MONITORING OF STORMWATER RUNOFF IN MELBOURNE

Matt Francey, Ana B. Deletic, Tim D. Fletcher, Hugh P. Duncan

Monash University, Institute for Sustainable Water Resources (Department of Civil Engineering), Co-operative Research Centre for Catchment Hydrology, Building 60, Melbourne, Vic 3800, Australia

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ABSTRACT

A monitoring program has been set up in Melbourne, Australia to assess the parameters of importance in the generation of urban runoff pollution. The program will collect short interval rainfall intensities, runoff rates and pollutant concentrations in order to assess the relative importance of causal variables. To balance the competing demands of representative monitoring and cost, analysis was undertaken to determine the number of events necessary to minimise uncertainty of catchment Event Mean Concentrations. A "bootstrapping" procedure was compared to regular statistical methods with both methods producing similar results. The results suggest that approximately 50-60 events will reduce uncertainty to a level comparable with the measurement uncertainty for Total Suspended Solids (TSS), 20-30 events for Total Nitrogen (TN) and 30-40 events for Total Phosphorus (TP). Preliminary results from the monitoring programme are also presented. The results will be used to further develop the Model for Urban Stormwater Improvement Conceptualisation (MUSIC), a commonly used tool in Australia for stormwater management.

INTRODUCTION

Accuracy of prediction of stormwater pollution is a need that parallels the rise in awareness and concern about the effects of urban pollution. There are three main needs addressed through improved modelling of stormwater, all of which contribute to a better environmental management of our urban surface waters:

- Better design of stormwater treatment measures, known as Water Sensitive Urban Design (WSUD) in Australia.
- More efficient prioritisation of restoration or pollutant reduction works.
- Better scientific support for planning and economic schemes aimed at addressing stormwater pollution.

The CRC for Catchment Hydrology's simulation model MUSIC (Model for Urban Stormwater Improvement Conceptualisation) is being widely used by stormwater managers in Australia to predict pollutant generation and performance of stormwater treatment measures. There remain, however, a number of limitations in our understanding of pollutant generation and treatment. Addressing these limitations is essential to improving the design and performance of stormwater treatment measures (particularly given the major investment being made by the industry to improve urban stormwater quality). The monitoring program developed to address these issues is described in this paper.

Pollutant concentrations within MUSIC are currently generated with a statistical approach, using catchment event mean concentrations (EMC's) and their standard deviations to generate a stochastic time series of pollutant concentrations. The monitoring program aims to improve the pollutant generation process in MUSIC in two ways:

Firstly, the data gathered in the program will be used to refine our knowledge about the statistical distribution of stormwater pollutants, and to quantify the uncertainties of the distributions being used. Secondly, the data will be used for development of a reliable event based model for characterisation of stormwater pollution in the Melbourne metropolitan area. Current models usually centre around three major processes, the "build-up" or availability of pollutants, the detachment of particles by raindrop impact, and the shear stress associated with flow. The relative importance of these factors for a variety of catchment types, sizes and scales will be assessed for local conditions. The program will investigate the various parameters that have been used worldwide to explain pollutant generation from impervious surfaces; these include runoff rate (Aalderink et al. 1990), rainfall volumes (Reinertsen 1981), runoff volume (Freund and Johnson 1980), rainfall intensity (Price and Mance 1978), (Coleman 1993) or combinations of these factors.

In order to design the Melbourne monitoring programme (minimise required costs without losing important information), it was important to find the optimal number of events that should be monitored at each catchment (and for each studied pollutant). This analysis is also the first step in attempting to quantify the uncertainty associated with stormwater model outputs, such as those from *MUSIC*. For stormwater models that use the statistical properties of water quality parameters (e.g. the catchment means and standard deviations of TSS, TP or TN), the level of uncertainty associated with these parameters is directly linked to the quality and amount of the stormwater data available for their calibration/verification. This would also provide important guidance to any organization wishing to collect stormwater quality data for calibration of stormwater models.

OBJECTIVES

The monitoring program has the following objectives:

1. Collect water quality data (TSS, TN, TP and some metals) from a range of urban land use catchments of various impervious fractions.
2. Collect short time interval rainfall intensity and flow data for each of the catchments.
3. Measure particle size distributions and size-fractionation (the proportion of each contaminant type that sits within each particle size range).
4. Quantify the relationship between rainfall intensity data and pollutant load generation, and compare calibration coefficients for this relationship between catchments.
5. Quantify cross-correlation between key water quality parameters (and quantify influences on degree of correlation).
6. Quantify temporal variation (serial correlation) in water quality parameters.
7. Determine the level of uncertainty surrounding these relationships, so confidence in resulting models can be quantified.

