FIRST FLUSH ANALYSIS IN THE AUCKLAND REGION

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ABSTRACT

This paper is concerned with examining the available Auckland stormwater quality data for evidence of contaminant first flush and its characteristics. The first flush refers to the situation of having a very high delivery of either concentration or mass of a pollutant during the early part of the storm runoff event. The data from sixteen sites in the Auckland region and ten water quality parameters were used in the analysis. The data contains water quality samples from eight urban network sites, four urban stream sites, a pond site, a rain garden site, a treatment train site and a permeable pavement site. In this study, the analysis for evidence of first flush is conducted using the mass-based framework which aims at developing a functional relationship between cumulative pollutant mass and volumes when expressed as dimensionless quantities. The analysis reported in this paper identifies the existence of first flush in the Auckland region.

KEYWORDS

(stormwater quality, contaminant first flush, mass-based framework, Auckland region, urban network sites, untreated runoff)

1 INTRODUCTION

The current paper is concerned with the analysis of the available Auckland stormwater quality data for evidence of contaminant first flush and its characteristics. In broad terms, the first flush is 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 concept first "foul" flush concept is not new and its origin can be traced back to 1910s (Metcalf and Eddy, 1916) where 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). However, the recent analysis of first flush considers more than 20 water quality parameters (Maestre et al., 2004; Obermann et al., 2009).

The existence of the first flush concept is 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., 1996; Pratt and Adams, 1984). The first flush can be more 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 which include drainage characteristics, immobility of the pollutant, the existence of continuous pollution sources and continuous discharges from sewer overflows. Other factors which affect first flush include rainfall and climate characteristics, type of pollutant and runoff quantity and quality characteristics.

Understanding of the first flush and its characteristics is paramount in stormwater management. 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 Best Management Practices (BMPs). Barco (2008) argued that a BMP focusing on treating the first flush, if exists, is regarded as a more economical approach for reducing pollutants from stormwater, as perhaps less runoff volume needs to be captured. 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.

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 used to identify the first flush. The mass-based framework appears to be the most widely used and is more objective. For this reason it has been used in this study to identify the first flush from the observed data.

In this paper, the first flush analysis is conducted using the data from 16 sites in the Auckland region. The analysis focuses on the first flush analysis for ten water quality parameters, prevalence of occurrence, and strength of the phenomenon. These results are limited to a subset of a comprehensive study investigating the first flush using twenty two water quality parameters. The 10 water quality parameters reported in this paper are: total suspended solids (TSS), dissolved copper (dCU), particulate copper (pCu), total copper (TCu), dissolved zinc (dZn), particulate zinc (pZn), total zinc (TZn), fluoride, Ecoli and particulate lead (pPb). TSS can be a pollutant itself but also often is used as an "indicator" pollutant and such a use is very well established in many storm water management manuals (ATC, 2000; NT 2008; CM, 2008). The implied assumption here is that the control of TSS leads to indirect control of other stormwater runoff pollutants (NT, 2008). Zinc and copper have been the primary contaminants of immediate concern in Auckland considering their potential impacts on declining estuarine sediment quality near shore and low energy coastal areas. Historically, lead was used as a surrogate of traffic pollution prior to its removal from petrol. Fluoride and E. coli are often used as indicators for sanitary or combined sewer overflows.

This paper first provides an overview of the sites used in the study. Secondly, the methodology used in identifying the first analysis is described. Thirdly, the application of the methodology to Auckland is presented. Finally, summary and conclusions are given.

2 OVERVIEW OF THE SITES USED IN THE STUDY

Water quality data used in this study has been obtained from three sources: the former Auckland Regional Council, Metrowater and Auckland City Council. Table A1 in Appendix A shows a summary description of the sites. The data contains water quality samples from eight urban network (storm sewer) sites, four urban stream sites, a pond site, a rain garden site, a treatment train site and a permeable pavement site. Data analysis from the latter four sites is restricted to the untreated runoff generated from small sections of roadways and parking lots, prior to entering any treatment device.

3 METHDOLOGY

The framework used is based on the development of dimensionless cumulative mass [M(t)] and volume [V(t)] curves. For each individual runoff event, these curves are calculated using the following equations:

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

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

where V(t) is the ratio of the total runoff at time t to that of the total volume runoff of the event, $Q(t_i)$ is the average volumetric flow rate between successive measured flow rates, $C(t_i)$ is the mean concentration of pollutant between successive measured concentrations, Δt_i is the i-th sampling interval and M(t) is the ratio of the total pollutant mass at time t to that of the total pollutant mass of the event.

Once the M and V curves are determined, a power law functional relation is developed in order to determine the existence or non-existence of first flush (Saget et al., 1996; Bertrand-Karjewiski, 1998). The power law takes the form:

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

where b is known as the first-flush coefficient indicating the difference/gap between the M-V curve and the bisector line. If the value of b calculated using equation 3 is less unity, then the first flush is regarded as occurred with the strength of the first flush being inversely proportional to the value of the parameter b. Bertrand-Karjewiski et al. (1998) developed a classification for the M-V curves based on the value of the coefficient b, and identified six zones of associated first flush strength (table 1 and figure 1). Zone 1, 2 and 3 indicates strong, moderate and weak first flush, respectively. The M-V curves for these three zones lie above the bisector line (45◦ line) which corresponds to the case of uniform pollutant. Zone 4 suggests no first flush. Zone 5 and 6 suggest no first flush with moderate and strong pollutant wash-off delay, respectively (Tabei and Droste, 2004). However, there are complicated cases of the M-V curve involving multiple pollutant sources and their depletion, which may give rise to mass-limited first flush (Obermann et al., 2009).

