48	>2,419.6	49	48	>241,960	22	4	336,000	336,000	49	48	>2,419.6	48	22	29,870	2	0	20,000	29,870
MB118		49	48	>2,419.6	49	46	198,630	20	3	288,000	198,630	49	48	>2,419.6	49	15	26,130	3	0	31,000	26,130	49	48	>2,419.6	49	12	22,470	0	0	<10,000	22,470
MB119				-			-			-	-			-			-			-	-			-			-			-	-

There is no representative value for this because the value should be greater than 214 960

High concentration might be due to the turbid water (white) flowing to the sampling point

Time sampled is the last two numbers of the sample name

Table A-4: Bras Basah Day 2:18th January 2011 (Dry-Weather)

Sample Name	Time Sampled	Total Coliform (Yellow)									Most Representative Total Coliform (MPN/100 mL)	E. coli (Yellow and Fluorescent)									Most Representative E. coli (MPN/100 mL)	Enterococci (Fluorescent)									Most Representative Enterococci (MPN/100 mL)
Dilutions		1			100			10,000				1			100			10,000				1			100			10,000			
		L	S	MPN	L	S	MPN	L	S	MPN		L	S	MPN	L	S	MPN	L	S	MPN		L	S	MPN	L	S	MPN	L	S	MPN	
MB1B1		1	0	1			-			-	1	0	0	<1			-			-	<1	0	0	<1			-			-	<1
MB108		49	48	>2,419.6	49	48	>241,960	45	10	1,354,000	1,354,000	49	48	>2,419.6	49	48	>241,960	31	4	529,000	529,000	49	48	>2,419.6	42	9	10,760	3	0	31,000	10,760
MB109		49	48	>2,419.6	49	48	>241,960	36	8	759,000	759,000	49	48	>2,419.6	49	46	198,630	15	1	187,000	198,630	49	48	>2,419.6	28	3	4,410	1	0	10,000	4,410
MB110		49	48	>2,419.6	49	48	>241,960	7	2	96,000	96,000	49	48	>2,419.6	49	43	141,360	0	0	<10,000	141,360	49	48	>2,419.6	35	0	5,680	0	0	<10,000	5,680
MB111		49	48	>2,419.6	49	48	>241,960	15	2	199,000	199,000	49	48	>2,419.6	49	36	86,640	5	1	63,000	86,640	49	48	>2,419.6	33	2	5,480	1	0	10,000	5,480
MB112		49	48	>2,419.6	49	48	>241,960	37	6	754,000	754,000	49	48	>2,419.6	49	41	120,330	11	3	156,000	120,330	49	48	>2,419.6	42	10	11,060	0	0	<10,000	11,060
MB1B2		0	0	<1			-			-	<1	0	0	<1			-			-	<1	0	0	<1			-			-	<1
MB113		49	48	>2,419.6	49	48	>241,960	18	1	231,000	231,000	49	48	>2,419.6	49	31	64,880	7	0	75,000	64,880	49	48	>2,419.6	41	15	11,910	0	0	<10,000	11,910
MB114		49	48	>2,419.6	49	48	>241,960	43	11	1,211,000	1,211,000	49	48	>2,419.6	49	47	241,960	15	0	175,000	241,960	49	48	>2,419.6	48	16	22,820	3	0	31,000	22,820
MB115		49	48	>2,419.6	49	48	>241,960	32	6	591,000	591,000	49	48	>2,419.6	49	21	36,540	3	1	41,000	36,540	49	48	>2,419.6	40	11	10,120	0	0	<10,000	10,120
MB116		49	48	>2,419.6	49	47	241,960	15	2	199,000	241,960	49	48	>2,419.6	49	38	98,040	10	1	121,000	98,040	49	48	>2,419.6	37	2	6,700	0	0	<10,000	6,700
MB1B3		2	1	3	-	-	-	-	-	-	3	2	1	3	-	-	-	-	-	-		0	0	<1	-	-	-	-	-	-	<1
MB117		49	48	>2,419.6	49	48	>241,960	17	5	266,000	266,000	49	48	>2,419.6	48	42	75,560	30	0	439,000	75,560	49	48	>2,419.6	49	13	23,590	3	0	31,000	23,590
MB118		49	48	>2,419.6	49	46	198,630	20	3	288,000	198,630	49	48	>2,419.6	49	15	26,130	3	0	31,000	26,130	49	48	>2,419.6	49	12	22,470	0	0	<10,000	22,470
MB119				-			-			-	-			-			-			-	-			-			-			-	-

There is no representative value for this because the value should be greater than 214,960

Highest concentration might be due to the turbid water (white) flowing to the sampling point

Time sampled is the last two numbers of the sample name

Table A-5: Verde Day 1: 6th January 2011 (Dry-weather)

Sample Name	Time Sampled	Total Coliform (Yellow)									Most Representative Total Coliform (MPN/100 mL)	E. coli (Yellow and Fluorescent)									Most Representative E. coli (MPN/100 mL)	Enterococci (Fluorescent)									Most Representative Enterococci (MPN/100 mL)
Dilutions		1			100			10,000				1			100			10,000				1			100			10,000			
		I	S	MPN	I	S	MPN	I	S	MPN		I	S	MPN	I	S	MPN	I	S	MPN		I	S	MPN	I	S	MPN	I	S	MPN	
KV1B1		2	0	2			-			-	2	0	0	<1			-			-	<1	0	0	<1			-			-	<1
KV108		49	48	>2,419.6	49	48	>241,960	20	4	301,000	301,000	49	48	>2,419.6	49	24	43,520	3	1	41,000	43,520	49	33	727	11	2	1,450	0	0	<10,000	1,450
KV109		49	48	>2,419.6	49	48	>241,960	46	13	1,616,000	1,616,000	49	48	>2,419.6	46	4	12,100	0	0	<10,000	12,100	49	29	579	6	0	630	0	0	<10,000	630
KV110		49	48	>2,419.6	49	48	>241,960	44	8	1,187,000	1,187,000	49	48	>2,419.6	49	37	92,080	9	0	98,000	92,080	49	48	>2,419.6	48	16	22,820	3	0	31,000	31,000
KV111		49	48	>2,419.6	49	48	>241,960	45	8	1,274,000	1,274,000	49	48	>2,419.6	49	18	30,760	6	0	63,000	30,760	49	48	>2,419.6	49	25	46,110	6	0	63,000	63,000
KV112		49	48	>2,419.6	49	48	>241,960	32	3	538,000	538,000	49	48	>2,419.6	49	8	18,720	1	0	10,000	18,720	49	48	>2,419.6	49	10	20,460	4	0	41,000	41,000
KV1B2		0	0	<1			-			-	<1	0	0	<1			-			-	<1	0	0	<1			-			-	<1
KV113		49	48	>2,419.6	49	48	>241,960	17	5	266,000	266,000	49	48	>2,419.6	23	18	5,560	2	1	30,000	5,560	49	48	>2,419.6	35	10	7,630	2	0	20,000	20,000
KV114				-			-			-	-			-			-			-	-			-			-			-	-
KV115		49	48	>2,419.6	49	47	241,960	20	2	275,000	241,960	49	48	>2,419.6	49	17	29,090	3	0	31,000	29,090	49	48	>2,419.6	32	1	5,040	1	0	10,000	10,000
KV116				-			-			-	-			-			-			-	-			-			-			-	-
KV117				-			-			-	-			-			-			-	-			-			-			-	-
KV118				-			-			-	-			-			-			-	-			-			-			-	-
KV119				-			-			-	-			-			-			-	-			-			-			-	-

Clear blue fluorescence reading. The other readings had unclear blue fluorescence

E coli concentrations at Verde were higher than Crescent.

Time sampled is the last two numbers of the sample name

Table A-6: Verde Day 2: 12th January 2011 (Dry-weather)

Sample Name	Time Sampled	Total Coliform (Yellow)									Most Representative Total Coliform (MPN/100 mL)	E. coli (Yellow and Fluorescent)									Most Representative E. coli (MPN/100 mL)	Enterococci (Fluorescent)									Most Representative Enterococci (MPN/100 mL)	
Dilutions		10			100			10,000				10			100			10,000				10			100			1,000				
		L	S	MPN	L	S	MPN	L	S	MPN		L	S	MPN	L	S	MPN	L	S	MPN		L	S	MPN	L	S	MPN	L	S	MPN		
KV2B1		1	0	1			-			-	1	0	0	<1			-			-	<1	0	0	<1			-			-	<1	blank was done at dilution 1.
KV208		49	48	>24,196	49	48	>241,960	47	16	1,989,000	1,989,000	49	48	>24,196	48	20	27,230	1	1	20,000	27,230	35	8	723	8	1	970	1	0	1,000	723	
KV209		49	48	>24,196	49	48	>241,960	48	9	1,722,000	1,722,000	49	42	12,997	44	7	11,530	1	0	10,000	12,997	34	8	689	7	0	750	2	0	2,000	689	
KV210		49	48	>24,196	49	48	>241,960	44	8	1,187,000	1,187,000	49	48	>24,196	49	38	98,040	12	0	135,000	98,040	49	27	5,172	33	4	5,830	5	0	5,200	5,172	
KV211		49	48	>24,196	49	48	>241,960	38	10	886,000	886,000	49	48	>24,196	49	23	41,060	4	0	41,000	41,060	46	9	1,421	21	1	2,790	1	0	1,000	1,421	
KV212		49	48	>24,196	49	48	>241,960	18	4	269,000	269,000	49	30	6,131	33	3	5,650	0	0	<10,000	6,131	27	4	435	4	1	520	0	0	<1,000	435	
KV2B2		0	0	<1			-			-	<1	0	0	<1			-			-	<1	0	0	<1			-			-	<1	blank was done at dilution 1.
KV213		49	48	>24,196	49	48	>241,960	46	15	1,725,000	1,725,000	49	33	7,270	39	4	7,890	0	0	<10,000	7,270	36	2	637	8	1	970	0	0	<1,000	637	
KV214		49	48	>24,196	49	48	>241,960	49	30	6,131,000	6,131,000	49	47	24,196	48	19	26,030	1	0	10,000	24,196	49	12	2,247	18	2	2,450	2	0	2,000	2,247	
KV215		49	48	>24,196	49	48	>241,960	49	18	3,076,000	3,076,000	49	35	8,164	20	3	2,880	2	0	20,000	8,164	49	43	14,136	27	3	4,200	5	1	6,300	4,200	
KV216		49	48	>24,196	49	47	241,960	17	1	216,000	241,960	49	36	8,664	40	6	8,820	2	0	20,000	8,664	16	1	201	1	0	100	0	0	<1,000	201	
KV2B3		0	0	<1			-			-	<1	0	0	<1			-			-	<1	0	0	<1			-			-	<1	blank was done at dilution 1.
KV217		49	48	>24,196	49	48	>241,960	40	4	833,000	833,000	49	39	10,462	45	7	12,360	3	0	31,000	10,462	23	2	327	4	0	410	0	0	<1,000	327	
KV218		49	48	>24,196	49	48	>241,960	40	7	908,000	908,000	49	47	24,196	32	14	7,380	4	0	41,000	7,380	46	16	1,782	15	3	2,110	2	0	2,000	1,782	
KV219		49	48	>24,196	49	48	>241,960	24	3	359,000	359,000	49	48	>24,196	48	24	32,820	6	0	63,000	32,820	48	26	3,609	24	4	3,730	3	0	3,100	3,609	

Inconsistent first and second dilution readings. Meanwhile, first dilution readings were taken

E coli concentrations at Verde were higher than Crescent.

