Stormwater First Flush Analysis in the Auckland Region

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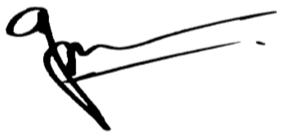

Name: Grace Wong

Position: Stormwater Technical Specialist

Organisation: Auckland Council

Date: March 2012

Approved for ARC Publication by:

Name: Dr Judy-Ann Ansen

Position Manager Stormwater Technical Services

Organisation: Auckland Council

Date: March 2012

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Stormwater First Flush Analysis in the Auckland Region

Asaad Y. Shamseldin

Prepared for
Auckland Council

Department of Civil and Environmental Engineering
University of Auckland
Private Bag 92019
Auckland Mail Centre
Auckland, 1142

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Executive Summary

In broad terms, this study is concerned with improving the scientific understanding of the water quality characteristics of stormwater runoff in the Auckland region. The main objective of this study is to undertake an assessment of existing water quality data in the Auckland region for evidence of contaminant first flush and its characteristics.

A literature review with regard to the first flush, the methods used to identify the first flush from field data and the management of first flush is given in this study. The literature review shows that designing Best Management Practices (BMPs) to focus on treating the first flush/early stormwater runoff which constitutes a small portion of the event runoff volume is considered as being a more economical approach for reducing pollutants from stormwater (Barco, 2008). As the pollutant concentration during an event generally decreases with time (Sansalone and Buchberger 1997; Larsen et al. 1998; Krebs et al.1999; Li et al. 2005), the enhancement of the treatment of the first flush runoff can lead improvements in the overall performance of the stormwater management facilities (Li et al., 2008).

The literature review reveals that the first flush has been the focus of hot debate between the believers and the disbelievers of its existence. The literature review has also discussed the concentration, the mass-based and the empirical frameworks used in identifying the existence/non-existence of the first flush from the observed data. These frameworks have different levels of subjectivity. However, the mass-based framework appears to be the most widely used and more objective as some of the methods which belong to this framework use an objective numerical criteria for identifying the first flush with less conceptual flaws. Furthermore, the identification of the first flush using these methods is not site-specific unlike the concentration based methods where the definition of the first flush can be site specific.

In this study, the first flush analysis is conducted using a comprehensive data set from 16 sites in the Auckland region. The analysis presented in this report focuses on the first flush analysis for 22 water quality parameters. The results of the first flush analysis confirm the existence of the first flush phenomena in the Auckland region. However, the strength of the first flush varies from site to site and also depends on other factors such as the water quality parameters being analysed.

1 LITERATURE REVIEW OF FIRST FLUSH

1.1 What is First Flush?

The first flush is normally defined as having "a disproportionately high delivery of either concentration or mass of a constituent during the initial portions of a rainfall-runoff event" (Sansalone and Cristina, 2004). The entrainment of pollutants deposited on exposed surfaces by rainfall-runoff processes during the initial phase of a rainfall-runoff event and the delivery of high pollutant load during the initial phase of the event produces the first flush phenomenon.

The first "foul" flush concept is not new and its origin can be traced back to 1910s (Metcalf and Eddy, 1916). At that time when the first flush concept was introduced, the constituents of major concerns were suspended and dissolved organic matter originating from equine fecal matter that was subsequently washed into receiving bodies (Sansalone and Cristina, 2004). At present, the first flush analysis considers more than 22 water quality constituents such as total suspended solids (TSS), volatile suspended solids (VSS), total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), organic nitrogen (org-N), nitrate and nitrite–nitrogen (NOx–N), ammonium–nitrogen (NH_4–N), biological oxygen demand (BOD), chemical oxygen demand (COD), fecal coliform, heavy metals and particles (Maestre et al., 2004; Obermann et al., 2009, Li et al., 2005).

However, the existence of the first flush concept is very controversial. As noted by Bertrand-Karjewiski et al. (1998), it has been the subject of hot debate between "those who have seen" and "those who do not believe in it". While there are many studies which confirm the existence of the first flush (Li-qing et al. 2007; Kang et al., 2008; Kim et al., 2005; Line et al., 1997), there are also many studies which confirm its non existence (Suarez and Puertas 2005; Saget et al., 1995; Pratt and Adams, 1984). The first flush can be easily observed in small catchments and many combined sewers networks as pointed out by Gupta and Saul (1996) and Sheng (2000). However, in the case of large catchments the first flush distinctive shape may be lost (Gupta and Saul, 1996).

NSWG-Australia (2009) has outlined some of the reasons why the first flush may not be observed. These reasons are;

- "The drainage characteristics of the catchment may prevent it. Particularly in large catchments, initial runoff from the most distant parts of the catchment may not reach the catchment outlet for some time after a storm starts. This time lag is rarely an issue for smaller, individual premises.

- The pollutants may not be very mobile. Rainfall does not remove some pollutants, like oils and greases, as easily or as quickly as soluble materials and fine dusts. Bare soils or vegetated surfaces are generally not 'cleansed' as easily or effectively as sealed surfaces.

- Pollutant sources that are effectively continuous may exist within the catchment. First flush is generally seen only where the supply of pollutants is limited. Sediment generated from soil erosion, for example, will not give a first flush because the supply of soil particles is (for all practical purposes) unlimited. In cases like this, on-line, flow-through pollution controls will be needed.

- In urban catchments during large storms, continuous discharges from sewer overflows may mask any first flush associated with stormwater runoff".

In New Zealand, Christchcurch City Council uses the first flush concept to size stormwater devices. The Christchurch City Council's Waterways Wetlands and Drainage Guide (CCC, 2003) recommends the capture of runoff from the first 25 mm of storm rainfall depth, but not less than 15 mm from hardstand areas with its use being limited to the design of ponds and wetlands (NZWRF, 2004). However, there are variations to the rainfall depth to be captured and treated. For example, "Environment Canterbury consent CR C000315 granted to the Christchurch City Council for green field development in the Upper Heathcote/Wigram area requires the capture and treatment of the first 12.5 mm of all rainfall events prior to discharge to ground. This first flush interception will achieve treatment of 58% of the Christchurch average annual rainfall depth falling on the recipient catchment" (NZWRF, 2004). Zollhoefer (2009) carried out a study on a 10-year old, 6.1 ha residential development in Christchurch to investigate first flush. The analysis of first flush was based on two storm events which were typical for Christchurch. The antecedent conditions of the two storms were drier than the average. Zollhoefer (2009) found that after the first 6 mm accumulated rainfall most monitored contaminants were below their relevant trigger levels or even below lab detection limits and noted that capturing the 25 mm first flush depth which is used in Christchurch may be very conservative.

1.2 Factors Affecting First Flush

The first flush is a very complex phenomenon and depends on many factors which include (Deletic, 1998);

- Rainfall and Climate characteristics, specifically, antecedent dry weather conditions, rainfall depth, rainfall duration and maximum rainfall intensity. Li-qing et al. (2007) noted that the amount of pollutants accumulated in the catchment is probably related to the antecedent dry weather period and events with longer antecedent conditions are most likely to produce higher pollutant loads.
- Catchment characteristics (e.g. size and landuse): Barco et al. (2008) noted that strong first flush events are usually associated with small impervious catchments such as highways and parking lots.
- Type of pollutant: Lee et al. (2002) found the magnitude of the first flush phenomenon to be greater for some pollutants and less for others depending on the landuse, catchment area and rainfall intensity. The dependence of the magnitude of the first with the type of pollutant can also be due to the mechanisms affecting the pollutant build-up (Sartor and Boyd, 1972).
- Runoff quantity characteristics, namely, event volume and maximum runoff rate.
- Runoff quality characteristics, namely, pH, conductivity and suspend solid loading rate.

1.3 Methods for Identifying first flush from data

The analysis of first flush can be regarded as important for effective management of stormwater runoff. Numerous research studies have noted that stormwater runoff is the leading cause of degradation of the receiving water bodies, especially during first flush (Bertrand et al., 1998; Butler and Davies, 2000; Deletic, 1998). Sansalone and Cristina (2004) noted that there are three main frameworks which can be used to identify the first-flush phenomenon from observed data. These three frameworks are;

- Concentration-based framework
- Mass-based framework
- Empirical framework

These three frameworks are discussed in more details in the following sections.

1.3.1 Concentration-based framework

In this framework, the identification of the first flush is based on whether or not a disproportionately high constituent concentration occurs in the early part of the event storm-runoff i.e. the rising limb of the runoff hydrograph (Sansalone and Cristina 2004). However, the concentration peak for different pollutants may differ during the same storm event and during different storm events in the same catchment (Gupta and Saul, 1996).

Thornton and Saul (1986) define the first flush effect as a more or less significant concentration peak occurring at the beginning of storm events. Bertrand-Karjewiski et al. (1998) noted that this later definition of the first flush effect is flawed. They argued that the definition of what constitutes a concentration peak is relative and defined with respect to the whole pollutograph. In this case, the assessment of the first flush is basically qualitative and can be very subjective as there is no agreed bench-mark or threshold concentration to define what constitutes a peak for different events objectively. A spike concentration can be regarded as a peak concentration in an event where the concentration is generally low on the basis that it has the maximum event concentration. However, when such a spike concentration is compared with peaks in other events with significantly higher concentrations, it is misleading to call such a spike a peak.

Sansalone and Cristina (2004) noted that the concentration based first flush can be observed in a variety of conditions including "the removal of heavy metals from rooftops (Forster 1996; He et al. 2001), the removal of oil and grease from roadway surfaces (Stenstrom et al. 1984), the wash off of nitrate from roadway surfaces (Cordery 1977; Barrett et al. 1997; Lee and Bang 2000) and the removal of particulate matter (Maidment 1993; Wanielista and Yousef 1993; Deletic 1998; Wu et al. 1998; Appel and Hudack 2001; Lee et al. 2001; Farm 2002)".

Other definitions of first-flush based on the concentration based framework also exist. For example, Drapper et al. (2000) define the "first flush" as occurring when the concentration of the first 20 L of runoff is higher than the event mean concentration (EMC). The definition of 20 L runoff is very subjective and can be site specific. It is very well known fact that the event runoff volume varies among different events and sites.

The US EPA (1993) defines the first flush based on the exceedance of the pollutant concentration, C(t), at any given time to a baseline concentration, C_b, during the runoff event (see Figure 1). This baseline concentration is the mean of the pollutant concentration during dry weather conditions. The first flush volume V_p is calculated by finding the integral between the time t_1 where C(t) first becomes greater than Cb and the time t_2 where C(t) first becomes less than C_b as illustrated in Figure 1. Bertrand-Karjewiski (1998) noted that the US EPA method for defining the first flush has two main deficiencies. The first deficiency is that it assumes storm events with pollutant concentrations below the baseline concentration do not require treatment and have no detrimental effects on the receiving environment which may not be true in all cases. The second deficiency is that when the concentration of the pollutant is higher than the baseline concentration for an extended period of time then the resulting volume to be treated is very large. Consequently, this larger volume contradicts the definition of the first flush volume associated with a smaller volume of runoff to be treated.

From the treatment point of view, several studies have concluded that first flush definitions based only on concentration are inadequate. The increases in the pollutant mass at lower concentrations might be more detrimental to receiving waters than lower flows with higher concentrations (Wanielista et al., 1977). The first flush definitions based on concentration could mislead designers of treatment controls and all first flush definitions based solely on concentration peaks are inadequate. It is necessary to qualify them with respect to the constituent mass (Bertrand-Karjewiski, 1998).

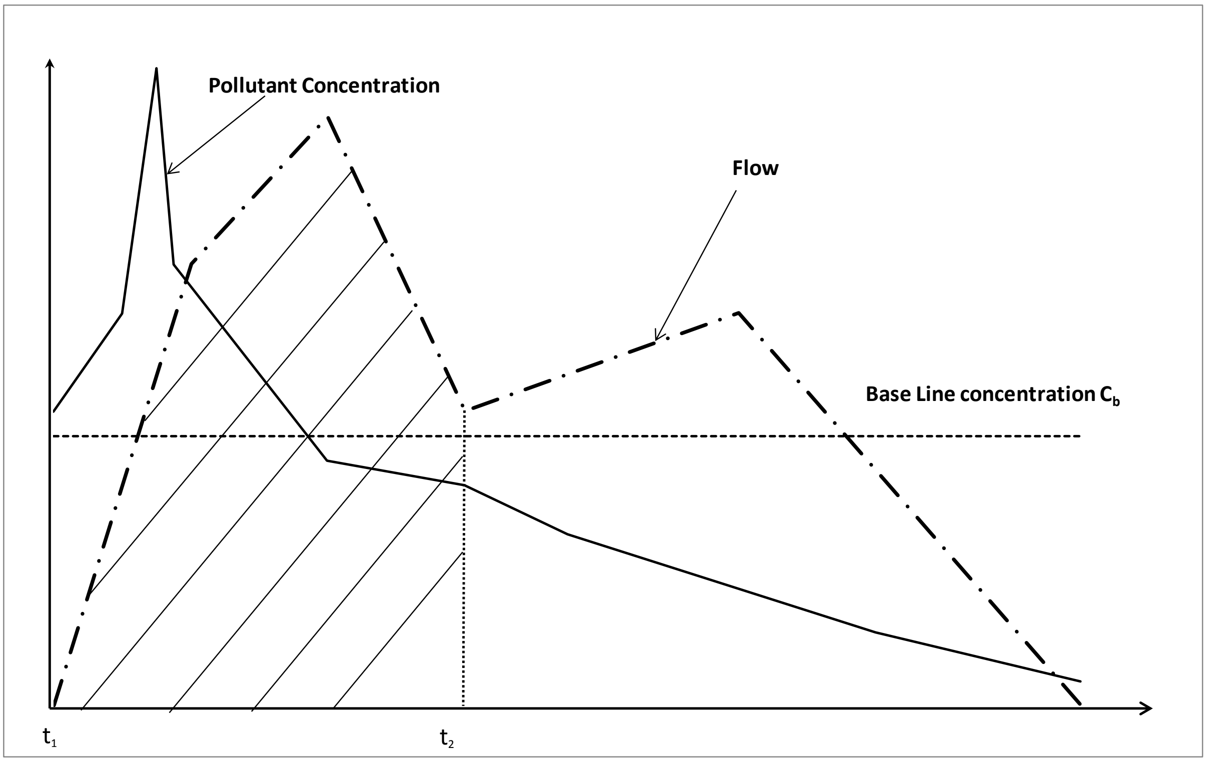

Figure 1: Determination of the first flush based on the US EPA (1993) after Bertrand-Karjewiski (1998).

1.3.2 Mass-based framework

This framework is based on the development of dimensionless cumulative mass M(t) and volume V(t) curves. For a particular runoff event, these curves can be calculated using the following equations:

$$V(t = k\Delta t) = \frac{\sum_{i=0}^{k} \bar{Q}(t_i)\Delta t_i}{\sum_{i=0}^{n} \bar{Q}(t_i)\Delta t_i} \quad (1)$$

$$M(t = k\Delta t) = \frac{\sum_{i=0}^{k} \bar{Q}(t_i)\bar{C}(t_i)\Delta t_i}{\sum_{i=0}^{n} \bar{Q}(t_i)\bar{C}(t_i)\Delta t_i} \quad (2)$$

Where,

V(t) is the ratio of the total runoff at time t to that of the total volume runoff of the event

$\bar{Q}(t_i)$ is the average volumetric flow rate between successive measured runoff rates (average of consecutive flow rates within sample interval

$\bar{C}(t_i)$ is the mean concentration of pollutant between successive measured concentrations

Δt_i is the i-th sampling interval

M(t) is the ratio of the total pollutant mass at time t to that of the total pollutant mass of the event

Based on these curves various definitions for the first flush have been proposed. Saget et al. (1995) defines the first flush as occurring when at least 80% of the total pollutant load is transported in the first 30%

of the stormwater runoff volume. Wanielista and Yousef (1993) define the first flush as the transporting of at least 50% of the constituent mass in the first 25% of the runoff volume. Vorreiter and Hicky (1994) define the first flush as the percentage of pollutant load in the first 25% of the runoff volume. Likewise, Deletic (1998) defines the first flush as the percentage of pollution contained in the first 20% of the runoff volume. In general, there are three main methods which can be used to identify the first flush based on the M-V curves. These curves are used to identify first flush and non-first flush events. These methods are described in the following sections.

1.3.2.1 Method I

This method is largely a graphical one. It is based on the comparison of the M and V curves when these curves are plotted as a function of normalized time obtained by dividing the time from the start of the storm by the total event duration. An example of this plot is shown in Figure 2. In this figure, the first flush is regarded as occurring when the M curve resides above the V curve.

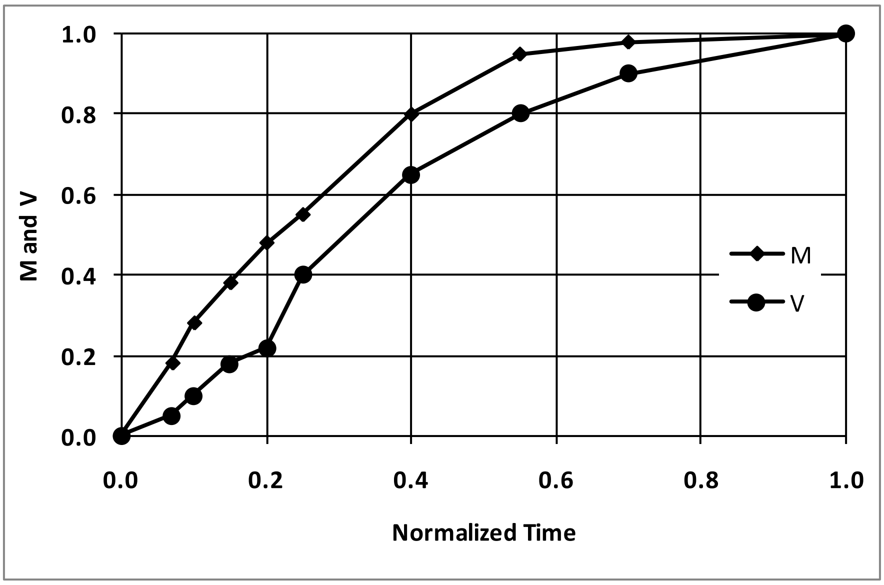

Figure 2: First flush Identification using Method 1 after Sansalone and Cristina, 2004).

1.3.2.2 Method II

This method is an extension to method I and can be regarded as a graphical method for identifying the first flush. The essence of this method is that it eliminates the time as the independent variable (Sansalone and Cristina, 2004). In this method, an X-Y plot of M against V is developed. On this plot a bisector line (45° line) is drawn. This bisector lines represents the situation of uniform pollutant removal from the catchment where the pollutant concentration is constant during the storm event. The first flush occurs when the M-V curve lies above the bisector line (see Figure 3). However, when the M-V curves lies below the bisector line it would represent the condition where the majority of the pollutants are delivered at the late stages of the event (Taebi and Droste, 2004). Geiger (1987) defined the first flush as occurring when the M-V curve has an initial slope greater than 45° i.e. the M-V curve is above the bisector line. The strength of the first flush is measured in terms of the maximum difference between the M-V curve and the bisector line. Geiger (1987) also considers that the first flush is significant when the maximum difference/gap between the M-V curve and the bisector line is greater than 0.2. However, the drawback of defining the first flush in this way is that the maximum gap could occur anywhere and extend over a portion of the curve. In this case, the resulting volume may not necessarily correspond to the first portion of the runoff event (Bertrand -Karjewiski et al., 1998).