METHOD

The program is aimed at producing maximum definition in the explanatory variables of runoff rate, rainfall intensity, antecedent dry period and land use. The idea is to study the processes of pollution generation on a wide range of catchments; from simple surfaces of uniform land use to complex urban catchments. To that end 8 sites will be monitored. Two of the sites are a roof and a carpark. The other six range from 8 to 195 ha and from 0.2 to 0.8 total impervious fraction, as listed in *Table 1*.

Rainfall intensity and runoff rate will be monitored continually at the selected catchments for a period of up to 2 years. Runoff will be analysed for major stormwater pollutants (as specified in Objectives 1-3 above).

Table 1: Main characteristics of the monitoring catchments in Melbourne

No	Name	Total Area [ha]	Total Impervious Fraction	Primary land use
1	**Eley Rd**	186.0	0.46	Residential
2	**Kilgerron Crt**	10.5	0.2	Low density residential
3	**Monash Carpark**	2.6	0.80	Carpark
4	**Monash Roof**	0.04	1.00	Coated aluminium roof
5	**Gilby Rd**	22.6	0.80	Light industrial
6	**Richmond**	88.5	0.74	High density residential
7	**Ruffey's Lake**	110.9	0.51	Residential
8	**Shepards Bush**	36.0	0.45	Residential

As explained in the introduction, analysis has been undertaken to quantify the errors involved in the pollutant sampling, the explanatory variables and the sampling procedure. The results were used in two ways; to determine the optimum number of events to sample at each site, and to establish the uncertainties associated with assessment of catchment Event Mean Concentration. Four existing data sets, identified in Table 2, were analysed:

Table 2: Data sets used in the analysis of uncertainty in assessment of catchment EMC

Catchment Characteristics				**Number of events, N (Kolmogorov-Smirnov p for log-normal distribution*)**		
Catchment (Location)	**Climate**	**Land use**	**Area**	**TSS**	**TP**	**TN**
Blackburn Lake (Melbourne)	Mediterranean	Urban mixed use	200ha	45 (0.66)	45(0.95)	45(0.88)
Sandy Ck (Brisbane)	Tropical/Sub Tropical	Primarily residential	220ha	90(0.80)	74(0.40)	74(0.53)
Cressy St (Brisbane)	Tropical/Sub Tropical	Primarily residential	107ha	110(0.95)	105(0.88)	99(0.92)
Lund (Sweden)	Cool Temperate	Carpark	270m^2	68 (0.67)		

There were differences in the data collection regimes at each of these sites; the Melbourne and Lund data being collected purely for research purposes, while the Brisbane data were collected for management and operational purposes; TSS was measured in collected water samples using standard filtering method for all catchments but Lund, where TSS was estimated using a turbidimeter calibrated against the local stormwater TSS data (Deletic and Maksimovic, 1998); TN and TP were not measured in Lund.

For each site, the data were log-transformed, and then tested for normality (successfully) using the Kolmogorov-Smirnov distribution test. The analysis was then carried out using two comparative methods.

- A “bootstrapping” (Chernick 1999) procedure where samples of different sizes were selected with replacement. Of N events in the data set, n=5, 10, 15 and so on, events were randomly selected (drawn with replacement). This procedure was repeated 1000 times. Each time the procedure was repeated the catchment mean (EMC) and the catchment standard deviation (SD) were calculated, resulting in a total of 1000 means and standard deviations for each of n sampled events.
- Using the properties of a normal distribution (based on central limit theorem). The 95% confidence interval was calculated using the area under a normal curve corresponding to z =1.96 in equation 1 below:

$$z = \frac{x}{\sigma / \sqrt{n}}$$ *(Equation 1)*

where σ is the standard deviation of the original data set (of N), x is size of the confidence interval for given z, and n is the sub-sample size (as above).

RESULTS AND DISCUSSION

Uncertainty Analysis

Table 3 shows the 95th percentile confidence interval ranges about the mean associated with each sample size using both the “bootstrapping” and normal distribution methods for Blackburn Lake. There were no significant differences between the results obtained through the “bootstrapping” and normal distribution methods. This is the expected result, since the log transformed data has already been shown to be approximately normal (Kolmogorov-Smirnov p>0.4 in all cases; Table 2).

