Effective monitoring and assessment of contaminants impacting the mid to lower Yarra catchments: a temporal scale assessment

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Executive summary

This study's aim was to identify the level and variability of an array of pollutants in urban stormwater systems which drain into Melbourne's Yarra River. Both dry weather flows and wet weather events were monitored for heavy metals, two indicator microorganisms (*Escherichia coli* and enterococci) and Total Petroleum Hydrocarbons (TPHs). The monitoring program was conducted at three residential and three industrial catchments.

Dry weather data was collected from the six catchments using an intensive monitoring regime. Three samples per day, for a seven day period, were withdrawn from each of the six catchment's outlet pipes. Wet weather data was also collected from the outlet pipes of two catchments (one residential and one industrial). In total, four rainfall events at both catchments were monitored using autosamplers which withdrew samples from the stormwater using flow weighted intervals.

Most pollutant levels were found to vary *between catchments* (i.e. from one catchment to another), temporally *within catchments* (i.e. from one sampling time to another at the same location) and temporally during wet weather events (i.e. pollutant concentrations vary over the hydrograph). In most cases, the magnitude of this variability was found to be specific to both the pollutant type and the catchment, with some pollutants exhibiting a large amount of variability at one catchment and a minimal variability at another. This was even the case between catchments of very similar land-uses, levels of imperviousness and degrees of development. For example, aluminium concentrations had a very high variation at two of the catchments (one industrial and one residential), whilst in another two catchments the concentrations remained largely similar (again, one industrial and one residential).

There were some pollutants which exhibited a constant amount of variability across all catchments. Strontium was the most constant within all catchments during dry and wet weather events, with standard deviations always far less than its mean concentration (indicating a low relative variation). It is noted that although its variability was small within each catchment, strontium concentrations were often different between catchments. Other examples of pollutants having a constant amount of variability across all catchments are *E. coli* and enterococci. These bacterial indicators constantly had the highest variation within all six catchments, with their standard deviations generally being greater than their mean. Both bacteria also varied significantly between each catchment during dry weather flows, with *E. coli* showing no real difference between land uses but enterococci always being an order of magnitude lower at the industrial catchments.

The variability of pollutants was found to have a large influence on the accuracy of certain sampling strategies for loading estimations. For example, accurately estimating dry weather loadings for a pollutant which has concentrations that vary considerably requires more samples than for a pollutant with a low amount of variability. This argument holds true for wet weather sampling also, with the variability in the pollutant's concentrations governing the number of samples required during each event for accurate wet weather pollutant load estimations. This finding has important implications on future sampling designs and will aid in more accurate load estimations whilst reducing monitoring costs.

Analyses were conducted to explain some of the observed variations. The correlation of pollutants during both dry and wet weather was most apparent for heavy metals, with many catchments showing statistically significant correlations between an array of different metals. Few metals were correlated with flow rates and indicator organisms were most significantly correlated with one another, although during wet weather the indicator organisms were also correlated with some

heavy metals (although never consistently at both wet weather catchments). Many of the heavy metals at the residential catchment showed a decline in concentrations from the start of wet weather events. This indicates that a first flush effect might be present for these metals at this catchment. Only a couple of heavy metals at the industrial catchment showed such a trend, with these trends always being less significant than that found at the residential catchment. *E. coli* and enterococci showed no consistent first flush trend at either of the two catchments.

Comparisons between estimated yearly dry and wet weather loads showed that for the residential catchment, the total annual load was mainly sourced from wet weather events. However, the opposite was true for the industrial catchment, with generally less than half of the total annual pollutant load being sourced from wet weather events. These results were highly dependent on the dry weather flow regimes found within each catchment, with the large residential catchment having very low flow rates while very high dry weather flows were found at the small industrial catchment. This was an interesting finding since baseflow rates found in stormwater are theoretically proportional to the size of the catchment (mainly the size of the pervious soil system). These results clearly demonstrate that anthropogenic sources of water exist in the industrial catchment and that these sources of water can result in high dry weather pollutant loads.

Although this dataset helps to understand the variability of pollutants between and within each study catchment, there is insufficient data to extrapolate these findings directly to other catchments. More data collection is required to understand the underlying population distribution of each pollutant at a range of different catchments. This population distribution can then be used to estimate the likely pollutant load coming from an unmonitored catchment. However, until this is completed, it will be necessary to monitor catchments to understand their pollutant levels and associated variability. This work has helped to inform these future monitoring regimes by understanding (1) the connection between pollutant variability and sampling frequency and (2) the typical variability of an array of pollutants in residential and industrial catchments during both dry and wet weather flows.

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1 Introduction & background information

1.1 Background information

Characterising pollutant levels from urban stormwater drains during dry and wet weather periods is important for a number of reasons, including: assessing and improving WSUD treatment technologies, assessing the impacts of stormwater runoff on downstream systems and for modelling purposes. However, in order to accurately characterise pollutant loads and concentrations, accurate monitoring methodologies must be used.

The sampling of dry weather urban stormwater flows is often conducted using a 'grab' sampling methodology (e.g. Leecaster et al., 2002; Fletcher & Deletic, 2007; Francey et al, *in press*). Furthermore, 'grab' sampling of wet weather flows in urban systems is often conducted and used in the literature to characterise a site's pollution level (e.g. Eleria and Vogel, 2005; Fletcher & Deletic, 2007; Soonthornnonda and Christensen, 2008). Most bacterial and toxicant sampling in rivers and drains conducted by the EPA Victoria is from a single sampling point using a 'grab' sample methodology. The adequacy of such a sampling methodology is dependent on a number of factors, including: the pollutant's variability (both spatially and temporally), the frequency of the sampling and the corresponding time period which is being characterised (i.e. are daily, weekly, monthly or annual loads being characterised?). As such, the representativeness of this form of sampling, in terms of quantifying pollutant levels, is unknown.

Discharges of faecal contamination in many stormwater drains discharging to the Yarra River were found to be highly variable (Melbourne Water and EPA Victoria, 2007a). An independent scientific review of the above investigation supported the recommendation made within the above report to further characterise the degree of spatial and temporal variability of pollutant loads within the system (Melbourne Water and EPA Victoria, 2007b). While EPA Victoria are currently undertaking a sampling program to assess the spatial variability of pollutants in the lower and Middle Yarra, temporal scale variability of pollutants entering the river is yet to be fully investigated.

1.2 Aims/objectives

This project aims at identifying the temporal variability of pollutants in urban stormwater feeding into the Yarra River. The outlet pipes of six urbanised catchments (3 residential and 3 industrial) were monitored during both dry and wet weather periods. The results have provided information to help increase the understanding of the temporal variability for bacterial, heavy metal and TPH contaminants leaving industrial and residential drainage systems during dry and wet weather periods. This information can be used to help improve the sampling design of future bacterial and toxicant pollutant investigations.

More specifically, there were a number of smaller aims/objectives which were used to address the above overall aim. These more specific aims include:

1. Identify and report the variability of each pollutant during *dry* weather periods to help understand this variability in industrial and residential catchments. This variability includes:
    a. how the pollutant varies between different study sites and within each study site; and,
    b. how the pollutant varies within each day (i.e. does it exhibit a diurnal fluctuation?).
2. Identify and report significant correlations between all dry weather pollutant levels and flow rates to help determine whether the behaviour and or source of one pollutant is captured in another, or is explained by flow rates.
3. Determine the errors associated with using just one grab sample per day to characterise weekly pollutant loads.

4. Identify and report the variability of each pollutant during *wet* weather periods to help understand this variability in industrial and residential catchments. This variability includes:
    a. how the pollutant varies between different study sites and within each study site; and,
    b. how the pollutant varies within each wet weather event.
5. Identify and report significant correlations between all wet weather pollutant levels and flow rates to help determine whether the behaviour and or source of one pollutant is captured in another, or is explained by flow rates.
6. Determine the errors associated with using one, two, three or four randomly taken samples during rainfall events to characterise a pollutant's wet weather event loads.
7. Identify differences in pollutant behaviour between dry and wet weather periods and determine whether dry or wet weather pollutant loads contribute the most to total annual loads.
8. Determine the uncertainty in the analytical procedure for typical stormwater pollutants (i.e. what is the error in the result obtained from the laboratory?).