Time sampled is the last two numbers of the sample name

Table A-7: Verde Day 3: 8th February 2011 (Wet-weather)

Sample Name	Time Sampled	Total Coliform (Yellow)									Most Representative Total Coliform (MPN/100 mL)	E. coli (Yellow and Fluorescent)									Most Representative E. coli (MPN/100 mL)	Enterococci (Fluorescent)									Most Representative Enterococci (MPN/100 mL)	
Dilutions		10			100			10,000				10			100			10,000				10			100			1,000				
		L	S	MPN	L	S	MPN	L	S	MPN		L	S	MPN	L	S	MPN	L	S	MPN		L	S	MPN	L	S	MPN	L	S	MPN		
KV301	1908	49	48	>2,419.6	49	31	64,880	3	0	31,000	64,880	49	19	326	19	6	3,110	1	0	10,000	326	24	1	33	2	1	300	0	0	<1,000	33	blank was done at dilution 1
KV302	1918	49	48	>24,196	49	47	241,960	21	1	279,000	241,960	49	34	7,701	43	11	12,110	0	0	<10,000	7,701	49	40	11,199	47	6	9,880	7	1	8,500	11,199	
KV303	1928	49	48	>24,196	49	31	64,880	5	1	63,000	64,880	49	20	3,448	35	7	7,030	0	0	<10,000	3,448	48	17	2,382	15	1	1,870	0	0	<1,000	2,382	
KV304	1938	49	48	>24,196	49	36	86,640	9	0	98,000	86,640	49	26	4,884	36	2	6,370	0	0	<10,000	4,884	46	10	1,467	13	1	1,600	0	0	<1,000	1,467	
KV305	1948	49	48	>24,196	49	42	129,970	10	1	121,000	129,970	49	37	9,208	41	7	9,590	1	0	10,000	9,208	49	15	2,613	19	2	2,590	4	0	4,100	2,613	
KV306	1958	49	48	>24,196	49	41	120,330	17	2	158,000	120,330	49	41	12,033	47	12	11,690	2	2	41,000	12,033	47	17	2,064	16	0	1,890	0	0	<1,000	2,064	
KV307	2008	49	48	>2,419.6	49	48	>241,960	24	4	373,000	373,000	49	47	2,420	48	11	18,600	2	0	20,000	2,420	49	40	1,120	40	8	9,330	12	2	15,800	1,120	blank was done at dilution 1
KV308	2018	49	48	>24,196	49	46	198,630	22	3	323,000	198,630	49	46	19,863	46	17	18,420	2	0	20,000	19,863	49	44	15,531	39	10	9,340	13	1	16,000	15,531	
KV309	2028	49	48	>24,196	49	47	241,960	20	2	275,000	241,960	49	35	8,164	47	15	19,180	2	0	20,000	8,164	46	13	1,616	15	1	1,870	1	0	1,000	1,616	
KV310	2038	49	48	>24,196	49	47	241,960	13	2	171,000	241,960	49	38	9,804	48	13	20,140	1	0	10,000	9,804	49	20	3,448	15	1	1,870	1	0	1,000	3,448	
KV311	2048	49	48	>2,419.6	49	48	>241,960	23	0	299,000	299,000	49	41	1,203	44	9	12,230	1	0	10,000	1,203	47	11	166	9	0	980	0	0	<1,000	166	blank was done at dilution 1
KV312	2058	49	48	>24,196	49	45	173,290	11	2	145,000	173,290	49	44	15,531	44	10	12,590	0	0	<10,000	15,531	30	6	537	7	1	850	0	0	<1,000	537	
KV313	2108	49	48	>24,196	49	48	>241,960	17	4	253,000	253,000	48	48	10,112	48	9	17,220	0	0	<10,000	17,220	31	2	495	5	0	520	0	0	<1,000	495	

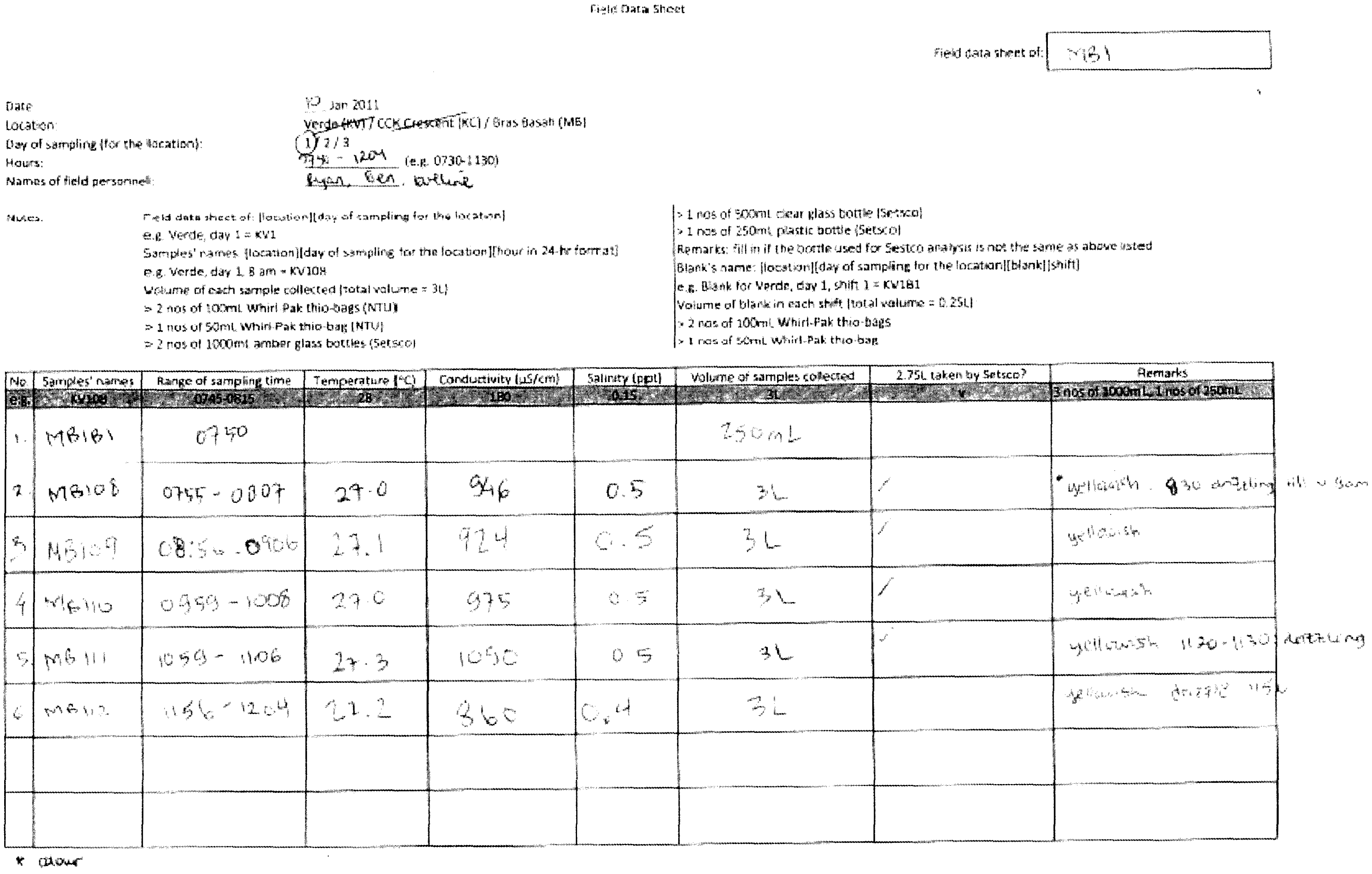
Inconsistent first and second dilution readings. Meanwhile, first dilution readings were taken.

E coli concentrations at Verde were higher than Crescent

Appendix B

Select Field Notes

Table B-1: Bras Basah Field Notes, taken on 10th January 2011 (Wet -weather)



Field Data Sheet

Field data sheet of: MB1

Date: 10 Jan 2011
Location: ~~Verde (KV)~~ / ~~CCK Crescent~~ (KC) / Bras Basah (MB)
Day of sampling (for the location): [✓ 1] / 2 / 3
Hours: 0750 - 1204 (e.g. 0730-1130)
Names of field personnel: Ryan, Ben, [illegible]

Notes:

Field data sheet of: [location][day of sampling for the location]
e.g. Verde, day 1 = KV1
Samples' names: [location][day of sampling for the location][hour in 24-hr format]
e.g. Verde, day 1, 8 am = KV108
Volume of each sample collected (total volume = 3L)
> 2 nos of 100mL Whirl Pak thio-bags (NTU)
> 1 nos of 50mL Whirl-Pak thio-bag (NTU)
> 2 nos of 1000mL amber glass bottles (Setsco)
> 1 nos of 500mL clear glass bottle (Setsco)
> 1 nos of 250mL plastic bottle (Setsco)
Remarks: fill in if the bottle used for Sestco analysis is not the same as above listed
Blank's name: [location][day of sampling for the location][blank][shift]
e.g. Blank for Verde, day 1, shift 1 = KV1B1
Volume of blank in each shift (total volume = 0.25L)
> 2 nos of 100mL Whirl-Pak thio-bags
> 1 nos of 50mL Whirl-Pak thio-bag

No	Samples' names	Range of sampling time	Temperature (°C)	Conductivity (µS/cm)	Salinity (ppt)	Volume of samples collected	2.75L taken by Setsco?	Remarks
e.g.	KV108	0745-0815	28	180	0.15	3L	✓	3 nos of 1000mL, 1 nos of 250mL
1.	MB1B1	0750				250mL		
2.	MB108	0755 - 0807	27.0	946	0.5	3L	✓	*yellowish. 830 drizzling till ~ 9am
3	MB109	08:56 - 0906	27.1	924	0.5	3L	✓	yellowish
4	MB110	0959 - 1008	27.0	975	0.5	3L	✓	yellowish
5.	MB111	1059 - 1106	27.3	1050	0.5	3L	✓	yellowish 1120-1130 drizzling
6	MB112	1156 - 1204	27.2	860	0.4	3L		yellowish drizzle 1156

* odour

Field Data Sheet

Field data sheet of: MB1

1

Date: 10 Jan 2011
Location: Verde (KV) / CCK Crescent (KC) / [✓ Bras Basah (MB)]
Day of sampling (for the location): [✓ 1] / 2 / 3
Hours: 1130 - 1630 (e.g. 0730-1130)
Names of field personnel: Ryan, Gem

Notes
Field data sheet of: [location][day of sampling for the location]
e.g. Verde, day 1 = KV1
Samples' names: [location][day of sampling for the location][hour in 24-hr format]
e.g. Verde, day 1, 8 am = KV108
Volume of each sample collected (total volume = 3L):
> 2 nos of 100mL Whirl-Pak thio-bags (NTU)
> 1 nos of 50mL Whirl-Pak thio-bag (NTU)
> 2 nos of 1000mL amber glass bottles (Setsco)
> 1 nos of 500mL clear glass bottle (Setsco)
> 1 nos of 250mL plastic bottle (Setsco)
Remarks: fill in if the bottle used for Setsco analysis is not the same as above listed
Blank's name: [location][day of sampling for the location][blank][shift]
e.g. Blank for Verde, day 1, shift 1 = KV1B1
Volume of blank in each shift (total volume = 0.25L)
> 2 nos of 100mL Whirl-Pak thio-bags
> 1 nos of 50mL Whirl-Pak thio-bag

No.	Samples' names	Range of sampling time	Temperature (°C)	Conductivity (µS/cm)	Salinity (ppt)	Volume of samples collected	2.75L taken by Setsco?	Remarks
1	MB1B2	110				250mL		
2	MB113	1259 - 108	26.7	922	0.5	3L		Drizzling
3	MB114	158 - 208	26.6	404.1	0.2	3L		1320 ~~drainwater turbid~~ gunite W level up by ~ 3cm Still flowing, oily sheen
4	MB115	255 - 306	26.7	3344	0.2	3L		Flow low again still higher than early AM
5	MB116	354 - 410	26.6	477.3	0.2	3L		Started to drizzle again 4pm
6	MB117	455 - 505	26.4	450.5	0.2	3L		Heavier rain - "slight rain" - steady 445-