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
$0 \le b < 0.185$	1	Strong first flush
$0.185 \le b < 0.862$	2	Moderate first flush
$0.862 \le b < 1.00$	3	Weak First flush
$1 \le b < 1.159$	4	No first flush
$1.159 \le b < 5.395$	5	No first flush with Moderate pollutant delay
$5.395 \le b < \infty$	6	No first flush with strong pollutant

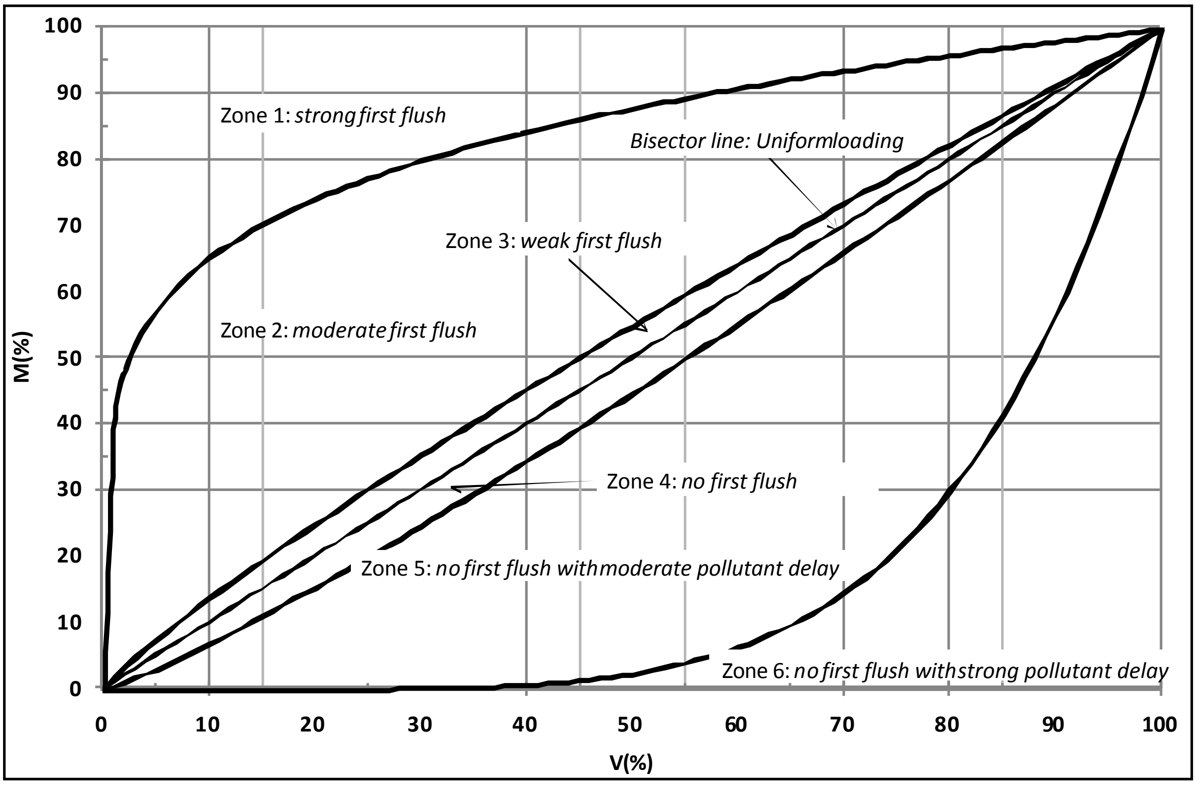

Figure (1): The M-V curve Zones depending of the value of the coefficient b adapted from Bertrand-Karjewiski (1998) and Tabei and Droste (2004).

4 RESULTS OF FIRST FLUSH ANALYSIS

4.1 Total Suspended Solids (TSS) First Flush Analysis

Table (A2) shows the percentage of events having a TSS first flush varies between 20% in the case of the Meola urban stream site to 100% in the case of the Albany treatment train site (parking lot runoff). Examination of the table also shows that the first flush coefficient b values vary in the range 0.09 to 3.53. Figure (2) shows the percentage of 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 can be classified as having strong, moderate and weak first flush, respectively. Figure (3) 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 maximum first flush coefficient, the figure indicates that there is a pollutant load delay with source 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 delivered in the first 25% of the total volume of the stormwater runoff event.

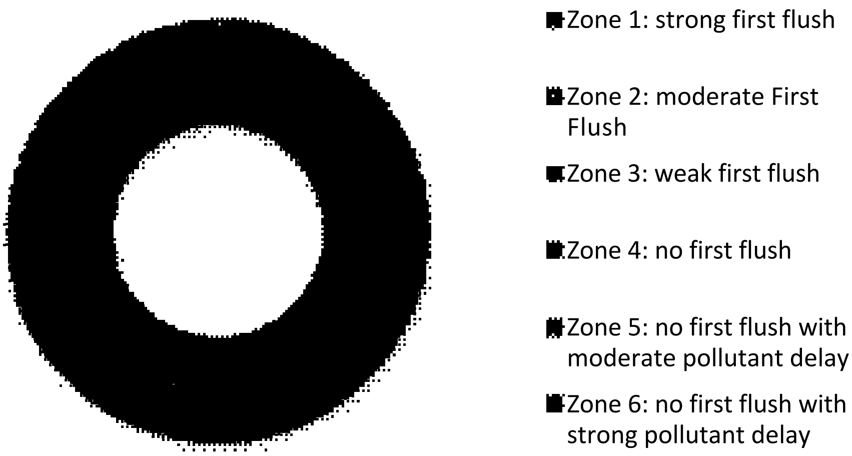

Figure (2): The percentage of TSS events in the different M-V zones.

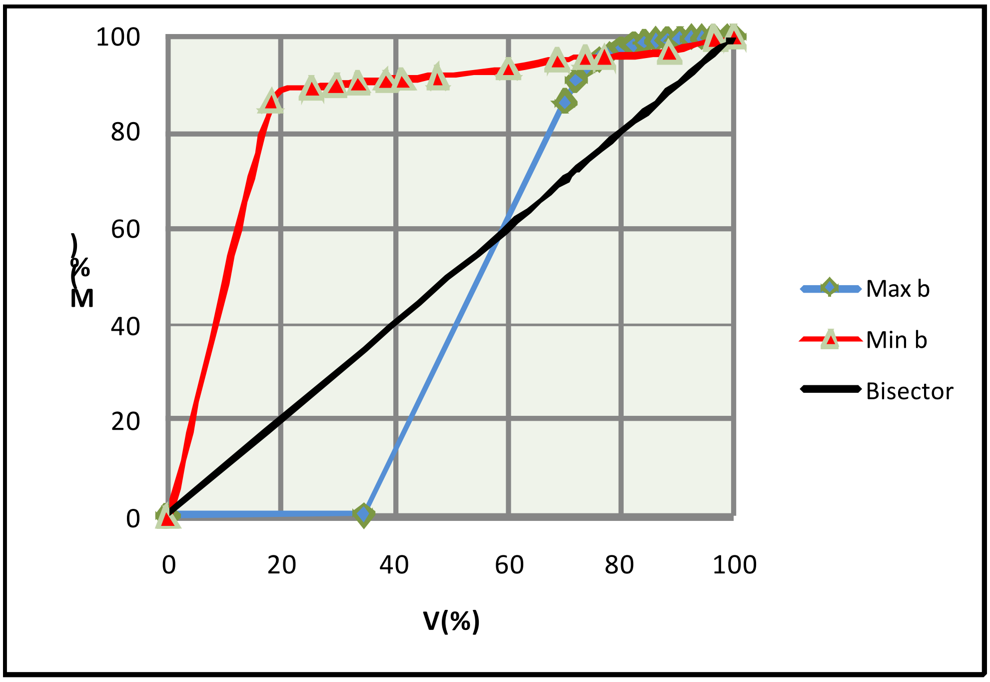

Figure (3): The M-V curves for events with the highest and the lowest TSS first flush coefficient values.