2 Methods

2.1 Study sites & equipment

2.1.1 Study site selection

Three residential and three industrial sites in Melbourne, Australia, were carefully selected as the study sites for this project. Their selection was based upon a number of different criteria, including:

- the selected sites must have a good representation of the required land-use, with the majority of the catchment being classified as either residential or industrial sectors;
- the site selection should be based on prior knowledge of key drains which have been shown to be influenced by microorganisms, heavy metals or hydrocarbons;
- the sites were relatively close to the base location of the sampling team (i.e. Monash University, Clayton) and were easily accessible from this location;
- the sites and the equipment needed to be installed in a location that was safe to access by sampling staff and in a location where the likelihood of vandalism was minimal;
- the sites needed sampling equipment and other sampling stations to be installed and, as such, approval from the local government was required; and,
- established catchments were chosen to ensure that construction and remediation works were kept to a minimum during the sampling period.

After careful consideration of the criteria above, six study sites were selected for use in this project. Table 1 shows a summary of the characteristics of the sites, whilst a brief explanation of each of the six study sites is provided below. An aerial photograph is shown in Figure 1 which shows the relative location of each site to Melbourne's Central Business District (CBD). It should be noted that the bolded names shown in Table 1 will be used to refer to each of the study sites (i.e. Hedgeley Dene Main Drain, Malvern East will be, from now on, referred to as just Hedgeley Dene).

Table 1. Site descriptions and catchment characteristics.

Site Name	Melways Reference of Outlet	Primary land-use[1]	Total catchment area[2] (ha)	Total impervious-ness[2] (% of area)	Catchment's outlet pipe dimensions [m]	Latitude, Longitude
Hedgeley Dene Main Drain, Malvern East	59 K10	Residential – medium density	160	45%	Square - 1.83W x 1.20H	37°51'57.70"S, 145° 3'36.87"E
Lara Street Main Drain, Malvern East	59 E5	Residential – medium density	110	55%	Circular – 0.61rad	37°50'48.32"S, 145° 2'24.08"E
Fairfield Main Drain, Fairfield	31 A11	Residential – medium density	337	68%	Circular – 1.00rad	37°46'57.69"S, 145° 1'19.48"E
Thornton Crescent, **Nunawading**	48 H10	Industrial, with a small proportion residential (<15%)	11	85%	Circular – 0.375rad	37°49'8.98"S, 145°11'15.30"E
Lexton Road, **Box Hill**	47 F7	Industrial, with a small proportion residential (<20%)	16	80%	Circular – 0.375rad	37°48'39.05"S, 145° 8'5.77"E
Railway Road, **Blackburn**	47 K10	Industrial, with some residential (<38%) and commercial (<30%)	44	65%	Circular – 0.525rad	37°49'13.19"S, 145° 9'7.05"E

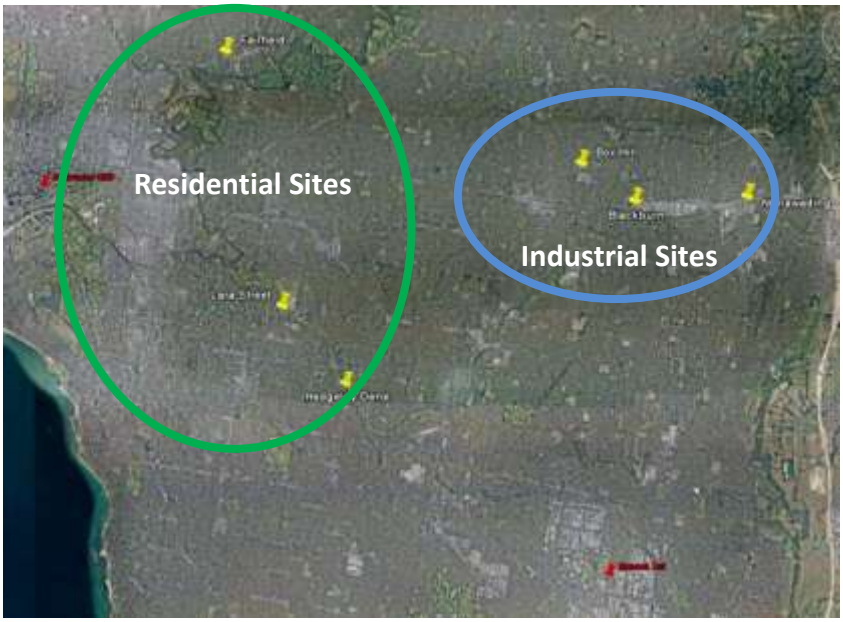

Figure 1. Location of the six study sites, in respect to Monash University and Melbourne's Central Business District.

Hedgeley Dene Main Drain, Malvern East

This is one of the largest sites used in this study, with a total catchment area exceeding 160ha. The site is mainly comprised of medium-density residential developments, with a small portion of commercial developments within its stormwater boundaries. Figure 2 shows an aerial photograph of the site indicating the boundaries of the catchment (left) and also shows a typical streetscape for the Hedgeley Dene site (right). Flow rates and physical parameters (including temperature, pH, electric conductivity, etc) were monitored during both dry and wet weather events using in-situ probes located at the catchment's outlet (Section 2.1.2). Other stormwater quality parameters were also monitored at this site using grab sampling methodologies during *both* dry and wet weather periods (Section 2.2).

Figure 2. Aerial photograph of the Hedgeley Dene site showing the approximate stormwater boundaries (left) and a photograph of the typical streetscape found within this site (right). × represents the location of the catchment outlet pipe/access pit used for sampling and installation of equipment.

Lara Street Main Drain, Malvern East

Located in a similar region as the Hedgeley Dene site, this site has a similar level of imperviousness (55%) and also contains mainly medium density residential developments within its stormwater boundary. This is the smallest residential development used in this study, with a catchment area of

approximately 110ha with almost all of this area being residential (with a small portion of commercial properties). Figure 3 shows an aerial photograph of the site indicating the boundaries of the catchment (left) and also shows a typical streetscape for the Lara Street site (right). Flow rates and physical parameters (including temperature, pH, electric conductivity, etc) were monitored during both dry and wet weather events using in-situ probes located at the catchment's outlet (described in detail below). Other stormwater quality parameters were also monitored at this site using grab sampling methodologies, but *only* during dry weather periods (also described below).

Figure 3. Aerial photograph of the Lara Street site showing the approximate stormwater boundaries (left) and a photograph of the typical streetscape found within this site (right). ✕ represents the location of the catchment outlet pipe/access pit used for sampling and installation of equipment.

Fairfield Main Drain, Fairfield

This is the largest residential catchment used in this study, with a catchment area of over 330ha and is also the most impervious residential catchment due to its level of development and proximity to Melbourne's CBD. Only a small amount of commercial precincts exist within the catchment, representing less than 5% of the catchment's area. Figure 4 shows an aerial photograph of the site indicating the boundaries of the catchment (left) and also shows a typical streetscape for the Fairfield site (right). Flow rates and physical parameters (including temperature, pH, electric conductivity, etc) were monitored during both dry and wet weather events using in-situ probes located at the catchment's outlet (described in detail below). Other stormwater quality parameters were also monitored at this site using grab sampling methodologies, but *only* during dry weather periods (also described below).

Figure 4. Aerial photograph of the Fairfield site showing the approximate stormwater boundaries (left) and a photograph of the typical streetscape found within this site (right). ✕ represents the location of the catchment outlet pipe/access pit used for sampling and installation of equipment.

Thornton Crescent, Nunawading

This is the smallest industrial estate monitored for this study, with a catchment area of just 11ha. The majority of the site is classified as industrial, with only a small portion of the catchment made up of residential premises (<15%). The medium to high level of development at this site produces a very high level of total imperviousness (85%). Figure 5 shows an aerial photograph of the site indicating the boundaries of the catchment (left) and also shows a typical streetscape for the Nunawading site (right). Flow rates and physical parameters (including temperature, pH, electric conductivity, etc) were monitored during both dry and wet weather events using in-situ probes located at the catchment's outlet (described in detail below). Other stormwater quality parameters were also monitored at this site using grab sampling methodologies during *both* dry and wet weather periods (also described below).

Figure 5. Aerial photograph of the Nunawading site showing the approximate stormwater boundaries (left) and a photograph of the typical streetscape found within this site (right). ✕ represents the location of the catchment outlet pipe/access pit used for sampling and installation of equipment.

Lexton Road, Box Hill

This small undulating catchment has an area of around 16ha, of which around 80% is impervious. The site is mostly comprised of industrial developments, but a small portion of the catchment contains medium-density residential land-uses (<20%). Figure 6 shows an aerial photograph of the site indicating the boundaries of the catchment (left) and also shows a typical streetscape for the Box Hill site (right). Flow rates and physical parameters (including temperature, pH, electric conductivity, etc) were monitored during both dry and wet weather events using in-situ probes located at the catchment's outlet (described in detail below). Other stormwater quality parameters were also monitored at this site using grab sampling methodologies, but *only* during dry weather periods (also described below).