Field Data Sheet

Field data sheet of: MB1

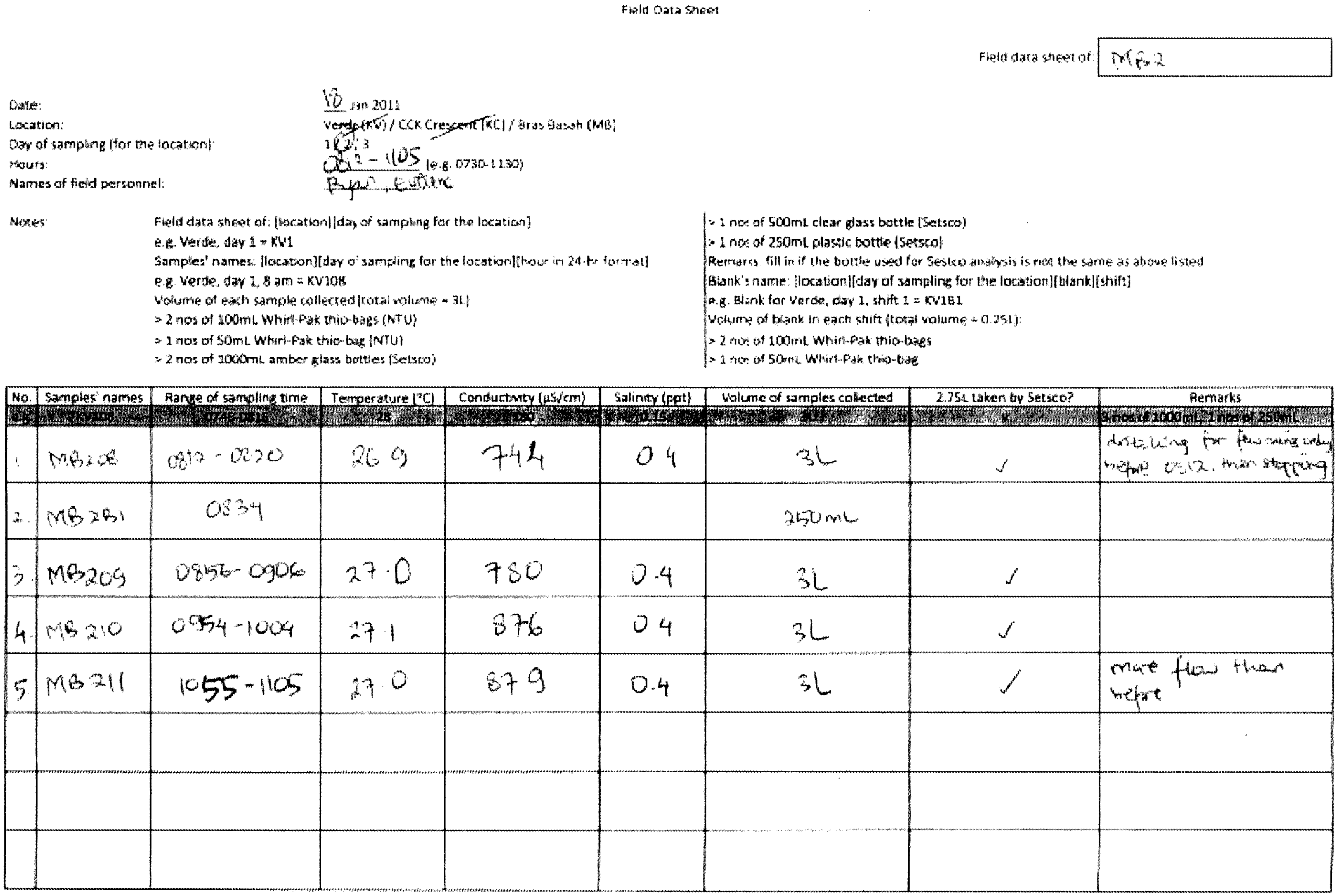
3

Date: 20 Jan 2011
Location: Verde (KV) / CCK Crescent (KC) / [✓ Bras Basah (MB)]
Day of sampling (for the location): [✓ 1] / 2 / 3
Hours: ________ (e.g. 0730-1130)
Names of field personnel: Ryan Green

Notes:
Field data sheet of: [location][day of sampling for the location]
e.g. Verde, day 1 = KV1
Samples' names: [location][day of sampling for the location][hour in 24 hr format]
e.g. Verde, day 1, 8 am = KV108
Volume of each sample collected (total volume = 3L):
> 2 nos of 100mL Whirl-Pak thio-bags (NTU)
> 1 nos of 50mL Whirl-Pak thio-bag (NTU)
> 2 nos of 1000mL amber glass bottles (Setsco)
> 1 nos of 500mL clear glass bottle (Setsco)
> 1 nos of 250mL plastic bottle (Setsco)
Remarks: fill in if the bottle used for Sestco analysis is not the same as above listed
Blank's name: [location][day of sampling for the location][blank][shift]
e.g. Blank for Verde, day 1, shift 1 = KV1B1
Volume of blank in each shift (total volume = 0.25L)
> 2 nos of 100mL Whirl-Pak thio-bags
> 1 nos of 50mL Whirl-Pak thio bag

No.	Samples' names	Range of sampling time	Temperature (°C)	Conductivity (µS/cm)	Salinity (ppt)	Volume of samples collected	2.75L taken by Setsco?	Remarks
e.g.	KV108	[illegible]	[illegible]	180	0.157	3L	[illegible]	2 nos of 1000mL, 1 nos of 250mL
1	MB1-1237	1237	26.7	730	0.4	250mL		Drizzles
2	MB1_1250	1250	27.1	758	0.4	250mL		Drizzles
3	MB1_1320	1320	27.1	831	0.3	250mL		turbid white water Drain filled 3cm higher oily green
4	MB1_1340	1340	26.7	479.2	0.2	250 mL		Cigarette butts plastic bags leaves
5	MB1-1420	1420	26.4	310.3	0.1	250 mL		
6	MB1-1440	1440	26.6	311.0	0.1	250 mL		
7	MB1-1530	1530	26.7	423.8	0.2	250 mL		
8	MB1-1630	~~1630~~ 1630	~~26.6~~ 26.7	~~[illegible]~~ 489.1	~~[illegible]~~ 0.2	250 mL		drizzle & light rain
9	MB1-1720	1720	26.7	314.6	0.2	250 mL		
10	MB1-1740	1740	26.1	230.3	0.1	250 mL		stormy
11	MB1-1800	1800	26.1	171.9	0.1	250 mL		

Table B-2: Bras Basah Field Notes Taken on 18th January 2011 (Dry-weather)



Field Data Sheet

Field data sheet of: MB2

Date: 18 Jan 2011
Location: ~~Verde (KV)~~ / ~~CCK Crescent (KC)~~ / Bras Basah (MB)
Day of sampling (for the location): 1 [✓ 2] 3
Hours: 0812 - 1105 (e.g. 0730-1130)
Names of field personnel: Ryan, Eutine

Notes:
Field data sheet of: [location][day of sampling for the location]
e.g. Verde, day 1 = KV1
Samples' names: [location][day of sampling for the location][hour in 24-hr format]
e.g. Verde, day 1, 8 am = KV108
Volume of each sample collected (total volume = 3L)
> 2 nos of 100mL Whirl-Pak thio-bags (NTU)
> 1 nos of 50mL Whirl-Pak thio-bag (NTU)
> 2 nos of 1000mL amber glass bottles (Setsco)
> 1 nos of 500mL clear glass bottle (Setsco)
> 1 nos of 250mL plastic bottle (Setsco)
Remarks: fill in if the bottle used for Sestco analysis is not the same as above listed
Blank's name: [location][day of sampling for the location][blank][shift]
e.g. Blank for Verde, day 1, shift 1 = KV1B1
Volume of blank in each shift (total volume = 0.25L):
> 2 nos of 100mL Whirl-Pak thio-bags
> 1 nos of 50mL Whirl-Pak thio-bag

No.	Samples' names	Range of sampling time	Temperature (°C)	Conductivity (µS/cm)	Salinity (ppt)	Volume of samples collected	2.75L taken by Setsco?	Remarks
e.g.	KV108	0748-0816	28	[illegible]1080	0.15	3L	✓	2 nos of 1000mL, 1 nos of 250mL
1	MB208	0812 - 0820	26.9	744	0.4	3L	✓	drizzling for few mins only before 0812, then stopping
2.	MB2B1	0834				250mL		
3.	MB209	0856-0906	27.0	780	0.4	3L	✓	
4.	MB210	0954-1004	27.1	876	0.4	3L	✓	
5	MB211	1055-1105	27.0	879	0.4	3L	✓	more flow than before

Field Data Sheet

Field data sheet of: MB2

Date: 18 Jan 2011
Location: ~~Verde (KV)~~ / CCK ~~Crescent (KC)~~ / Bras Basah (MB)
Day of sampling (for the location): 1 / [✓ 2] / 3
Hours: 1155-1601 (e.g. 0730-1130)
Names of field personnel: Ryan, Eveline

Notes:
Field data sheet of: [location][day of sampling for the location]
e.g. Verde, day 1 = KV1
Samples' names. [location][day of sampling for the location][hour in 24-hr format]
e.g. Verde, day 1, 8 am = KV108
Volume of each sample collected (total volume = 3L):
> 2 nos of 100mL Whirl-Pak thio-bags (NTU)
> 1 nos of 50mL Whirl-Pak thio-bag (KTU)
> 2 nos of 1000mL amber glass bottles (Setsco)
> 1 nos of 500mL clear glass bottle (Setsco)
> 1 nos of 250mL plasic bottle (Setsco)
Remarks: fill in if the bottle used for Sestco analysis is not the same as above listed
Blank's name: [location][day of sampling for the location][blank][shift]
e.g. Blank for Verde, day 1, shift 1 = KV1B1
Volume of blank in each shift (total volume = 0.25L):
> 2 nos of 100mL Whirl-Pak thio-bags
> 1 nos of 50mL Whirl-Pak thio-bag

No.	Samples' names	Range of sampling time	Temperature (°C)	Conductivity (µS/cm)	Salinity (ppt)	Volume of samples collected	2.75L taken by Setsco?	Remarks
e.g.	KV108	0745-0815	28	180	0.15	3L	v	3 nos of 1000mL, 1 nos of 250mL
1.	MB212	1155-1207	27.0	649	0.3	5L including duplicate	✓	~~less~~ flow than MB211 than more flow after 1207
2	MB2B2	1217				250mL		
3	MB213	1255-1307	27.9	765	0.4	5L including duplicate		
4	MB214	1355-1407	27.6	776	0.4	5L including duplicate		less flow
5.	MB215	1455-1504	27.7	847	0.4	3L		
6.	MB216	1553-1601	27.5	838	0.4	3L		more flow (less than MB211)