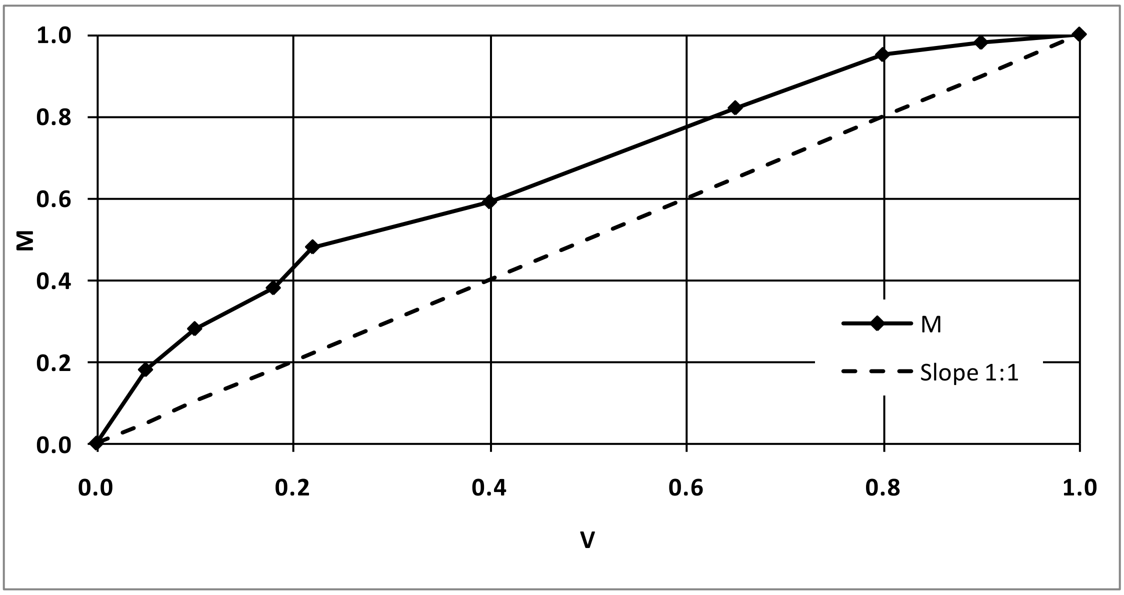

Figure 3: First flush Identification using Method II after Sansalone and Cristina (2004).

The M-V curves also yield important information about the temporal distribution of pollutant loadings over the event duration. This would enable the classification of the pollutograph in terms of the temporal distribution of loadings during the storm event (Obermann et al., 2009). Figure 4 shows the boundaries of the M-V based on artificial scenarios reported in Obermann et al. (2009). Based on this figure six scenarios can be identified;

1. Constant concentration: When the pollutant concentration is constant during the storm event the resulting M-V curve would be equal to the bisector line.
2. Constant load: In this case, a strong dilution can be observed especially around the peak flow. The resulting M-V curve would be very close to the bisector line.
3. Storage Depletion of pollutant source: In this case, the concentration increases with the flow until the pollutant storage is depleted. The M-V curve is very steep and reaching its maximum value before the end of the storm event. This result in a strong first flush. This type of first flush is also known as "mass-limited first flush".
4. Load delay can cause the peak concentration to occur in the recession limb of the flow hydrograph. This situation can happen when the pollutant is mainly coming from a sub-catchment. It can also happen when the pollutant requires some time before becoming available for transport.
5. Delay and depletion: This is basically a combination of scenarios (3) and (4).
6. Two different pollutant storages: An example of this is the first pollutant storage being directly available for transport, but the other is only available for transport after some time.

In this case, the M-V curve increases at beginning of the event and after a certain time it stagnates having a constant value and thereafter it starts increasing again.

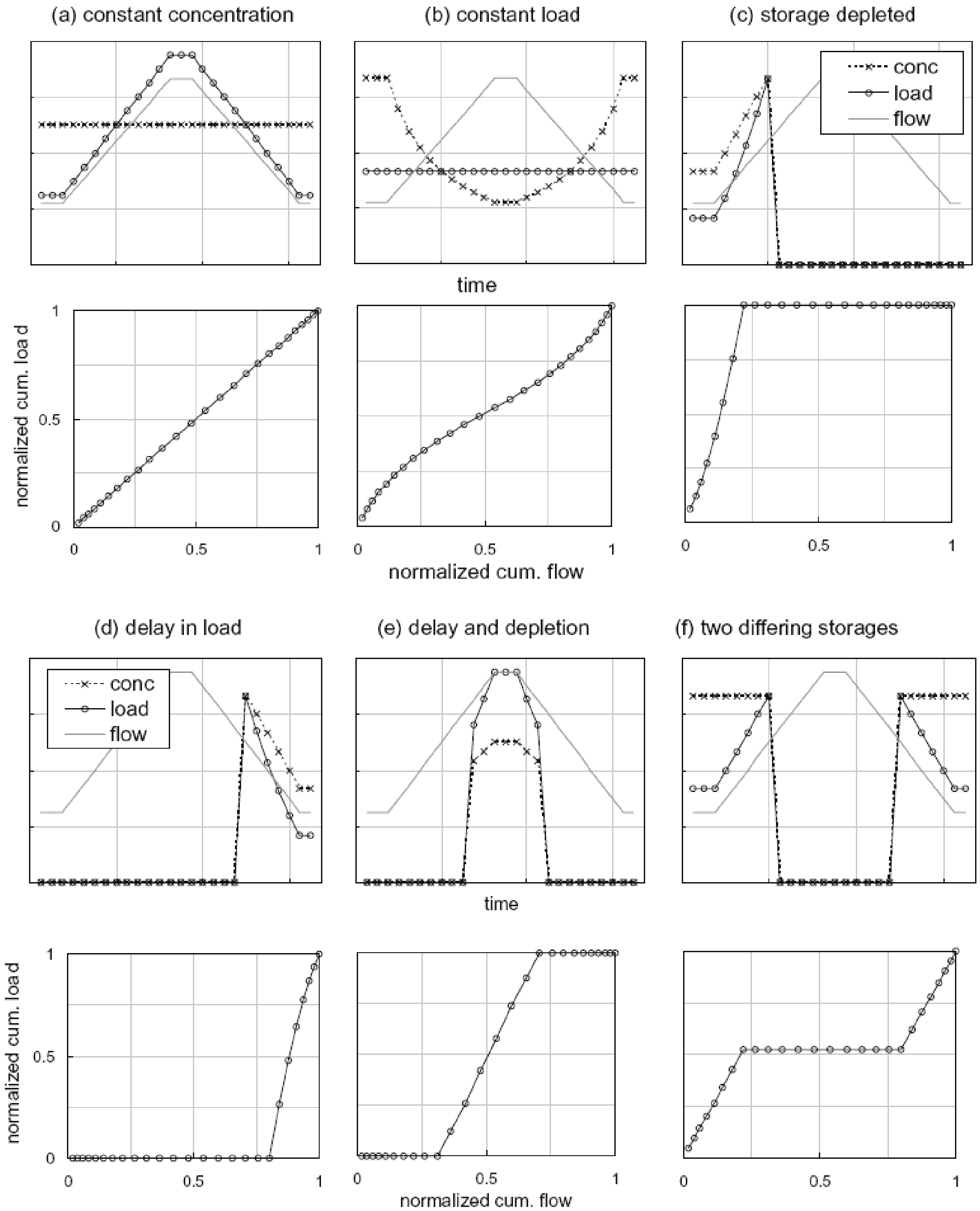

Figure 4: Boundaries of the M-V curve based on artificial scenarios (Obermann et al., 2009).

1.3.2.3 Method III

This method is essentially a more elegant formulation of method II. It is based on developing a power law functional relation between M(t) and V(t) having the following form (Saget et al., 1996; Bertrand-Karjewiski, 1998)

$$M(t) = V(t)^b \qquad (3)$$

Where,

b is known as the first-flush coefficient indicating the difference/gap between the M-V curve and the bisector line (see Figure 5).

V(t) is the ratio of the total runoff at time t to that of the total volume runoff of the event

M(t) is the ratio of the total pollutant mass at time t to that of the total pollutant mass of the event

The fitting of this function is usually considered satisfactory when $r^2 \geq 0.9$. If the value of b is less unity then the first flush is regarded as having occurred with the strength of the first flush being inversely proportional to the value of the parameter b for b values less than unity (see Figure 5). Bertrand et al. (1998) developed a classification for the M-V curves based on the value of the coefficient b (see Table 1 and Figure 6). This method for first flush identification is essentially a numerical one and does not involve subjective identification of first flush based on graphs as in methods I and II.

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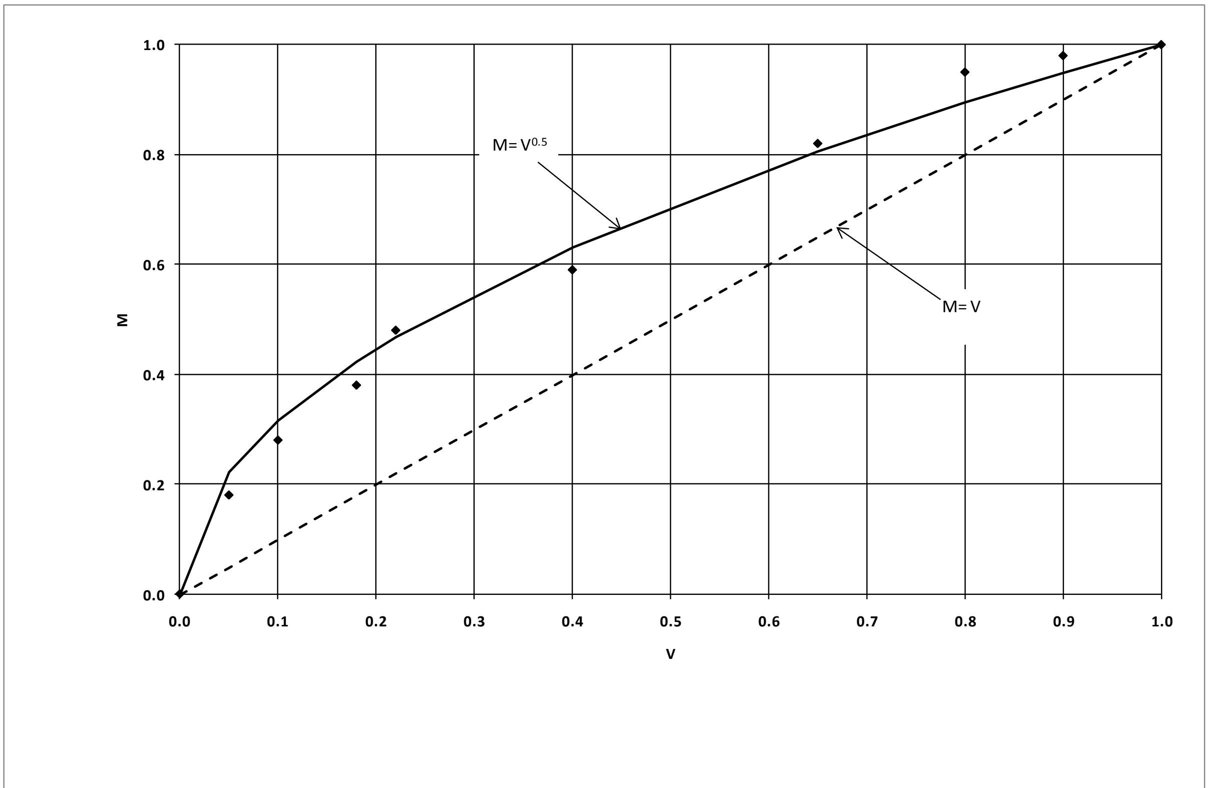

Figure 5: Identification of first flush based on Method III after Sansalone and Cristina (2004).

Table 1: Topology of the M-V curves base of the coefficient b after adapted from Bertrand-Karjewiski (1998) and Tabei and Droste (2004).

Value of b	Zone	Description
0 ≤ b < 0.185	1	Strong first flush
0.185≤ b < 0.862	2	Moderate first flush
0.862 ≤ b < 1.00	3	Weak First flush
1≤ b < 1.159	4	No first flush
1.159 ≤ b < 5.395	5	No first flush with Moderate pollutant delay
5.395 ≤ b < ∞	6	No first flush with strong pollutant

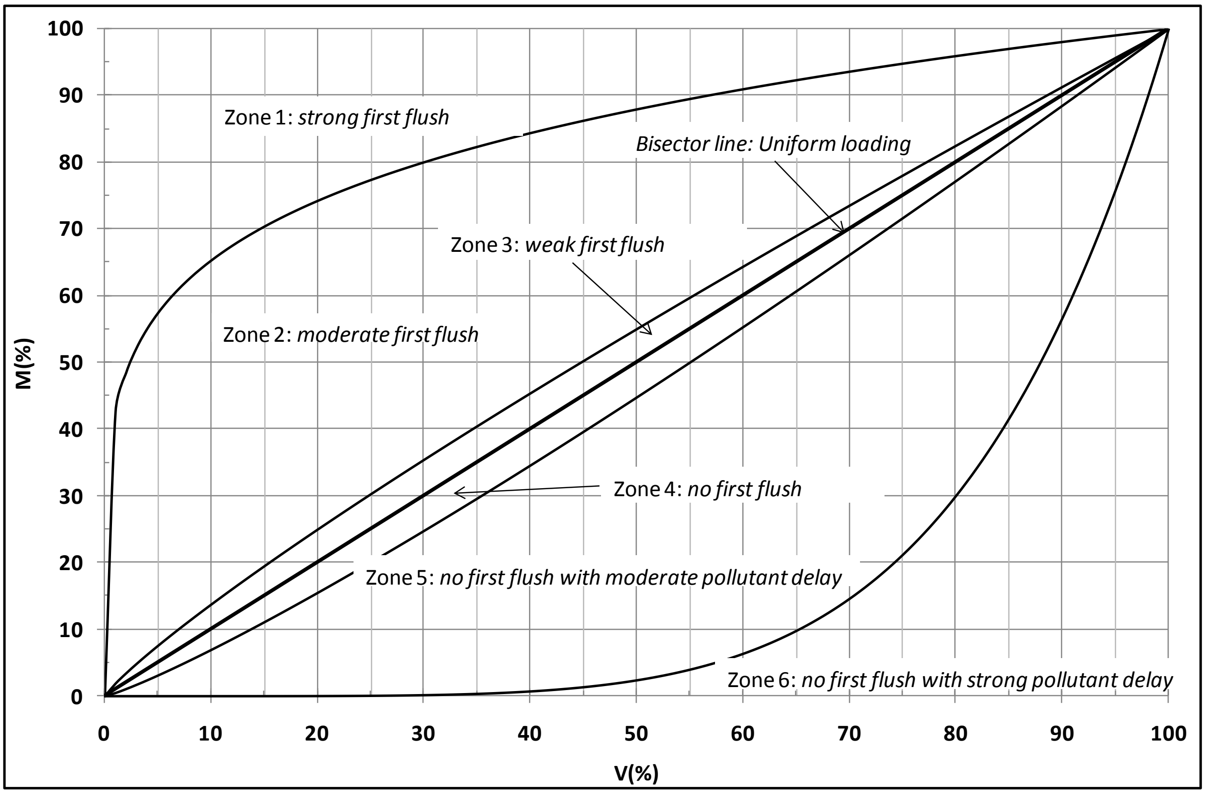

Figure 6: The M-V curve Zones depending of the value of the coefficient b adapted from Bertrand-Karjewiski (1998) and Tabei and Droste (2004).

1.3.3 Empirical Framework

Sansalone and Cristina (2004) noted that there are other methods used to define the first flush which do not belong to the above two noted frameworks. These methods include the multiple-linear regression introduced by Gupta and Saul (1996) based on establishing relationships between the first-flush pollutant load and independent variables such as rainfall intensity, rainfall duration and antecedent dry weather. Grisham (1995) defines the first flush as the first 1.27 cm of runoff per drainage area. Schueler (1987) defines the first flush as the first 0.5 inches of runoff per impervious area or the volume of runoff produced by one inch of rainfall. Likewise, State of California (2001) noted the first flush is the volume of water obtained by a 0.75 inch rainfall. In some studies, the first flush concept has been used to determine the critical initial runoff volume to be captured and treated. This critical volume is commonly known as the water quality volume (WQV) (Shamseldin, 2010; Chang et al., 2008, City of Boise 1998; Barrett 1999; State of Idaho 2001).

1.4 Management of First Flush

The treatment of urban stormwater through volume control and removal of pollutant is recognised by urban water managers as the key in effectively reducing the impacts of stormwater on the receiving environment. It is also recognised that the understanding of the relationships between pollutant concentration, storm event size, and regional climatic patterns is vital in allowing planners and engineers to design Best Management Practices (BMPs) to intercept specific volumes of runoff at the peak pollutant concentration to capture and reduce pollutant loads (Batroney et al., 2010).

Batroney et al. (2010) noted that consideration of the first flush is necessary when developing water quality sampling programs as well as in the process of designing and evaluating BMPs. Barco el al., (2008) noted that BMP focusing on treating the first flush, if it exists, is regarded as being a more economical approach for reducing pollutants from stormwater. In general, the size of the BMP is proportional to the volume to be treated i.e. the more volume to be captured and treated the larger is the BMP size which will have cost implications. In many cases due to space limitations the construction of larger BMP is not feasible. Batroney et al. (2010) mentioned that "If a first flush does not exist for a pollutant in a drainage area, then capturing the most volume will ensure the most pollutant load is captured. If, on the other hand, a pollutant does exhibit a first flush, then a larger percentage of the pollutant load is captured for a smaller captured volume". Batroney et al. (2010) also noted that a first flush with higher initial pollutant concentrations early in runoff has another significant interrelation with the removal efficiency of the BMP. It is a well known fact that various BMPS (e.g. filters and sedimentation devices) operate at a higher efficiency when the pollutant concentration is high (CASQA, 2003). However, Strecker et al. (2001) questioned the validity of the use of treatment efficiency as an indicator of BMP performance. They advocated that the use of effluent concentration provides more robust measures for estimating BMP performance.

In order to manage first flush some of the storm water management devices are fitted with first-flush diverters. Batroney et al. (2010) noted that the operation of the BMP devices can be modified so it behaves as a "first flush friendly" device. This can be achieved through the preferential treatment of the early part of runoff over the later part of runoff. For example, some of the stormwater treatment devices such as sedimentation tanks and dry ponds are specifically designed to treat the first flush runoff and bypass the reminder of runoff (Li et al., 2008).. Likewise, a two compartment settling has been proposed for treating highway runoff. In this settling tank, one compartment is used to capture and retain the first flush runoff and the other compartment which functions as a clarifier is used for treating the rest of the runoff (Li et al., 2008).

1.5 Summary and Conclusions

A literature review presented in this part of the report provided an overview about the first flush concept the methods used in its quantification as well as the management implication of the first flush. The literature review conducted as a part of this report shows that the first-flush concept is not new and can be found in the work of Metcalf and Eddy (1916). The first flush concept has been the focus of hot debate between the believers and the disbelievers of its existence. The concentration, the mass-based and the empirical frameworks used in identifying the existence/no-existence of the first flush from the observed data have been discussed. These frameworks have different levels of subjectivity. However, Method III of the mass-based framework discussed in section 1.3.2.3 of this reports appears to be the most widely used and more objective as it provides an objective numerical criteria for identifying first flush and does not involve subjective graphical interpretation of graphs to identify the first flush. Furthermore, the results obtained from empirical frameworks can be site specific and non transferable. Likewise, the definition of the first flush based on the concentration based framework has a number conceptual weakness as noted by Bertrand-Karjewiski et al. (1998) (see Section (1.3.2) for further details). For these reasons, Method III has been chosen for dtat analysis. Also discussed were the management implications of the first flush concept, namely, water quality sampling programs and sizing of stormwater management devices as well as their removal efficiencies. It is concluded that designing stormwater management devices to focus on treating the first flush, if it exists, is regarded as being a more economical approach for removing pollutants from stormwater.

2 DESCRIPTION AND QUALITY CONTROL OF DATA

2.1 Introduction

This part of the report provides an overview of the data used in the first flush analysis. It describes the data sources and the data screening process adopted in this study.

2.2 First Flush Data Sources

The first flush data used in this study has been obtained from two main sources:

- Auckland Regional Council
- Metrowater and Auckland City Council

The data supplied to investigate first flush includes the measured flow rates and the concentration of 22 water quality variables with the corresponding total number of events which are shown in Table 2. In total, the data from 16 sites is used in the present study. Table 3 shows a summary description of the sites. However, not all of these 22 parameters are measured at all sites for all events.

Table 2: List of Water Quality Parameters and the total number of measured events for each parameter.

No	Variable	No of Events
1	Dissolved Copper (dcu)	100
2	Dissolved Zinc (dZn)	100
3	Fluoride	67
44	Enterococci	74
5	Total suspended solids (TSS)	134
6	Suspended Solids Copper (ssCu)	74
7	Suspended Solids Zinc (ssZn)	74
8	Suspended Solids Lead (ssPb)	74
9	Copper (pCu)	87
10	Zinc (pZn)	87
11	Lead (pPb)	80
12	Dissolved Reactive Phosphorus (DRP)	70
13	Ammonium Nitrogen (NH4-N)	70
14	Nitrate Nitrogen (NO3-N)	70
15	Total Dissolved Nitrogen (TDN)	70
16	Total Dissolved Phosphorus (TDP)	70
17	Particle Size Total Petroleum Hydrocarbons (TPH)	39
18	Polycyclic Aromatic Hydrocarbons (PAH)	26
19	E. Coli	26
20	Total Zn	35
21	Total Cu	35
22	Total Dissolved Solids (TDS)	3

Table 3: Summary description of the first flush sites.