Figure 6. Aerial photograph of the Box Hill site showing the approximate stormwater boundaries (left) and a photograph of the typical streetscape found within this site (right). ✕ represents the location of the catchment outlet pipe/access pit used for sampling and installation of equipment.

Railway Road, Blackburn

While this is the largest of our industrial catchments (44ha), it also has the lowest level of imperviousness (65%). The size and imperviousness of the catchment may be due to the relatively high proportion of medium density residential development located within this site which occupies around 30% of the catchment. Figure 7 shows an aerial photograph of the site indicating the boundaries of the catchment (left) and also shows a typical streetscape for the Blackburn site (right). Flow rates and physical parameters (including temperature, pH, electric conductivity, etc) were monitored during both dry and wet weather events using in-situ probes located at the catchment's outlet (described in detail below). Other stormwater quality parameters were also monitored at this site using grab sampling methodologies, but *only* during dry weather periods (also described below).

Figure 7. Aerial photograph of the Blackburn site showing the approximate stormwater boundaries (left) and a photograph of the typical streetscape found within this site (right). ✕ represents the location of the catchment outlet pipe/access pit used for sampling and installation of equipment.

2.1.2 Equipment installation

Obtaining permits

Once each site was selected, it was necessary to consult with local councils and water authorities to obtain permits for the installation of the equipment at the six study sites. As briefly mentioned above, each site was equipped with instruments to measure flow rates and physical water quality parameters. This equipment needed to be fixed to the inside of the stormwater pipe and, as such, confined space entry permits had to be acquired from the appropriate authority. For the residential

catchments, this was Melbourne Water since all drains were Melbourne Water assets, while for the industrial sites the local council (City of Whitehorse) was the authorising body.

For the two sites which were being monitored during wet weather events (Hedgeley Dene and Nunawading), some equipment also needed to be installed on the surface of the catchment to allow for automatic sampling. These sites required extra permits from the councils for the installation of monitoring huts (see Figure 8) since they were located on nature strips of property owners and were close to roads (see see Figure 2 and Figure 5 for these locations).

Figure 8. An example of the monitoring huts located at both the Hedgeley Dene and Nunawading sites. These huts contain the autosampling equipment required to conduct wet weather sampling at these sites. This picture was taken at the Nunawading site.

Flow measurement

Each site was equipped with a flow meter and a flow probe installed in the invert of the outlet pipe (HACH 910 at sites monitored for dry weather only and HACH 950 for sites monitored for both dry and wet weather – see Figure 9). These flow meters measure stormwater depths using pressure transducers to calculate the 'wetted area' of the flow using the measured pipe radius or cross section (see Table 1). They also employ two ultrasonic transducers to estimate the average velocity of the flow by converting Doppler shifts in returned ultrasounds to velocity readings (see HACH, 2005 for more information).

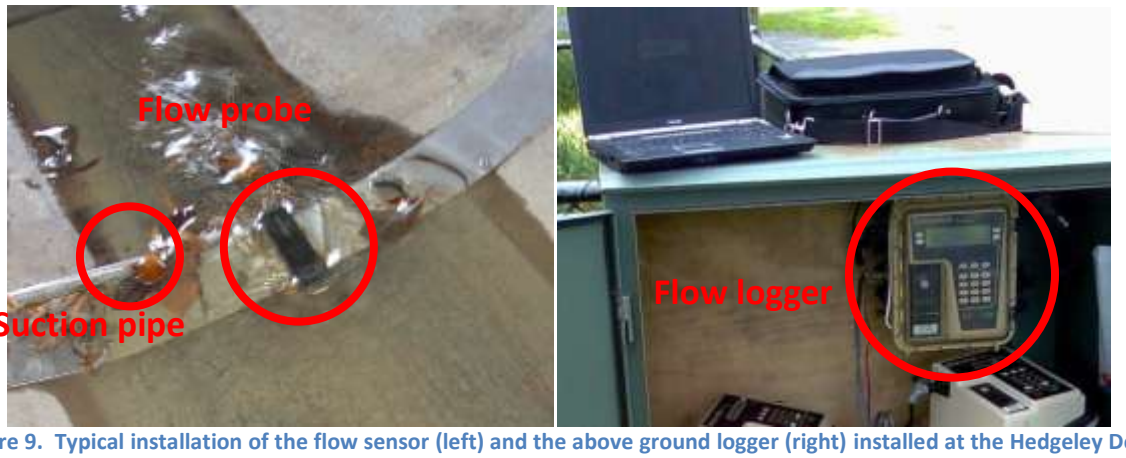

Figure 9. Typical installation of the flow sensor (left) and the above ground logger (right) installed at the Hedgeley Dene and Nunawading sites.

Prior to installation within the pipe, these flow probes and meters were calibrated using a flume within Monash University's hydraulics laboratory. Each probe (and associated meter) was placed within the flume and water with three known flows (measured using a magnetic based flow meter),

velocities (measured using a velocity probe) and depths (measured using a ruler) was passed through the flume. These known parameters were then compared to the parameters estimated by the probe, and any discrepancies were minimised by the calibration of the device.

Once installed, the accuracy of the depth measurement was checked on a regular basis (every two weeks) and if any discrepancy was detected the meter and probe were calibrated in-situ to ensure an accurate reading was obtained. The calibration of the velocity measurement in-situ was not possible, however the checking of the probe prior and after use showed that the probe's velocity measurement did not drift from calibration.

The meters were set to log water depth, water velocity and calculated water flow rates at six minute intervals (it was sometimes possible to achieve slightly better resolution for some probes). The meters were downloaded on a weekly basis.

These flow meters are often able to measure water depths to a reasonably low level. However, for depths less than 1-2cm, the measurement often is inaccurate. Velocity measurement is often not possible at low water depths because the device measuring the Doppler shift is not submerged. Furthermore, they have limited velocity measurement accuracy, and so velocities of less than 0.01m/s are not recorded. As such, during dry weather flows it is hard to achieve conditions whereby an accurate flow measurement is obtained. In actual fact, it was often the case in some catchments that the dry weather flow depth is so low that not only was the depth measurement inaccurate, the velocity was often not recorded since the device is not properly submerged. As a result, Monash tried many different weir formations to try and alleviate this problem. However, even a very small weir downstream of the probe resulted in problems. Increasing the depth of the water often meant creating a dam, which therefore reduced water velocity and often to levels which were below detection (i.e. <0.01m/s). Furthermore, the creation of the weir led to blockages which, even when cleaned on a weekly basis, meant that the probe was inundated with sediment and litter, rendering it useless for accurate measurements. As such, after much trial and error, these weirs were removed since it was decided that the measurement of higher flow rates (which could be detected without a weir) was better than having no measurements at all due to obstruction. This only was a real problem at two sites: Hedgeley Dene and Box Hill.

In-situ water quality probes

In-situ water quality probes were required to be installed at the invert of each outlet pipe for the six study catchments to measure physical (and one chemical) properties of the stormwater, including: temperature, Dissolved Oxygen (DO), pH, Electric Conductivity (EC), turbidity and ammonium. The probes were installed to provide results for at least 14 days of dry weather flows prior to any water quality sampling (dry weather or wet weather). This required the probes to be in the drain for over a month prior to sampling, because wet weather events often occurred during these periods and since dry weather data was required, the stormwater levels had to return to dry weather levels before it could be counted as a dry weather day (i.e. usually 3 days after more than 1mm of rainfall was required to allow the drain to return to baseflow conditions). This data was used to identify peaks in pollutant levels during dry weather periods, which helped select the dry weather grab sampling times (see Section 2.2, below for more information). The analysis to determine these peak dry weather pollutant levels is presented only as an appendix to this report, since the results of this analysis was only used to determine these sampling times (see Appendix 1).

The probes remained in the pipes for the duration of the project. However, apart from that described above, the remainder of the report will not focus on using this collected data. This is because the aim of this project was to use the dry weather and wet weather collected water quality sample results to determine the temporal variation in bacterial and toxicant levels from these

stormwater drains (as opposed to the temporal variability of physical parameters which were monitored by these probes). Further work may focus on using this great database to further understand the variability of different water quality characteristics of stormwater during both wet and dry weather periods.