Field Data Sheet

Field data sheet of MB2

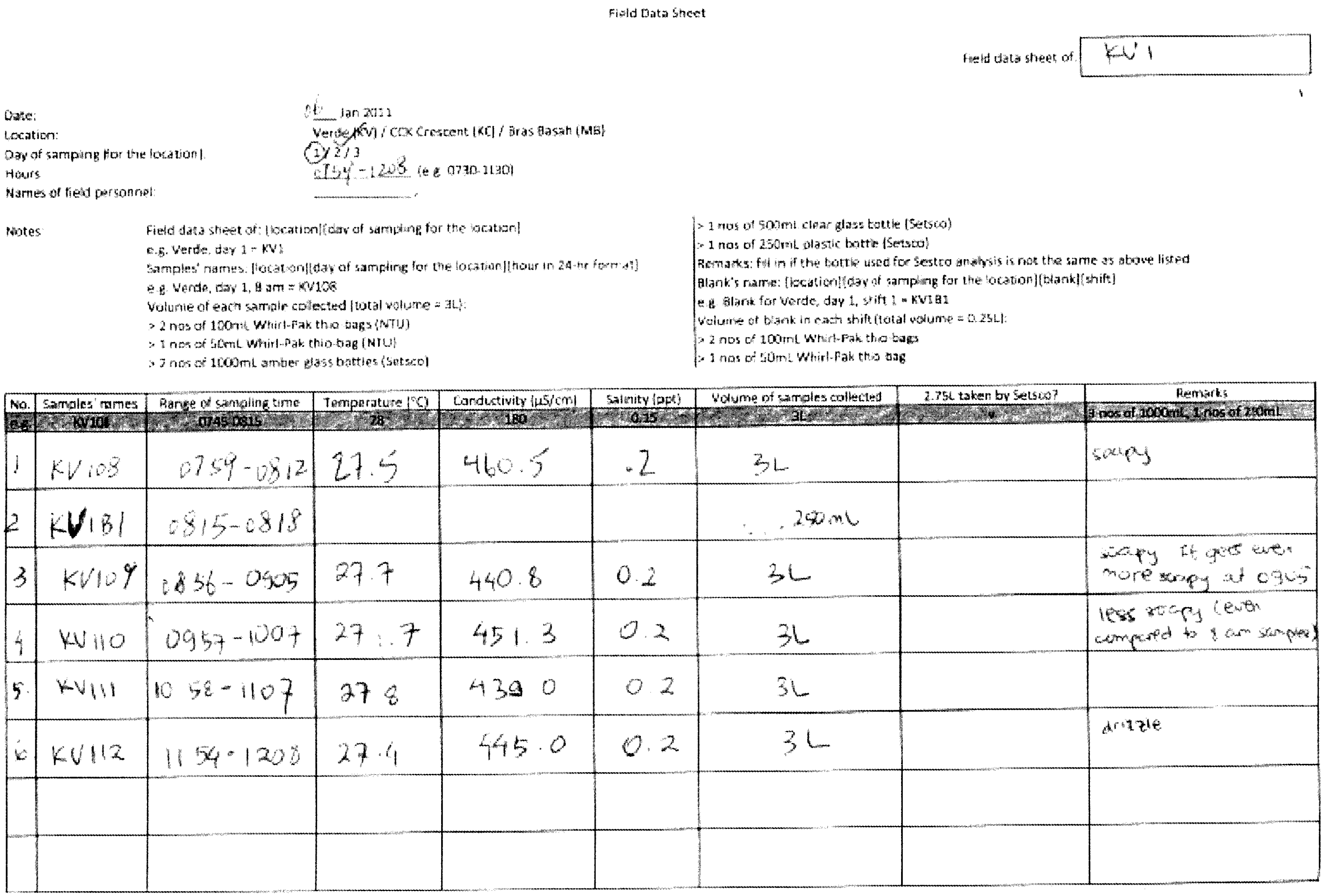
Date: [illegible] Jan 2011
Location: Verde (KV) / CCK Crescent (KC) / Bras Basah (MB)
Day of sampling (for the location): 1 / [✓ 2] / 3
Hours: 4.30pm-7.30pm (e.g. 0730-1130)
Names of field personnel: Ryan Sim

Notes:

Field data sheet of: [location][day of sampling for the location]
e.g. Verde, day 1 = KV1
Samples' names: [location][day of sampling for the location][hour in 24-hr format]
e.g. Verde, day 1, 8 am = KV108
Volume of each sample collected (total volume = 3L):
> 2 nos of 100mL Whirl-Pak thio-bags (NTU)
> 1 nos of 50mL Whirl-Pak thio-bag (NTU)
> 2 nos of 1000mL amber glass bottles (Setsco)
> 1 nos of 500mL clear glass bottle (Setsco)
> 1 nos of 250mL plastic bottle (Setsco)
Remarks: fill in if the bottle used for Sestco analysis is not the same as above listed
Blank's name: [location][day of sampling for the location][blank][shift]
e.g. Blank for Verde, day 1, shift 1 = KV1B1
Volume of blank in each shift (total volume = 0.25L):
> 2 nos of 100mL Whirl-Pak thio-bags
> 1 nos of 50mL Whirl-Pak thio-bag

No.	Samples' names	Range of sampling time	Temperature (°C)	Conductivity (µS/cm)	Salinity (ppt)	Volume of samples collected	2.75L taken by Setsco?	Remarks
e.g.	KV108	0745-0815	28	180	0.15	3L	Y	3 nos of 1000mL, - nos of 250mL
10	MB217	1656 1708	28.0	744	0.4	3L		
11	MB218	1756-1806	27.6	812	0.4	3L		
12	MB219	1855-1905	27.1	818	0.4	3L		

Table B-3: Verde Field Notes, taken 6th January 2011 (Dry-weather)



Field Data Sheet

Field data sheet of: KV1

Date: 06 Jan 2011

Location: [✓ Verde (KV)] / CCK Crescent (KC) / Bras Basah (MB)

Day of samping (for the location): [✓ 1] / 2 / 3

Hours: 0759-1208 (e.g. 0730-1130)

Names of field personnel:

Notes

Field data sheet of: [location][day of sampling for the location]

e.g. Verde, day 1 = KV1

Samples' names: [location][day of sampling for the location][hour in 24-hr format]

e.g. Verde, day 1, 8 am = KV108

Volume of each sample collected (total volume = 3L):

> 2 nos of 100mL Whirl-Pak thio-bags (NTU)

> 1 nos of 50mL Whirl-Pak thio-bag (NTU)

> 2 nos of 1000mL amber glass bottles (Setsco)

> 1 nos of 500mL clear glass bottle (Setsco)

> 1 nos of 250mL plastic bottle (Setsco)

Remarks: fill in if the bottle used for Sestco analysis is not the same as above listed

Blank's name: [location][day of sampling for the location][blank][shift]

e.g. Blank for Verde, day 1, shift 1 = KV1B1

Volume of blank in each shift (total volume = 0.25L):

> 2 nos of 100mL Whirl-Pak thio-bags

> 1 nos of 50mL Whirl-Pak thio-bag

No.	Samples' names	Range of sampling time	Temperature (°C)	Conductivity (μS/cm)	Salinity (ppt)	Volume of samples collected	2.75L taken by Setsco?	Remarks
e.g.	KV108	0745-0815	28	180	0.15	3L	Y	3 nos of 1000mL, 1 nos of 250mL
1	KV108	0759-0812	27.5	460.5	.2	3L		soapy
2	KV1B1	0815-0818				250mL		
3	KV109	0856-0905	27.7	440.8	0.2	3L		soapy It gets even more soapy at 0905
4	KV110	0957-1007	27.7	451.3	0.2	3L		less soapy (even compared to 8 am sample)
5.	KV111	1058-1107	27.8	439.0	0.2	3L		
6	KV112	1154-1208	27.4	445.0	0.2	3L		drizzle

Field Data Sheet

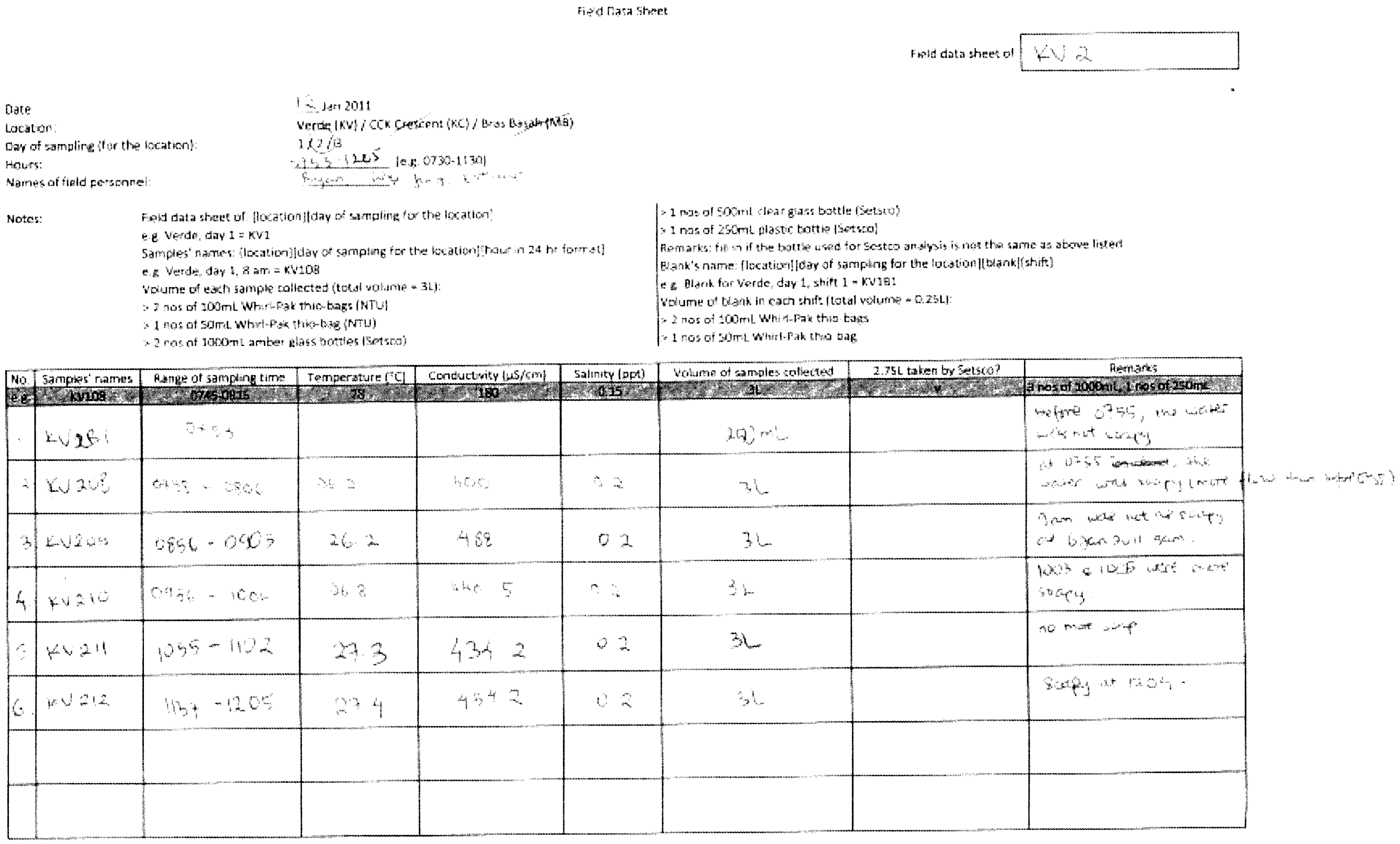
Field data sheet of: KV1

Date: 06 Jan 2011
Location: [✓ Verde (KV)] / CCK Crescent (KC) / Bras Basah (MB)
Day of sampling (for the location): [✓ 1] / 2 / 3
Hours: 1255 - 1508 (e.g 0730-1130)
Names of field personnel: Yongyue, Ryan

Notes:
Field data sheet of: [location][day of sampling for the location]
e.g. Verde, day 1 = KV1
Samples' names: [location][day of sampling for the location][hour in 24-hr format]
e.g. Verde, day 1, 8 am = KV108
Volume of each sample collected (total volume = 3L):
> 2 nos of 100mL Whirl-Pak thio-bags (NTU)
> 1 nos of 50mL Whirl-Pak thio-bag (NTU)
> 2 nos of 1000mL amber glass bottles (Setsco)
> 1 nos of 500mL clear glass bottle (Setsco)
> 1 nos of 250mL plastic bottle (Setsco)
Remarks: fill in if the bottle used for Sestco analysis is not the same as above listed
Blank's name: [location][day of sampling for the location][blank][shift]
e.g. blank for Verde, day 1, shift 1 = KV1B1
Volume of blank in each shift (total volume = 0.25L):
> 2 nos of 100mL Whirl-Pak thio-bags
> 1 nos of 50mL Whirl-Pak thio-bag