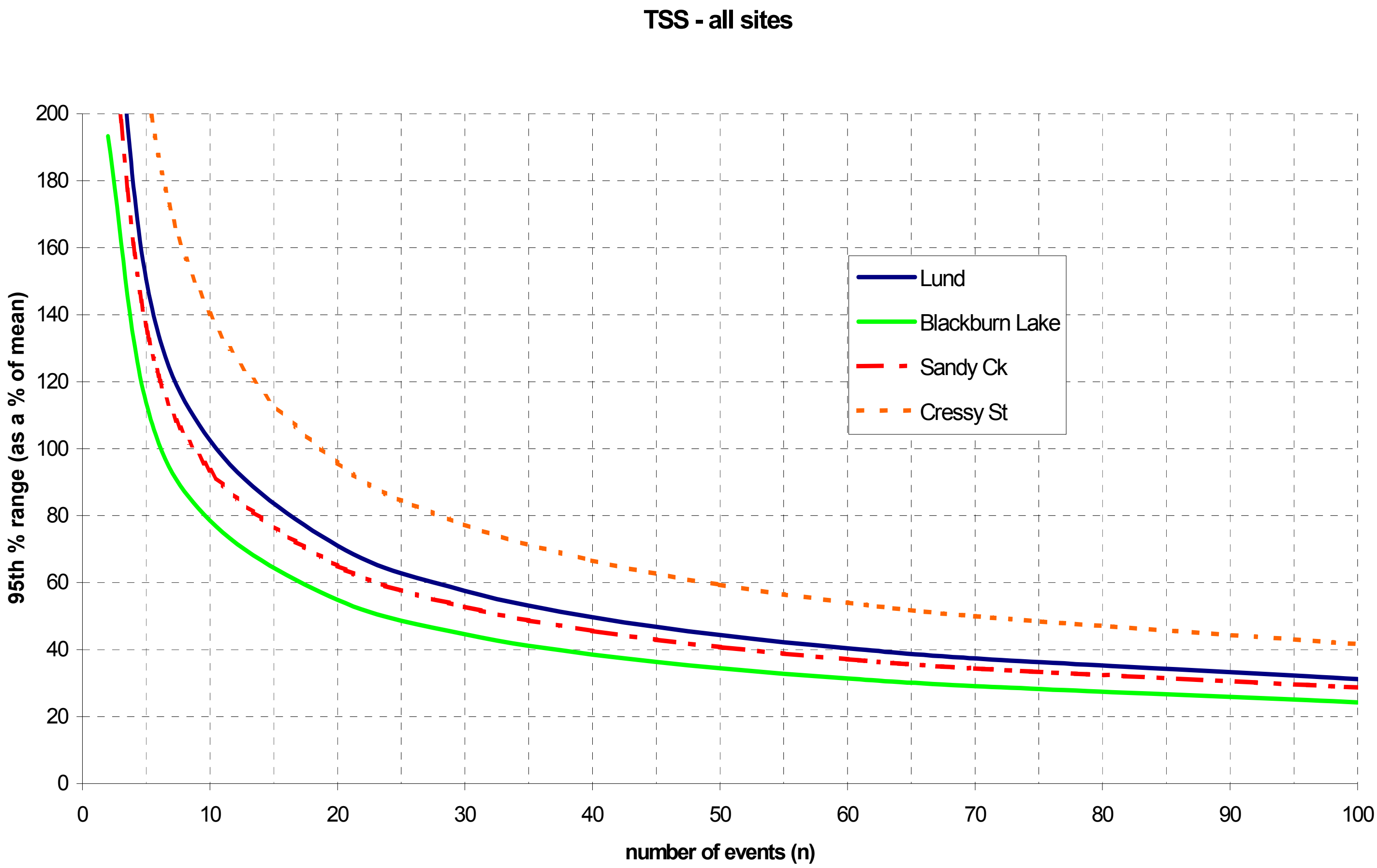
Table 3 – Comparison of 95%ile confidence interval ranges calculated using “bootstrapping” and normal distribution methods

Blackburn Lake (TSS)								
n	2	5	10	20	30	40	50	60
Log transformed data, using properties of a normal distribution								
Relative interval size (% of mean)	193	114	79	55	45	39	34	31
Log transformed MEAN (Bootstrapping)								
Relative interval size (% of mean)	192	112	76	53	46	38	32	31

Due to the simplicity of the normal distribution method, that method was used to present the remaining parameters and sites.