4.2 Dissolved Copper (dCu) First Flush Analysis

Table (A3) shows the percentage of events having first flush 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 (4) 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 can be classified as having moderate and weak first flush, respectively. Figure (5) 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 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.

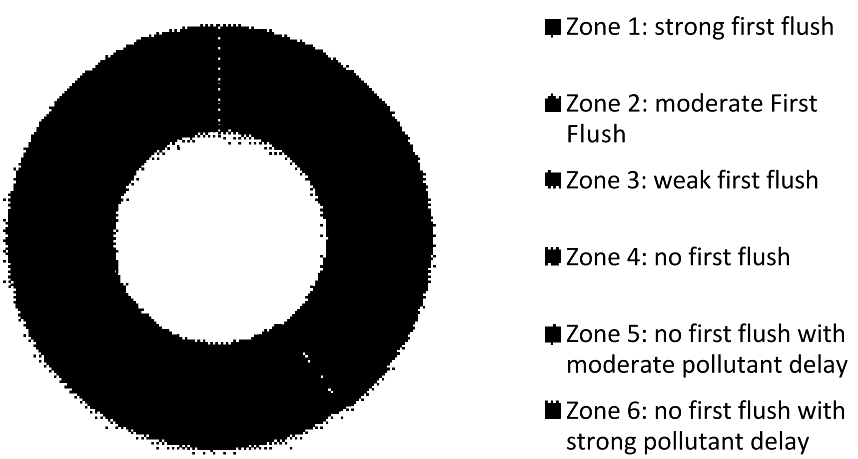

Figure (4): The percentage of events in the different M-V zones in the case of dCu.

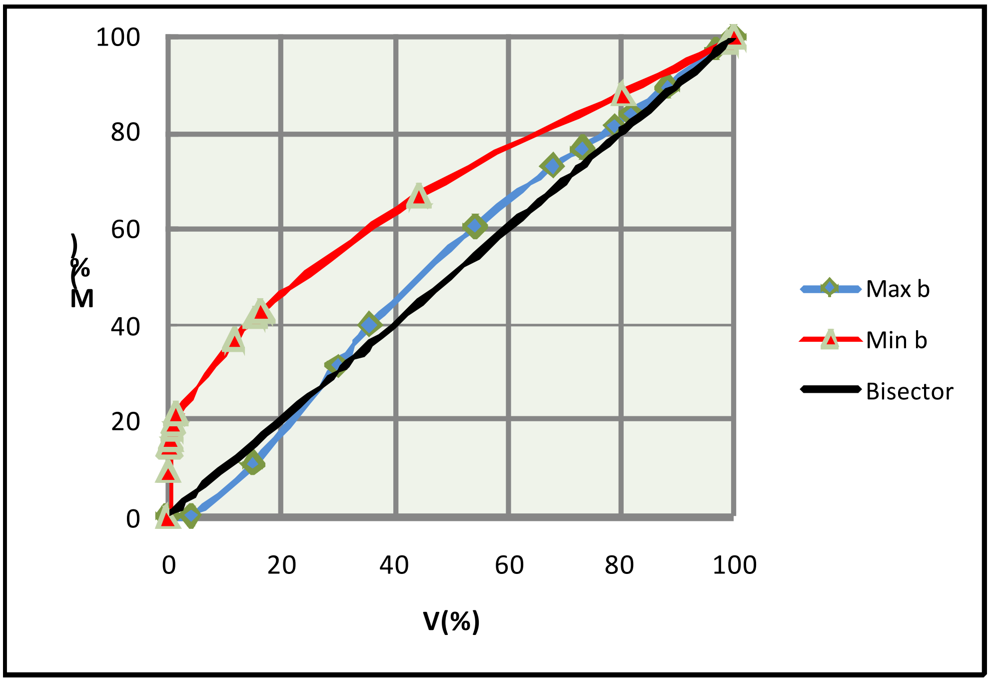

Figure (5): The M-V curves for events with the highest and the lowest dCu first flush coefficient values.

4.3 Particulate Copper (pCu) First Flush Analysis

Table (A4) shows the percentage of events having first flush varies 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 (6) shows the percentage of events in the different M-V zones. Examination of the figure shows that 45% and 16 % of the 87 events analyzed can be regarded as having moderate and weak first flush, respectively. Figure (7) 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 maximum first flush coefficient, the figure indicates that there is a pollutant load delay with possible source 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.

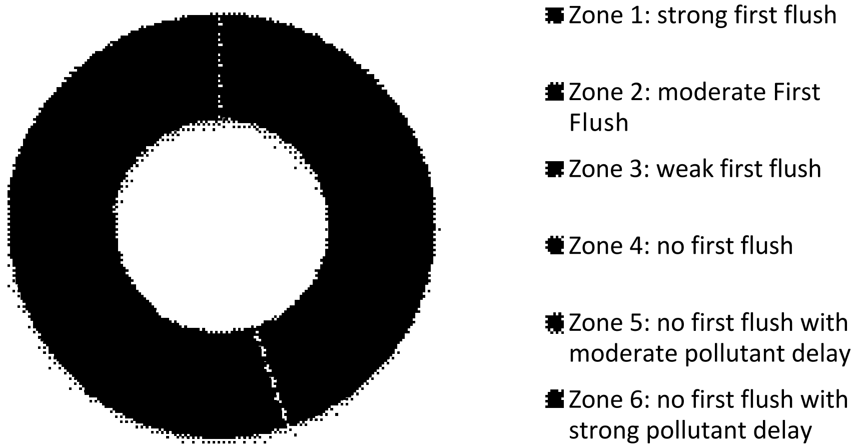

Figure (6): The percentage of events in the different M-V zones in the case of pCu.