No.	Samples' names	Range of sampling time	Temperature (°C)	Conductivity (µS/cm)	Salinity (ppt)	Volume of samples collected	2.75L taken by Setsco?	Remarks
e.g.	KV108	0745-0815	28	180	0.15	3L	[illegible]	3 nos of 1000mL, 1 nos of 250mL
1	KV113	1255 - 1305	27.4	370.7	0.2	3L		
2	KV1B2	1307-1308				2.5L		
3	KV115	1500 - 1508	27.2	198.3	0.1	3L		rains during 13:30 - 14:30 not so heavily. no [illegible] surface runoff

Table B-4: Verde Field Notes, taken 12th January 2011 (Dry-weather)



Field Data Sheet

Field data sheet of: KV 2

Date: 12 Jan 2011
Location: [✓ Verde (KV)] / CCK Crescent (KC) / Bras Basah (MB)
Day of sampling (for the location): 1 / [✓ 2] / 3
Hours: 0755-1205 (e.g. 0730-1130)
Names of field personnel: [illegible]

Notes:
Field data sheet of: [location][day of sampling for the location]
e.g. Verde, day 1 = KV1
Samples' names: [location][day of sampling for the location][hour in 24 hr format]
e.g. Verde, day 1, 8 am = KV108
Volume of each sample collected (total volume = 3L):
> 2 nos of 100mL Whirl-Pak thio-bags (NTU)
> 1 nos of 50mL Whirl-Pak thio-bag (NTU)
> 2 nos of 1000mL amber glass bottles (Setsco)
> 1 nos of 500mL clear glass bottle (Setsco)
> 1 nos of 250mL plastic bottle (Setsco)
Remarks: fill in if the bottle used for Sestco analysis is not the same as above listed
Blank's name: [location][day of sampling for the location][blank][shift]
e.g. Blank for Verde, day 1, shift 1 = KV1B1
Volume of blank in each shift (total volume = 0.25L):
> 2 nos of 100mL Whirl-Pak thio bags
> 1 nos of 50mL Whirl-Pak thio bag

No.	Samples' names	Range of sampling time	Temperature (°C)	Conductivity (µS/cm)	Salinity (ppt)	Volume of samples collected	2.75L taken by Setsco?	Remarks
e.g.	KV108	0745-0815	28	180	0.15	3L	✓	3 nos of 1000mL, 1 nos of 250mL
1	KV2B1	0755				250 mL		before 0755, the water was not soapy
2	KV208	0755 - 0806	26.2	500	0.2	3L		at 0755 ~~[illegible]~~, the water was soapy (more flow than before 0755)
3	KV209	0856 - 0903	26.2	482	0.2	3L		9am was not as soapy as before 9am.
4	KV210	0956 - 1004	26.8	446.5	0.2	3L		1003 & 1005 were more soapy.
5	KV211	1055 - 1102	27.3	434.2	0.2	3L		no more soap
6	KV212	1157 - 1205	27.4	454.2	0.2	3L		Soapy at 1204.

Field Data Sheet

Field data sheet of: KV2

1

Date: 5 Jan 2011
Location: Verde (KV) / CCK Crescent (KC) / Bras Basah (MB)
Day of sampling (for the location): 1 / [✓ 2] / 3
Hours: 1220 - 1903 (e.g. 0730-1130)
Names of field personnel: [illegible]

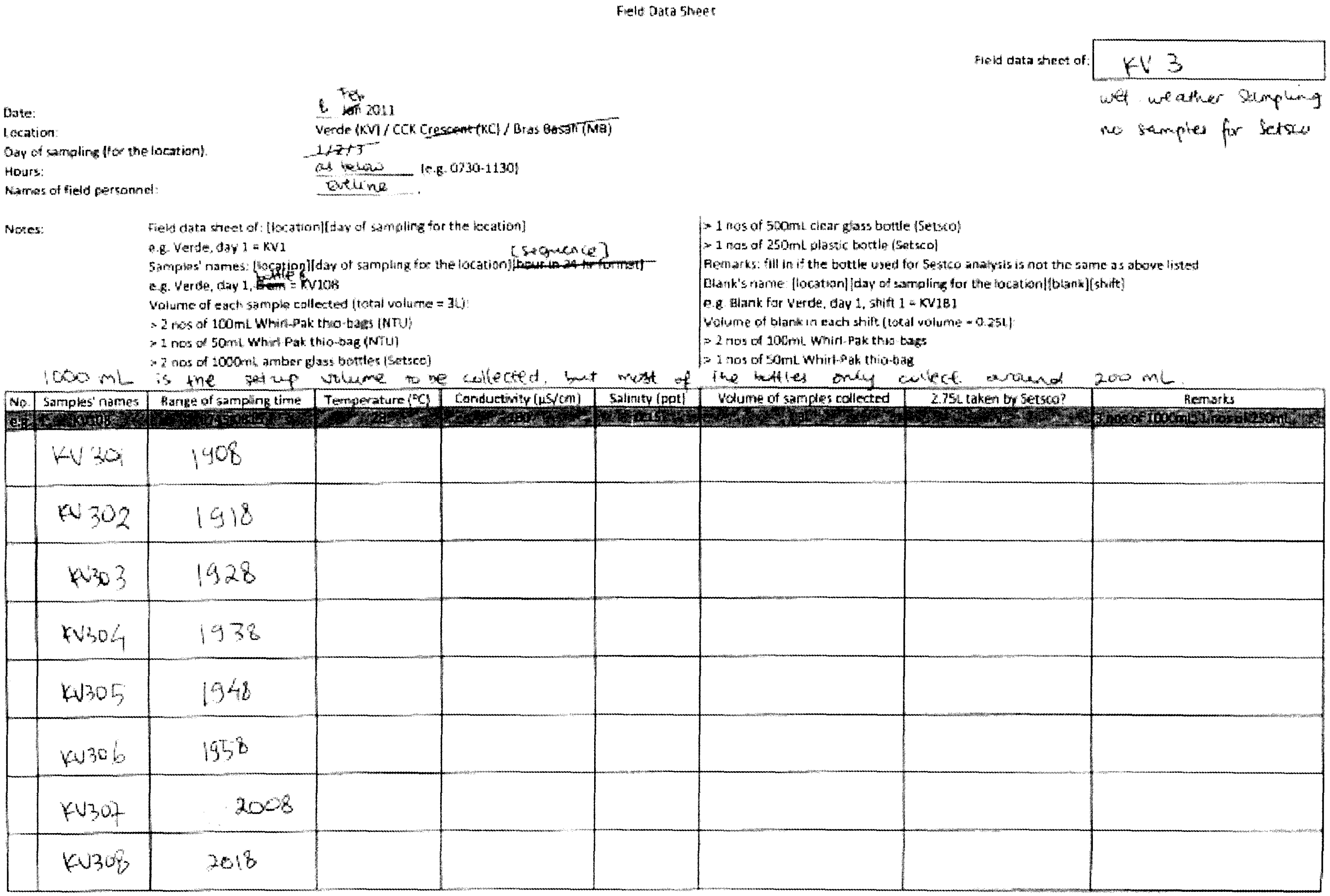
Notes:

Field data sheet of [location][day of sampling for the location]
e.g. Verde, day 1 = KV1
Samples' names: [location][day of sampling for the location][hour in 24-hr format]
e.g. Verde, day 1, 8 am = KV108
Volume of each sample collected (total volume = 3L):
> 2 nos of 100mL Whirl-Pak thio-bags (NTU)
> 1 nos of 50mL Whirl Pak thio bag (NTU)
> 2 nos of 1000mL amber glass bottles (Setsco)
> 1 nos of 500mL clear glass bottle (Setsco)
> 1 nos of 250mL plastic bottle (Setsco)
Remarks: fill in if the bottle used for Sestco analysis is not the same as above listed
Blank's name: [location][day of sampling for the location][blank][shift]
e.g. Blank for Verde, day 1, shift 1 = KV1B1
Volume of blank in each shift (total volume = 0.25L)
> 2 nos of 100mL Whirl-Pak thio-bags
> 1 nos of 50mL Whirl-Pak thio-bag

No	Samples' names	Range of sampling time	Temperature (°C)	Conductivity (μS/cm)	Salinity (ppt)	Volume of samples collected	2.75L taken by Setsco?	Remarks
e.g.	KV108	0745-0815	28	980	0.15	3L	Y	3 nos of 1000mL, 1 nos of 250mL
1	KV2B2	1220				250ml		
2	KV213	1256 - 1305	27.7	450.1	0.2	3L		Sunny weather, [illegible] [illegible] [illegible] [illegible] [illegible]
3	KV214	1355 - 1408	28.9	[illegible]	0.2	3L		Clear water [illegible] [illegible] Sunny
4	KV215	1454 - 1503	27.6	600.6	0.3	3L		Sunny water [illegible] [illegible] [illegible] [illegible]
5	KV216	1550 - 1604	29.2	434.4	0.2	3L		Sunny weather
6	KV217	1654 - 1705	28.1	440.6	0.2	3L		Clear water, [illegible] [illegible] [illegible] [illegible]
7	KV218	1754 - 1804	29.[illegible]	[illegible]	0.2	3L		Clear water, [illegible] [illegible] at time 1800.
8	KV219	1854 - 1903	[illegible]	290.0	0.2	3L		clear water

9 KV2B3 18:5 250ml

Table B-5: Verde Field Notes, taken 8th February 2011 (Wet-weather)



Field Data Sheet

Field data sheet of: KV 3

wet weather sampling
no samples for Setsco

Date: 8 ~~Jan~~ Feb 2011
Location: Verde (KV) / CCK ~~Crescent (KC)~~ / Bras Basah (MB)
Day of sampling (for the location): ~~1/2/~~3
Hours: as below (e.g. 0730-1130)
Names of field personnel: Eveline

Notes:

Field data sheet of: [location][day of sampling for the location]
e.g. Verde, day 1 = KV1
Samples' names: [location][day of sampling for the location]~~[hour in 24-hr format]~~ [sequence]
e.g. Verde, day 1, ~~8am~~ bottle 8 = KV108
Volume of each sample collected (total volume = 3L):
> 2 nos of 100mL Whirl-Pak thio-bags (NTU)
> 1 nos of 50mL Whirl-Pak thio-bag (NTU)
> 2 nos of 1000mL amber glass bottles (Setsco)
> 1 nos of 500mL clear glass bottle (Setsco)
> 1 nos of 250mL plastic bottle (Setsco)
Remarks: fill in if the bottle used for Sestco analysis is not the same as above listed
Blank's name: [location][day of sampling for the location][blank][shift]
e.g. Blank for Verde, day 1, shift 1 = KV1B1
Volume of blank in each shift (total volume = 0.25L):
> 2 nos of 100mL Whirl-Pak thio bags
> 1 nos of 50mL Whirl-Pak thio-bag

1000 mL is the set up volume to be collected, but most of the bottles only collect around 200 mL.