Three types of in-situ water quality probes were used for this study, including (with their respective parameters measured):

1. Greenspan CS304 – temperature, DO, pH, EC (see Figure 10, left)
2. Hydrolab MS5a – temperature, pH, EC, turbidity, ammonium (see Figure 10, right)
3. Hydrolab MS5b – temperature, DO, pH, EC, turbidity (see Figure 10, right)

Figure 10. Pictures of the water quality probes used in this study, with the Greenspan CS304 (left) and the Hydrolab MS5 (right).

At the sites where dry and wet weather water quality sampling was conducted (i.e. Hedgeley Dene and Nunawading), both the Greenspan CS304 and Hydrolab MS5a probes were installed in the invert of the catchments' outlet pipes. It was decided that the sites which had wet weather sampling would also have the better water quality probes which also monitor turbidity and ammonium (i.e. the MS5a probe). Installing two probes in the same drain provided an extra degree of redundancy.

At the Blackburn site, the Hydrolab MS5b probe was used and this was because concurrent work was being conducted by the EPA Victoria and the probe was already installed when this study began. At the rest of the study sites (Lara Street, Fairfield and Box Hill), the standard Greenspan CS304 probes were installed.

For the water quality probes used in this study (except for the MS5b probe which was not installed by Monash University), calibration of all parameters was conducted prior to installation. This was done to ensure the probes were correctly functioning and to ensure that the probes were producing accurate results. Calibration involved purchasing standard solutions for pH, EC, turbidity, and ammonium, together with a calibrated thermometer, from Monash's Water Studies Centre. Using these solutions and the thermometer, each of the probe's parameters were checked and re-calibrated if necessary. The DO probes were calibrated using the method outlined in the user manual, which involves assuming the zero value of the probe does not drift (which is a safe assumption according to the manufacturers) and using the current atmospheric pressure. The results of the calibration of the probes can be found in Appendix 1. To ensure the probes operated correctly for the span of the project, a post-calibration was also conducted for all of the water quality probes once they were removed from the stormwater drains.

The probes were set to log at six minute intervals (except for the Blackburn site where the data was collected using 15 minute intervals – this was because the EPA had already set this value and it was decided that the entire dataset is best kept in the same format). This high resolution of logging for most of the probes caused two major problems. Firstly, the battery consumption of the MS5 probes was very high and, as such, the batteries needed replacement each week. Furthermore, the significant amount of data logged over a one week span meant that the probes had to be

downloaded every week to avoid excessive downloading times. Hence, every week of the project, the probes were removed from the invert of the pipe, batteries were replaced, maintenance was performed on the probes (i.e. general cleaning) and the information in the probes was downloaded.

Weirs were installed downstream of all water quality probes, to ensure it was submerged in the stormwater during dry weather periods. These dams were thoroughly cleaned out each week. However, even weekly clean-outs were sometimes insufficient to avoid sediment and litter building up around the probes, which could have an adverse affect on the results of these probes.

Wet weather sampling equipment.

As discussed above, wet weather water quality sampling was conducted at two of the study sites: one residential (Hedgeley Dene) and one industrial (Nunawading). To facilitate this sampling, two automatic samplers were installed in each of the sites' monitoring huts (Figure 11). These autosamplers were programmed to collect up to 24 1L samples according to flow weighted intervals (these intervals are discussed in Section 2.3, below) during any one event. Clean, reinforced sampling tubes were installed from each autosampler to the outlet pipe's invert (Figure 9). The tubes were installed 3cm above the invert of the pipe to avoid debris and sediment causing blockages. The position of the tubes is near the outlet of the catchment – see Figures Figure 2 to Figure 7 for these locations. Prior and after withdrawing the sample from the stormwater, the autosamplers go through a purge process designed to clean the suction pipes. The purge process involves withdrawing water from the pipe up until this water reaches the pump located on the sampler. Water is then pushed back out of the suction pipe and the process is repeated.

Figure 11. An example of the autosamplers used for wet weather water quality sampling. Two samplers were required for the samples analysed. This picture was taken at the Nunawading site.

Rainfall data

Rainfall data for the two wet weather sampling sites were obtained from Melbourne Water. The files listed rainfall totals in six minute intervals, and included data from the start of 2007 until the 24th June 2009. The gauge selected to be representative of the Hedgeley Dene site was Gardiner (Melbourne Water gauge ID 229624) and for Nunawading the Mitcham gauge was used (Melbourne Water gauge ID 586006).

2.2 Dry weather sampling

Dry weather samples were taken from the stormwater pipes and analysed for a range of water quality constituents. Three samples per day were taken from each of the six drains in order to identify the variability in pollutants during the day. This was conducted for a seven day period in order to determine any variability in the diurnal fluctuation of pollutants between different days of the week. For the residential sites, the dry weather sampling was conducted on seven consecutive days, from the 10th to the 16th February 2009 (i.e. including weekends). Unfortunately, for the industrial sites, it was not possible to conduct the sampling in seven consecutive days due to a very

small amount of rainfall within the catchment areas. As such, the sampling was conducted from the 12th to the 19th May 2009, with some of the 15th and 16th May missing due to this minor rainfall (<1mm fell during this event).

The times at which samples were withdrawn from the stormwater pipes were chosen based upon a number of criteria. These included ensuring the times selected for sample collection:

1. captured the probable variation in each constituent during each day (i.e. using the results of the analysis found in Appendix 2, the times at which peak physical characteristics occurred are adequately sampled);
2. maintained a safe working environment for the sampling staff (i.e. samples could only be taken during daylight hours to ensure visibility was satisfactory, and needed to be spaced far enough apart to ensure staff were well rested for each sampling run);
3. meant that the majority of samples could be taken straight to the laboratory, or taken to a laboratory within 12 hours of collection; and,
4. meant that there was enough time to get from one site to another, to the analysis laboratories and back to the base (Monash University) by the time the next sample is due.

Considering these criteria, with special attention paid to the data presented in Appendix 2, the sampling times were determined for the six study sites (see Table 2). It should be noted that from this point in the report, the three sampling times each day will be referred to as the *Morning*, *Afternoon* and *Evening* sampling times. Furthermore, while the dry weather sampling for the residential catchments was conducted during daylight savings time, the industrial sampling was conducted in May, hence the sampling had to finish much earlier in the industrial estates than that for the residential estates.

Table 2. Sampling times chosen for the six study sites. They are labelled as Morning, Afternoon and Evening samples for ease of comparisons.

Site	Morning	Afternoon	Evening
Hedgeley Dene	7:00am	1:30pm	8:00pm
Lara Street	7:30am	2:00pm	8:30pm
Fairfield	8:00am	2:30pm	9:00pm
Nunawading	8:00am	12:45pm	5:30pm
Box Hill	7:00am	11:45am	4:30pm
Blackburn	7:30am	12:15pm	5:00pm

The dry weather samples were withdrawn from the invert of the stormwater pipe using a clean, sterile procedure to ensure no contamination of the sample. This included things such as using sterilised (or clean where appropriate) sampling bottles, sampling collection tools (such as disposable gloves, etc) and most importantly always sampling water upstream of the sampler. The collected sample was equally divided into sample bottles (there was one bottle for each water quality parameter being tested) using a method previously described to ensure even replication between samples (McCarthy *et al*., 2008). In summary, the sample bottles were arranged in a circle and the sample was poured in increments so that at the end of each rotation each sample bottle had received 10% of the containers volume. As such, a total of around 10 rotations were required to fill all of the sample bottles. At the end of each rotation, the sample being distributed was rapidly shaken to ensure suspension/mixing was maintained. The samples were then placed in a cooler to ensure that all bottles were kept at 4°C during transportation to their respective laboratories for analysis. Morning and Afternoon samples were taken immediately to the laboratory (i.e. within 1hour of collection), whilst evening samples were kept in the fridge overnight and delivered to the laboratory with the samples taken on the next morning sampling run.

Whenever a dry weather sample was collected, an estimation of the flow rate was performed by collecting the entire stormwater flow in a large plastic bag and timing the length of time used to fill this bag. The contents of the bag were then estimated using measuring cylinder. This was conducted since some of the dry weather flows were so low that the flow probes were not sensitive enough to accurately measure these flows. This was despite the efforts of constructing many types of weirs and water control structures (as explained in Section 2.1.2). Although this is only a very rough estimate of the flow rate, it was considered this type of estimate was better than having no estimate at all.

2.3 Wet weather sampling

Samples were withdrawn from a number of wet weather events at the Hedgeley Dene and Nunawading sites using two automatic samplers. These samplers were programmed to take samples using flow weighted intervals and were arranged so that each autosampler (containing 24 sample bottles) would be triggered at the same time. One autosampler was dedicated to collecting samples for microbiological and heavy metal analyses and another was dedicated to collecting samples for hydrocarbon analyses. The former autosampler contained cleaned and sterilised plastic bottles, and the latter contained cleaned glass bottles.