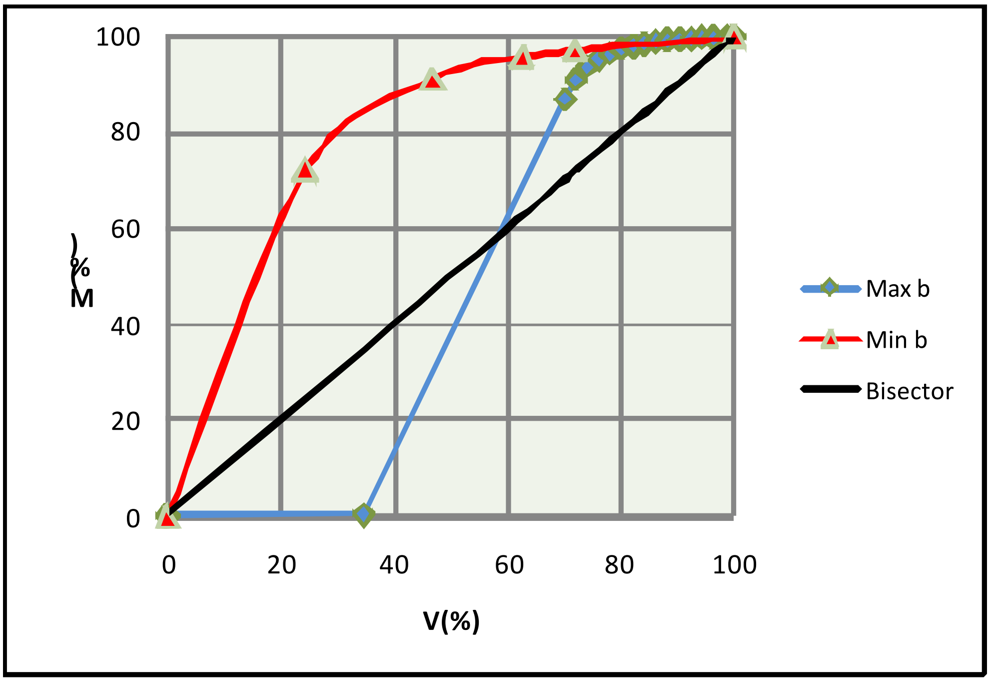

Figure (7): The M-V curves for events with the highest and the lowest pCu first flush coefficient values.

4.4 Total Copper (TCu) First Flush Analysis

Table (A5) shows that 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 (8) 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 can be classified as having strong, moderate and weak first flush, respectively. Figure (9) 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 70% 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 possible source depletion.

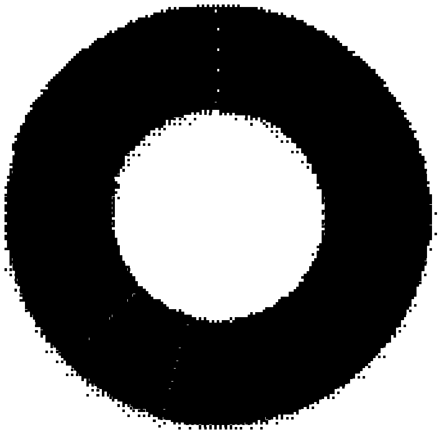

Figure (8): The percentage of events in the different M-V zones in the case of TCu.

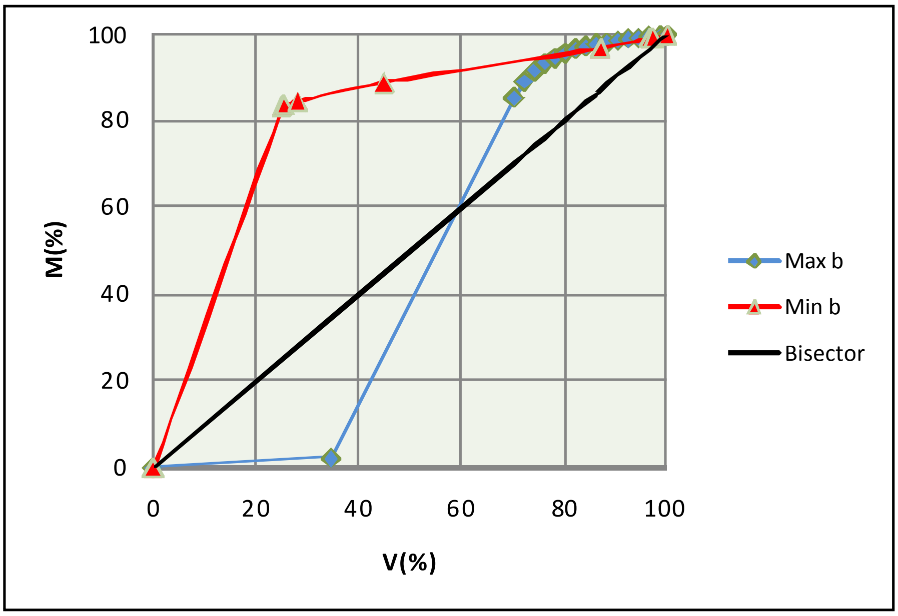

Figure (9): The M-V curves for events with the highest and the lowest TCu first flush coefficient values.

4.5 Dissolved Zinc (dZn) First Flush Analysis

Table (A6) 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 sites. Examination of the table also shows that the first flush coefficient values vary in the range 0.27 to 3.48. Figure (10) 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 can be classified as having moderate and weak first flush, respectively. Figure (11) 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 40% of the pollutant load is delivered in the first 20% of the total volume of the stormwater runoff event.

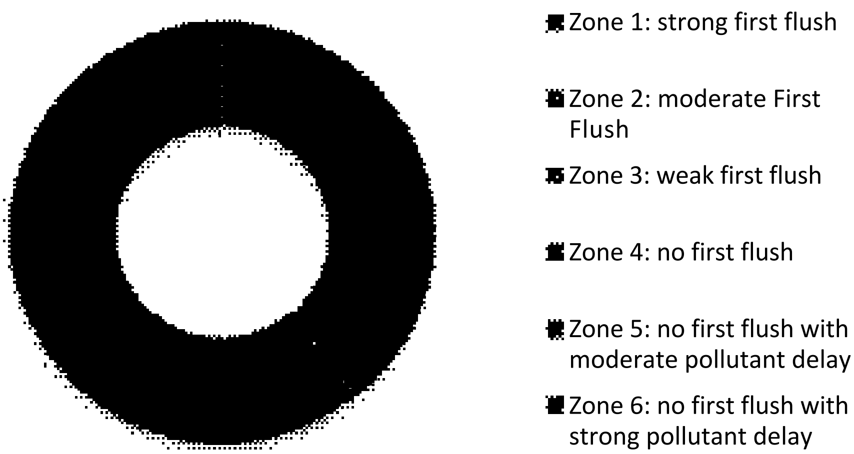

Figure (10): The percentage of events in the different M-V zones in the case of dZn.