No.	Samples' names	Range of sampling time	Temperature (°C)	Conductivity (µS/cm)	Salinity (ppt)	Volume of samples collected	2.75L taken by Setsco?	Remarks
e.g.	KV108	[illegible]	28	[illegible]	[illegible]	[illegible]	[illegible]	3 nos of 1000mL, 1 nos of 250mL [illegible]
	KV301	1908						
	KV302	1918						
	KV303	1928						
	KV304	1938						
	KV305	1948						
	KV306	1958						
	KV307	2008						
	KV308	2018						

Field Data Sheet

Field data sheet of: KV3

Date: 8 Sep Jan 2011
Location: Verde (KV) / CCK ~~Crescent~~ (KC) / ~~Bras Basah~~ (KB)
Day of sampling (for the location): ~~1/2/3~~
Hours: 24 hours (e.g. 0730-1130)
Names of field personnel: Evelyne

Notes

Field data sheet of: [location][day of sampling for the location]
e.g. Verde, day 1 = KV1
Samples' names: [location][day of sampling for the location]~~[hours in 24-hr format]~~ (sequence no.)
e.g. Verde, day 1, ~~8am~~ = KV108
Volume of each sample collected (total volume = 3L)
> 2 nos of 100mL Whirl-Pak thio-bags (NTU)
> 1 nos of 50mL Whirl-Pak thio-bag (NTU)
> 2 nos of 1000mL amber glass bottles (Setsco)
> 1 nos of 500mL clear glass bottle (Setsco)
> 1 nos of 250mL plastic bottle (Setsco)
Remarks: fill in if the bottle used for Sestco analysis is not the same as above listed
Blank's name: [location][day of sampling for the location][blank][shift]
e.g. Blank for Verde, day 1, shift 1 = KV1B1
Volume of blank in each shift (total volume = 0.25L)
> 2 nos of 100mL Whirl-Pak thio-bags
> 1 nos of 50mL Whirl-Pak thio-bag

1000 ml is the set up volume to be collected, but most of the bottles only collect around 200 ml.

No	Samples' names	Range of sampling time	Temperature (°C)	Conductivity (uS/cm)	Salinity (ppt)	Volume of samples collected	2.75L taken by Setsco?	Remarks
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	KV309	2028						
	KV310	2038						
	KV311	2048						
	KV312	2058						
	KV313	2108						It was recorded as incorrect sample at sampler

Appendix C

WinTR-55 Required Information

Table C-1: Land Use Areas from ArcGIS and Corresponding Curve Numbers

Sub-catchments		**Peng Siang**	**Curve Number**		**Peng Siang**	**Curve Number**		**Kangkar**	**Curve Number**		**Pangsua**	**Curve Number**	
		(Bricklands)			**(CCKAve4)**			**(AMK1)**			**(Sg Pangsua)**		
Landuse	**WinTR-55 Equivalence**	**CP1**			**CP2**			**CP6**			**CP7**		
Agriculture (Farms)	Row Crops (Straight Row)	-	-		-	-		0.1134	81B		-	-	
Commercial & Residential	1/8 acre or less	0.0368	C	0.037	0.0202	C		-	-		0.1127	C	
Residential	1/8 acre or less	1.3298	B		0.8121	C		-	-		3.7939	C	
Residential with Commercial at 1st Storey	1/8 acre or less	0.0044	B	1.334	0.0034	C	0.836	-	-		0.0029	C	3.910
Commercial	Commercial & Business	-	-		0.0291	B		-	-		0.0115	B	
Educational Institution	Commercial & Business	0.2516	B	0.252	0.1138	C		-	-		0.5618	B	
Health & Medical Care	Commercial & Business	0.0024	C	0.002	0.0122	C	0.126	-	-		0.0036	B	0.577
Open Space	Newly graded areas	-	-		-	-		1.8632	C		1.8645	B	
Cemetery	Open Space (Fair Condition – grass cover 50-75%)	-	-		-	-		0.0136	79C		-	-	
Sports & Recreation	Open Space (Fair Condition – grass cover 50-75%)	0.0671	C	0.067	0.0509	D		-	-		0.0504	B	
Park	Open Space (Good Condition – grass cover > 75%)	0.5254	C	0.525	0.0216	C		-	-		0.4438	B	
Civic & Community Institution	Open Space (Poor condition – grass cover < 50%)	0.0174	.5B/.5C		0.0103	C		-	-		0.0329	B	
Open Space in Urban	Open Space (Poor condition – grass cover < 50%)	0.231	B	0.250	0.0881	C		-	-		0.5758	B	
Place of Worship	Open Space (Poor condition – grass cover < 50%)	0.0198	.5B/.5C	0.019	0.0098	C		-	-		0.0581	B	0.667
Light Rapid Transit	Paved parking lots, roofs, driveways etc	-	-		0.0026	98C		-	-		0.008	98C	
Mass Rapid Transit	Paved parking lots, roofs, driveways etc	0.0066	98C		-	-		-	-		-	-	
Transport Facilities	Paved parking lots, roofs, driveways etc	0.002	98C	0.009	0.004	98C	0.007	-	-		0.0085	C	0.017
Road	Paved; curbs and storm sewers	0.419.	98C	0.419	0.2464	C		0.1146	B		1.5686	C	
Reserve Site (Rubber Trees)	Woods - grass combination (Fair)	1.5977	B	1.598	0.0003	C		0.0136	65B		1.2401	B	
Special Use (Rubber Trees)	Woods - grass combination (Fair)	0.4683	C	0.468	0.1191	C	0.119	1.0021	65B	1.016	1.0902	B	2.330
Utility	Developing Urban Area (No Vegetation)	0.0198	C		0.0086	.5C/.5D		0.0152	C		0.0425	C	
Waterbody		0.0984	C	0.118	0.0046	C		-	-		0.2554	C	
SUM		**5.0975**			**1.5571**			**3.1357**			**11.7252**		

Figure C-2: Time of Concentration Travel Path from Point of Highest Elevation to KC1

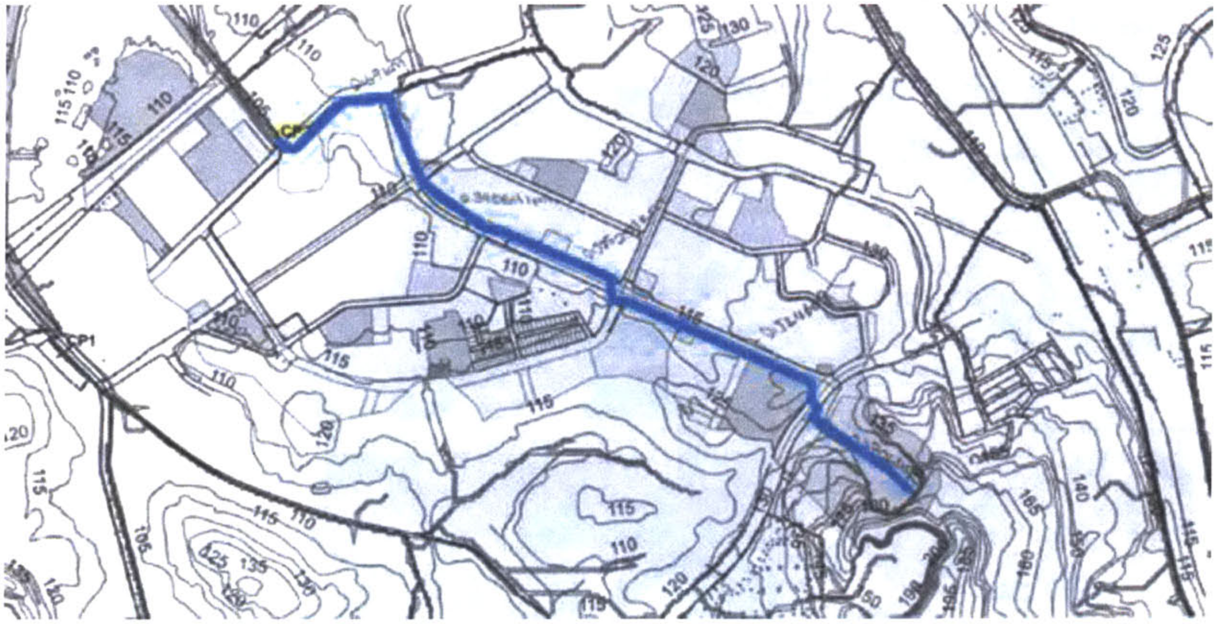


Figure C-3: Time of Concentration Travel Path from Point of Highest Elevation to KC2

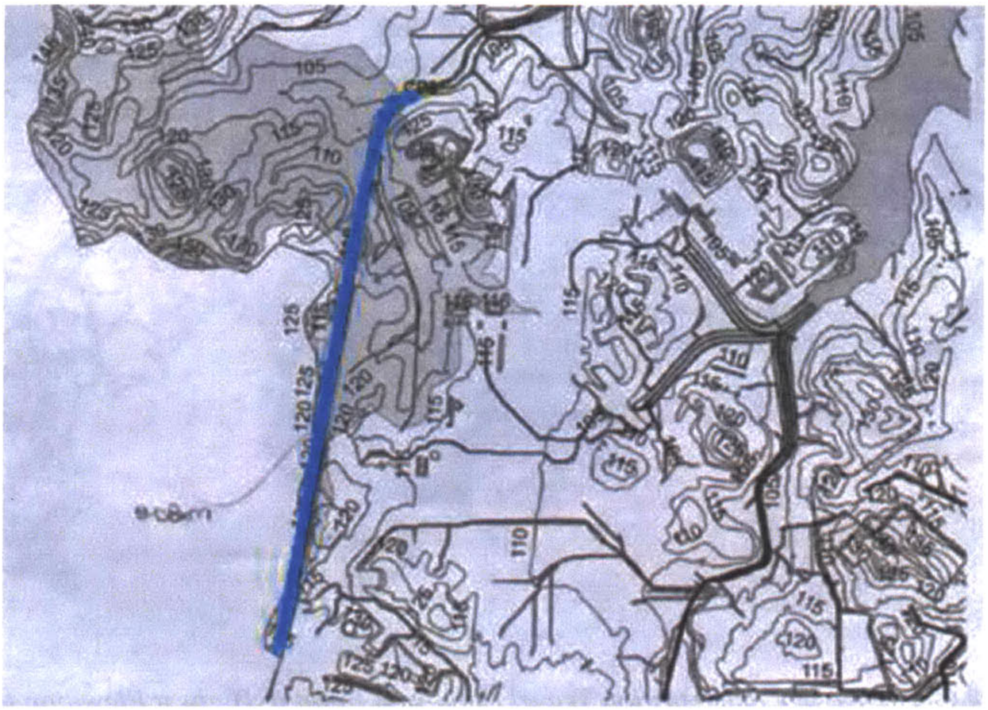


Figure C-4: Time of Concentration Travel Path from Point of Highest Elevation to KC6

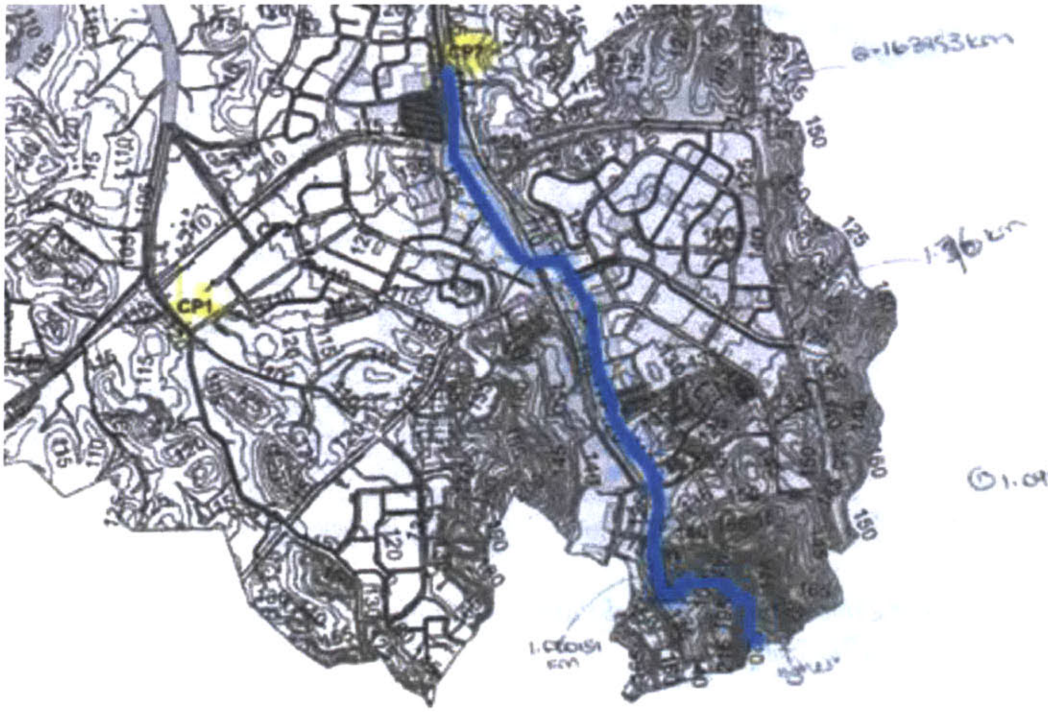


Figure C-5: Time of Concentration Travel Path from Point of Highest Elevation to KC7