No	Site	Landuse	Location	Manhole	Monitoring period
1	CBD (Aotea Square)	Commercial	Between Aotea Centre and Ferguson Building	AF060	November 2000 – March 2002
2	Mission Bay	Residential with separated	Beside Aotea Reserve	AA150	November 2000 – December 2001
3	Onehunga	Residential and Industrial	In the SEMCO yard off 360 Neilson Street	MH#7.19	November 2000 – December 2001
4	Orakei	Residential with separated	Orakei Domain	AA070	February 2001 – July 2001 April 2002 – July
5	Tamaki	Industrial	University of Auckland Tamaki Campus, Glen Innes	BN220	February 2001 – July 2001 April 2002 – July 2002
6	Mayoral	Commercial	Beside Mayoral Drive	GA005	February 2001 – July 2001 April 2002 – July 2002
7	Cox's Bay	Residential with combined	❑ Grey Lynn Park	❑ AA200	❑ April 2002 – July 2002 February 2003
8	Remuera (Combes Road)	Residential	On downhill side of Combes Road	AA410	April 2002 – July 2002 February 2003 – April
9	Block house Bay	Residential, Commercial &	below the culvert under Wolverton Road	--	Jan 2002 – Jul 2002
10	Oakley Creek	Residential, Commercial &	just upstream of the culvert under	--	Jan 2003-April 2003
11	Pond Study	Residential	Northern end of the Nukumea viaduct and	--	2007
12	Waitakere Rain Garden	Industrial	Waitakere Vehicle Testing Site	--	Nov 2006 – June 2007
13	Birkdale permeable pavement	Industrial	Birkdale road	--	March 2006 – Dec 2008
14	Albany Treatment train	Industrial	Albany Park-N-Ride bus Station	--	May 2009 – July 2009
15	Motions	Residential, Commercial &	Western Spring Park		May 2005 - July 2006
16	Meola	Residential	Great North RD		May 2005 - November 2005

2.3 Screening of Data used in First Flush Analysis

This part of the report deals with the screening of the water quality data used in the first flush analysis at the different sites. The event data measured at the different sites covers different time periods and the events are not necessarily synchronous.

For each site, the data was supplied in two different files. The first data file contains the flow rates (discharges) and the second data file contains the flow rates for storm events and the pollutant concentration for different events. Inspection of these files shows that the flow rates recorded in the first (discharge) file and the second (event) file are measured by two different pieces of equipment. Further inspection of the files indicates that data supplied had a number of error types and deficiencies. In some cases a particular event had a number of error types. A summary of these error types and deficiencies is outlined below.

2.3.1 Sampler measurement error

Table 4 shows an example for the sampler measurement error. As can be seen from the table the discharge rate has increased from 28.38 L s^{-1} to 525.1 L s^{-1} in 10 seconds, which is not realistic.

Table 4: Event Data from the CBD site.

Date	Time	Flow L s^{-1}
12-Feb-02	10:05:00	28.38
12-Feb-02	10:05:10	525.1
12-Feb-02	10:10:00	36.036

2.3.2 Time Synchronization Error

This type of error arises when the clock settings for the equipment used in water quality and quantity measurements are not the same. Table 5 shows an example of the time synchronization error. The table shows two discharge time series, one is obtained from the event file and the other obtained from the discharge file. Inspection of the table shows the time at which a particular discharge is recorded in the event file differs by 1 hour from that at which the same discharge value is recorded in the discharge file. The possible cause of this error type is that the equipment clock settings were not adjusted for day light savings.

Table 5: Time Synchronization error in the Onehunga Site data.

Source Discharge File		Source Event File	
Time	Flow L s^{-1}	Time	Flow L s^{-1}
28/03/2001 16:28	158.67	28/03/2001 15:28	158.67
28/03/2001 16:29	146.42		
28/03/2001 16:30	167.06		
28/03/2001 16:31	168.86		
28/03/2001 16:32	147.19		
28/03/2001 16:33	156.94		
28/03/2001 16:33	146.85	28/03/2001 15:33	146.85
28/03/2001 16:34	153.82		
28/03/2001 16:35	149.94		
28/03/2001 16:36	146.49		
28/03/2001 16:37	131.94		
28/03/2001 16:38	145.28		
28/03/2001 16:39	150.44		
28/03/2001 16:39	137.3	28/03/2001 16:39	137.30

2.3.3 Significant differences in the recorded flow values in different files.

This refers to the situation where the flow values recorded in different files are significantly different. Example of this error is shown in Table 6. Inspection of the table shows the recorded flow value in the event file is approximately 1.7 times the recorded flow in the discharge file.

Table 6: Recorded flow values in Mission Bay site in different files

Source Discharge File		Source Event File	
Time	Flow L s^{-1}	Time	Flow L s^{-1}
8-Mar-01 0:50	98.18	8-Mar-01 0:50	166.6

2.3.4 Missing Data

In some case the time and/or the flow rate is not recorded. Table 7 shows an example of missing data.

Table 7: Example of missing data from Cox's Bay site.

Date	Time	Discharge	dCu	dZn	Fluoride
		L s^{-1}	g m^{-3}	g m^{-3}	g m^{-3}
30-May-01			0.0046	0.639	0.035
30-May-01			0.0033	0.639	0.025
30-May-01			0.0022	0.409	0.025
30-May-01			0.0035	0.599	0.010
30-May-01			0.0033	0.549	0.010

2.3.5 Event Definition

There is no clear definition of what constitutes a storm runoff event with the data supplied from the different sources. Examination of the event and the discharge files shows in some cases the event is not complete and the event can be further subdivided into a number of separate events. Figure 7 shows that the sole use of the data that from the event file misses the fact that the event has multiple peaks and can be further divided into two separate events.

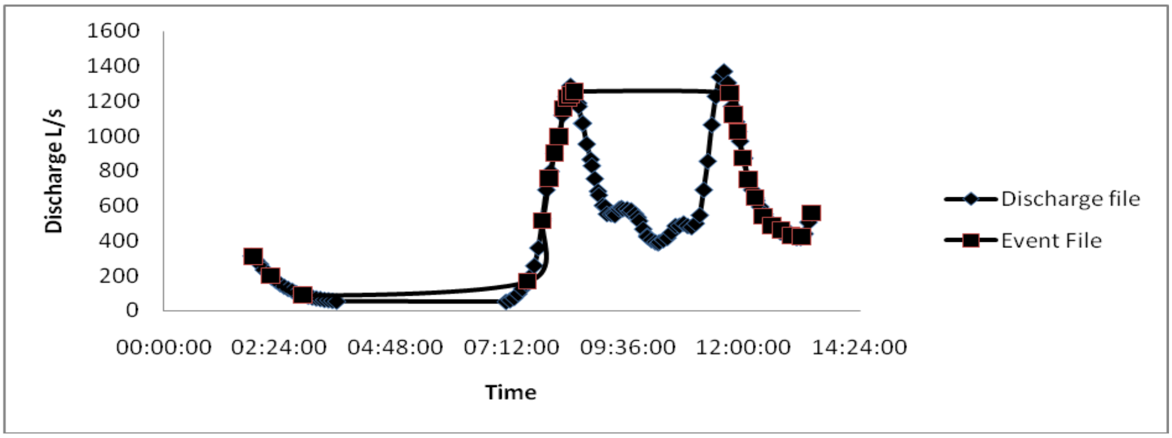

Figure 7: Storm runoff events obtained for different files at the Blockhouse Bay site for 28-March 2003.

2.3.6 Water Quality Sampling Adequacy

This refers to the situation where the water quality sampling is not carried out in a significant portion of the event duration. For example, Figure 8 shows that there was no water quality sampling being carried in almost the second half of the event duration. This may create considerable uncertainty when estimating the M-V curves.

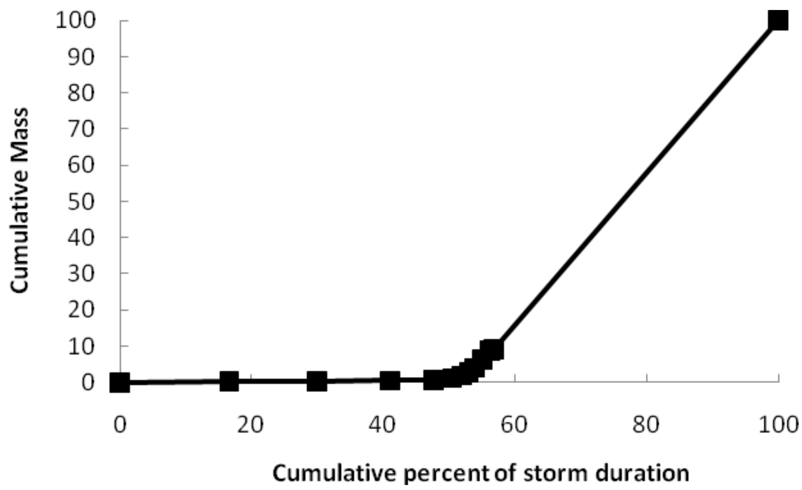

Figure 8: Example of deficiency in water quality sampling.

2.3.7 Sources of Particle Size Distribution Data

The particle size distribution (PSD) data used in this study is that collected between 2001 and 2003 by Auckland City Council (ACC) and Metrowater (MW) as a part of the water quality and quantity data monitored at sites in eight stormwater networks and in two urban streams (Griffiths and Timperley, 2005). The names and locations of these sites are reported in Skeen et al. (2010) and shown in Table 8 and Figure 9. The PSD data was analysed at NIWA Hamilton using a Galai WCIS-100 particle size analyser, a "time of flight" instrument. This analyser measures the particle size and shape as they cross a laser beam. The frequency of occurrence of particles in each size range is recorded from which the PSD is derived (Skeen et al., 2010) .

Table 8: Summary description the eleven PSD monitoring sites (Skeen et al., (2010)).

Location	Landuse	Site
Mayoral	Commercial	Piped network
Orakei	Residential	Piped network
Cox's Bay	Residential, commercial	Piped network
Aotea Square (CBD)	Commercial	Piped network
Mission Bay	Residential	Piped network
Remuera	Residential	Piped network
Tamaki	Industrial	Piped network
Onehunga	Residential, industrial	Piped network
Whau 1 (Blockhouse Bay)	Residential	Stream
Whau 2 (Wolverton)	Residential	Stream
Oakley	Residential, commercial, industrial	Stream

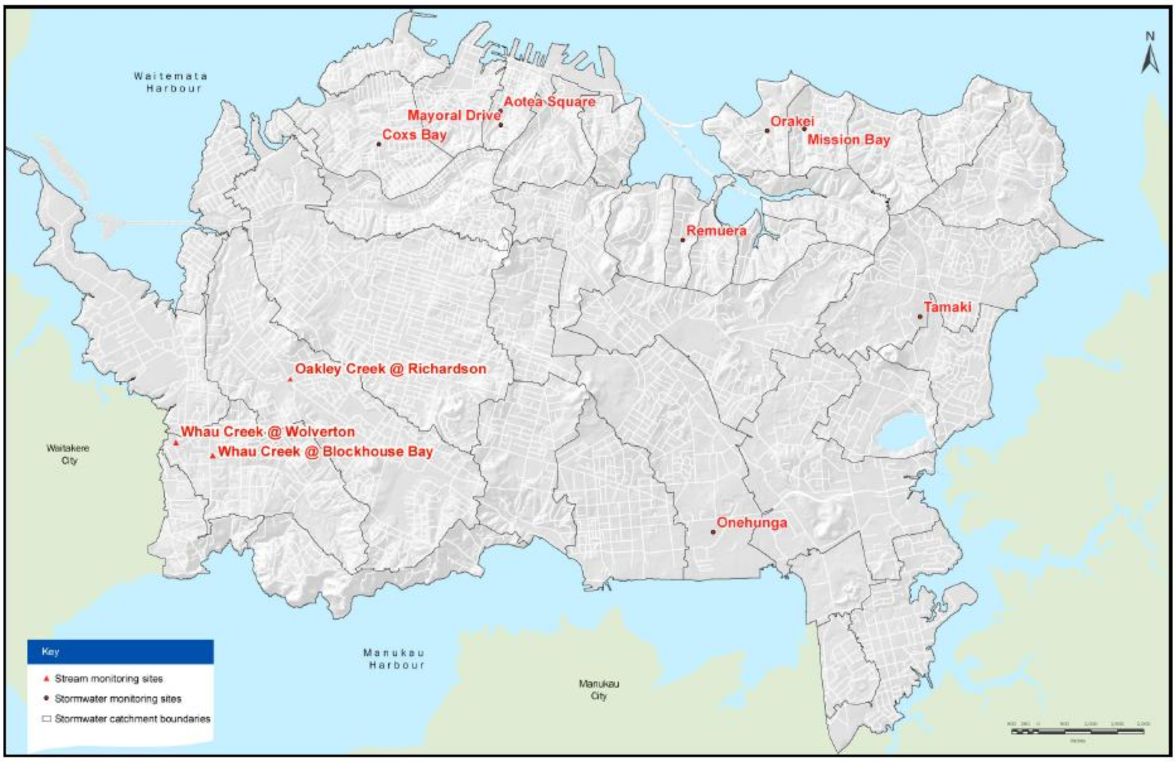

Figure 9: Location of PSD monitoring sites (Skeen et al., 2010).

3 First Flush Data Analysis in the Auckland Region

3.1 Introduction

This section of the report deals with applying the mass-based framework discussed in Section 1 to investigate the first flush phenomena in the Auckland region. The mass-based method III is used in the investigation as it is more objective and the calculations can be automated very easily. Method III is applied to the data of the 16 sites described in Section 2 of this report. The analysis presented in this part of the report focuses on the first flush analysis for 22 water quality parameters. These parameters are listed in Table 2 shown in Section 2 of this report.

3.2 First Flush Analysis Results and Discussion

3.2.1 TSS First Flush Analysis

The first flush coefficient b (Equation 3) values were calculated for the events available at the different sites. The values of the first flush coefficient obtained at the different sites and events are shown in Table A1 in Appendix A. The last column of Table A1 shows the percentage of events exhibiting first flush. This percentage varies between 20% in the case of the Meola site to 100% in the case of the Albany treatment train site. Examination of the table also shows that the first flush coefficient b values vary in the range 0.09 to 3.53. Figure 10 shows the percentage of the 134 events analyzed in the different M-V zones. Examination of the figure shows that 54% of the total number of events can be regarded as having first flush with 1%, 40% and 13% of the events classified as having strong, moderate and weak first flush (Table 1), respectively. Figure 11 shows the M-V curves for the two events having the maximum and the minimum value of first flush coefficients occurring in the Meola and the Birkdale sites, respectively. In the case of the event having the maximum first flush coefficient, the figure indicates that there is a pollutant load delay with pollutant storage depletion. It is possible that this delay at the outlet is caused by pollutant mainly coming from a sub-catchment. In the case of the event having the minimum first flush coefficient value, the figure shows around 90% of the pollutant load being delivered in the first 25% of the total volume of the stormwater runoff event.

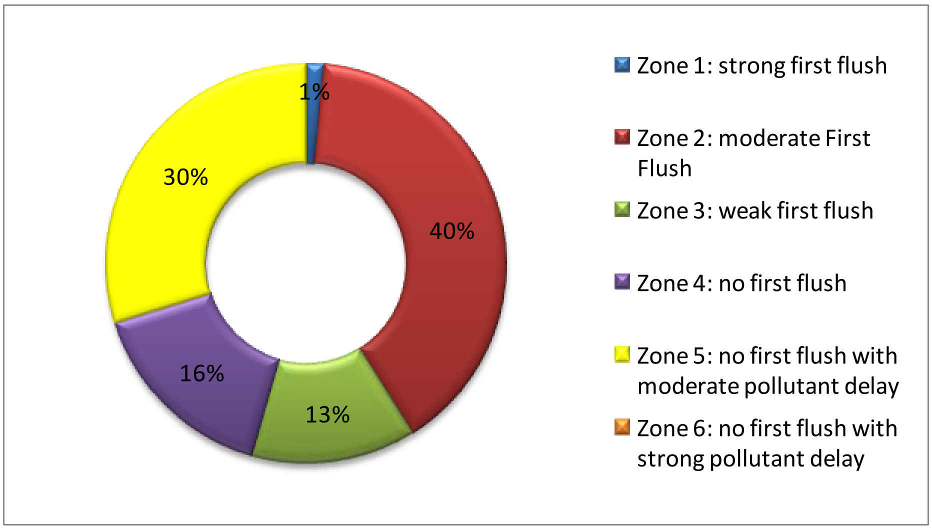

Figure 10: The percentage of TSS events in the different M-V zones

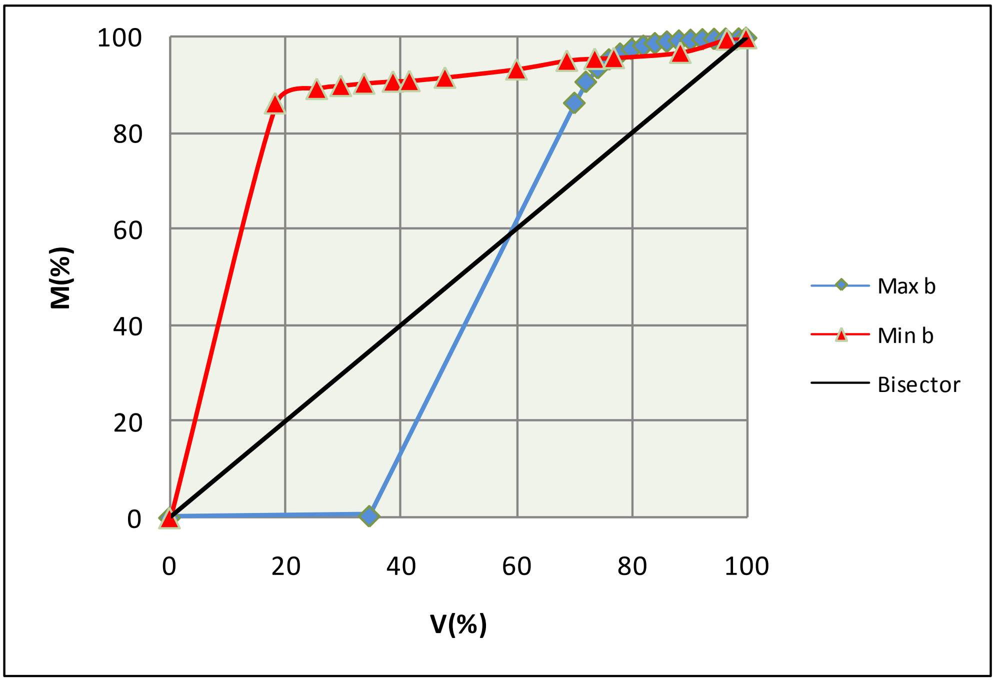

Figure 11: The M-V curves for events with the highest and the lowest TSS first flush coefficient values.

3.2.2 dCu First Flush Analysis

The values of the first flush coefficient obtained at the different sites and events are shown in Table A2 in Appendix A. The last column of Table A2 in Appendix A shows the percentage of events having first flush. This percentage varies between 0% in the case of the Albany treatment train site to 100% in the case of the Motions and Tamaki sites. Examination of the table also shows that the first flush coefficient values vary in the range 0.36 to 1.58. Figure 12 shows the percentage of the 100 events analyzed in the different M-V zones. Examination of the figure shows that 70% of the total number of events can be regarded as having first flush with 40% and 30% of the events classified as having moderate and weak first flush, respectively. Figure 13 shows the M-V curves for the two events having the maximum and the minimum value of first flush coefficients occurring in the Waitakere rain garden and the Tamaki sites, respectively. In the case of the event having the maximum first flush coefficient, the figure suggests a constant pollutant load. In the case of the event having the minimum first flush coefficient value, the figure shows around 45% of the pollutant load is delivered in the first 25% of the total volume of the stormwater runoff event.