The intervals used for the two sites were different, because of their varying degree of impervious areas. However, each site was programmed so that a 30mm rainfall event could be captured without having to refill the autosamplers (i.e. 30mm rainfall event would be characterised by 24 sample bottles). This setup was based upon a large history of sampling wet weather events in Melbourne, and was primarily focused on capturing a one in three month average recurrence interval event for Melbourne. However, it should be noted that the collection of samples was skewed so that the initial portion of the event was characterised by more samples than the end of the event, so as to more properly ascertain whether a first flush effect was present.

It was initially proposed that three wet weather events, with around 15 samples in each, would be collected from these two sites (i.e. 45 samples from each site). However, it was decided that the collection of events would continue until a total of 45 samples was reached, meaning that more or less than three events could be monitored, depending on the size of these events.

2.4 Laboratory analyses & uncertainty analysis

NATA accredited laboratories were used to analyse the collected wet weather samples and the 126 dry weather samples. Samples were analysed using standard laboratory techniques and, as such, these techniques are not explicitly described and the reader is asked to refer to standard laboratory manuals for more information on these methods. The following water quality parameters were quantified for each collected sample using the named laboratories [detection limits presented in square brackets]:

- *E. coli* (Colilert technique) [1 MPN/100mL] – Ecowise Environmental, Scoresby, Victoria
- Enterococci (Enterolert technique) [1 MPN/100mL] – Ecowise Environmental, Scoresby, Victoria
- Heavy metals (aluminium [0.1mg/L], antimony [0.01mg/L], arsenic [0.01mg/L], barium [0.01mg/L], beryllium [0.01mg/L], boron [0.2mg/L], cadmium [0.002mg/L], chromium [0.01mg/L], cobalt [0.01mg/L], copper [0.01mg/L], iron [0.2mg/L], lead [0.01mg/L], manganese [0.01mg/L], mercury [0.001mg/L], molybdenum [0.01mg/L], nickel [0.01mg/L], selenium [0.01mg/L], silver [0.01mg/L], strontium [0.01mg/L], thallium [0.01mg/L], tin [0.01mg/L], titanium [0.01mg/L], vanadium [0.01mg/L] and zinc [0.01mg/L]) – Ecowise Environmental, Scoresby, Victoria
- Total Petroleum Hydrocarbons (TPHs) [0.01mg/L] – Leeder Consulting, Mitcham, Victoria

- Total Nitrogen (TN) and nitrogen species (NOx, NH_3) – Water Studies Centre, Monash University, Australia (this data is not included in the analysis of the report – see Appendix 3 and 4 for the data).

On one occasion at each site, extra sample volume was collected from the stormwater drains during the dry weather sampling period. This extra volume was used to create triplicate samples in order to test the accuracy of the laboratory analyses. Once the sample was withdrawn, it was decanted into three separate bottles, filling each bottle a maximum of 10% during each rotation. This procedure ensured that each sample was as close as possible to 'true' replicates. Using these results, it is possible to determine the uncertainty in the laboratories' analytical procedures (see McCarthy *et al.*, 2008 for more information on this sampling method).

2.5 Analysis & presentation of collected data

This section explains the analysis of the data collected during the dry weather and wet weather sampling regimes. The following is split into two main subsections, one for dry weather data analyses and another for wet weather data analyses. Within each of these subsections, headings are provided which relate to the aims presented in Section 1.2.

2.5.1 Analysis of dry weather data

Between- and within-site variability

Summary descriptive statistics are provided in the main body of the report for pollutants which were regularly above their corresponding detection limits. Mean pollutant concentrations, together with Relative Standard Deviations (RSD = the coefficient of variation expressed as a percentage), of the collected pollutants were calculated for each site, using all 21 samples collected during the regime. If the pollutant was not detected in all samples, then these samples were removed from the calculation of the mean and RSD for that pollutant and the final number of samples used in the analysis was presented. Removal of these numbers was necessary since their absolute number was not known.

For visual comparisons, it was decided to display the results of selected pollutants using boxplots. Each boxplot contains the pollutant concentrations obtained from the 21 samples collected at the respective study site. When samples had pollutant levels less than its detection limit, then these samples were left out of the boxplot. For comparative purposes, boxplots of the measured flow rates at the catchment were also provided.

Within-day variability of pollutants

Boxplots were created to help visualise how some pollutants vary between morning, afternoon and evening samples. Since the aim of this section was to determine diurnal variations, the variability between days was removed from the analysis by standardising all concentrations using the daily averages (i.e. each of the 7 morning [M], afternoon [A] and evening [E] sample concentrations obtained from a site were divided by their respective daily average for that site). These standardised values for each pollutant and site were then plotted in three boxplots, each containing the morning, afternoon and evening values. Since there are seven days of collection (and hence seven morning, seven afternoon and seven evening samples per site), each boxplot has a maximum of seven standardised values (some have less due to pollutant levels being below detection).

Providing boxplots for all pollutants was not possible because of the space required for these plots. Instead, Student's t-Tests were performed to determine whether there were significant differences in morning, afternoon and evening samples. These tests were performed with the same dataset used to create the above boxplots (i.e. standardised values were used), and tests were performed for each pollutant at each site to determine:

- whether there was a significant difference between morning and afternoon sample concentrations (reported as MvA);
- whether there was a significant difference between morning and evening sample concentrations (reported as MvE); and,
- whether there was a significant difference between afternoon and evening sample concentrations (reported as EvA).

If there was a statistically significant difference (at the 95% level) in concentrations, then the corresponding p-value was reported in the results and discussion section. There was often insufficient data to conduct the statistical testing (due to pollutants being below their detectable level). As such, if the number of values used for the testing of a variable (i.e. the number of samples above detection in either M, A or E) is less than five then no testing was performed for this variable. This is because with samples of less than five, these statistical tests are not robust. In fact, even with the seven samples used in each variable, the results of these tests should be used with caution.

Correlation analyses

To determine whether any pollutants had significant relationships with other pollutants or flow rates, a correlation analysis was conducted. Correlation coefficients (*R*) were calculated for every combination of pollutants and flow rates. Statistical tests were performed to determine the significance of these correlation coefficients, and only correlations which were statistically significant at the 95% significance level were reported. The correlation analysis was conducted for each of the six sites, indicating a maximum of 21 data points area available in each of the two variables used in the analysis (i.e. 21 variable pairs). However, since the pollutants were sometimes below their detection limit, this number varied considerably. As with the previous section, correlation coefficients which were estimated using less than five variable pairs were not reported, even if the statistical test showed it was significant. This was because statistical tests are not robust when using such small numbers of points. Furthermore, since so many variable pairs were significantly correlated, it was not possible to report on all of these in the main body of the report. Instead, the report concentrates on those variable pairs which were significantly correlated at three or more sites, with Appendix 5 giving a full list of all correlations found.

Errors in weekly loads using just one sample per day

To determine whether randomly taking one sample per day is sufficient to estimate weekly pollutant loads, the following analysis was conducted. One sample was randomly selected from the three available samples for that day. This was repeated for each of the seven days of the week and these seven samples were then used to estimate the weekly pollutant load by multiplying the total volume measured each day by the corresponding sample concentration. The total of the seven loads is referred to as the 'estimated' weekly pollutant load. This process was repeated 500 times to capture most of the possible pollutant concentration combinations. These 500 'estimated' pollutant loads were compared to the pollutant load calculated when using all samples collected during the monitoring program (referred to as the 'actual' weekly load). Ratios of 'estimated' to 'actual' pollutant loads were used to determine the amount of error in the 'estimated' load. In total, 500 ratios were calculated for each pollutant at each study site and the results are presented using boxplots.

Since it was not possible to present all pollutants using boxplots, it was decided to represent the spread of these boxplots using the 95% confidence interval from the 500 ratios calculated for each pollutant at each site. The spread of the boxplots helps identify the most probable amount error involved in predicting weekly pollutant loads using just one sample per day. The calculation of this confidence interval was not possible for some pollutants, where there were a number of samples below its detection limit. For pollutants where there were more than 5 samples (out of the 21 taken at each site) which were less than their respective detection limit, the confidence interval was not

reported. This decision was based on the fact that for samples which are less than the detection limit, the concentration used in this analysis was half of the detection limit. If more than 5 samples with these values were used in the analysis, it would skew the results to a point where the confidence interval no longer is truly representative of the errors involved in this process (because there would be 5 constant numbers, which would lead to narrow confidence intervals).