Table C-2: Calculations for WinTR-55

SC	Type of Flow	L (km)	Elev$_1$	Elev$_2$	Disp (km)	Disp (ft)	Slope	C	a (m^2)	p$_w$(m)	r (m) = a/p$_w$	n	V (m/sec)	V (ft/sec)	Tot Rain	T$_t$ (hr)	T$_c$ (hr)	Q$_p$ (m^3/s)	T$_p$ (hr)
KC1	Open channel flow	2.01106	0.130	0.105	2.011061	6597.969	0.01243		0.717	2.93853	0.2439997	0.012	3.62801	11.9029	2.8	0.154	0.154	-	-
KC2	Overland flow	0.3048	0.180	**0.130**	0.3048	1000	0.16404	0.15								0.500	1.074	0.07	10.54
		0.12784	0.130	**0.125**	0.12784	419.4226	0.03911	0.15								0.317			
	Open channel flow	0.52461																	
		0.52525	0.125	0.115	1.4405	4726.05	0.00694		0.25341	2.01498	0.1257652	0.011	1.90133	6.23796		0.210			
		0.39064																	
		0.65	0.115	0.110	0.4224	1385.827	0.01184		0.25341	2.01498	0.1257652	0.011	2.48278	8.14559		0.047			
KC6 (1)	Open channel flow	3.08	0.125	0.11	3.08	10104.99	0.00487		0.11451	0.84823	0.135	0.012	1.53042	5.02107	2.8	0.559	0.559	-	-
KC6 (2)		3.08	0.125	0.11	3.08	10104.99	0.00487		0.11451	0.84823	0.135	0.012	1.53042	5.02107	22.7	0.559	0.559	1.20	8.63
KC7 (1)	Sheet flow (1)	0.09	0.26	0.252	0.09	295.2756	0.08889	0.2				0.15		5.9	0.4	0.300	0.987	-	-
KC7 (2)	Sheet flow (2)	0.09	0.26	0.252	0.09	295.2756	0.08889				0.15	2640		5.9	4.4	0.300	0.987	-	-
	Shallow concentrated flow	1.0089	0.252	0.125	0.6951	2280.512	0.18271							8.5		0.075			
	Open channel flow	1.06015	0.125	0.114	1.060151	3478.186	0.01038		1.65794	5.30003	0.3128172	0.011	4.26724	14.0001		0.069			
		3.92395	0.114	0.105	3.923953	12873.86	0.00229		1.65794	5.30003	0.3128172	0.011	2.00629	6.58232		0.543			

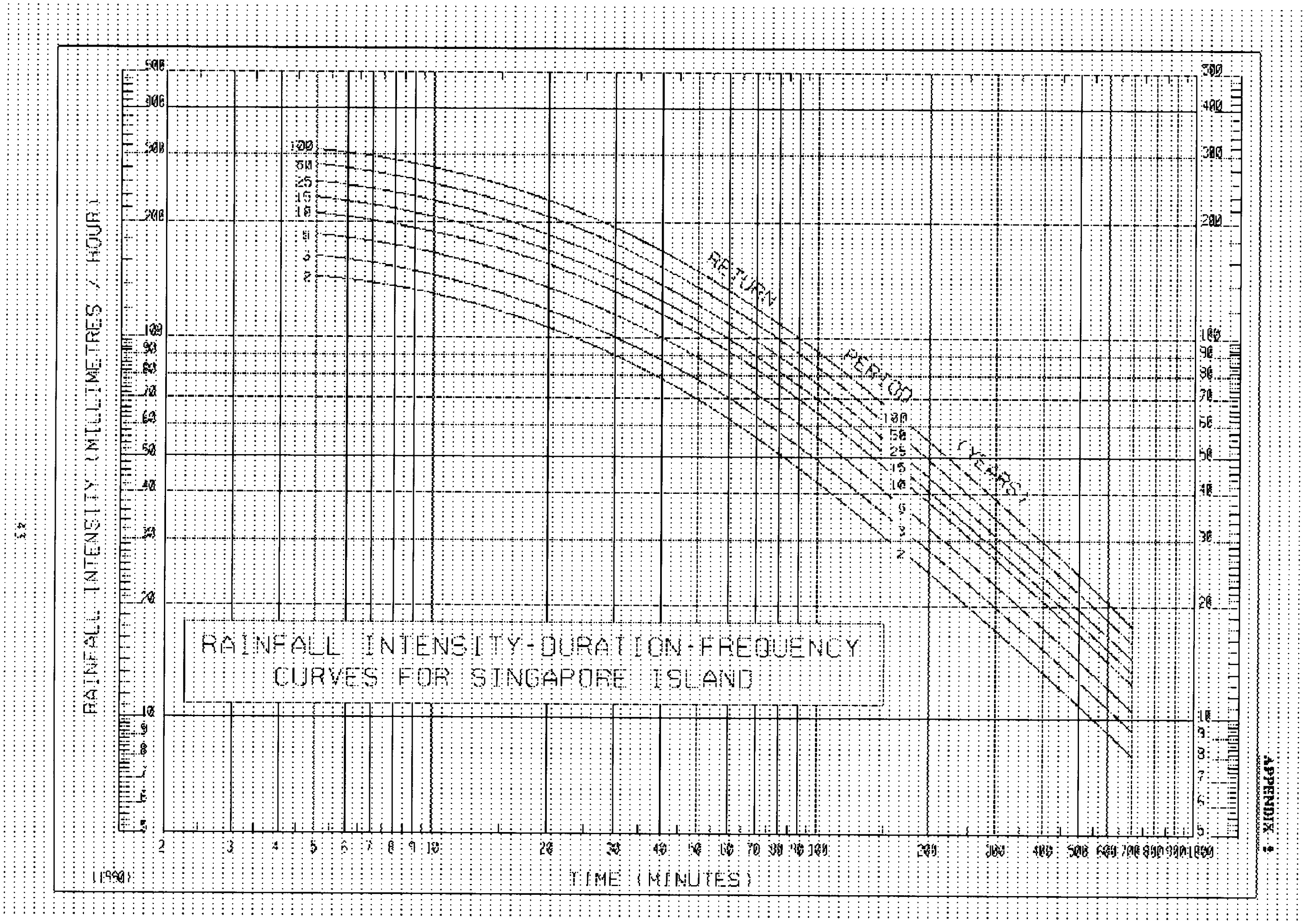
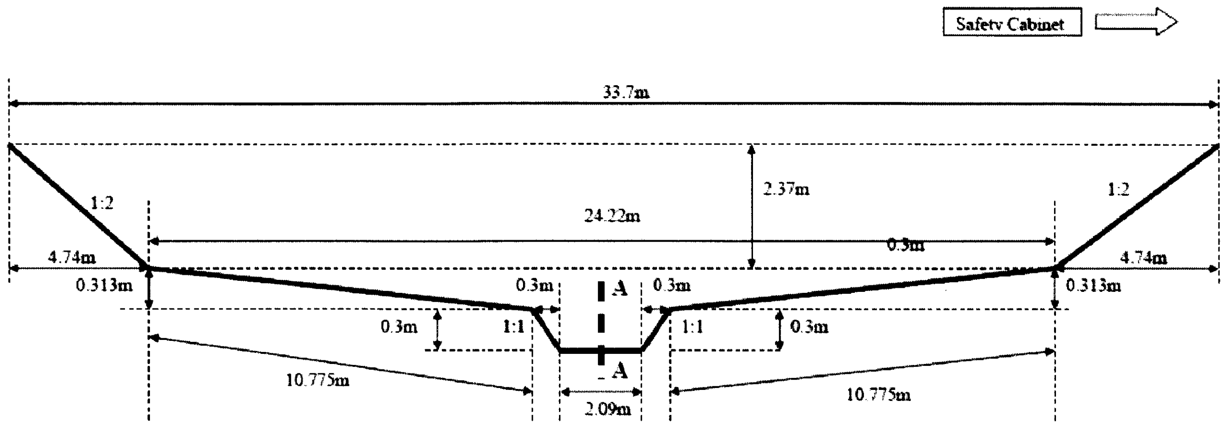


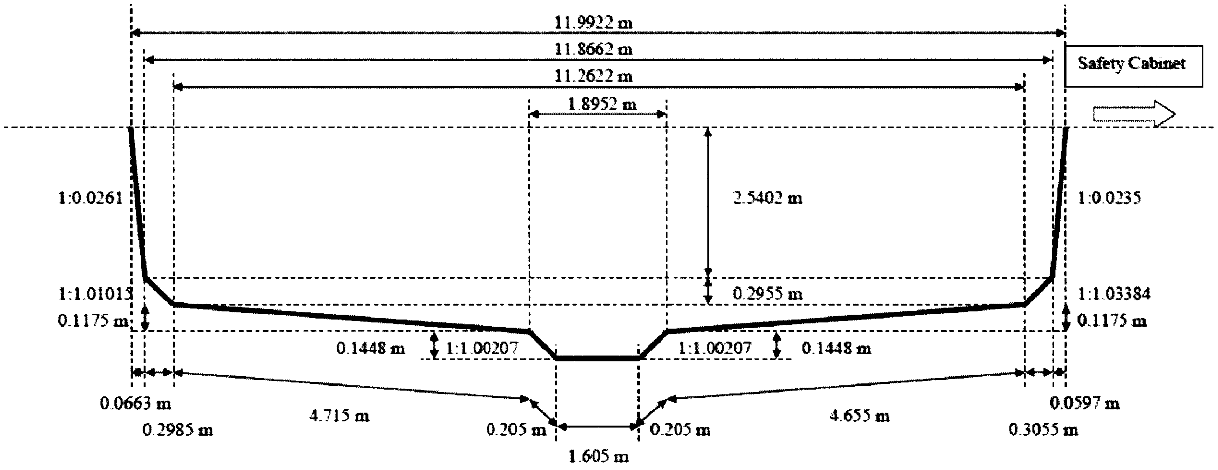
Figure C-6: Singapore Intensity-Duration-Frequency Curves (PUB, 2010)



Cross Section at CS1 (Bricklands)

Longitudinal slope = 1:1600, length = 393m
n (Dry weather) = 0.0195, n (Overbank flow) = 0.012

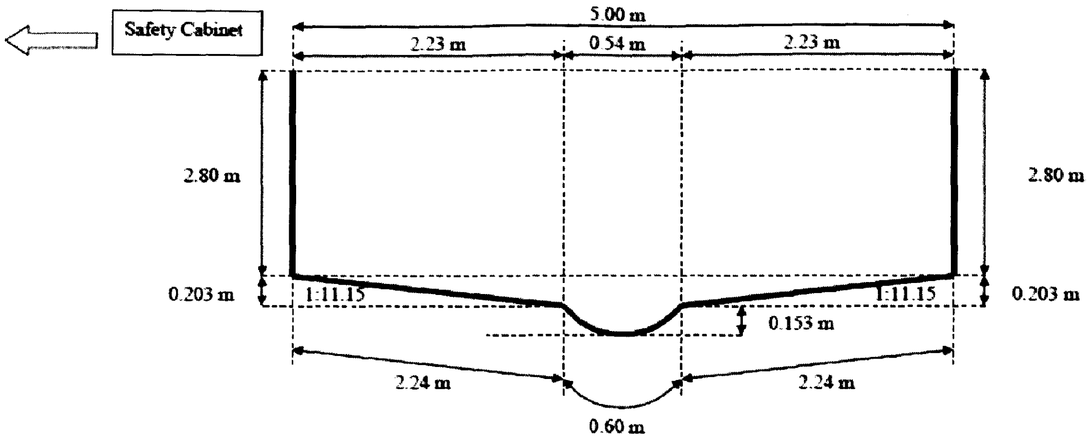
Detail survey done by Stephen Tan Boon Kean & Ruby Tok, 8 May 2006, 10am – 1.00pm