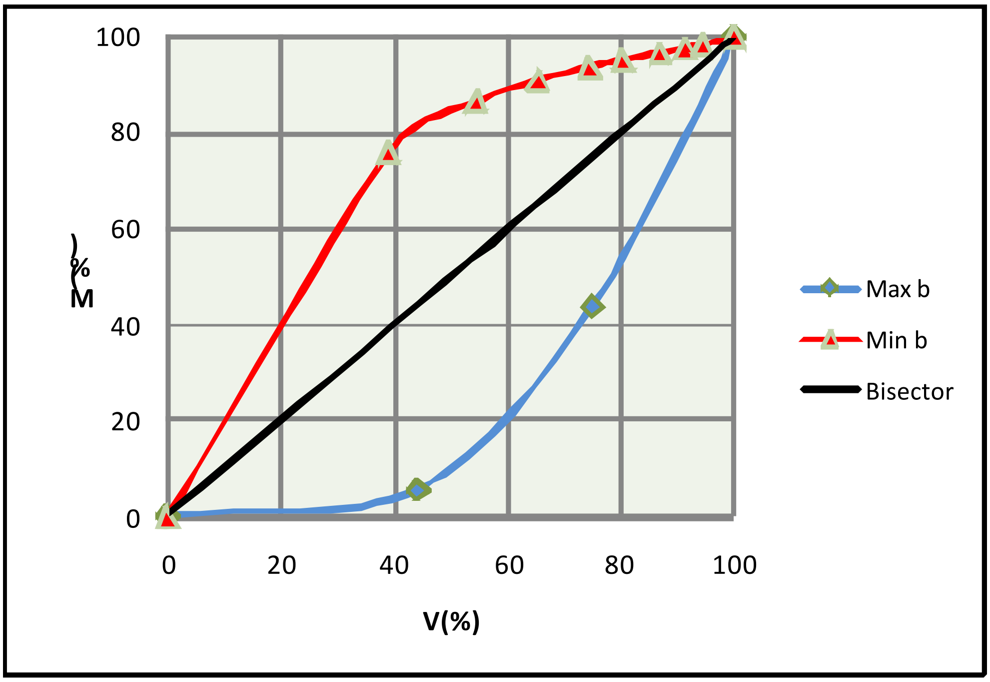

Figure (11): The M-V curves for events with the highest and the lowest dZn first flush coefficient values.

4.6 Particulate Zinc (pZn) First Flush Analysis

Table (A7) shows that 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 (12) 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 can be 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. In the case of the event having the maximum first flush coefficient, the figure indicates that there is a pollutant load delay with possible source depletion. In the case of the event having the minimum first flush coefficient value, the figure shows around 55% of the pollutant load delivered in the first 20% of the total volume of the stormwater runoff event.

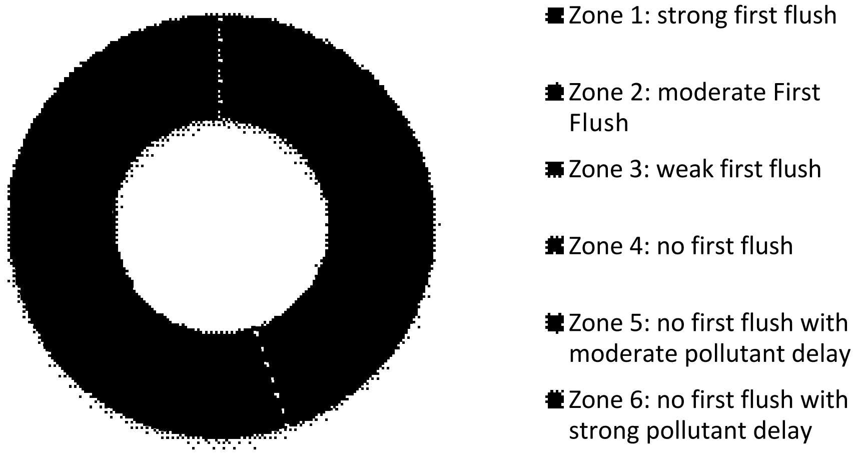

Figure (12): The percentage of events in the different M-V zones in the case of pZn.

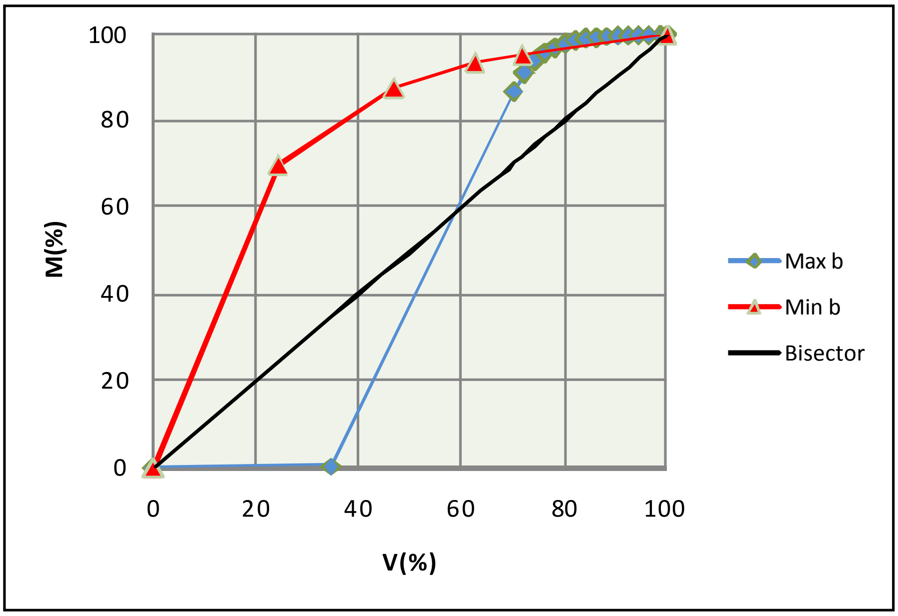

Figure (13): The M-V curves for events with the highest and the lowest pZn first flush coefficient values.