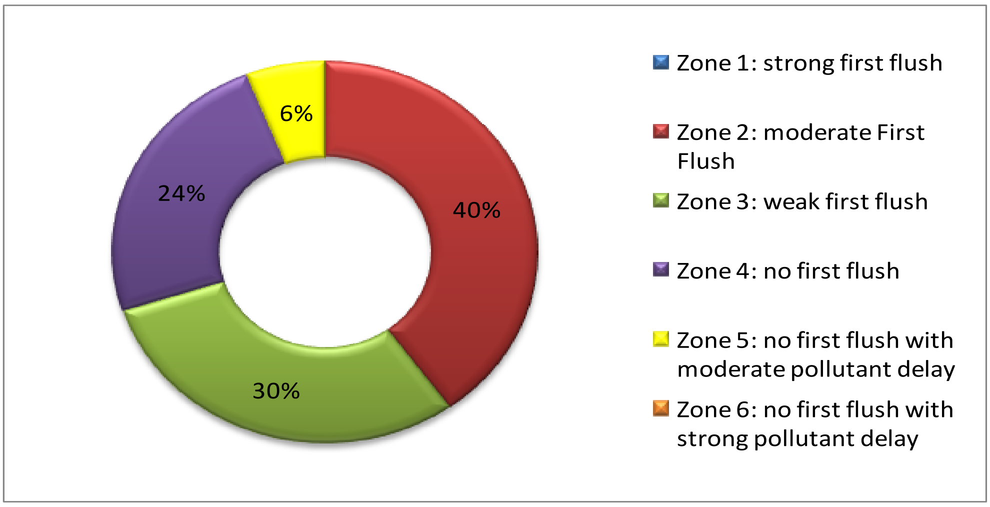

Figure 12: The percentage of events in the different M-V zones in the case of dCu.

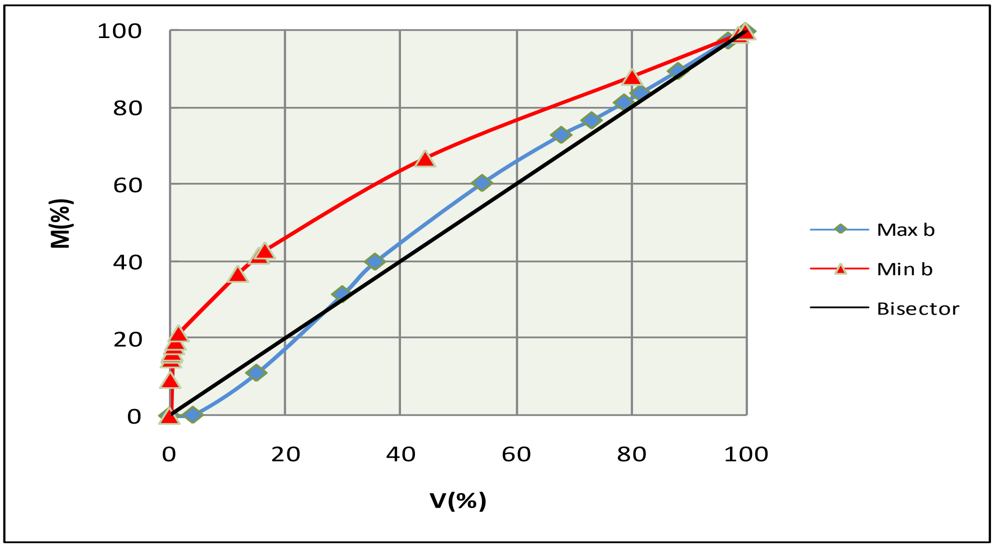

Figure 13: The M-V curves for events with the highest and the lowest dCu first flush coefficient values.

3.2.3 dZn First Flush Analysis

Table A3 in Appendix A shows the values of the dZn first flush coefficient. The table shows that the percentage of events having first flush varies between 0% in the case of the Meola site to 100% in the case of the CBD, Tamaki and Albany treatment train site sites. Examination of the table also shows that the first flush coefficient values vary in the range 0.27 to 3.48. Figure 14 shows the percentage of the 87 events analyzed in the different M-V zones. Examination of the figure shows that 65% of the total number of events can be regarded as having first flush with 39% and 26% of the events classified as having moderate and weak first flush, respectively. Figure 15 shows the M-V curves for the two events having the maximum and the minimum value of first flush coefficients occurring in the Blockhouse Bay and the Albany treatment train sites, respectively. In the case of the event having the minimum first flush coefficient value, the figure shows around 40% of the pollutant load is delivered in the first 20% of the total volume of the stormwater runoff event.

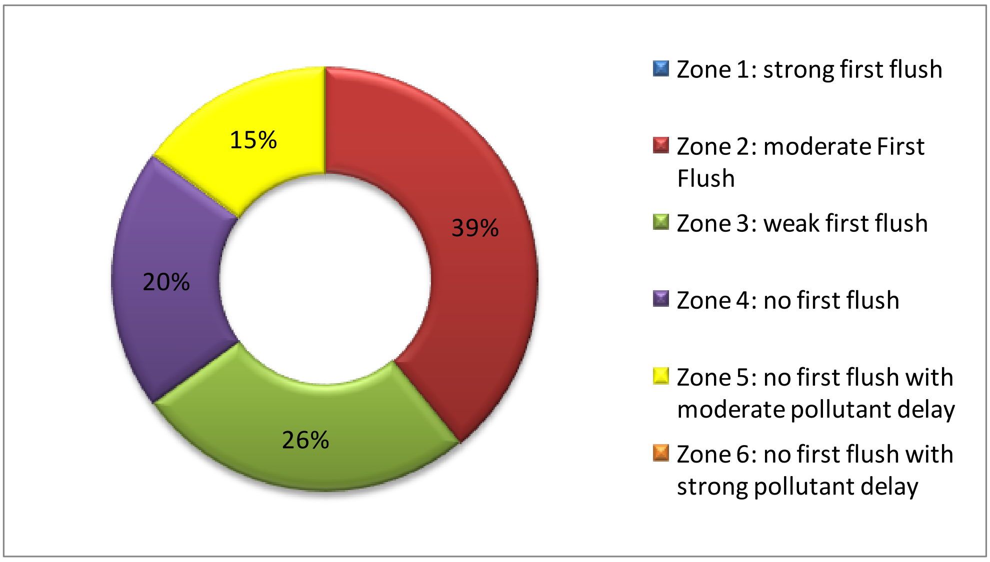

Figure 14: The percentage of events in the different M-V zones in the case of dZn.

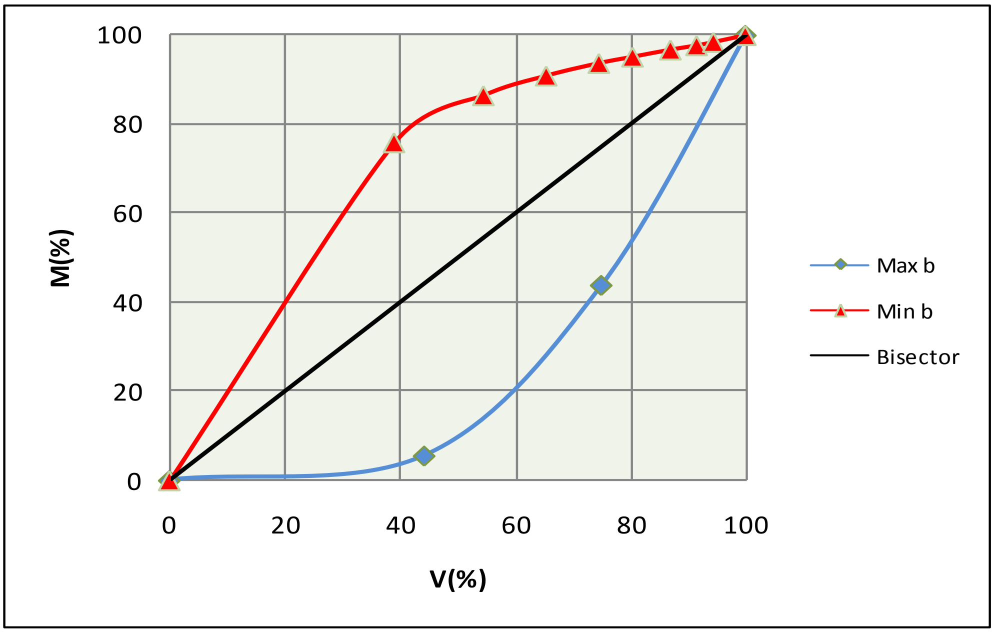

Figure 15: The M-V curves for events with the highest and the lowest dZn first flush coefficient values.

3.2.4 pCu First Flush Analysis

Table A4 in Appendix A shows the values of the first flush coefficient obtained at the different sites and events. The percentage of events having first flush varies between 20% in the case of the Meola site to 100% in the case of the Tamaki site. Examination of the table also shows that the first flush coefficient values vary in the range 0.19 to 3.52. Figure 16 shows the percentage of the 87 events analyzed in the different M-V zones. Examination of the figure shows that 61% of the total number of events can be regarded as having first flush with 45% and 16% of the events can be regarded as having moderate and weak first flush, respectively. Figure 17 shows the M-V curves for the two events having the maximum and the minimum value of first flush coefficients occurring in the Meola and the Orakei sites, respectively. In the case of the event having the maximum first flush coefficient, the figure indicates that there is a pollutant load delay with possible storage depletion. In the case of the event having the minimum first flush coefficient value, the figure shows around 60% of the pollutant load is delivered in the first 20% of the total volume of the stormwater runoff event.

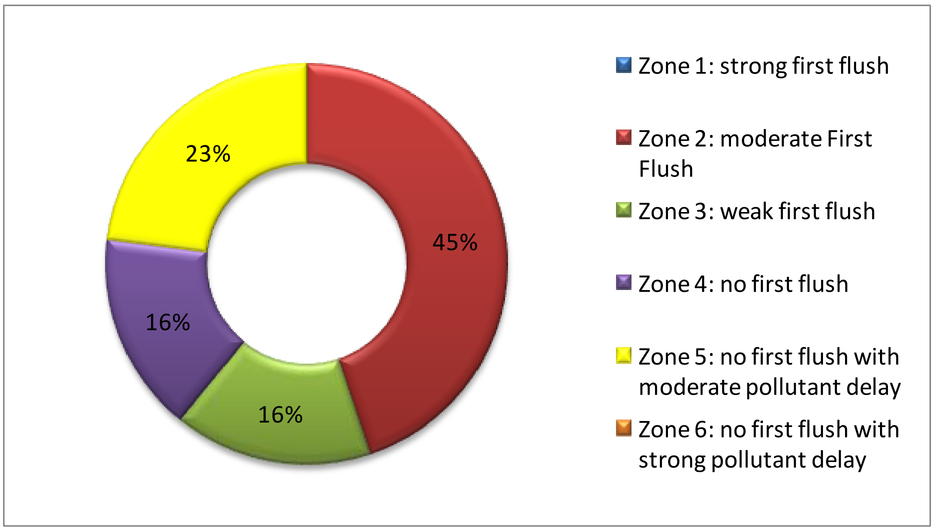

Figure 16: The percentage of events in the different M-V zones in the case of pCu.

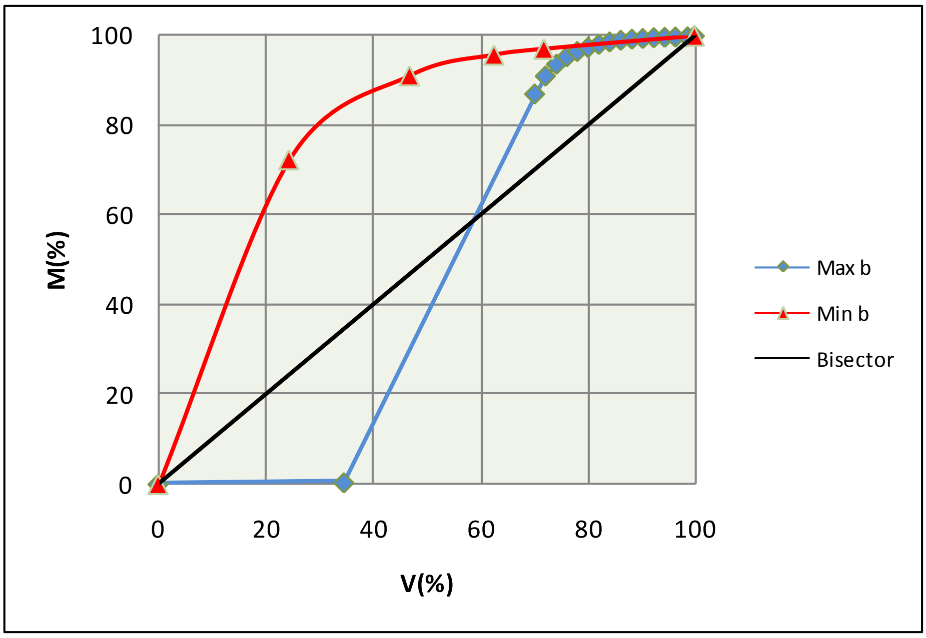

Figure 17: The M-V curves for events with the highest and the lowest pCu first flush coefficient values.

3.2.5 pZn First Flush Analysis

Table A5 in Appendix A shows the values of the first flush coefficient obtained at the different sites and events. The percentage of events having first flush varies between 20% in the case of Meola site to 100% in the case of the Tamaki site. Examination of the table also shows that the first flush coefficient values vary in the range 0.22 to 3.64. Figure 18 shows the percentage of 87 events analyzed in the different M-V zones. Examination of the figure shows that 66% of the total number of events can be regarded as having first flush with 45% and 21% of the events classified as having moderate and weak first flush, respectively. Figure 19 shows the M-V curves for the two events having the maximum and the minimum value of first flush coefficients occurring in the Meola and the Orakei sites, respectively. In the case of the event having the maximum first flush coefficient, the figure indicates that there is a pollutant load delay with possible storage depletion. In the case of the event having the minimum first flush coefficient value, the figure shows around 55% of the pollutant load being delivered in the first 20% of the total volume of the stormwater runoff event.

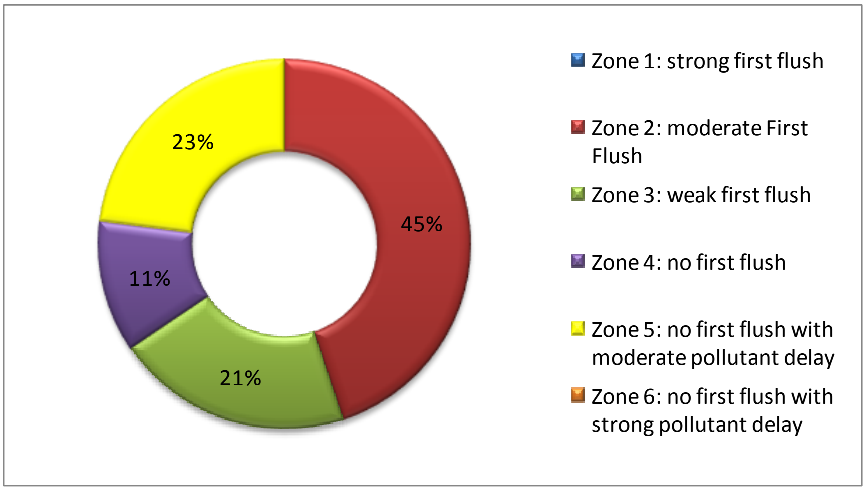

Figure 18: The percentage of events in the different M-V zones in the case of pZn.

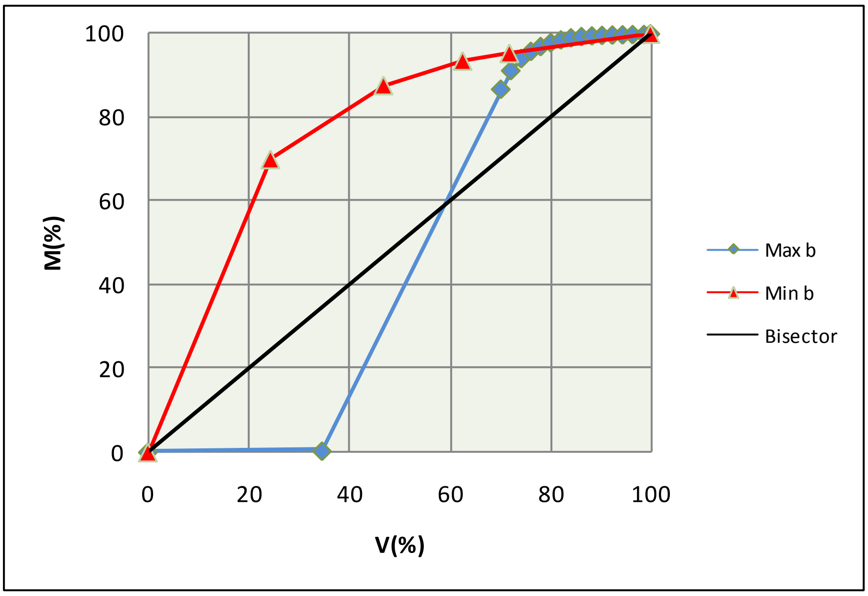

Figure 19: The M-V curves for events with the highest and the lowest pZn first flush coefficient values.

3.2.6 pPb First Flush Analysis

Table A6 in Appendix A shows the values of the first flush coefficient obtained at the different sites and events. The percentage of events having first flush varies between 20% in the case of Meola site to 100% in the case of the Tamaki site. Examination of the table also shows that the first flush coefficient values vary in the range 0.28 to 3.76. Figure 20 shows the percentage of the 80 events analyzed in the different M-V zones. Examination of the figure shows that 54% of the total number of events can be regarded as having first flush with 40% and 14% of the events classified as having moderate and weak first flush, respectively. Figure 21 shows the M-V curves for the two events having the maximum and the minimum value of first flush coefficients occurring in the Meola and the Orakei sites, respectively. In the case of the event having the maximum first flush coefficient, the figure indicates that there is a pollutant load delay with storage depletion. In the case of the event having the minimum first flush coefficient value, the figure shows around 55% of the pollutant load is being delivered in the first 20% of the total volume of the stormwater runoff event.

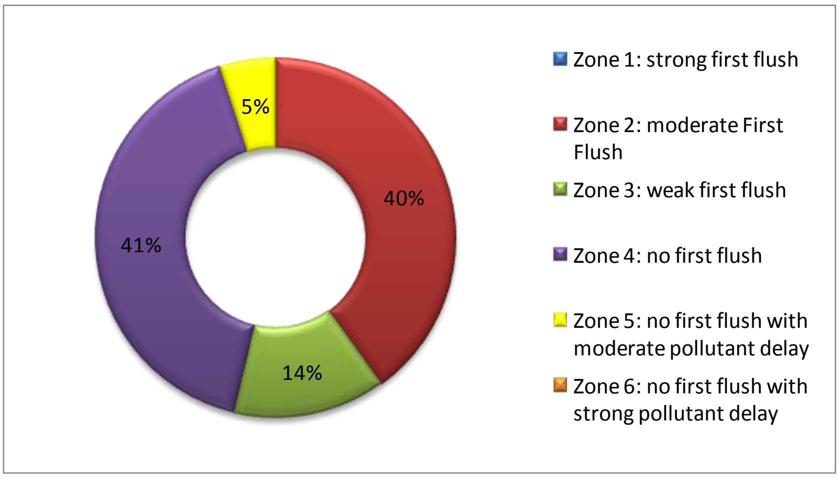

Figure 20: The percentage of events in the different M-V zones in the case of pPb.

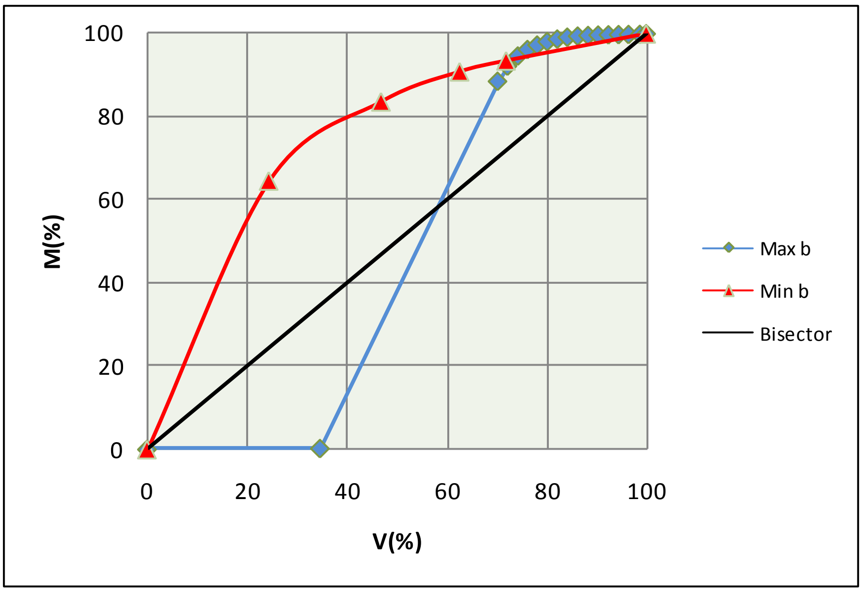

Figure 21: The M-V curves for events with the highest and the lowest pPb first flush coefficient values.