Cross Section at CP2 (Detail Survey)

Longitudinal slope = 1:1400, length = 1059m
n (Dry weather)=0.077, n (Overbank flow) = 0.011

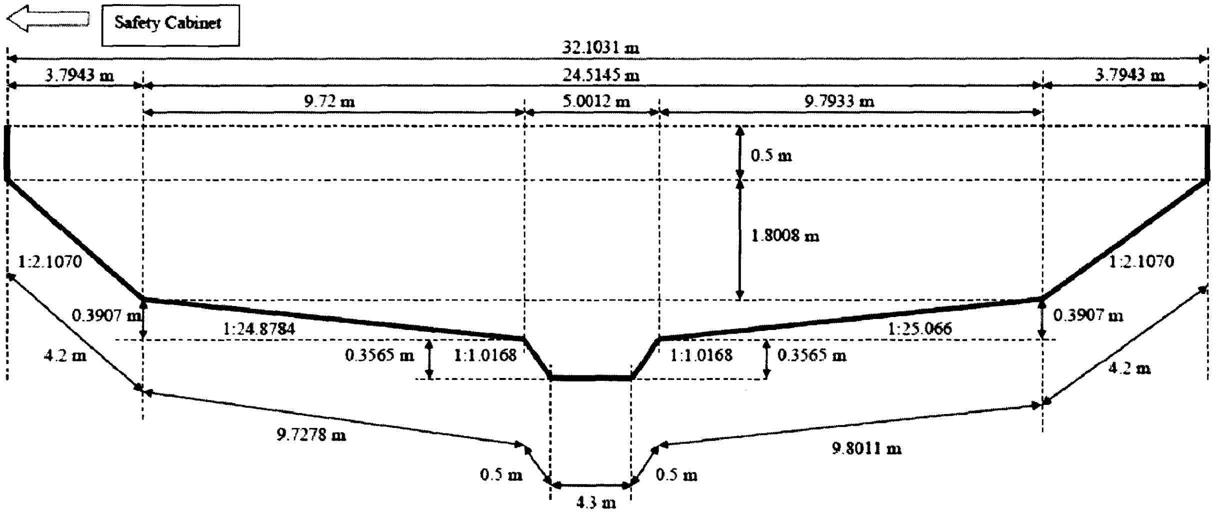
Detail survey done by Lim Wee Ho & Lim Lai Wan, 2 June 2006, 10am –.12pm



Cross Section at CP6

Longitudinal slope = 1:2000, length = 1492m,
n (Dry weather) = 0.09, n (Overbank flow) = 0.012

Detail Survey done by:
Lim Wee Ho, Yee Woon Kang, Ruby Tok, Chia Key Huat, 4 October 2006, 3:42pm – 4:48pm.



Cross Section at Sg Pangsua

Longitudinal slope = 1:1000, length = 3831m,
n (Dry weather) = 0.077, n (Overbank flow) = 0.011

Detail Survey done by Lim Wee Ho & Lim Lai Wan, 7 September 2006, 10:20am – 12:24pm

Figure C-7: Drain Cross Sections

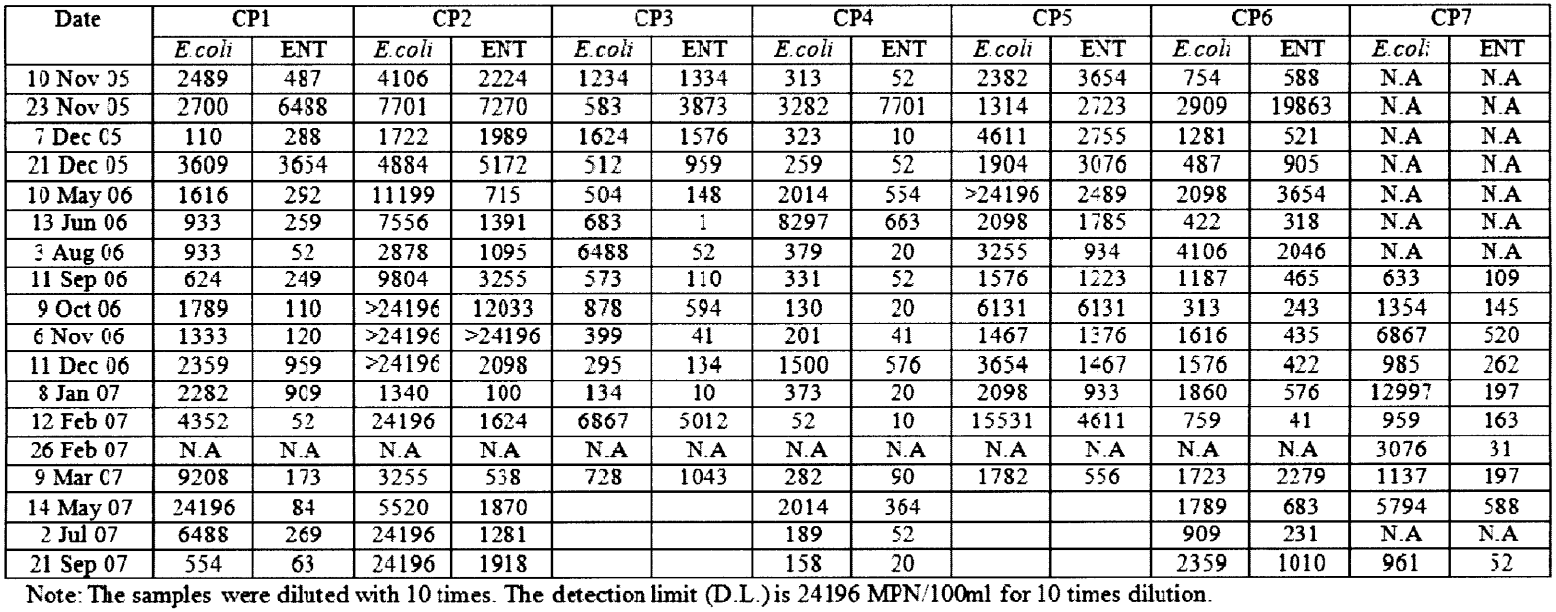
Appendix D

Previous Years' Wet and Dry Weather Data

Table D-1: E. coli and Enterococci Densities (MPN/100ml) for the Kranji Reservoir (Dry Weather)

Date	Station 1		Station 3		Station 4		Junction		Peng Siang		Tengah		Kangkar	
	E.coli	ENT	*E.coli*	ENT	*E.coli*	ENT	*E.coli*	ENT	*E.coli*	ENT	*E.coli*	ENT	*E.coli*	ENT
15 Sep 05	6.3	4.1	1	1	16.9	2	3.1	4.1	517.2	38.4	6.3	13.4	5.2	14.5
29 Sep 05	N.A	N.A	1	4.1	1	5.1	N.A	N.A	261.3	770.1	13.4	9.8	2	1
12 Oct 05	N.A	N.A	1	3	1	5.1	N.A	N.A	11	7.4	2	14.3	1	3.1
16 Nov 05	N.A	N.A	1	4.1	2	1	N.A	N.A	16.1	8.4	3.1	8.5	13.5	1
19 Jun 06	N.A	N.A	1	4.1	1	5.1	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A
26 Jul 06	1	2	1	3.1	N.A	N.A	1	5.2	24.3	12.1	13.1	4.1	8.5	8.4
4 Sep 06	6.3	4.1	1	4.1	7.5	3	3	2	60.2	16.9	6.2	22.6	3	2
2 Oct 06	1	1	1	2	1	11.1	1	1	7.5	9.9	7.5	8.7	1	7.5
16 Nov 06	2	N.A	N.A	1	1	N.A	2	N.A	129.8	11.1	4.2	8.7	22.2	6.4
18 Dec 06	200.5	200.5	59.1	34.4	6.4	11.1	200.5	200.5	200.5	200.5	200.5	200.5	200.5	200.5
22 Jan 07	530	73	10		10	10	86	20	173	84	20	10	703	20
5 Feb 07	16.9	18.5	7.3	6.2	6.3	4.1	24.9	39.1	24.6	25.6	25.3	24.3	5.2	6.2
19 Mar 07	25.4	20.7	20.7	N.A	3.1	1	28.8	22.2	200.5	N.A	23.8	N.A	165.2	N.A
23 Apr 07	201.2	25.9	2	2	2	2	165.8	53.5	2419.6	1986.3	206.4	218.7	18.9	15
21 May 07	1	3	1	1	1	1	1	12.7	10	1	2	49.7	3.1	7.5
5 Jun 07	27.5	23.9	5.2	2	1	1	104.6	31.7	2419.6	1553.1	51.2	43.9	8.5	15.3
9 Jul 07	135	63	10	10	20	73	1842	199	20	10	84	41	84	134
20 Aug 07	146.7	122.3	133.4	107.1	137.4	67	290.9	62.2	1732.9	177.5	125.9	22.5	98.5	54.4

Table D-2: E. coli and Enterococci Densities (MPN/100ml) for the Kranji Catchment (Dry Weather)



Date	CP1		CP2		CP3		CP4		CP5		CP6		CP7	
	E.coli	ENT	*E.coli*	ENT	*E.coli*	ENT	*E.coli*	ENT	*E.coli*	ENT	*E.coli*	ENT	*E.coli*	ENT
10 Nov 05	2489	487	4106	2224	1234	1334	313	52	2382	3654	754	588	N.A	N.A
23 Nov 05	2700	6488	7701	7270	583	3873	3282	7701	1314	2723	2909	19863	N.A	N.A
7 Dec 05	110	288	1722	1989	1624	1576	323	10	4611	2755	1281	521	N.A	N.A
21 Dec 05	3609	3654	4884	5172	512	959	259	52	1904	3076	487	905	N.A	N.A
10 May 06	1616	292	11199	715	504	148	2014	554	>24196	2489	2098	3654	N.A	N.A
13 Jun 06	933	259	7556	1391	683	1	8297	663	2098	1785	422	318	N.A	N.A
3 Aug 06	933	52	2878	1095	6488	52	379	20	3255	934	4106	2046	N.A	N.A
11 Sep 06	624	249	9804	3255	573	110	331	52	1576	1223	1187	465	633	109
9 Oct 06	1789	110	>24196	12033	878	594	130	20	6131	6131	313	243	1354	145
6 Nov 06	1333	120	>24196	>24196	399	41	201	41	1467	1376	1616	435	6867	520
11 Dec 06	2359	959	>24196	2098	295	134	1500	576	3654	1467	1576	422	985	262
8 Jan 07	2282	909	1340	100	134	10	373	20	2098	933	1860	576	12997	197
12 Feb 07	4352	52	24196	1624	6867	5012	52	10	15531	4611	759	41	959	163
26 Feb 07	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	3076	31
9 Mar 07	9208	173	3255	538	728	1043	282	90	1782	556	1723	2279	1137	197
14 May 07	24196	84	5520	1870			2014	364			1789	683	5794	588
2 Jul 07	6488	269	24196	1281			189	52			909	231	N.A	N.A
21 Sep 07	554	63	24196	1918			158	20			2359	1010	961	52

Note: The samples were diluted with 10 times. The detection limit (D.L.) is 24196 MPN/100ml for 10 times dilution.

Note: The samples were diluted with 10 times. The detection limit (D.L.) is 24196 MPN/100ml for 10 times dilution.