4.7 Total Zinc (TZn) First Flush Analysis

Table (A8) shows that 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 (14) 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 can be 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. In the case of the event having the minimum first flush coefficient value, the figure shows around 60% of the pollutant load 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 source depletion.

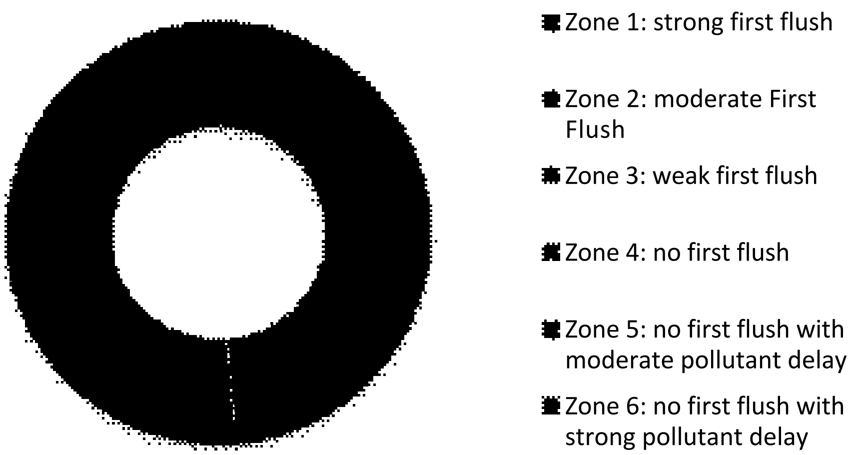

Figure (14): The percentage of events in the different M-V zones in the case of TZn.

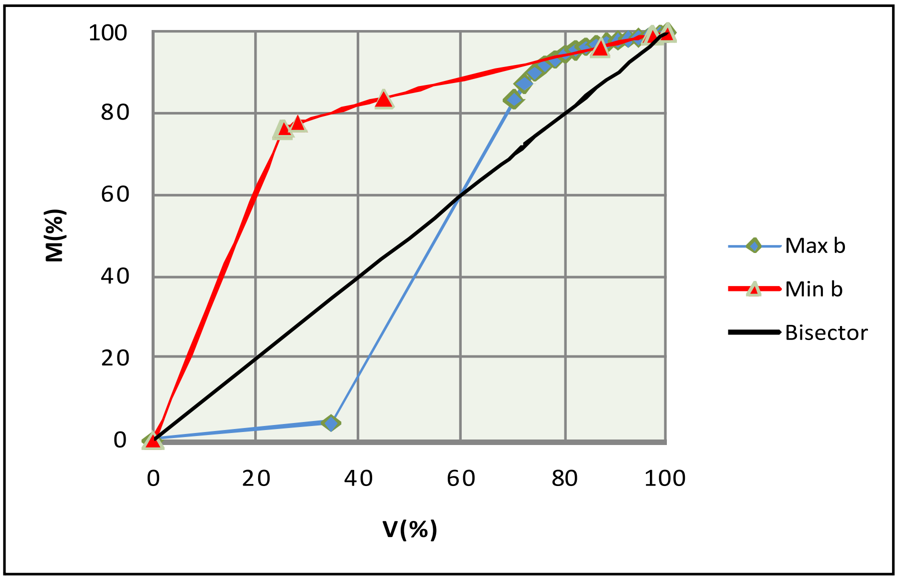

Figure (15): The M-V curves for events with the highest and the lowest TZn first flush coefficient values.

4.8 E. Coli First Flush Analysis

Table (A9) shows that the percentage of events having first flush varies between 0% in Meola site to 100% Remuera site. Examination of the table also shows that the first flush coefficient values vary in the range 0.63 to 4.4. Figure (17) 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 can be classified 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. 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.

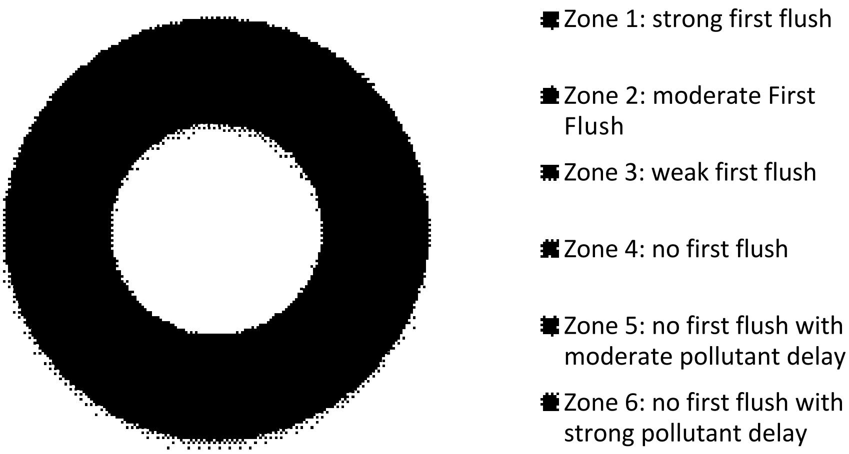

Figure (16): The percentage of events in the different M-V zones in the case of E. Coli.