3.2.7 TCu First Flush Analysis

Table A10 in Appendix A shows the values of the first flush coefficient obtained at the different sites and events. The percentage of events having first flush varies between 20% in the case of Meola site to 75% in the case of the Remuera site. Examination of the table also shows that the first flush coefficient values vary in the range 0.13 to 2.44. Figure 28 shows shows the percentage of the 87 events analyzed in the different M-V zones. Examination of the figure shows that 64% of the total number of events can be regarded as having first flush with 6%, 49% and 9% of the events classified as having strong, moderate and weak first flush, respectively. Figure 29 shows the M-V curves for the two events having the maximum and the minimum value of first flush coefficients occurring in the Meola and the Birkdale sites, respectively. In the case of the event having the minimum first flush coefficient value, the figure shows around 70% of the pollutant load is being delivered in the first 20% of the total volume of the stormwater runoff event. In the case of the event having the maximum first flush coefficient, the figure indicates that there is a pollutant load delay with possible storage depletion.

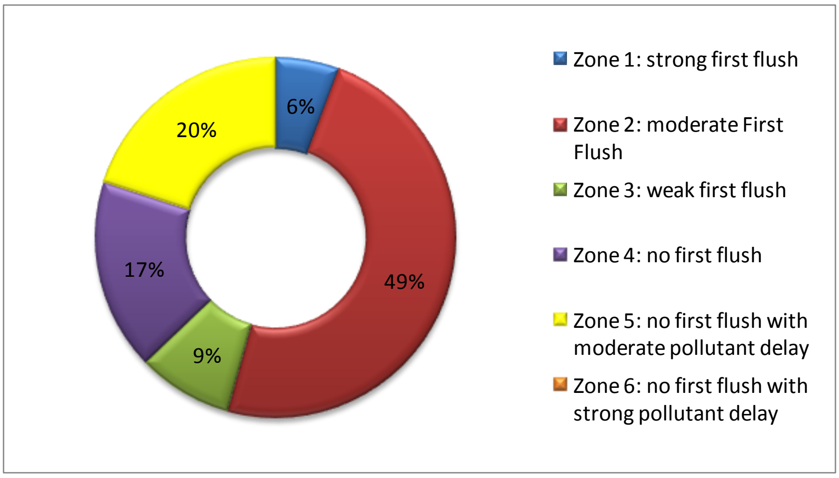

Figure 28: The percentage of events in the different M-V zones in the case of TCu.

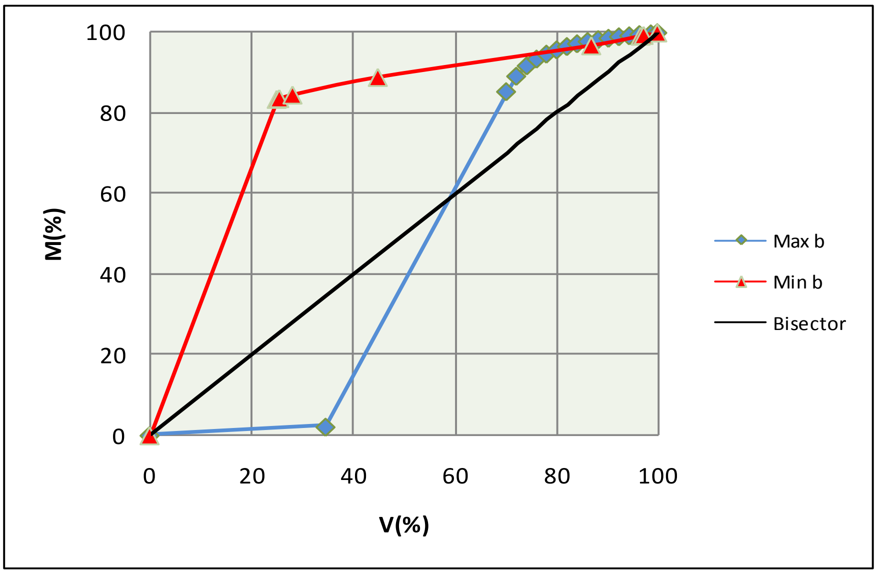

Figure 29: The M-V curves for events with the highest and the lowest TCu first flush coefficient values.

3.2.8 TZn First Flush Analysis

Table A11 in Appendix A shows the values of the first flush coefficient obtained at the different sites and events. The percentage of first flush events varies between 20% in the case of Meola site to 100% in the case of the Albany treatment train site. Examination of the table also shows that the first flush coefficient values vary in the range 0.20 to 2.04. Figure 30 shows the percentage of 35 events analyzed in the different M-V zones. Examination of the figure shows that 72% of the total number of events can be regarded as having first flush with 49% and 23% of the events classified as having moderate and weak first flush, respectively. Figure 31 shows the M-V curves for the two events having the maximum and the minimum value of first flush coefficients occurring in the Meola and the Birkdale sites, respectively. In the case of the event having the minimum first flush coefficient value, the figure shows around 60% of the pollutant load being delivered in the first 20% of the total volume of the stormwater runoff event. In the case of the event having the maximum first flush coefficient, the figure indicates that there is a pollutant load delay with possible storage depletion.

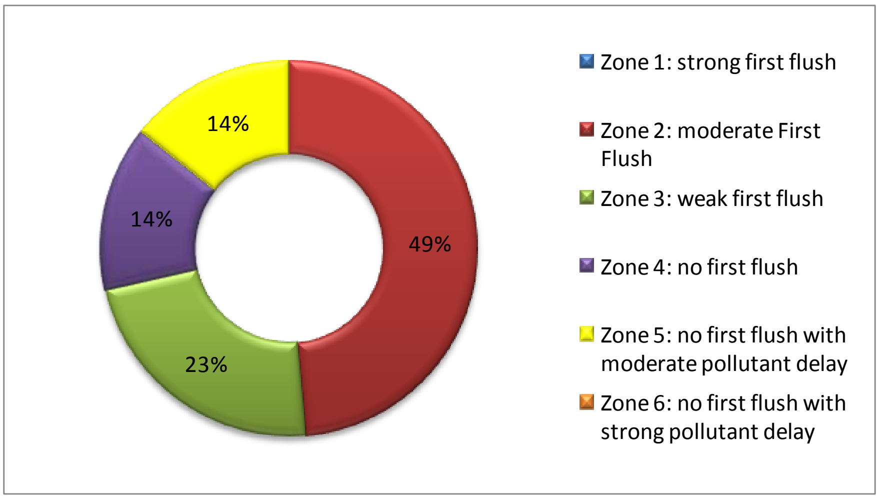

Figure 30: The percentage of events in the different M-V zones in the case of TZn.

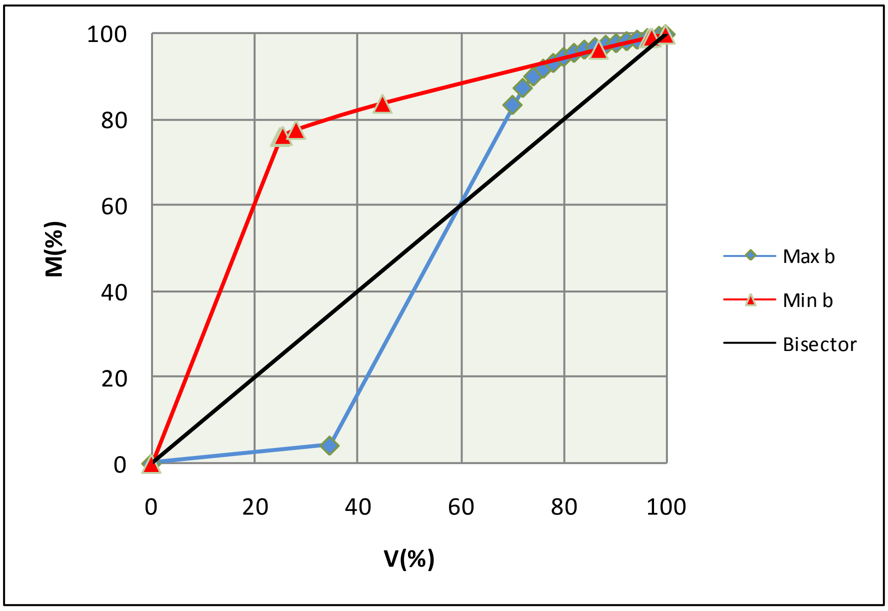

Figure 31: The M-V curves for events with the highest and the lowest TZn first flush coefficient values.

3.2.9 NH_4-N First Flush Analysis

Table A12 in Appendix A shows the values of the first flush coefficient obtained at the different sites and events. The percentage of first flush events varies between 0% in the case of the Tamaki site to 85% in the case of the CBD site. Examination of the table also shows that the first flush coefficient values vary in the range 0.28 to 2.70. Figure 32 shows the percentage of 70 events analyzed in the different M-V zones. Examination of the figure shows that 54% of the total number of events can be regarded as having first flush with 40% and 14% of the events classified as having moderate and weak first flush, respectively. Figure 33 shows the M-V curves for the two events having the maximum and the minimum value of first flush coefficients occurring in the Onehunga and the CBD sites, respectively. In the case of the event having the minimum first flush coefficient value, the figure shows around 65% of the pollutant load is being delivered in the first20% of the total volume of the stormwater runoff event. In the case of the event having the maximum first flush coefficient, the figure indicates that there is a pollutant load delay.

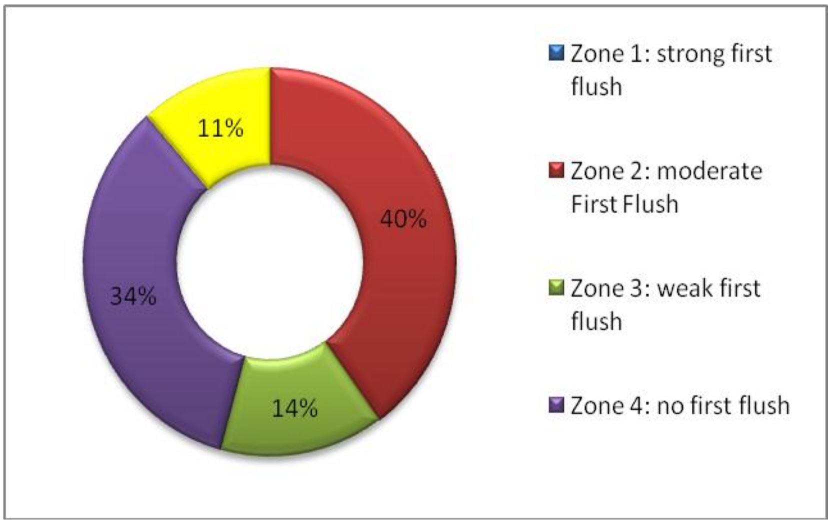

Figure 32: The percentage of events in the different M-V zones in the case of NH4-N.

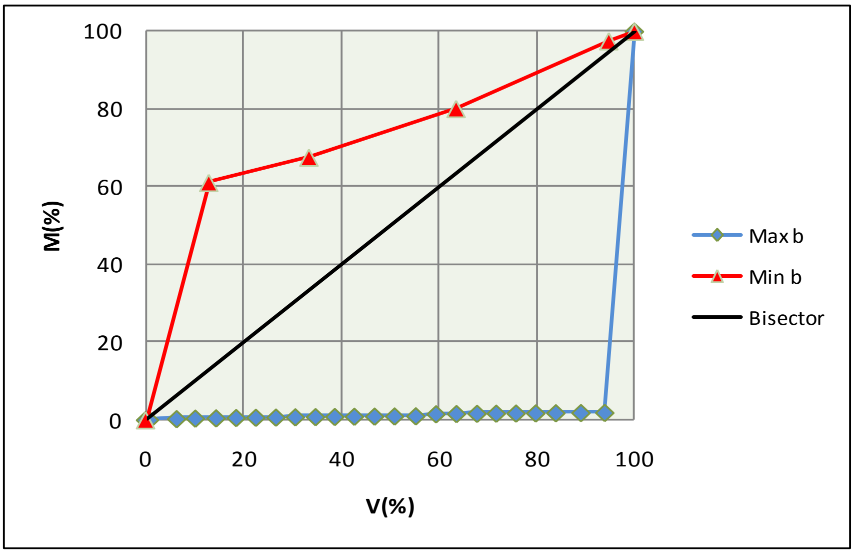

Figure 33: The M-V curves for events with the highest and the lowest NH4-N first flush coefficient values.

3.2.10 NO_3-N First Flush Analysis

Table A13 in Appendix A shows the values of the first flush coefficient obtained at the different sites and events. The percentage of events having first flush varies between 25% in the case of the Orakei site to 69% in the case of the CBD site. Examination of the table also shows that the first flush coefficient values vary in the range 0.28 to 2.70. Figure 34 shows the percentage of 70 events analyzed in the different M-V zones. Examination of the figure shows that 55% of the total number of events can be regarded as having first flush with 24% and 31% of the events classified as having moderate and weak first flush, respectively. Figure 35 shows the M-V curves for the two events having the maximum and the minimum value of first flush coefficients occurring in the Onehunga and the CBD sites, respectively. In the case of the event having the minimum first flush coefficient value, the figure shows around 60% of the pollutant load is delivered in the first 20% of the total volume of the stormwater runoff event. In the case of the event having the maximum first flush coefficient, the figure indicates that there is a pollutant load delay.

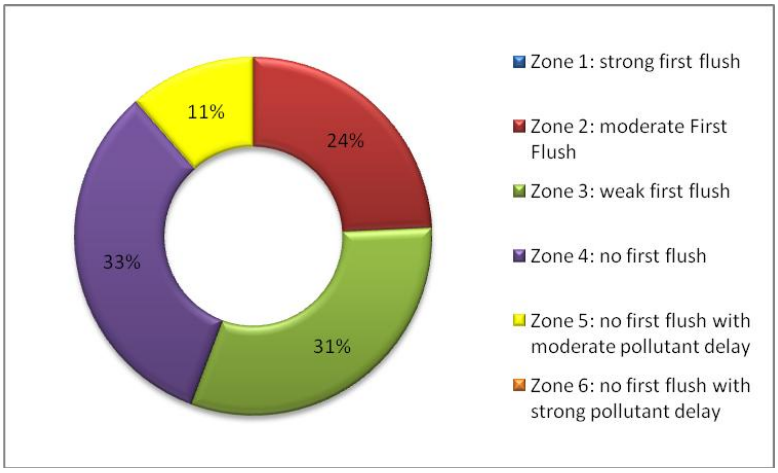

Figure 34: The percentage of events in the different M-V zones in the case of NO3-N.

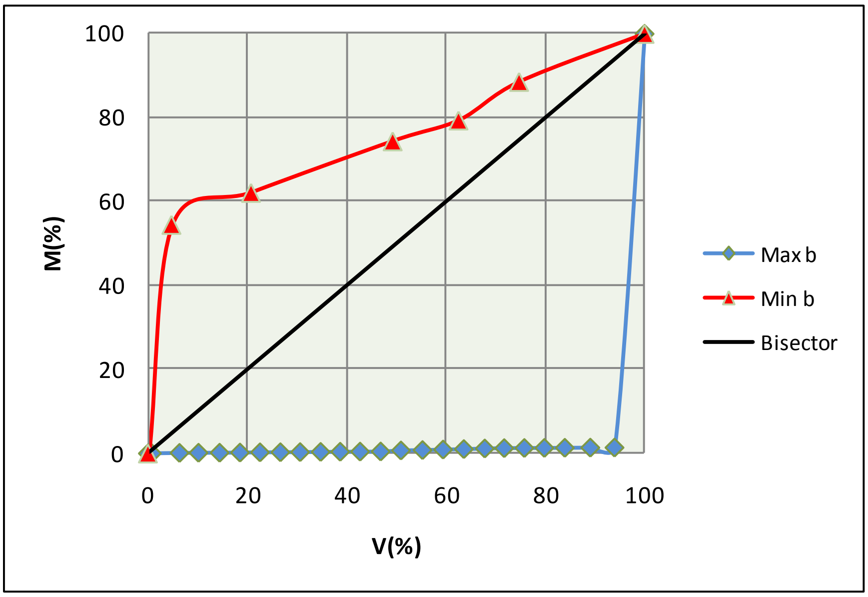

Figure 35: The M-V curves for events with the highest and the lowest NO3-N first flush coefficient values.

3.2.11 DRP First Flush Analysis

Table A14 in Appendix A shows the values of the first flush coefficient obtained at the different sites and events. The percentage of first flush events varies between 13% in the case of the Orakei site to 69% in the case of the CBD site. Examination of the table also shows that the first flush coefficient values vary in the range 0.30 to 4.42. Figure 36 shows the percentage of 70 events analyzed in the different M-V zones. Examination of the figure shows that 42% of the total number of events can be regarded as having first flush with 21% and 21% of the events classified as having moderate and weak first flush, respectively. Figure 37 shows the M-V curves for the two events having the maximum and the minimum value of first flush coefficients occurring in the Orakei and the CBD sites, respectively. In the case of the event having the minimum first flush coefficient value, the figure shows around 65% of the pollutant load is delivered in the first 20% of the total volume of the stormwater runoff event. In the case of the event having the maximum first flush coefficient, the figure indicates that there is a pollutant load delay with storage depletion.

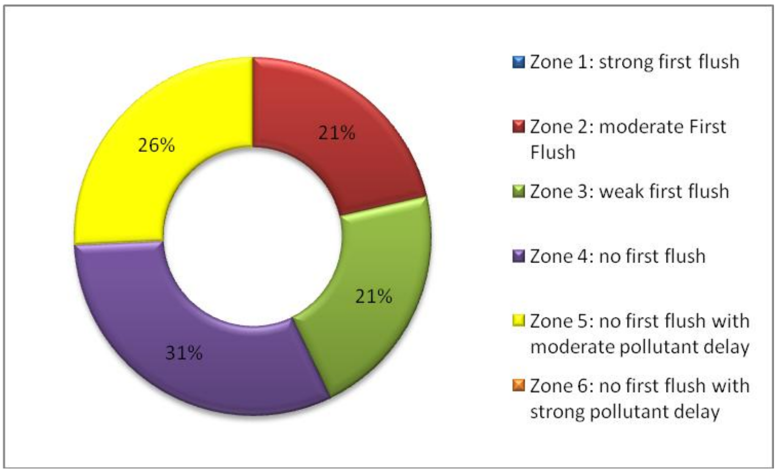

Figure 36: The percentage of events in the different M-V zones in the case of DRP.

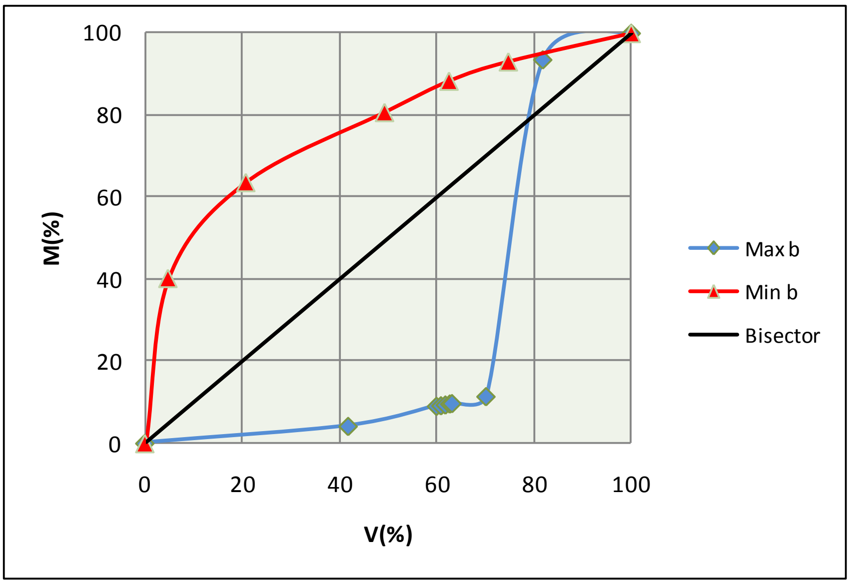

Figure 37: The M-V curves for events with the highest and the lowest DRP first flush coefficient values.