2.5.2 Analysis of wet weather data

Between- and within-site variability

As with the dry weather data, summary descriptive statistics are provided in the main body of the report for pollutants which were regularly above their corresponding detection limits. Mean pollutant concentrations, together with the RSD, of the collected pollutants were calculated for each site, using all wet weather samples collected. If the pollutant was not detected, then these samples were removed from the calculation of the mean and RSD for that pollutant and the final number of samples used in the analysis was presented.

For visual comparisons, it was again decided to display the results of select pollutants using boxplots. Each boxplot contains the pollutant concentrations measured in all wet weather samples. If some of the samples had levels of the pollutant of less than its detection limit, then these samples were left out of the boxplot.

Within-event variability of pollutants

In order to understand whether the pollutants at the two wet weather sites experienced a first flush, plots of pollutant concentrations against cumulative runoff depth (i.e. cumulative volumes converted to runoff depth using the effective impervious area for the site) were created for select pollutants. These plots contain the results from all samples collected from all wet weather events. If samples were below detection, then they were included on the plot, for illustrative purposes only, at half of their detection limit. One plot was constructed for each study site.

It was not possible to present a plot of wet weather concentrations against cumulative runoff depths for each pollutant. Instead, a linear correlation analysis was conducted to determine whether any significant trends were present. Only statistically significant correlation coefficients are presented in the results section (i.e. $p<0.05$). Furthermore, this correlation analysis was not performed on pollutants which had less than five data points for the analysis due to non detection.

Correlation analyses

Similarly to the dry weather dataset, a correlation analysis was conducted to determine whether any pollutants had significant relationships with other pollutants or flow rates. Correlation coefficients (R) were calculated for every combination of pollutants and flow rates. Statistical tests were performed to determine the significance of these correlation coefficients, and only correlations which were statistically significant at the 95% significance level were reported. The correlation analysis was conducted using all the data collected during wet weather flows. As with the previous section, correlation coefficients which were estimated using less than five variable pairs were not reported, even if the statistical test showed it was significant. This was because statistical tests are not robust when using such small numbers of points.

Errors in event loads using a few samples in each event

A boot strapping methodology was employed to determine the impact of randomly taking a 'grab' sample during a wet weather event to estimate wet weather event loads. In fact, this method was employed to determine the accuracy of using one, two, three and four randomly selected samples to estimate the total wet weather pollutant load. Using the 'three samples per event' as an example, three samples were randomly selected from each wet weather event using a uniform distribution (i.e. each sample had the same probability of being selected, but no sample could be picked more

than once). The concentrations in these three samples were then averaged and multiplied by the total event volume to achieve the event's total 'estimated' pollutant load. This was repeated for each event which was monitored at the specific site. The summed loads from all events (known as the 'estimated' total load) were then compared to the loads calculated using all of the samples collected within the events (referred to as 'actual' wet weather event load). This 'actual' event load is estimated using a flow-weighted approach. The process was repeated 500 times to ensure that most possible combinations were captured.

Once again, boxplots of ratios between 'estimated' and 'actual' total wet weather loads are presented in the results section. Since it was not possible to present all pollutants using boxplots, it was decided to represent the spread of these boxplots using the 95% confidence interval from the 500 ratios calculated for each pollutant at each site. However, the calculation of this confidence interval was not possible for some pollutants, where there were a number of samples below its detection limit. For pollutants where there were more than 5 samples which were less than their respective detection limit, the confidence interval was not reported. This decision was based on the same explanation provided above in Section 2.5.1 "Errors in weekly loads using just one sample per day".

2.5.3 Comparison between wet weather and dry weather pollutant levels

Boxplots were constructed for the two wet weather monitoring sites to compare the concentrations obtained in dry weather with those obtained in wet weather events for select pollutants. In order to compare the importance of dry weather loads against wet weather loads, the following procedure was conducted for each pollutant. Using the 'actual' dry weather and wet weather loads it was possible to extrapolate this data to estimate the approximate contribution of each to total annual pollutant loads. To obtain annual dry weather pollutant loads, it was assumed that the monitored week is representative of the pollutant characteristics for an entire year. As such, the weekly load was multiplied by 52 to obtain an approximate annual dry weather load. There are obviously huge issues related to such an assumption, and the results from this section of the report are for indicative purposes only. The wet weather events taken at each site were also assumed to be somewhat representative of the pollution levels found in typical rainfall events. As such, the total 'actual' load from the monitored events was divided by the total rainfall in these events and then this was subsequently multiplied by the site's average annual rainfall to achieve an approximate annual wet weather pollutant load. As above, this is a large assumption and these results are to be used with caution. A summary table was created in the main body of the report to compare these dry and wet weather loads.

3 Results and discussions

3.1 Dry weather data

The following sections will be divided into four separate sections, each addressing one of the key questions presented in Section 1.2:

1. Between- and within-site variability – to attempt to provide details about how each pollutant is varying between, and within, each different site during dry weather periods
2. Within-day variability – to provide information about how each pollutant varies diurnally (i.e. during each day)
3. Correlation analysis – to determine the relationship between pollutant concentrations and other pollutants and flow rates for dry weather flows
4. Errors in weekly load estimations – to assess the accuracy of random grab sampling methodologies during dry weather events to estimate total weekly dry weather loads.

3.1.1 Between- and within-site variability

Appendix 3 shows detailed data for all pollutants monitored during the dry weather campaign, while Table 3 shows only the mean and Relative Standard Deviations (RSD = coefficient of variation divided by the mean expressed as a percentage) for the detected pollutants for each study site. Figure 12 shows boxplots for the 21 concentrations obtained during the monitoring period for iron, zinc, *E. coli* and enterococci. Flow rates are also shown in this figure for comparative purposes.

Table 3. Mean and Relative Standard Deviations (RSD = standard deviation divided by mean, expressed as a percentage) of detected constituents in the 21 dry weather samples collected at each study site. A superscript indicates the number of samples used to calculate the mean and RSD, with all other samples not detected. Absent superscripts indicate all samples were above detection. Heavy metals and TPHs are measured in mg/L, *E. coli* and enterococci are both measured in MPN/100mL.

	Hedgeley Dene	Lara Street	Fairfield	Box Hill	Blackburn	Nunawading
Aluminium	1.09 (142%)^{16}	0.52 (49%)^{20}	0.22 (75%)^{20}	0.21 (35%)^{20}	2.14 (307%)^{11}	0.17 (25%)
Barium	0.06 (50%)	0.04 (40%)	0.03 (19%)	0.07 (38%)	0.04 (145%)	0.03 (7%)
Copper	0.03 (74%)^{14}	0.02 (29%)	0.02 (71%)^{2}	0.07 (95%)^{17}	0.04 (106%)^{9}	ND
Iron	2.65 (108%)^{11}	0.45 (36%)^{20}	0.60 (0%)^{2}	1.03 (54%)	1.73 (271%)^{14}	0.33 (14%)
Lead	0.05 (90%)^{7}	0.01 (0%)^{1}	ND	0.02 (76%)^{2}	0.03 (143%)^{3}	0.01 (0%)^{1}
Manganese	0.16 (129%)^{11}	0.01 (0%)^{1}	0.03 (94%)^{2}	0.08 (53%)	0.06 (199%)^{14}	0.06 (9%)
Molybdenum	ND	0.01 (0%)^{1}	ND	0.03 (88%)^{9}	0.10 (138%)^{2}	ND
Nickel	0.01 (43%)^{3}	ND	ND	0.10 (108%)	0.01 (93%)^{3}	ND
Strontium	0.22 (33%)	0.21 (37%)	0.05 (16%)	0.09 (15%)	0.04 (32%)	0.08 (3%)
Titanium	0.04 (106%)^{10}	0.03 (41%)^{15}	0.01 (43%)^{3}	0.02 (76%)^{5}	0.02 (79%)^{4}	ND
Zinc	0.30 (108%)	0.08 (21%)	0.10 (156%)	1.17 (50%)	0.64 (99%)	0.07 (60%)
E. coli	655 (134%)	2732 (196%)	12360 (103%)	2374 (168%)	2361 (117%)	3 (71%)^{9}
Enterococci	1331 (165%)	1326 (117%)	4746 (148%)	80 (98%)^{19}	112 (305%)	2 (86%)^{17}
TPHs	0.15 (0%)^{1}	ND	0.19 (0%)^{1}	0.42 (100%)^{16}	0.42 (126%)^{9}	ND

antimony was only detected four times at Box Hill (0.01mg/L and 0.02mg/L); arsenic was only detected five times at Hedgeley Dene (0.01mg/L) and nine times at Lara Street (0.01mg/L to 0.02mg/L); beryllium was not detected at any site; boron was only detected at Box Hill (0.6mg/L) and Blackburn (0.5mg/L); cadmium was detected once at Fairfield (0.003mg/L); chromium was only detected once at Hedgeley Dene (0.01mg/L), Box Hill (0.001mg/L) and Blackburn (0.04mg/L); cobalt was detected nine times at Box Hill (between 0.01mg/L and 0.05mg/L) and once at Blackburn (0.01mg/L); mercury was not detected at any site; selenium was not detected at any site; silver was detected 8 times at Blackburn (between 0.01mg/L and 0.16mg/L); thallium was not detected at any site; tin was only detected once at the Box Hill site (0.001mg/L); vanadium was only detected twice at Hedgeley Dene (0.01mg/L and 0.02mg/L) and once at Blackburn (0.02mg/L).