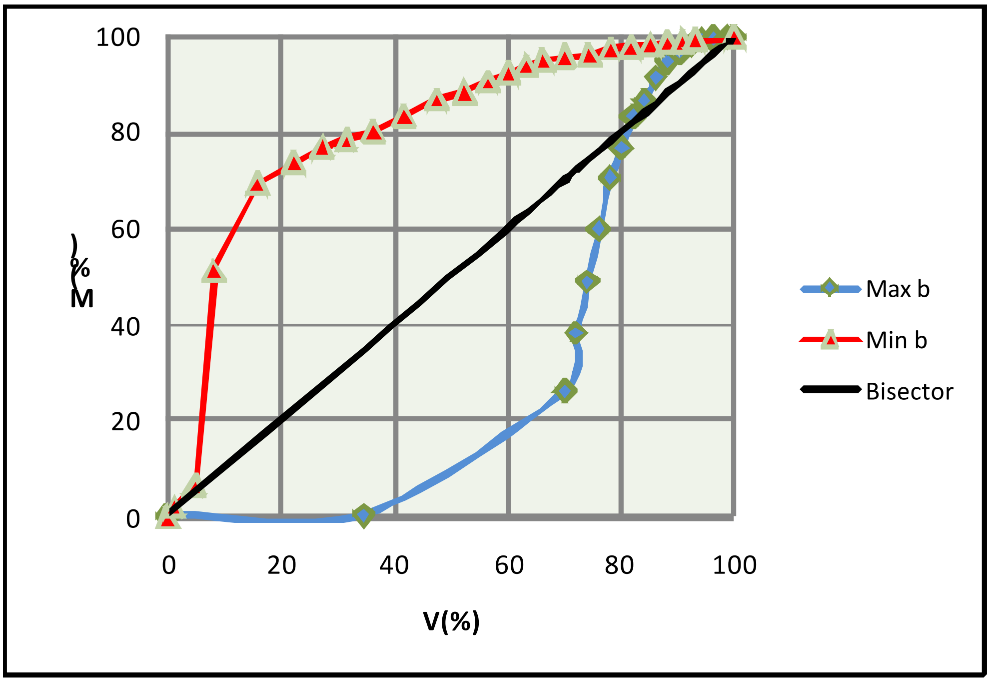

Figure (17): The M-V curves for events with the highest and the lowest E. Coli first flush coefficient values.

4.9 Fluoride First Flush Analysis

Table (A10) table shows that 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 (18) 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 can be 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. The figure shows examples of strong first flush (min b) with around 70% of the pollutant load delivered in the first 20% of the total volume of the stormwater runoff event. The presence of fluoride in stormwater runoff may be due to combined or sanitary sewer overflows.

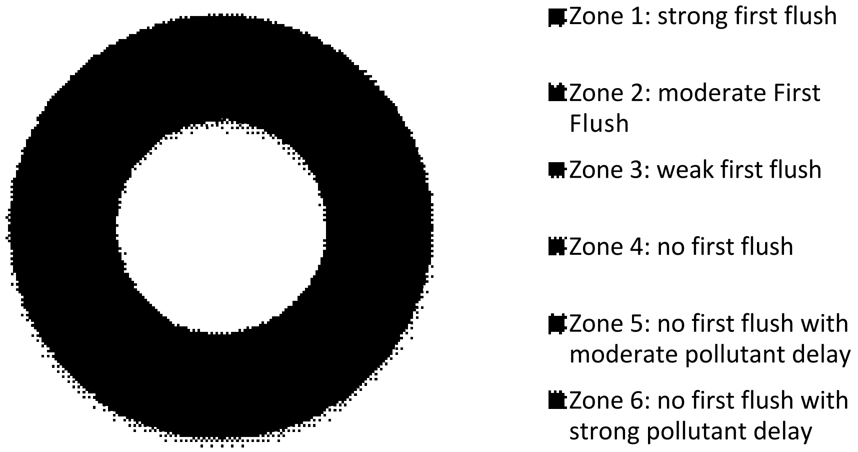

Figure (18): The percentage of events in the different M-V zones in the case of Fluoride.

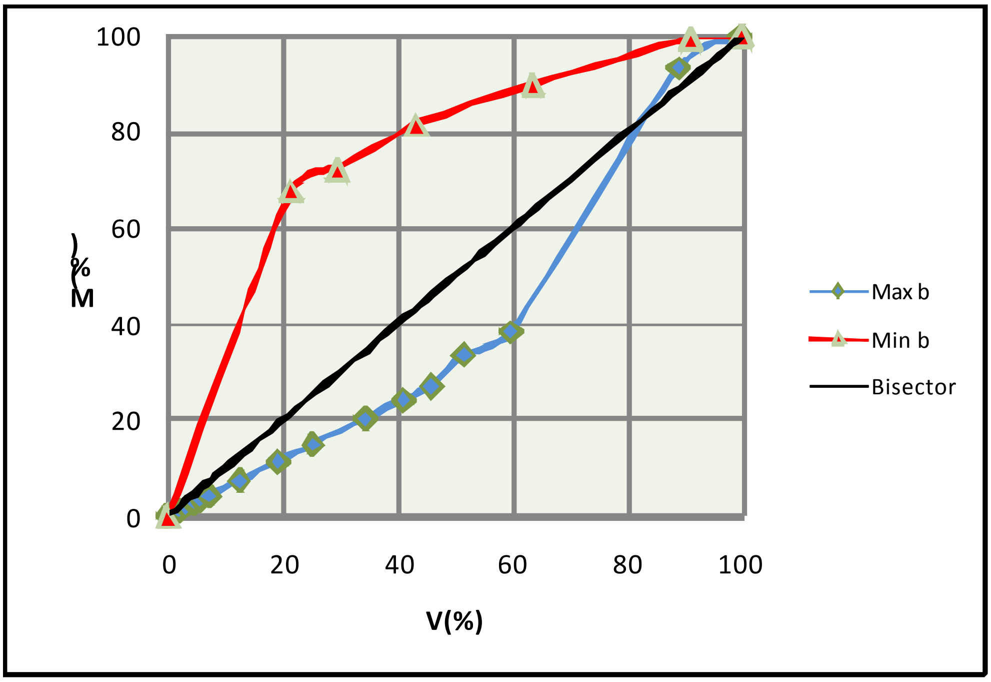

Figure (19): The M-V curves for events with the highest and the lowest Fluoride first flush coefficient values.

4.10 Particulate Lead (pPb) First Flush Analysis

Table (A11) shows that 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 67 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 can be 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. In the case of the event having the maximum first flush coefficient, the figure indicates that there is a pollutant load delay with source depletion. In the case of the event having the minimum first flush coefficient value, the figure shows around 55% of the pollutant load is delivered in the first 20% of the total volume of the stormwater runoff event.

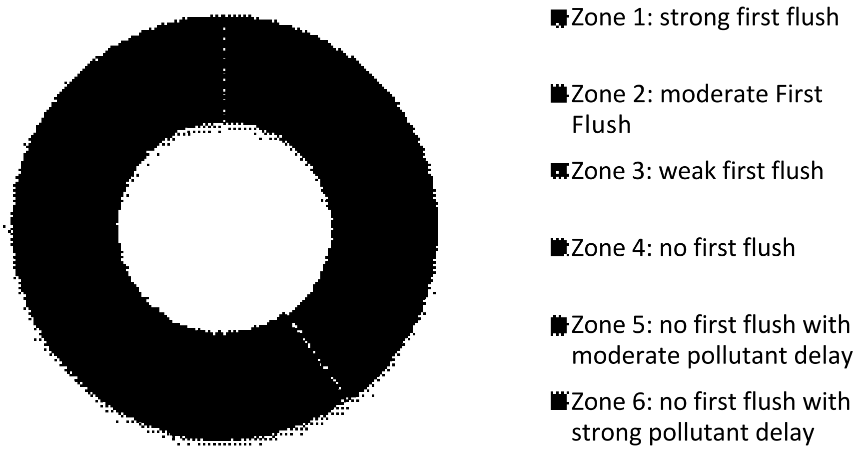

Figure (20): The percentage of events in the different M-V zones in the case of pPb.