3.2.12 TDN First Flush Analysis

Table A15 in Appendix A shows the values of the first flush coefficient obtained at the different sites and events. The percentage of first flush varies between 50% in the case of the Blockhouse Bay, Orakei and Remuera sites to 100% in the case of the Tamakai site. Examination of the table also shows that the first flush coefficient values vary in the range 0.34 to 2.90. Figure 38 shows the percentage of 70 events analyzed in the different M-V zones. Examination of the figure shows that 65% of the total number of events can be regarded as having first flush with 29% and 36% of the events classified as having moderate and weak first flush, respectively. Figure 39 shows the M-V curves for the two events having the maximum and the minimum value of first flush coefficients occurring in the Onehunga and the CBD sites, respectively. In the case of the event having the minimum first flush coefficient value, the figure shows around 50% of the pollutant load is delivered in the first 20% of the total volume of the stormwater runoff event. In the case of the event having the maximum first flush coefficient, the figure indicates that there is a pollutant load delay.

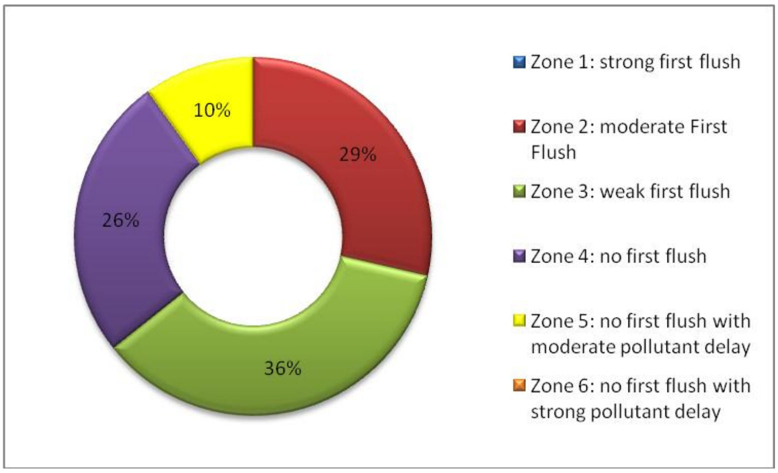

Figure 38: The percentage of events in the different M-V zones in the case of TDN.

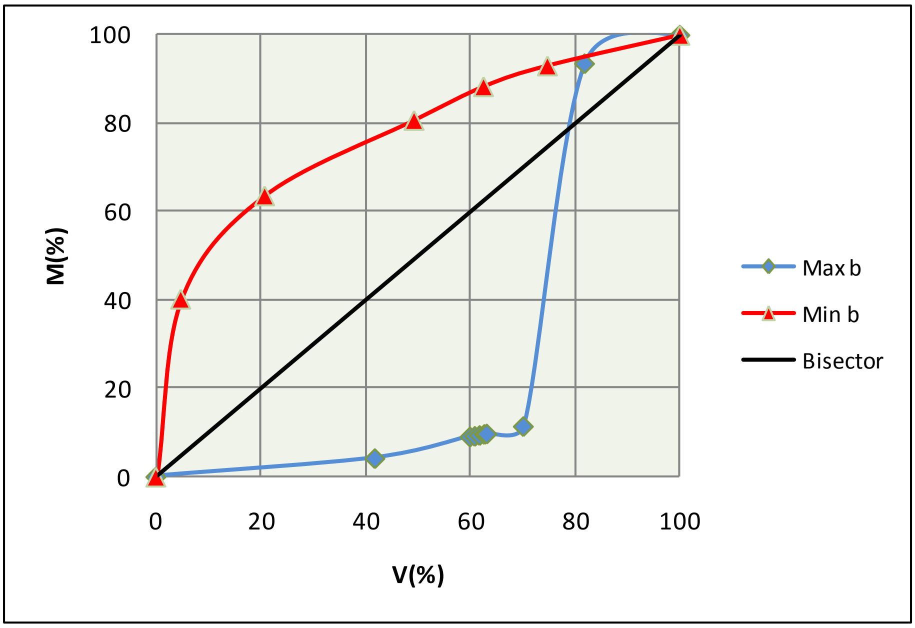

Figure 39: The M-V curves for events with the highest and the lowest DRP first flush coefficient values.

3.2.13 TDP First Flush Analysis

Table A16 in Appendix A shows the values of the first flush coefficient obtained at the different sites and events. The percentage of events having first flush varies between 25% in the case of the, Orakei to 69% in the case of the CBD site. Examination of the table also shows that the first flush coefficient values vary in the range 0.34 to 3.33. Figure 40 shows the percentage of 70 events analyzed in the different M-V zones. Examination of the figure shows that 49% of the total number of events can be regarded as having first flush with 19% and 30% of the events classified as having moderate and weak first flush, respectively. Figure 41 shows the M-V curves for the two events having the maximum and the minimum value of first flush coefficients occurring in the Orakei and the CBD sites, respectively. In the case of the event having the minimum first flush coefficient value, the figure shows around 60% of the pollutant load is delivered in the first 20% of the total volume of the stormwater runoff event. In the case of the event having the maximum first flush coefficient, the figure indicates that there is a pollutant load delay and depletion.

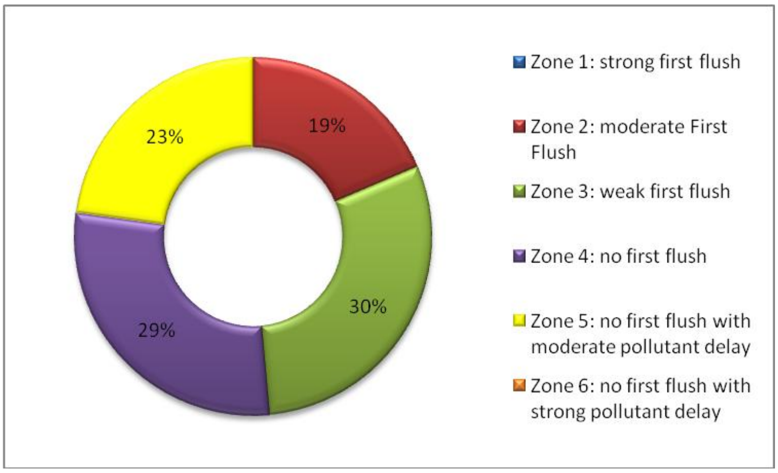

Figure 40: The percentage of events in the different M-V zones in the case of TDP.

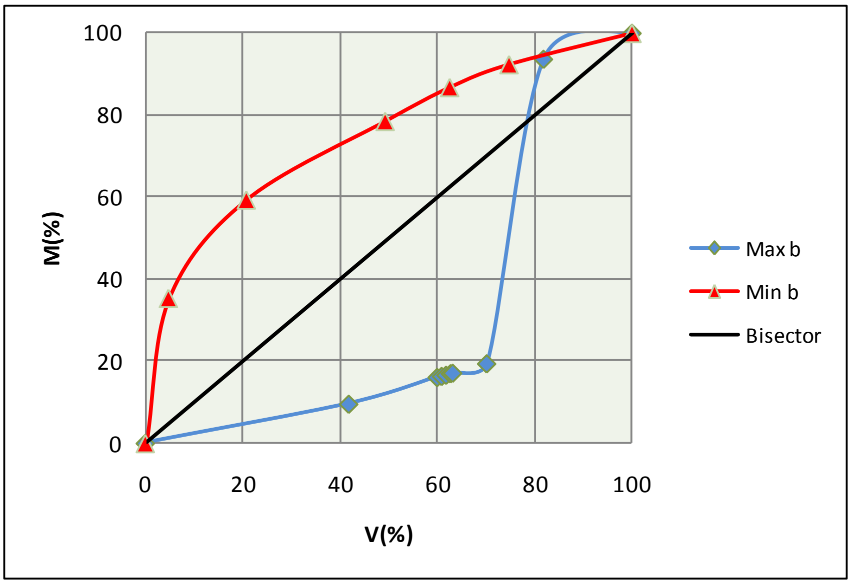

Figure 41: The M-V curves for events with the highest and the lowest TDP first flush coefficient values.

3.2.14 TPH First Flush Analysis

Table A17 in Appendix A shows the values of the first flush coefficient obtained at the different sites and events. The percentage of events having first flush varies between 0% in the case of the, Waitakere Rain Garden site to 80% in the case of the CBD site. Examination of the table also shows that the first flush coefficient values vary in the range 0.5 to 1.76. Figure 42 shows the percentage of 39 events analyzed in the different M-V zones. Examination of the figure shows that 47% of the total number of events can be regarded as having first flush with 26% and 21% of the events classified as having moderate and weak first flush, respectively. Figure 43 shows the M-V curves for the two events having the maximum and the minimum value of first flush coefficients occurring in the Onehunga and the Mission Bay sites, respectively. In the case of the event having the minimum first flush coefficient value, the figure shows around 45% of the pollutant load is delivered in the first 20% of the total volume of the stormwater runoff event.

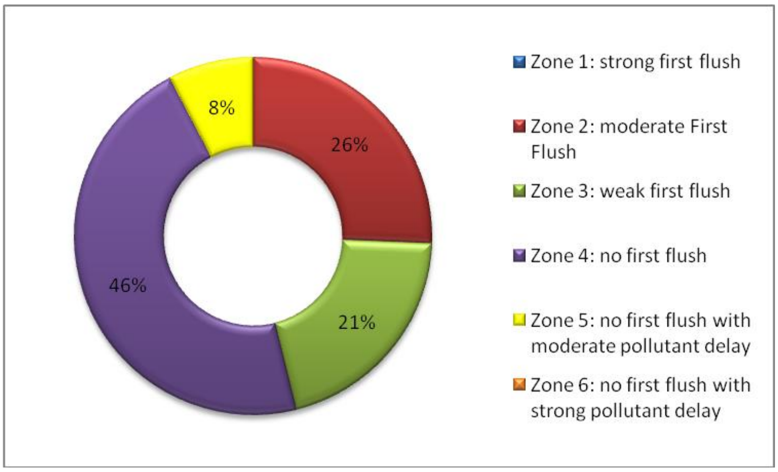

Figure 42: The percentage of events in the different M-V zones in the case of TPH.

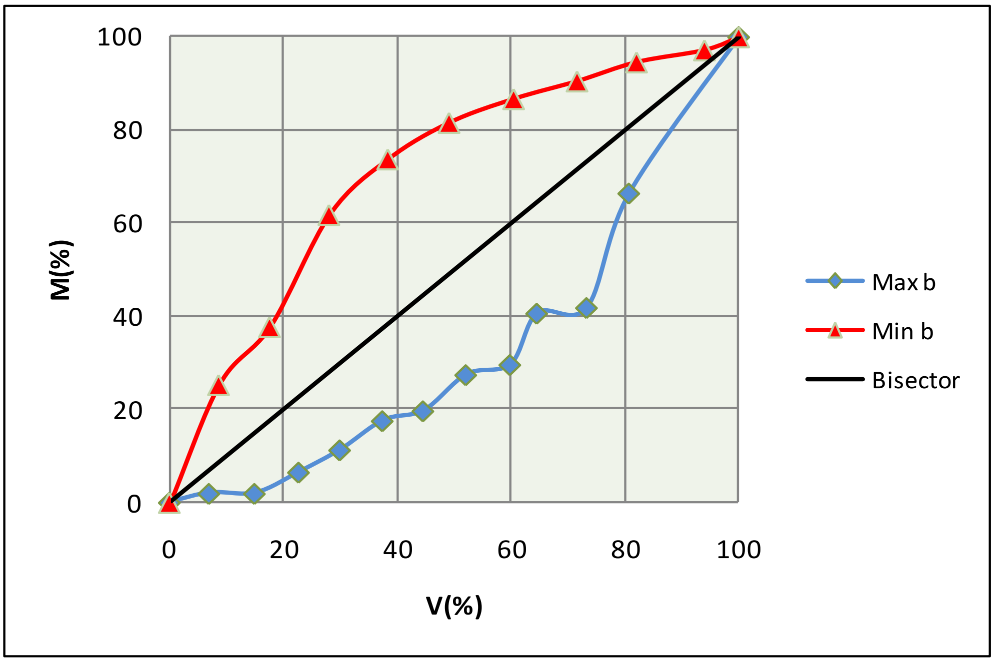

Figure 43: The M-V curves for events with the highest and the lowest TPH first flush coefficient values.

3.2.15 PAH First Flush Analysis

Table A18 in Appendix A shows the values of the first flush coefficient obtained at the different sites and events. The percentage of events having first flush varies between 20% in the case of the, CBD site to 44% in the case of the Onehunga site. Examination of the table also shows that the first flush coefficient values vary in the range 0.26 to 1.64. Figure 44 shows the percentage of 39 events analyzed in the different M-V zones. Examination of the figure shows that 34% of the total number of events can be regarded as having first flush with 19% and 15% of the events classified as having moderate and weak first flush, respectively. Figure 45 shows the M-V curves for the two events having the maximum and the minimum value of first flush coefficients occurring in the Remuera and the Onehunga sites, respectively. In the case of the event having the minimum first flush coefficient value, the figure shows a strong first flush with almost the entire pollutant load is delivered in the first 20% of the total volume of the stormwater runoff event. In the case of the event having the maximum first flush coefficient, the figure indicates that the method used to identify th e first flush effects fail to recognize that this event lies above the bisector line. This failure may be due to the complexity of the shape M-V curve.

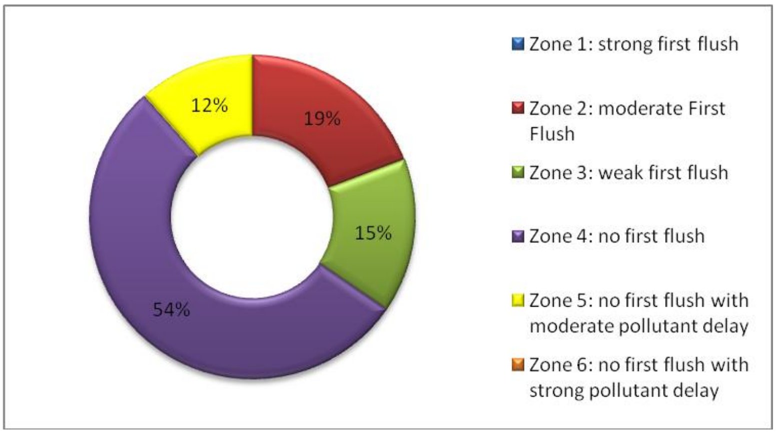

Figure 44: The percentage of events in the different M-V zones in the case of PAH.

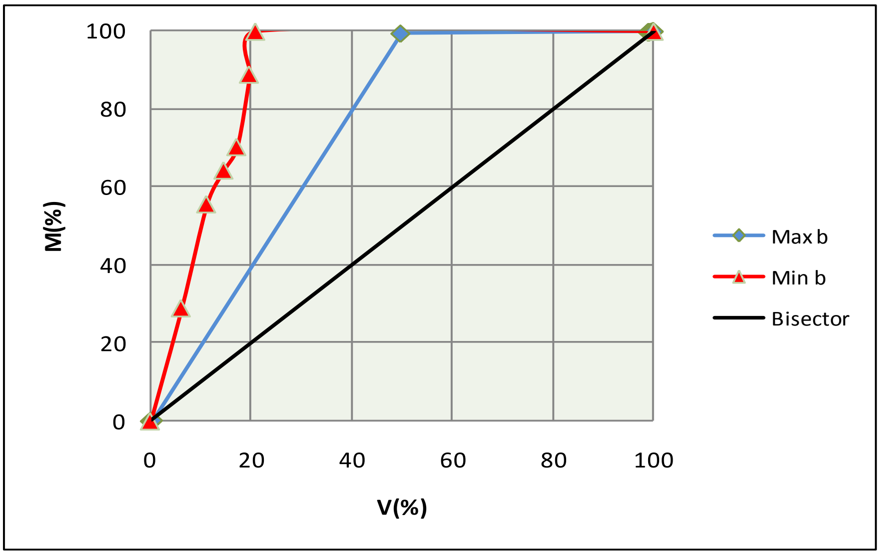

Figure 45: The M-V curves for events with the highest and the lowest PAH first flush coefficient values.

3.2.16 E Coli First Flush Analysis

Table A19 in Appendix A shows the values of the first flush coefficient obtained at the different sites and events. The percentage of events having first flush varies between 0% in the case of the Meola to 100% in the case of the Remuera site. Examination of the table also shows that the first flush coefficient values vary in the range 0.63 to 4.4. Figure 46 shows the percentage of 26 events analyzed in the different M-V zones. Examination of the figure shows that 34% of the total number of events can be regarded as having first flush with 15% and 19% of the events classified as having moderate and weak first flush, respectively. Figure 47 shows the M-V curves for the two events having the maximum and the minimum value of first flush coefficients occurring in the Meola and the Oakley Creek sites, respectively. In the case of the event having the minimum first flush coefficient value, the figure shows around 70% of the pollutant load is delivered in the first 20% of the total volume of the stormwater runoff event.

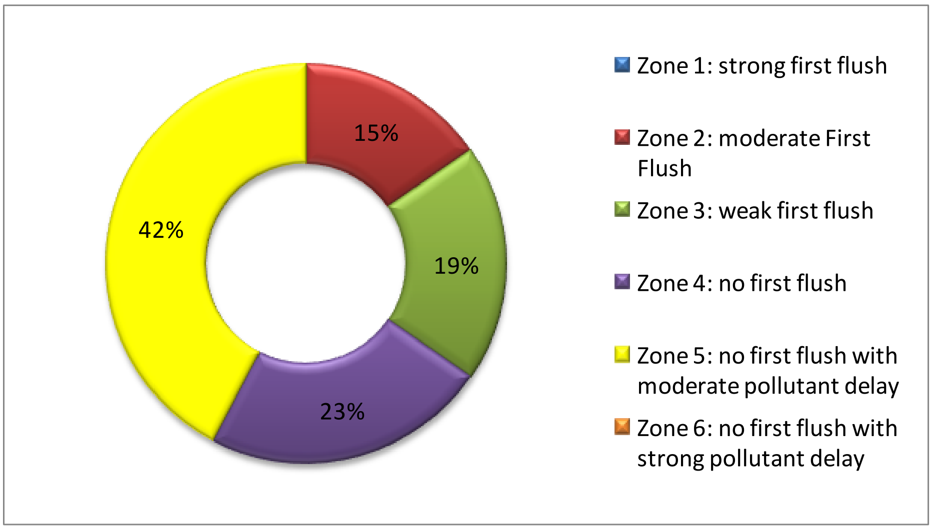

Figure 46: The percentage of events in the different M-V zones in the case of E Coli.

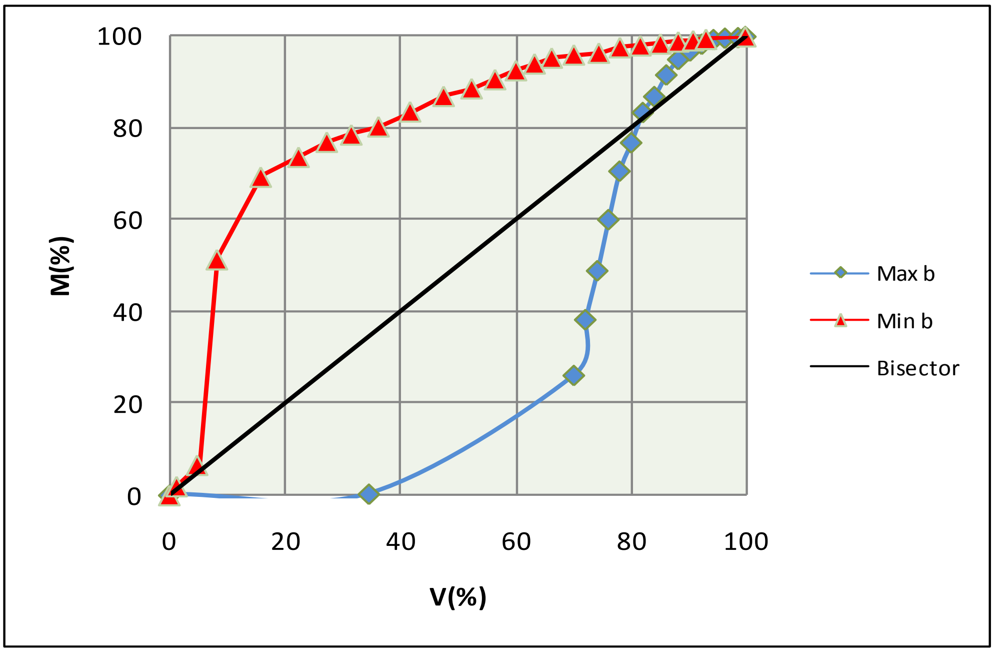

Figure 47: The M-V curves for events with the highest and the lowest E-coli first flush coefficient values.