A number of heavy metals were not detected (beryllium, mercury, selenium and thallium) at any of the study sites during the seven day program, with many more only being detected in a minimal

number of samples (antimony, arsenic, boron, cadmium, chromium, cobalt, silver, tin and vanadium). Silver was detected only detected at the Blackburn site, on just eight occasions. This could be indicative of illegal discharges, albeit intermittent, from coating/plating businesses which are located in this industrial catchment. The eight detections always occurred in pairs (in the afternoon 12pm and evening 5:00pm) and never in the morning samples (7:30am).

Nickel was only regularly detected at the Box Hill site (with all samples being above detection), with a general trend that the evening samples were higher than the morning samples (Section 3.1.2 will develop this trend in further detail). This again indicates the possibility of illegal releases into the stormwater system, again probably from the coating/plating industries located within this catchment.

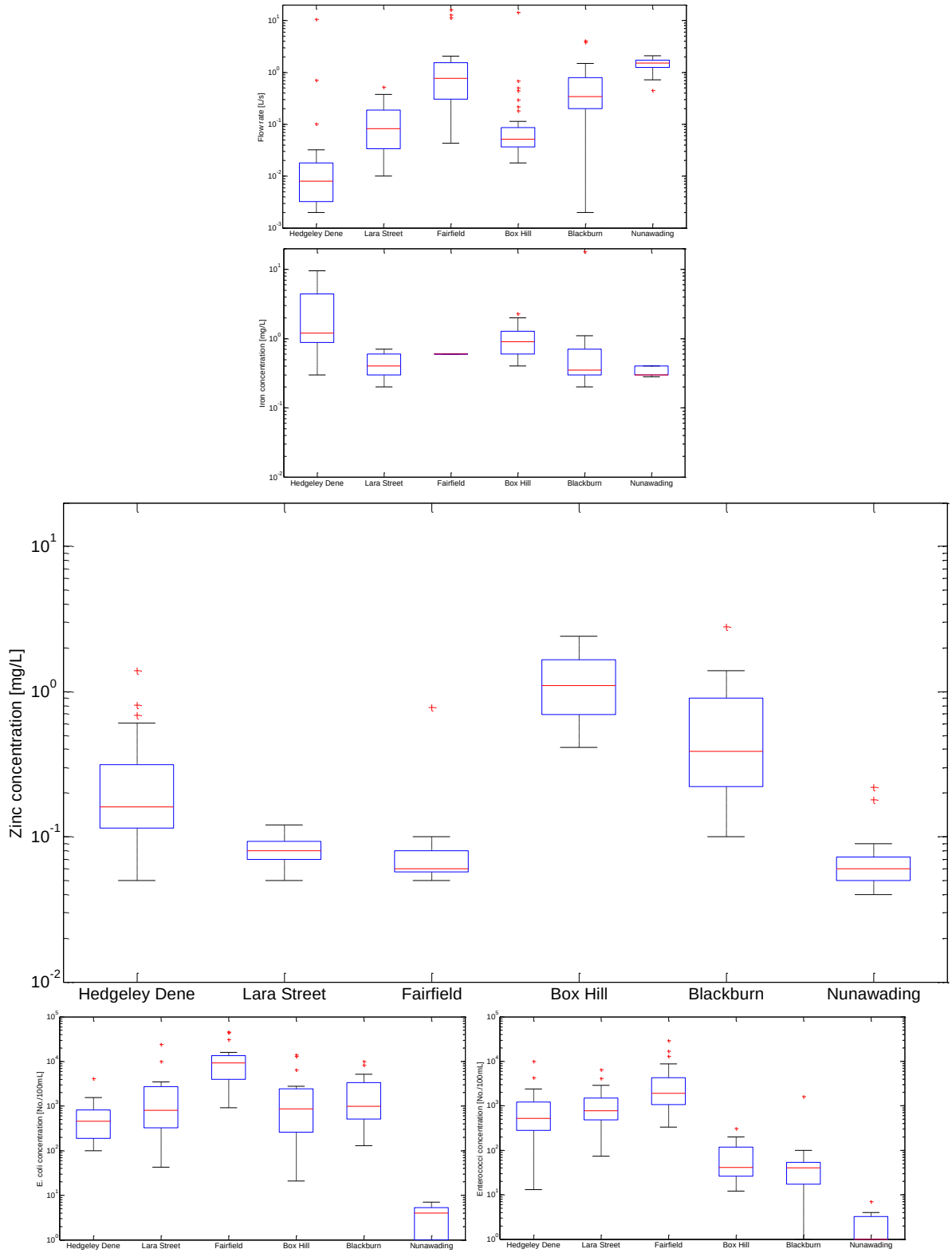

Figure 12. Boxplots showing the distributions of flow rates (top) and dry weather sample concentrations found at each study site for iron (middle left), zinc (middle right), *E. coli* (bottom left) and enterococci (bottom right).

Aluminium was regularly detected at all the study sites, with positive detection in 86% of the samples collected at the six study sites (Table 3). The variability of this constituent between sites is particularly high, while its variability within a site is very much site-dependent. For example, Blackburn has the highest average concentration (2.14 mg/L) and the highest RSD (307%), while

another industrial site (Nunawading) has the lowest average aluminium concentration (0.17 mg/L) and the lowest RSD (25%).

Iron (detected in 71% of samples) and zinc (detected in all samples) follow a similar trend to that of aluminium and this is reflected in Figure 12 which shows the high variability of these constituents between sites, and sometimes extreme variability within sites (e.g. at Hedgeley Dene). Furthermore, there seems to be an inverse relationship between the flow rate and the concentrations of these two pollutants (Figure 12), with sites which have higher flow rates obtaining lower iron and zinc concentrations. Dilution of the pollutants in higher flow rate systems could explain this inverse relationship. In fact, Section 3.1.3 shows that there is a significant negative relationship between flow and zinc concentrations. Figure 12 also indicates there is a positive correlation between iron and zinc concentrations, and Section 3.1.3 will investigate this correlation in more detail.

Barium (detected in 100% of samples), copper (detected in 51% of samples), lead (detected in just 11% of samples) and titanium (detected in 30% of samples) all follow a slightly different trend to aluminium, iron and zinc, with fairly consistent concentrations between study sites and usually low variability within each site. Strontium is the only detected constituent which has a consistently low variability within each study site, with a maximum RSD of just 37% (compared to its closest pollutant of copper with a maximum RSD of 106%). However, this heavy metal still varies considerably between sites.

Detection of TPHs was generally low, with just 21% of samples having TPH levels above detection. However, there was a significant variability between sites, with some sites having nearly 80% of its samples above detection, while other sites' samples never being above detection. The most interesting trend was that the industrial sites had a much higher detection rate (40%) and concentrations (up to 1.8mg/L) than the residential sites (3% and up to 0.2mg/L, respectively), indicating that the sources of hydrocarbons are more prevalent in industrial stormwaters. This is logical, since all of the industrial catchments have motor repair businesses within their catchment boundaries. Hydrocarbons were mostly detected at the Box Hill site, where oil slicks in the stormwater, together with occasional petroleum smells within the stormwater drain, were recorded when sampling. Detection at the Blackburn site was less common, with less than 50% of samples taken at this site being above detection. No samples taken at the Nunawading site had detectable levels of hydrocarbons, possibly due to its very high, constant, flow rate which may have diluted the concentrations to below detection.

As might be expected, the variability of the two microbial indicators (*E. coli* and enterococci) between-sites and within-sites was large (Table 3 and Figure 12). Mean *E. coli* concentrations varied by over an order of magnitude between the three residential sites, and over two orders of magnitude between the three industrial sites. Variability of enterococci between sites was generally smaller. Detection for both indicators was high at all sites except Nunawading, where less than half of the samples had detectable levels of *E. coli* (most samples had detectable levels of enterococci).