Figure 1 shows the 95% confidence interval curves for TSS for the four catchments. The 95% confidence interval around the mean of each sample is presented as a percentage of the mean. We can also compare the observed uncertainty with the underlying errors associated with sampling and measurement methods. Recent research has reported these to be at least 30% for TSS (Bertrand-Krajewski and Bradin 2002; Orr 2002). To achieve an analysis uncertainty in the same range requires 50 - 60 monitored events at Blackburn Lake, and rather more at the other sites.

Figure 1: 95th Percentile curves for TSS – all sites



The TP and TN data shown in Figures 2 and 3 suggest that fewer events are necessary for prediction of EMC's at a given level of accuracy than in the case of TSS, although we do not have similar estimates of measurement errors for these pollutants. The number of events needed to achieve a given level of analysis uncertainty depends on the standard deviation of the Event Mean Concentrations. The higher the standard deviation, the larger the number of events needed (Equation 1). It is not yet clear whether the differences in observed behaviour (Figures 1 to 3) are due to climatic differences between the sites, or to differences between research and operational data, or to some other effect. Certainly there are climatic differences. Rainfall intensity is considerably higher and more variable in Brisbane than at the other sites. But since the new monitoring program is a research project located in Melbourne, the Blackburn Lake data appears to be the most applicable on both counts. Hence the results from Blackburn Lake will be used initially to quantify the uncertainty for the current monitoring program.