3.2.17 Enterococci First Flush Analysis

Table A20 in Appendix A shows the values of the first flush coefficient obtained at the different sites and events. The percentage of events having first flush varies between 0% in the case of the Tamakai site to 67% in the case of the Motions site. Examination of the table also shows that the first flush coefficient values vary in the range 0.37 to 4.29. Figure 48 shows the percentage of 26 events analyzed in the different M-V zones. Examination of the figure shows that 34% of the total number of events can be regarded as having first flush with 20% and 14% of the events classified as having moderate and weak first flush, respectively. Figure 49 shows the M-V curves for the two events having the maximum and the minimum value of first flush coefficients occurring in the Meola and the Onehunga sites, respectively. In the case of the event having the minimum first flush coefficient value, the figure shows around 55% of the pollutant load being delivered in the first 20% of the total volume of the stormwater runoff event. In the case of the event having the maximum first flush coefficient, the figure indicates that there is a pollutant load delay and depletion.

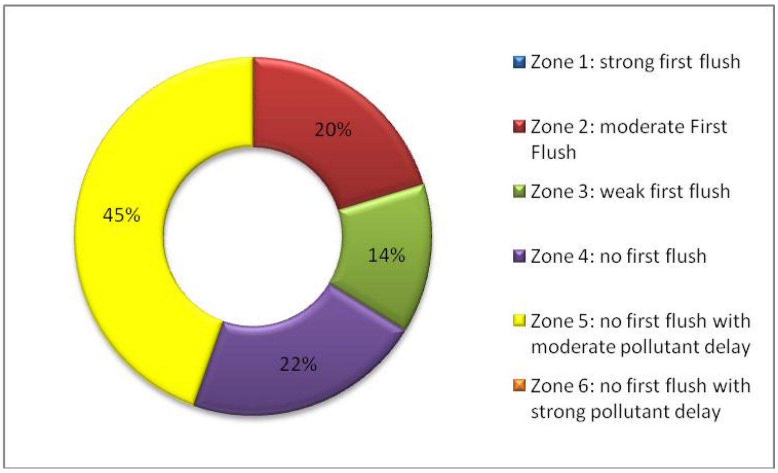

Figure 48: The percentage of events in the different M-V zones in the case of Enterococci.

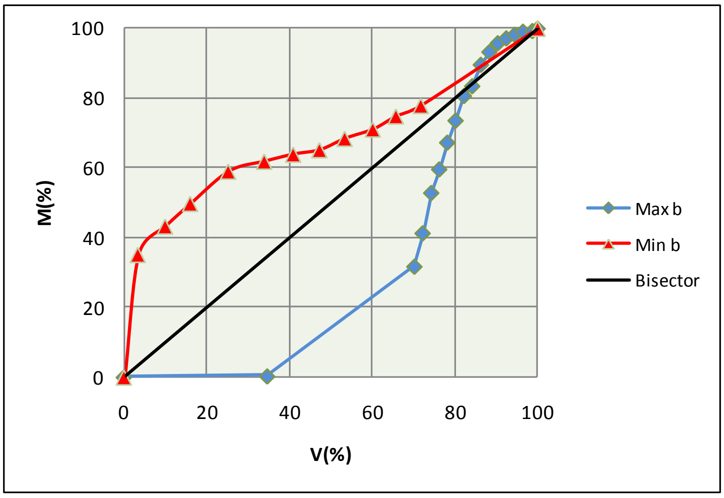

Figure 49: The M-V curves for events with the highest and the lowest Enterococci first flush coefficient values.

3.2.18 Fluoride First Flush Analysis

The fluoride first flush coefficient values obtained at the different sites and events are shown in Table A21 in Appendix A. The table shows the percentage of first flush events varies between 25% in the case of the Remuera site to 100% in the case of the Blockhouse Bay, Onehunga and Tamaki sites. Examination of the table also shows that the first flush coefficient values vary in the range 0.26 to 1.2. Figure 50 shows the percentage of the 80 events analyzed in the different M-V zones. Examination of the figure shows that 84% of the total number of events can be regarded as having first flush with 60% and 24% of the events classified as having moderate and weak first flush, respectively. Figure 51 shows the M-V curves for the two events having the maximum and the minimum value of first flush coefficients occurring in the Orakei and the CBD sites, respectively. The figure shows examples of strong first flush (min b) with around 70% of the pollutant load being delivered in the first 20% of the total volume of the stormwater runoff event. The presence of Fluoride in stormwater runoff can be due to sewer overflows.

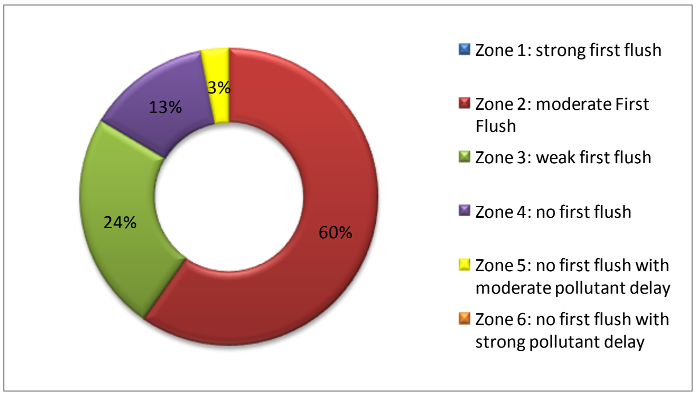

Figure 50: The percentage of events in the different M-V zones in the case of Fluoride.

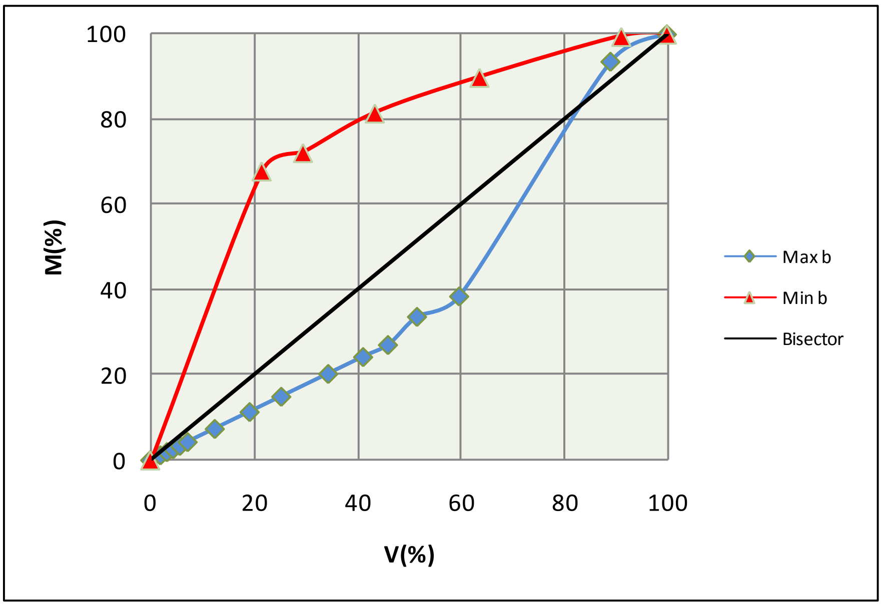

Figure 51: The M-V curves for events with the highest and the lowest Fluoride first flush coefficient values.

3.2.19 TDS First Flush Analysis

TDS measurements are available for three events at only one site- Albany treatment site. The results for TDS first flush analysis are shown in Table A22 in Appendix A. The table shows the first flush coefficient values vary in the range 0.20 to 1.16. Figure 52 shows the M-V curves for the two events having the maximum and the minimum value of first flush coefficients. In the case of the event having the minimum first flush coefficient value, the figure shows around 45% of the pollutant load being delivered in the first 20% of the total volume of the stormwater runoff event.

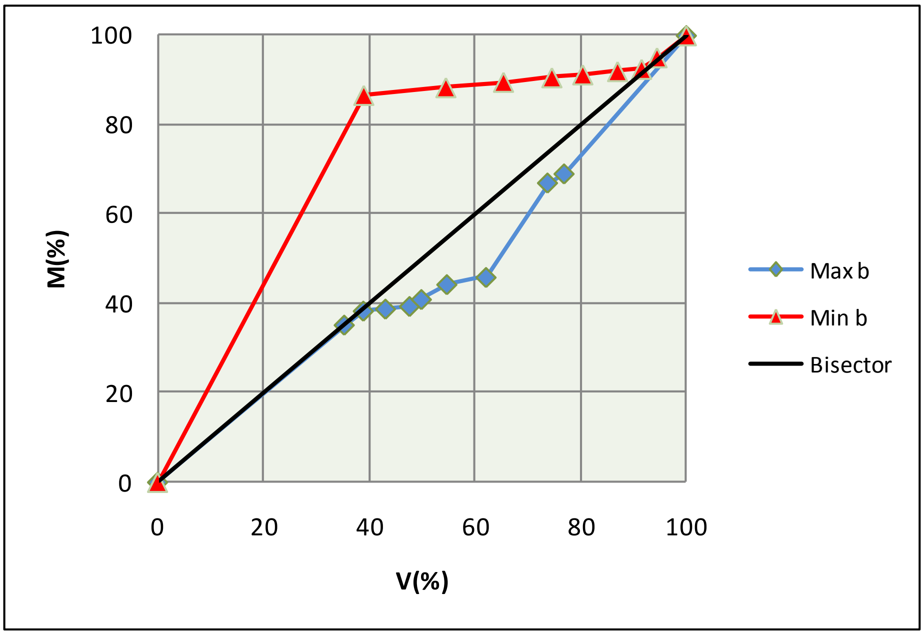

Figure 52: The M-V curves for events with the highest and the TDS first flush coefficient values.

3.3 Summary and Conclusions

In this part of the report, the first flush analysis is conducted using the data from 16 sites in the Auckland region. The analysis is presented for 22 water quality parameters. The results of the first flush analysis confirm the existence of the first flush phenomena in the Auckland region. The results reported in this study also confirm that the first flush strength depends on the water quality parameter being analysed and that an event can have first flush in a suite of water quality parameters. This conclusion is supported by the results shown in Table A23 in Appendix A which displays the first flush analysis for the CBD site. For the first event, the table shows that the first flush coefficient values vary between 0.4 indicating a strong first flush in the case of pZn to 0.99 suggesting a weak first flush in the case of dCU. Further examination of the table shows that an event can have first flush in a range of water quality parameters. This conclusion is supported by the fact that the percentages of first flush events at different sites depend on the water quality parameters being analyzed (see Figure 53).

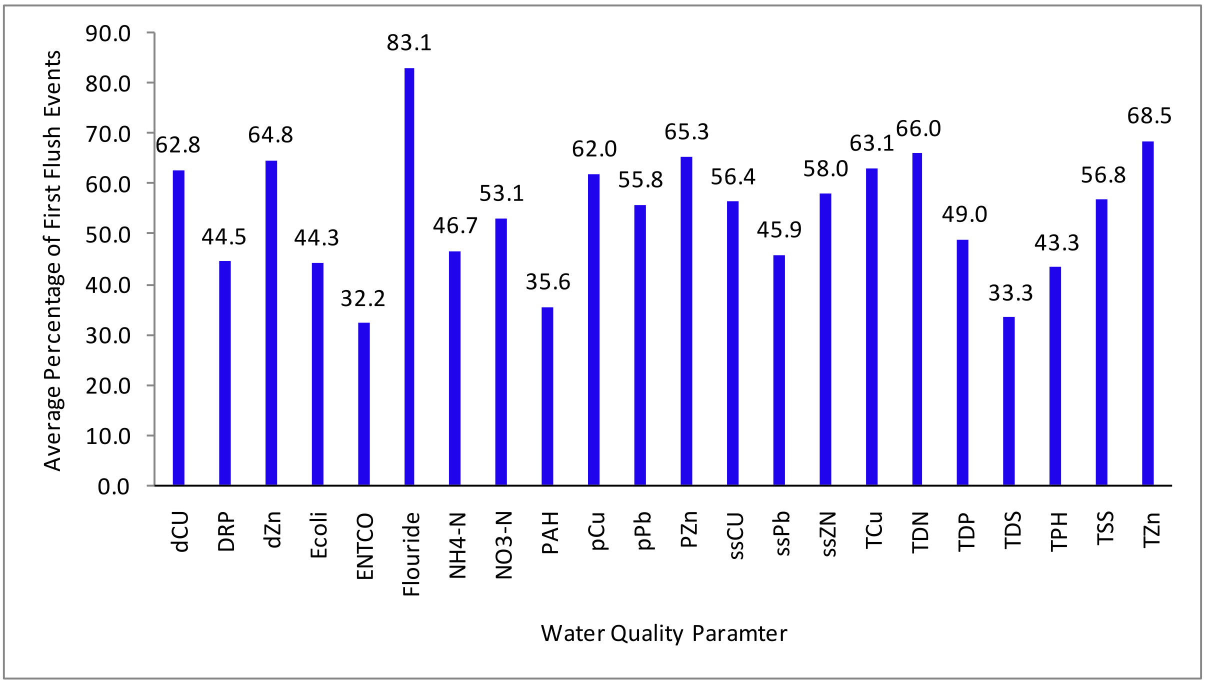

Figure 53: Average percentage of first flush events across all sites.

4 Summary and Conclusions

This study examines the existing stormwater quality data in the Auckland region for evidence of contaminant first flush and its characteristics.

As a part of the study, a literature review is conducted with regard to the methods which can be used to identify the first flush from the observed data. The literature review suggests that the first flush has been the focus of hot debate between the believers and the disbelievers of its existence.

There are three broad frameworks for first flush analysis, namely, mass-based, concentration-based and empirical. These frameworks have different degrees of subjectivity in the manner they use to identify the first flush. However, the mass-based framework appears to be the most widely used and more objective as it provides a numerical criteria for identifying first flush. For these reasons it has been used in this study to identify the first flush from the available data. As a part of the literature review a discussion about the management implications of the first flush concept, namely, water quality sampling programs and sizing of stormwater management devices as well as their removal efficiencies, is presented. Numerous studies have noted that designing stormwater management devices to focus on treating the first flush, if it exists, is regarded as being a best value added approach for reducing pollutants from stormwater.

This study uses a comprehensive storm runoff event data set of 22 water quality parameters from 16 sites in its assessment for evidence of contaminant first flush and its characteristics in the Auckland region. The event data measured at the different sites covers different time periods and the events are not necessarily synchronous. The number of recorded events differs from site to site. Furthermore, the total number of events measured at all sites varies depending on the measured water quality parameter. The total number of events for the 16 sites varies in the range 3 to 135. Excluding the Total Dissolved Solids (TDSs) where only three events are measured at all sites, the minimum value of the total number of events is 26 (see Table 2 for further details).

In this study, the data set used in the analysis has been subjected to an extensive data screening process. The screening process shows that the data has many deficiencies. These deficiencies include, sampler measurement error, time synchronization error, missing event definition, water quality sampling adequacy and discrepancies between the recorded values in different files.

In this study, the analysis for evidence of first flush was conducted using the mass-based framework which develops a functional relationship between the cumulative pollutant mass and the corresponding cumulative volume when expressed as dimensionless quantities. The exponent of the relationship is known as the first flush coefficient. The analysis conducted in this report has indicated that the first flush exists in the Auckland region. Table 9 shows the percentage of first flush events for different water quality parameters. However, the strength of the first flush varies from site to site and also depends on other factors such as the water quality parameters being analyzed (see Tables A1 to A23 in Appendix A).

Table 9: Percentage of first Flush Events for selected water quality parameters.

Location	Monitoring Period	TSS	Tcu	Dcu
Birkdale Permeable Pavement	March 2006 – Dec 2008	75% (9)*	91%(10)	82%(9)
Blockhouse Bay	April 2002 – July 2002 & February 2003 – April 2003	63%(5)		50%(4)
CBD (Aotea Square)	November 2000 – March 2002	57%(12)		93%(13)

Meola	May 2005 - November 2005	20%(1)	20%(1)	20%(1)
Mission Bay	November 2000 – December 2001	41%(7)		79%(11)
Motions	May 2005 - July 2006	50%(3)	50%(3)	100%(6)
Oakley Creek	Jan 2003-April 2003	50%(4)		38%(3)
Onehunga	November 2000 – December 2001	29%(5)	55%(6)	82%(9)
Orakei	February 2001 – July 2001 April 2002 – July 2002	64%(9)		63%(5)
Nukumea Pond	2007 & Dec 2008 – May 2009	43%(3)		
Remuera	April 2002 – July 2002 February 2003 – April 2003	50%(2)		25%(1)
Tamaki	February 2001 – July 2001 & April 2002 – July 2002	67%(2)		100%(2)
Albany Treatment Train	May 2009 – July 2009	100%(5)	100%(2)	0%(0)
Waitakere Rain garden	Nov 2006 – June 2007	86%(6)		86%(6)

*The number between brackets in the number of events

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Appendix A

Table A1: The TSS first flush coefficient values for different sites and events

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Birkdale Permeable Pavement	1.12	0.96	0.38	0.09	1.08	0.88	0.50	1.25	0.64	0.53	0.36	0.79										75
Blockhouse Bay	1.69	0.45	1.33	0.87	1.47	0.42	0.40	0.72														63
CBD	1.00	2.02	0.51	0.99	1.54	1.06	0.72	0.37	1.12	1.01	1.38	0.98	1.06	0.86	0.63	0.97	0.71	1.37	1.16	0.79	0.72	57
Meola	0.57	3.53	1.36	1.14	1.88																	20
Mission Bay	1.01	1.18	0.55	0.61	0.82	1.59	1.17	1.18	0.65	0.42	1.29	0.76	1.35	1.02	1.23	1.73	0.78					41
Motions	0.98	1.30	0.64	1.14	1.95	0.36																50
Oakley Creek	0.64	0.90	0.93	1.11	0.89	1.05	1.17	1.21														50
Onehunga	1.09	0.84	0.75	0.57	1.24	1.04	1.16	1.13	1.32	1.44		1.24	1.42	0.76	0.90	1.34	1.47	1.43				29
Orakei	0.33	0.69	0.22	0.46	0.78	1.16	0.95	1.03	0.77	0.69	1.07	0.90	1.47	1.19								64
Nukumea Pond	1.41	0.75	0.94	1.09	1.19	0.95	2.75															43
Remuera	0.94	0.75	1.31	1.37																		50
Tamaki	0.42	1.06	0.94																			67
Albany Treatment Train	0.34	0.28	0.24	0.39	0.14																	100
Waitakere Rain garden	1.15	0.66	0.65	0.67		0.76	0.75	0.70														86

The values shown in red indicate the existence of first-flush effects.

Table A2: The dCu first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Birkdale		**0.65**	**0.57**	**0.96**	**0.75**	1.04	**0.87**	**0.84**	**0.67**	**0.69**	1.15	**0.78**										82
Blockhouse Bay	**0.84**	1.07	**0.91**	1.15	1.03	1.22	**0.90**	**0.69**														50
CBD (Aotea Square)	**0.99**	**0.73**	1.01	**0.85**	**0.75**							**0.90**	**0.59**	**0.80**	**0.70**	**0.66**	**0.78**	**0.69**		**0.63**	**0.77**	93
Meola	**0.96**	1.32	1.04	1.06	1.12																	20
Mission Bay	**0.96**	**0.99**	1.11	**0.80**	**0.83**	**0.65**	**0.89**	1.08			**0.91**	**0.94**	**0.93**	**0.92**	1.00		**0.85**					79
Motions	**0.98**	**0.95**	**0.94**	**0.99**	**0.55**	**0.69**																100
Oakley Creek	1.20	1.01	**0.93**	**0.94**	**0.98**	1.07	1.01	1.10														38
Onehunga	1.24	**0.73**	**0.85**	**0.90**	**0.85**	**0.67**	**0.89**	**0.94**							**0.87**	1.49	**0.80**					82
Orakei	**0.89**	**0.93**	**0.98**	1.11	**0.86**	1.02	1.16	**0.69**														63
Remuera	1.03	1.12	1.01	**0.97**																		25
Tamaki	**0.72**	**0.36**																				100
Albany Treatment Train		1.02	1.14																			0
Waitakere Rain Garden_	**0.51**	**0.78**	1.58	**0.50**		**0.50**	**0.76**	**0.96**														86

The values shown in red indicate the existence of first-flush effects.