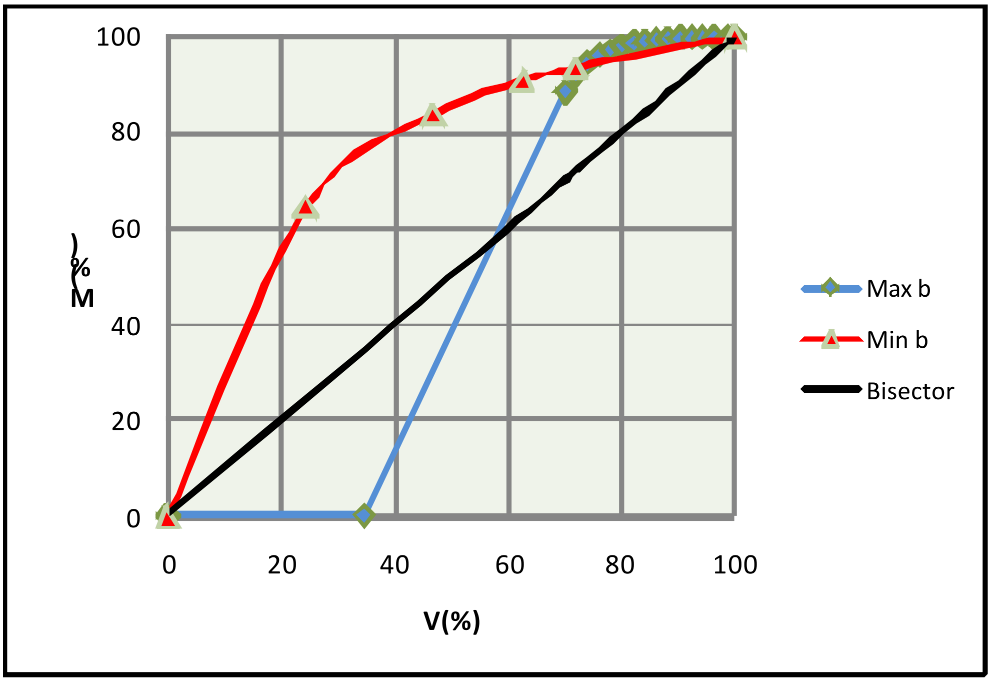

Figure (21): The M-V curves for events with the highest and the lowest pPb first flush coefficient values.

5 SUMMARY AND CONCLUSIONS

A first flush analysis was conducted using the data from 16 sites in the Auckland region, including eight urban network sites, four urban stream sites, and the untreated runoff discharging to a pond site, a rain garden site, a treatment train site and a permeable pavement site. The analysis is presented for 10 water quality parameters, namely, suspended solids (TSS), dissolved copper (dCU), particulate copper (pCu), total copper (TCu), dissolved zinc (dZn), particulate zinc (pZn), total Zinc (TZn), fluoride, E. coli and particulate lead (pPb).

Altogether, the current analysis unequivocally confirms the existence of a first flush phenomenon in the Auckland region. Further comprehensive analysis carried by Shamseldin (2011) confirms the existence of first flush for contaminants other than those reported in this paper. The strength of the first flush may vary depending on the water quality parameter and source area. Further studies should investigate the potential relationships between first flush descriptors (i.e. strength) and influencing factors such land use, catchment size, storm rainfall intensity and duration in order to provide better understanding of the variability of first flush across different sites or source areas.

The work to date has been aimed at determining whether or not there is evidence of a first flush at all in the Auckland region, and has considered all events equally. It is unsurprising to observe a strong first flush from untreated runoff sources such as parking lots and roadways. However, the presence of a strong first flush from in-stream sampling locations may suggest that stream flows are dominated by untreated runoff during wet weather events. Additional investigation is required to consider implications of grouping data according to individual sites.

In principle, designing stormwater management devices to focus on treating the first flush, if it exists, may be a more economical approach for reducing pollutants from stormwater (Barco et al., 2010). Further studies can therefore also investigate the implication of first flush on stormwater management in Auckland.

Acknowledgements

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Appendix-A

Table (A1): Summary description of the first flush sites.

No	Site	Land use	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 wastewater overflows	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 wastewater overflows	Orakei Domain	AA070	February 2001 – July 2001 April 2002 – July 2002
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 wastewater overflows	Grey Lynn Park	AA200	April 2002 – July 2002 February 2003 – April 2003
8	Remuera (Combes Road)	Residential	On downhill side of Combes Road	AA410	April 2002 – July 2002 February 2003 – April 2003
9	Block house Bay	Residential, Commercial & Industrial	below the culvert under Wolverton Road upstream of the culvert under Blockhouse Bay Road	--	Jan 2002 – Jul 2002 Jan 2003 – May 2003
10	Oakley Creek	Residential, Commercial & Industrial	just upstream of the culvert under Richardson Road	--	N/A
11	Pond Study	Residential	Northern end of the Nukumea viaduct and the Hillcrest Rd Bridge Silverdale North	--	2007 Dec 2008 – May 2009
12	Waitakere Rain Garden	Industrial	Waitakere Vehicle Testing Site (parking lot)	--	Nov 2006 – June 2007
13	Birkdale permeable pavement	Asphalt road	Birkdale road	--	March 2006 – Dec 2008
14	Albany Treatment train	Asphalt parking lot	Albany/Oteha Valley Rd. Park-N-Ride commuter parking lot	--	May 2009 – July 2009
15	Motions	Residential, Commercial & Industrial	Western Spring Park		May 2005 - July 2006
16	Meola	Residential	Great North RD		May 2005 - November 2005

Table (A2): The TSS first flush coefficient values for different sites and events[1].

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

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

Table (A3): 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

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

Table (A5): 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
Onehung	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

Table (A6): 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

Table (A7): 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 Analytical	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

Table (A8): 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

Table (A9): 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

Table (A10): 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

Table (A11): 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 Analytical	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