Figure 2: 95th Percentile curves for TP – all sites

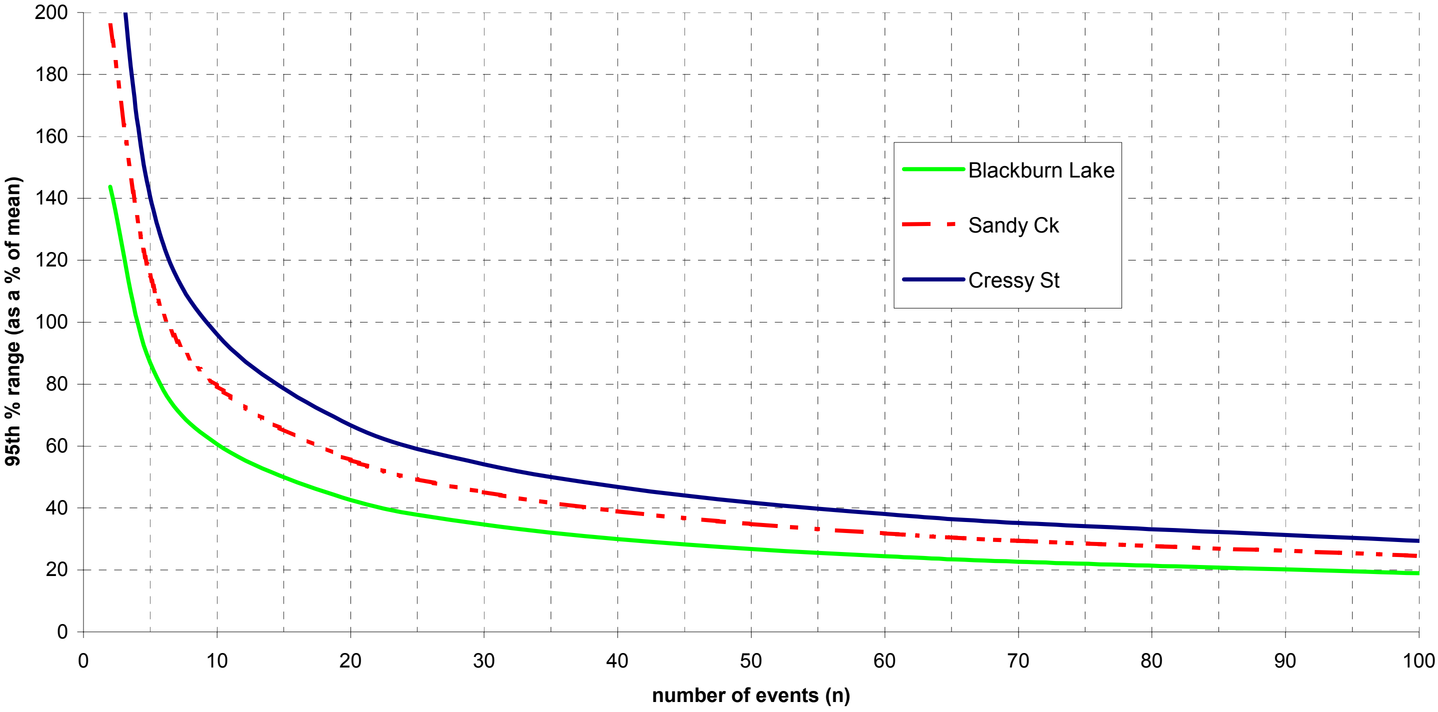
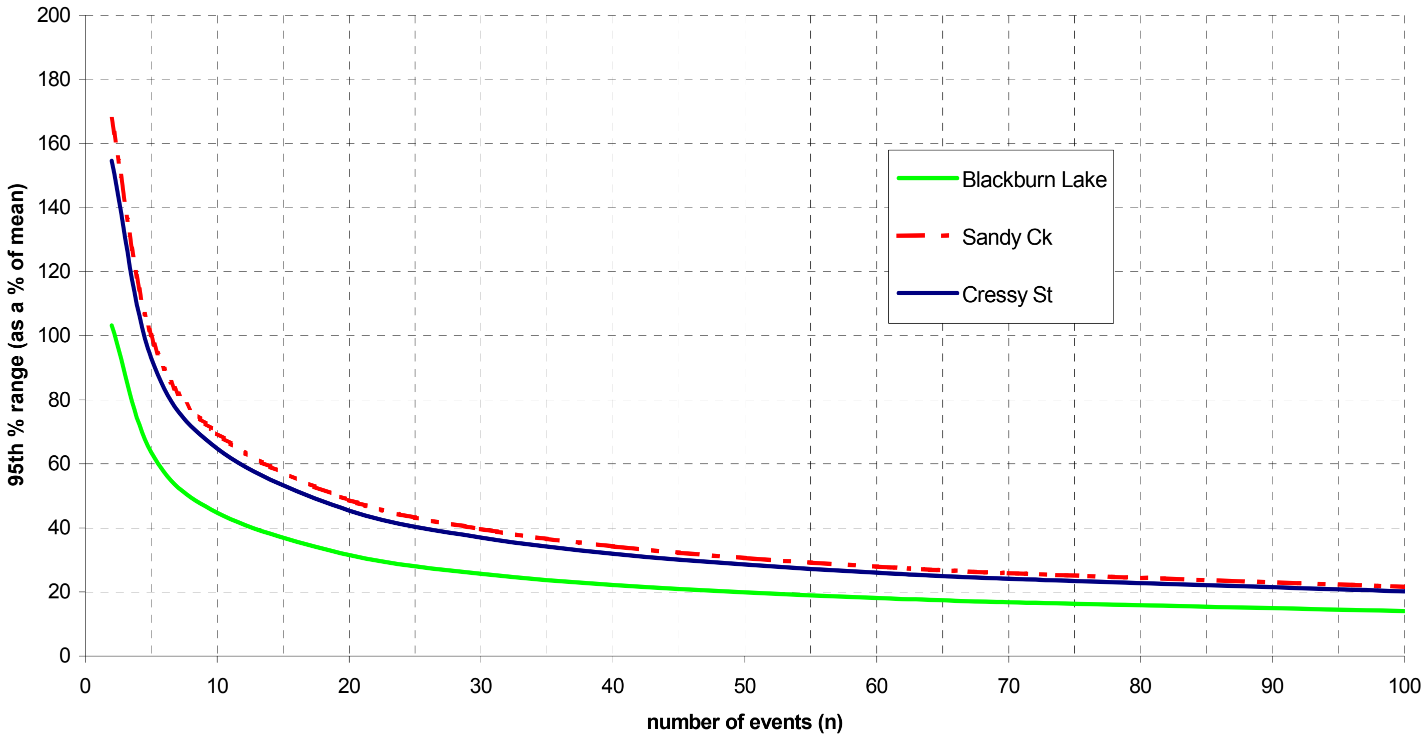
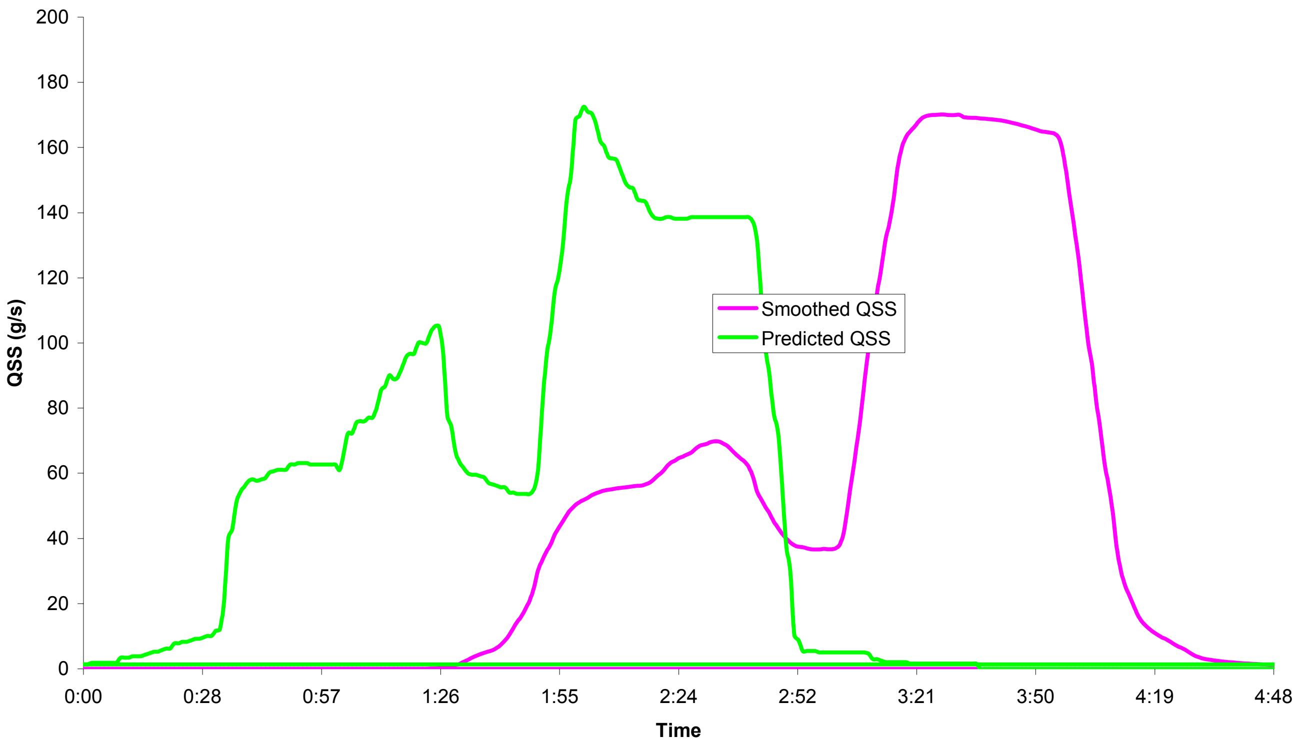