Table A3: The dZn first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Birkdale		0.84	0.88	1.88	0.75	0.80	0.89	1.02	0.80	0.77	0.53	0.85										82
Blockhouse Bay	1.06	1.18	1.07	1.67	1.03	1.05	3.48	1.14														0
CBD (Aotea Square)	0.84	0.75	0.93	0.90	0.69							0.69	0.80	0.70	0.84	1.00	0.74	0.74		0.73	0.85	100
Meola	1.05	1.25	1.29	1.11	1.25																	0
Mission Bay	0.84	0.96	1.42	0.90	0.88	0.89	1.00	0.77			0.31	1.04	0.71	1.12	1.13		0.99					64
Motions	0.87	0.94	0.95	1.00	0.70	1.03																83
Oakley Creek	1.61	1.56	1.00	1.20	1.16	1.15	1.20	0.99														13
Onehunga	0.98	0.67	0.62	0.57	0.86	0.68	0.88	0.88							0.71	1.15	0.86					91
Orakei	0.93	1.00	1.31	1.10	0.98	0.94	0.94	1.08														63
Remuera	0.93	0.99	1.20	0.92																		75
Tamaki	0.75	0.77																				100
Albany Treatment Train		0.27	0.79																			100
Waitakere Rain Garden	0.53	0.70	1.39	0.62		0.63	0.82	1.05														71

The values shown in red indicate the existence of first-flush effects.

Table A4: The pCu first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Blockhouse Bay	1.49	0.58	1.45	0.87	1.51	0.43	0.51	0.65														63
CBD (Aotea Square)	0.70	1.57	0.40	0.88	1.22							0.72	1.22	0.72	0.36	0.51	0.52	1.16		0.47	0.62	71
Meola	0.62	3.52	1.35	2.64	1.82																	20
Mission Bay	0.73	1.03	0.51	0.57	0.66	1.22	0.95	1.09			1.00	0.75	1.15	0.91	0.84	0.94	0.65					67
Motions	0.93	1.04	0.95	0.95	0.87	0.95																83
Oakley Creek	0.61	1.02	0.76	1.18	1.06	1.10	1.23	1.09														25
Onehunga	1.02	0.62	0.56	0.48	1.25	0.91	1.25	1.17							0.81	1.36	1.56					45
Orakei	0.30	0.65	0.19	0.49	0.67	1.15	0.89															86
Remuera	0.94	0.75	1.13	1.33																		50
Tamaki	0.28	0.68																				100
Waitakere Rain Garden	0.86	0.71	0.75	0.68		0.92	1.18	1.03														71

The values shown in red indicate the existence of first-flush effects.

Table A5: The pZn first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Blockhouse Bay	1.60	0.63	1.41	0.85	1.49	0.48	0.53	0.73														63
CBD (Aotea Square)	0.40	1.83	0.39	0.90	1.34							0.79	1.46	0.79	0.47	0.99	0.51	1.21		0.71	0.65	71
Meola	0.57	3.64	1.44	2.63	1.96																	20
Mission Bay	0.55	1.06	0.64	0.59	0.68	1.38	0.89	0.99			0.93	0.80	1.16	0.94	0.96	0.98	0.62					80
Motions	0.95	0.96	0.97	0.94	0.82	0.91																100
Oakley Creek	0.61	0.97	0.94	1.15	1.05	1.05	1.19	1.06														38
Onehunga	0.89	0.65	0.62	0.44	1.11	0.91	1.27	1.04							0.78	1.32	1.57					55
Orakei	0.28	0.59	0.22	0.42	0.64	1.14	0.82															86
Remuera	0.91	0.70	1.31	1.34																		50
Tamaki	0.56	0.78																				100
Waitakere Rain Garden	0.79	0.69	1.19	0.57		0.78	1.16	1.05														57

The values shown in red indicate the existence of first-flush effects.

Table A6: The pPb first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Blockhouse Bay	1.61	0.49	1.47	0.84	1.50	0.45	0.66	0.75														63
CBD (Aotea Square)	0.50	1.86	0.56	0.92	1.41							1.09	1.29	0.62	0.41	1.08	0.65	1.41		0.82	0.72	57
Meola	0.44	3.76	1.43	1.42	1.96																	20
Mission Bay	0.74	1.11	0.58	0.69	0.75	1.49	1.24	1.09			0.94	0.82	1.22	1.07	0.98	1.19	0.78					53
Motions	0.90	1.03	0.96	0.99	1.06	1.05																50
Oakley Creek	0.64	1.04	0.91	1.14	1.11	1.11	1.24	1.10														25
Onehunga	0.93	0.61	0.48	0.59	1.09	0.91	1.22	1.08							0.83	1.40	1.55					55
Orakei	0.35	0.79	0.28	0.48	0.72	1.12	0.86															86
Remuera	0.94	0.72	1.34	1.34																		50
Tamaki	0.47	0.59																				100

The values shown in red indicate the existence of first-flush effects.

Table A7: The ssCu first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Blockhouse Bay	0.84	1.27	1.12	1.00	1.05	1.04	1.20	0.94														38
CBD (Aotea Square)	0.74	0.63	0.85	0.87	0.69							0.88	1.17	0.86	0.69	0.53	0.82	0.83		0.70	0.89	93
Meola	1.08	1.04	1.00	1.16	0.94																	20
Mission Bay	0.93	0.87	1.08	0.94	0.80	0.62	0.80	0.90			0.73	1.07	0.88	0.89	0.75	0.76	0.85					87
Oakley Creek	1.12	1.17	0.81	1.07	1.19	1.07	1.07	0.88														25
Onehunga	0.88	0.73	0.78	0.68	0.96	0.85	1.10	1.04							0.89	1.05	1.08					64
Orakei	0.93	1.06	0.85	1.14	0.87	1.12	0.97															57
Remuera	1.01	1.10	0.84	1.04																		25
Tamaki	0.75	0.63																				100

The values shown in red indicate the existence of first-flush effects.

Table A8: The ssZn first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Blockhouse Bay	0.91	1.26	1.06	0.95	1.03	1.16	1.21	1.02														25
CBD (Aotea Square)	0.42	0.83	0.84	0.90	0.82							0.80	1.42	0.93	0.83	1.03	0.83	0.88		0.94	0.92	86
Meola	1.00	1.04	1.07	1.09	1.10																	20
Mission Bay	0.72	0.87	1.40	0.95	0.86	0.74	0.75	0.82			0.68	1.12	0.89	0.92	0.90	0.71	0.80					87
Oakley Creek	1.11	1.10	1.03	1.02	1.17	1.00	1.01	0.86														25
Onehunga	0.75	0.76	0.84	0.74	0.88	0.85	1.11	0.92							0.87	1.03	1.08					73
Orakei	0.87	1.02	1.03	0.93	0.87	1.13	0.88															57
Remuera	0.97	0.96	1.00	0.99																		100
Tamaki	1.30	0.72																				50

The values shown in red indicate the existence of first-flush effects.

Table A9: The ssPb first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Blockhouse Bay	0.91	1.08	1.14	0.95	1.03	1.06	1.44	1.05														25
CBD (Aotea Square)	0.53	0.86	1.04	0.91	0.88							1.38	1.24	0.74	0.73	1.09	0.95	1.03		1.01	1.00	50
Meola	0.84	1.09	1.05	1.30	1.08																	20
Mission Bay	0.95	0.94	1.06	1.08	0.92	0.83	1.12	0.91			0.66	1.12	0.89	1.06	0.90	0.94	0.99					67
Oakley Creek	1.17	1.19	0.98	1.05	1.22	1.08	1.07	0.90														25
Onehung	0.74	0.73	0.69	0.94	0.88	0.85	1.08	0.96							0.92	1.09	1.09					73
Orakei	1.00	1.18	1.23	1.14	0.94	1.05	0.93															29
Remuera	0.99	0.92	1.02	0.97																		75

Tamaki	1.19	**0.54**																				50

The values shown in red indicate the existence of first-flush effects.

Table A10: The TCu first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Birkdale		**0.78**	**0.60**	**0.18**	**0.82**	**0.87**	**0.79**	1.05	**0.61**	**0.45**	**0.13**	**0.65**										91
Meola	**0.75**	2.44	1.18	1.10	1.59																	20
Motions	**0.90**	1.25	**0.65**	1.07	1.63	**0.42**																50
Onehunga	1.18	**0.69**	**0.68**	**0.63**	**1.00**	**0.80**	1.08	1.14							**0.81**	1.41	1.14					55
Albany Treatment Train		**0.37**	**0.51**																			100

The values shown in red indicate the existence of first-flush effects.

Table A11: The TZn first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Birkdale		**0.87**	**0.92**	**0.36**	**0.77**	**0.81**	**0.73**	1.07	**0.42**	**0.52**	**0.20**	**0.67**										91
Meola	**0.92**	2.04	1.32	1.10	1.64																	20
Motions	**0.89**	1.08	**0.75**	1.02	1.34	**0.47**																50
Onehunga	**0.97**	**0.67**	**0.62**	**0.50**	**0.90**	**0.75**	**0.95**	**0.95**							**0.71**	1.20	1.04					82
Albany Treatment Train		**0.24**	**0.43**																			100

The values shown in red indicate the existence of first-flush effects.

Table A12: The NH4-N first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Blockhouse Bay	**0.92**	1.75	1.11	1.12	**0.70**	1.34	1.45	1.07														25
CBD (Aotea Square)	2.42	**0.76**	**0.79**	**0.82**	**0.93**							**0.28**	1.08	**0.94**	**0.41**	**0.44**	**0.92**	**0.85**			**0.67**	85
Mission Bay	1.26	1.47	**0.92**	**0.56**	**0.85**	**0.66**	1.43	1.16			**0.85**	1.10	1.02	**0.74**	**0.97**	**0.73**	**0.75**					60
Oakley Creek	1.65	1.08	**0.82**	**0.84**	**0.78**	**0.78**	**0.92**	1.22														63
Onehunga	1.02	**0.77**	1.05	1.48	**0.92**	**0.81**	1.02								2.70	1.84	**0.78**		2.02	**0.86**		42
Orakei	1.08	**0.84**	**0.95**	**0.61**	**0.91**	1.12	1.34	1.88														50
Remuera	**0.78**	**0.58**	1.39	1.19																		50
Tamaki	1.57	1.10																				0

The values shown in red indicate the existence of first-flush effects.

Table A13: The NO3-N first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Blockhouse Bay-	1.06	1.10	1.02	**0.87**	**0.86**	1.23	**0.91**	**0.74**														50
CBD (Aotea Square)	**0.87**	1.16	**0.82**	1.12	**0.93**							1.35	**0.23**	**0.34**	**0.84**	**0.60**	**0.72**	**0.86**			1.10	69
Mission Bay	1.12	1.20	**0.98**	1.06	**0.95**	**0.85**	**0.95**	1.27			**0.78**	1.13	**0.99**	**0.98**	**0.89**	**0.70**	1.10					60
Oakley Creek	1.31	1.17	**0.91**	**0.89**	**0.94**	**0.95**	**0.93**	1.27														63
Onehunga	**0.88**	**0.84**	1.08	1.12	1.15	**0.90**	**0.81**								2.97	**0.26**	**0.93**		**0.41**	1.23		58
Orakei	1.02	**0.89**	1.08	1.18	1.03	1.19	1.48	**0.97**														25
Remuera	**0.98**	1.09	1.28	**0.93**																		50
Tamaki	**0.91**	1.22																				50

The values shown in red indicate the existence of first-flush effects.

Table A14: The DRP first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Blockhouse Bay	0.94	0.84	0.91	1.00	0.83	1.04	0.79	1.98														63
CBD (Aotea Square)	1.47	0.80	0.96	0.92	0.68							0.52	0.30	1.14	0.78	0.65	1.72	1.06			0.94	69
Mission Bay	1.77	1.12	1.26	1.04	0.95	0.56	1.13	1.42			1.23	0.94	1.13	1.06	1.35	2.62	1.11					20
Oakley Creek	1.20	1.01	0.73	0.97	1.00	0.99	0.87	1.32														50
Onehunga	0.76	1.11	1.10	1.66	1.01	1.21	0.90								3.07	1.15	0.60		0.74	0.87		42
Orakei	1.31	1.07	1.11	0.94	1.03	1.04	1.28	4.42														13
Remuera	1.04	1.09	1.00	0.91																		50
Tamaki	1.80	0.80																				50

The values shown in red indicate the existence of first-flush effects.

Table A15: The TDN first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Blockhouse Bay	1.03	1.13	1.02	0.67	0.84	1.24	0.95	0.78														50
CBD (Aotea Square)	0.83	1.03	0.81	1.01	0.91							0.83	0.34	0.48	0.70	0.63	0.76	0.84			0.92	85
Mission Bay	1.05	1.14	1.01	0.91	0.90	0.56	0.93	1.25			0.83	1.07	0.99	0.97	0.90	0.71	1.01					60
Oakley Creek	1.21	0.98	0.90	0.86	0.93	0.95	0.92	1.24														75
Onehunga	0.96	0.82	1.01	1.05	1.09	0.87	0.86								2.90	0.48	0.91		0.60	1.15		58
Orakei	0.92	0.91	0.98	1.02	0.97	1.16	1.43	1.13														50
Remuera	0.91	0.90	1.08	1.00																		50
Tamaki	0.8	0.8																				100

	3	3																				

The values shown in red indicate the existence of first-flush effects.

Table A16: The TDP first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Blockhouse Bay	0.89	1.00	0.95	1.00	0.89	1.05	1.32	1.14														38
CBD (Aotea Square	1.16	0.74	0.89	0.89	0.69							0.54	0.34	1.09	0.74	0.43	1.26	1.04			0.87	69
Mission Bay	1.44	1.32	1.24	0.95	0.88	0.60	1.10	1.61			1.11	0.97	1.05	1.03	1.31	1.04	1.00					27
Oakley Creek	1.04	1.00	0.86	0.88	0.98	0.97	0.87	1.29														75
Onehunga	0.85	0.98	1.14	1.42	1.32	0.95	0.92								3.07	1.20	0.60		0.85	0.82		58
Orakei	1.20	1.06	1.13	0.94	0.99	1.04	1.27	3.33														25
Remuera-	0.98	1.03	1.03	0.89																		50
Tamaki	1.54	0.57																				50

The values shown in red indicate the existence of first-flush effects.

Table A17: The TPH first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Blockhouse Bay	0.85	1.39	1.37	1.11	1.46	1.25		0.93														29
CBD (Aotea Square)	0.88	1.54		0.73	0.95	0.90																80
Mission Bay	1.07	0.63	0.50	0.50	0.97	1.02	1.07	0.87	0.78													67
Oakley Creek									1.23	0.62												50
Onehunga	1.09	0.71	0.87	0.63	0.98	1.76	1.27	1.09	1.18													44
Remuera		0.69	1.54	1.51																		33
Waitakere Rain Garden	1.00	1.00		1.00			1.28															0

The values shown in red indicate the existence of first-flush effects.

Table A18: The PAH first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
CBD (Aotea Square)	1.21	1.07		0.81	1.26	1.31																20
Mission Bay	1.29	1.39	0.65	0.82	1.00	1.39	1.00	1.11	1.56													33
Onehunga	1.09	0.26	1.22	1.20	0.96	0.98	1.03	1.30	0.96													44
Remuera		0.63	1.60	1.64																		33

The values shown in red indicate the existence of first-flush effects.

Table A19: The E Coli first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Blockhouse Bay	1.16	1.52	1.54	1.16	1.38	0.65		0.98														29
Meola	1.69	4.40	1.92	1.12	1.48																	0
Motions	0.91	1.05	0.88	1.43	0.70	1.01																50
Oakley Creek	0.63	1.15		0.66	1.15	1.06	0.95	1.39														43
Remuera	0.86																					100

The values shown in red indicate the existence of first-flush effects.

Table A20: The Enterococci first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Blockhouse Bay	0.83	1.65	1.79	0.87	1.64	1.32		0.96														43
CBD (Aotea Square)	1.02	1.12		0.81	1.30				1.13	1.82	1.18			1.06	1.78	2.37			1.38		1.09	8
Meola	1.42	4.29	1.73	0.91	2.04																	20
Mission Bay	0.94		3.82	1.07	1.00	1.38	1.18	1.67	1.55				1.30	0.87	1.36	1.92						25
Motions	0.97	1.13	0.82	1.46	0.80	0.55																67
Oakley Creek	0.55	0.78		0.64	1.06	1.03	1.16	1.26														43
Onehunga	1.48			0.97	1.06	1.15	1.24	0.37			0.69	1.61		0.86				1.98	1.22	0.92		42
Orakei	0.71	0.69	0.68	0.58	1.48			1.13		1.19			1.09									50
Remuera	0.89	1.17	1.05	1.01																		25
Tamaki	1.13																					0

The values shown in red indicate the existence of first-flush effects.

Table A21: The Fluoride first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Blockhouse Bay	0.83	0.72	0.64	0.84	0.59	0.64	0.58	0.52														100
CBD (Aotea Square)	0.72	0.59	0.80	1.03	1.00							0.44	0.97	0.32	0.64	0.26		0.94		0.62	0.84	92
Mission Bay	0.82	0.81	1.09	0.90	0.83	0.87	1.00	1.02			0.96	0.98	0.92	0.92	0.92							85
Oakley Creek	0.87	0.68	1.02	0.75	0.92	0.95	0.76	1.15														75
Onehunga	0.74	0.47	0.83	0.76	0.82	0.75	0.84	0.66							0.51	0.80	0.94					100
Orakei	0.89	0.76	0.79	0.72	0.88	1.20	0.85	0.71														88
Remuera	1.09	1.20	0.80	1.12																		25
Tamaki	0.89	0.79																				100

The values shown in red indicate the existence of first-flush effects.

Table A22: The TDS first flush coefficient values for different sites and events.

Event no/Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	First flush events (%)
Albany Treatment Train	1.08	0.20	1.16																			33

The values shown in red indicate the existence of first-flush effects.

Table A23: First Flush Analysis for CBD site.

Water Quality Parameter	Events																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
dCu	0.99	0.73	1.01	0.85	0.75							0.90	0.59	0.80	0.70	0.66	0.78	0.69		0.63	0.77
DRP	1.47	0.80	0.96	0.92	0.68							0.52	0.30	1.14	0.78	0.65	1.72	1.06			0.94
dZn	0.84	0.75	0.93	0.90	0.69							0.69	0.80	0.70	0.84	1.00	0.74	0.74		0.73	0.85
Enterococci	1.02	1.12		0.81	1.30				1.13	1.82	1.18			1.06	1.78	2.37			1.38		1.09
Fluoride	0.72	0.59	0.80	1.03	1.00							0.44	0.97	0.32	0.64	0.26		0.94		0.62	0.84
NH4-N	2.42	0.76	0.79	0.82	0.93							0.28	1.08	0.94	0.41	0.44	0.92	0.85			0.67
NO3-N	0.87	1.16	0.82	1.12	0.93							1.35	0.23	0.34	0.84	0.60	0.72	0.86			1.10
PAH	1.21	1.07		0.81	1.26	1.31															
pCu	0.70	1.57	0.40	0.88	1.22							0.72	1.22	0.72	0.36	0.51	0.52	1.16		0.47	0.62
pPb	0.50	1.86	0.56	0.92	1.41							1.09	1.29	0.62	0.41	1.08	0.65	1.41		0.82	0.72
pZZn	0.40	1.83	0.39	0.90	1.34							0.79	1.46	0.79	0.47	0.99	0.51	1.21		0.71	0.65
ssCU	0.74	0.63	0.85	0.87	0.69							0.88	1.17	0.86	0.69	0.53	0.82	0.83		0.70	0.89
ssPb	0.53	0.86	1.04	0.91	0.88							1.38	1.24	0.74	0.73	1.09	0.95	1.03		1.01	1.00
ssZn	0.42	0.83	0.84	0.90	0.82							0.80	1.42	0.93	0.83	1.03	0.83	0.88		0.94	0.92
TDN	0.83	1.03	0.81	1.01	0.91							0.83	0.34	0.48	0.70	0.63	0.76	0.84			0.92
TDP	1.16	0.74	0.89	0.89	0.69							0.54	0.34	1.09	0.74	0.43	1.26	1.04			0.87
TPH	0.88	1.54		0.73	0.95	0.90															
TSS	1.00	2.02	0.51	0.99	1.54	1.06	0.72	0.37	1.12	1.01	1.38	0.98	1.06	0.86	0.63	0.97	0.71	1.37	1.16	0.79	0.72

The values shown in red indicate the existence of first-flush effects.