Figure 3: 95th Percentile curves for TN – all sites



Initial Results of the Melbourne Monitoring Programme
The monitoring program is in its initial stages with only 3 – 6 events being captured at each site, therefore catchment EMCs and the assessment of different explanatory variables cannot be presented with any confidence. Figure 5 shows the event recorded at Gilby Rd catchment (Table 1). This was a large event with average return interval greater than 6 months. It transported 80% of the sediment total for the five-recorded events. In this graph, TSS load, and load predicted by rainfall intensity squared at one-minute timesteps is plotted versus time. The linearity of the relationship between the two can be noted. This relationship will be studied in data that is being collected.

Figure 5: Event No 2 recorded at Gilby Rd catchment



CONCLUSION
The study has shown that the properties of a normal distribution can be used to assess confidence intervals for various sample sizes – if the distribution is known to be (or can be transformed to be) approximately normal. We can conclude that between 50 and 60 events is sufficient to give us a reliable estimate of the catchment event mean concentration for TSS, and its variability. However, the study showed that only 20-30 events for TN and 30-40 events for TP should be collected to reduce uncertainty to approximately 30% of the mean.

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Corresponding Author:
Matt Francey. Melbourne Water
GPO Box 4342, Melbourne VIC 3001,Australia
61 3 9235 2221 (phone)
61 3 9235 7170
matt.francey@melbournewater.com.au