As opposed to iron and zinc, neither of the indicators followed the trend of higher concentrations in catchments with lower flow rates. In fact, for the residential catchments the opposite was true, with sites having higher flow rates also having higher indicator organism concentrations. Another trend observed in Figure 12 is that the *E. coli* and enterococci concentrations found at the residential sites are often very similar (in median values and ranges), whereas large differences (in median values and ranges) are found at the industrial sites.

The results presented Appendix 3, Table 3 and Figure 12 all indicate that the presence, variability and magnitude of pollutants is different for different land uses, and often times different for

catchments which have the same land use. This makes it difficult to extrapolate this type of information to other catchments, even if they have similar land uses. Only the collection of more data from different catchments could potentially yield enough information to help identify the real population distributions of these pollutants which could then be used for extrapolation.

Moreover, the immense variability observed for many of the pollutants within a site over just one week in a year raises more concerns. Many of the pollutants vary so much during one week that even routine weekly, or more commonly monthly, 'grab' sampling methodologies (which are often employed to estimate annual pollutant loading rates to downstream systems) will not accurately portray a yearly loading rate. Moreover, since these pollutant levels (and flow rates) will more than likely vary from week-to-week, these sampling methodologies may become even less accurate for load estimations (especially for routine monthly methods). Section 3.1.4 will investigate this type of accuracy problem in more detail. Appendix 6 also describes an analysis which was conducted to determine the number of samples required per year in order to accurately estimate annual sediment loads from an urban catchment not used in this study. This study found that two samples were required to be taken each week (randomly) in order to estimate mean annual sediment loads to within 50% of the actual values.

3.1.2 Within-day variability of pollutants

While the previous section focussed on the variability of the pollutants between- and within- sites, this section focuses on how these pollutants vary within each day. In particular, it attempts to determine whether there is any consistent diurnal variation of the pollutants during the day (i.e. are pollutant concentrations generally higher in the morning than in the evening?, etc).

The boxplots in Figure 13 help identify the diurnal variation of pollutants at each site (N.B. the standardised values on the y-axis). Table 4 identifies statistically significant differences in concentrations of pollutants between different times of the day for each study site. The significance values presented in Table 4 were created using the same dataset from that used to create Figure 13, and indicate whether there are any statistical differences in morning, afternoon and evening samples for each pollutant at each site. Many pollutants are either missing from this table, or blank cells are located in the table, which indicate there was insufficient data to perform statistical analyses (mainly caused by detection limits).

For the four pollutants plotted in Figure 13, there is no consistent trend for any of the pollutants at all sites. For example, iron concentrations at the Box Hill site appear to increase from morning to night, whilst the same pollutant decreases at the Lara Street site (even though the two sites have similar land-uses). Furthermore, these differences were found to be statistically significant at both sites (see Table 4).

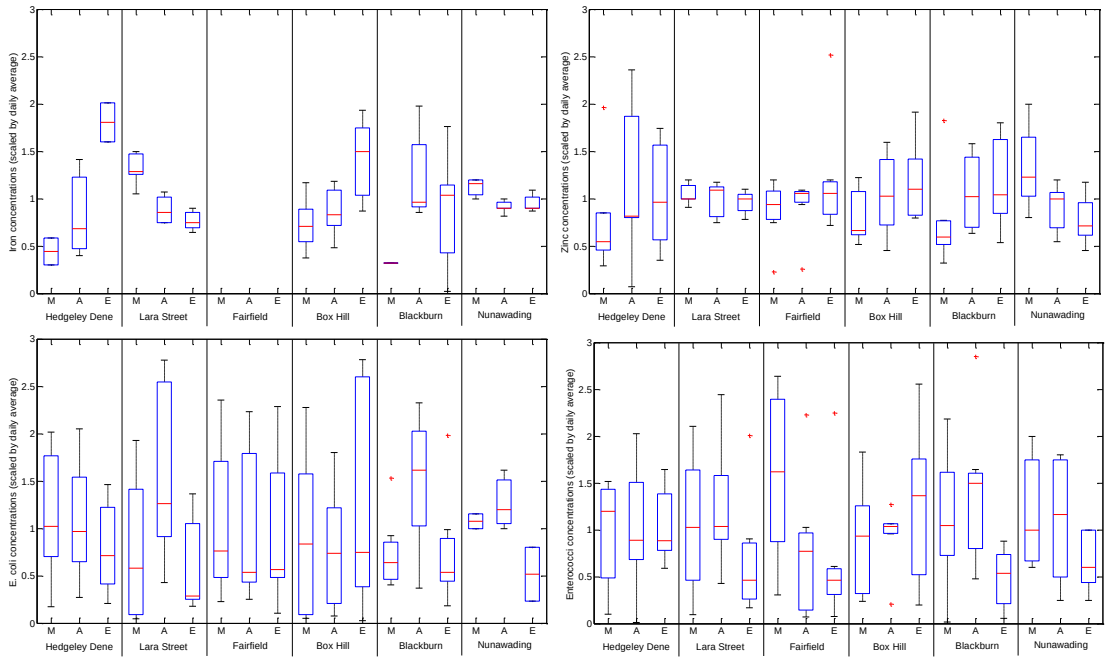

Figure 13. Boxplots showing the diurnal variation of iron (top left), zinc (top right), *E. coli* (bottom left) and enterococci bottom right). As an example, data in each 'M' box plot are comprised of ratios between the morning sample concentrations and the daily average concentration (taken as the average of the morning [M], afternoon [A] and evening [E] sample concentrations). Missing boxplots indicates that not enough data was available for plotting (i.e. samples were below detection).

Figure 13 shows some correlation between the behaviour of the two heavy metals (iron and zinc) during the day, within each study site (see Section 3.1.3 for more information on this correlation). That is, if iron tends to increase throughout the day, zinc will generally increase also at that catchment. This trend could indicate similar sources of these two heavy metals within each catchment. It is interesting to note that, although not as strong, this trend is also observed for the indicator organisms (i.e. a site which shows a diurnal pattern for *E. coli* will generally show a similar pattern for enterococci). It should be stressed that the dataset used for this type of analysis is very small, so it is difficult to identify these trends accurately. This caution rolls into the statistical information presented in Table 4 as well.

Table 4. Significant probabilities (p-values < 0.05) obtained using a Student's t-Test to determine whether the null hypothesis that the two datasets (either M vs. A, M vs. E or E vs. A) are from the same population. Blanks indicate the two datasets were not statistically different (i.e. p > 0.05) and NA indicates there was not enough data to calculate the p-value. The number of points in these tests is unusually low, with each dataset containing only 7 values. No adjustment has been made for this small number of data points.

	T-test	Hedgeley Dene	Lara Street	Fairfield	Box Hill	Blackburn	Nunawading
Al [mg/L]	MvA		0.00				
	MvE		0.00				
	EvA				0.04		
Ba [mg/L]	MvA						
	MvE		0.04		0.02	0.04	
	EvA						
Cu [mg/L]	MvA			NA		NA	NA
	MvE			NA	0.01	NA	NA
	EvA			NA			NA
Fe [mg/L]	MvA		0.00	NA		NA	0.00
	MvE	NA	0.00	NA	0.00	NA	0.00
	EvA			NA	0.01		
Mn [mg/L]	MvA		NA	NA			0.02
	MvE	NA	NA	NA	0.00		
	EvA		NA	NA	0.01		
Ni [mg/L]	MvA	NA	NA	NA		NA	NA
	MvE	NA	NA	NA	0.02	NA	NA
	EvA	NA	NA	NA		NA	NA
Sr [mg/L]	MvA						
	MvE		0.00				
	EvA	0.03					
Zn [mg/L]	MvA						0.05
	MvE						0.02
	EvA						
E. coli [MPN/100mL]	MvA					0.03	
	MvE						
	EvA		0.03			0.04	
Enterococci [MPN/100mL]	MvA						
	MvE					0.06	
	EvA					0.02	

3.1.3 Correlations between pollutants and flow rates

Appendix 5 shows a matrix of the significant correlation coefficients between two measured water quality pollutants (from the dry weather sampling). These correlation coefficients are presented for each of the six study sites. As a summary, the pairs of water quality parameters which were found to be statistically correlated at three or more sites are provided in Table 5.

Table 5. Statistically significant (i.e. p>0.05) correlation coefficients (R) between water quality pollutants and flow rates monitored during dry weather periods. Only pairs of pollutant variables which had p<0.05 at three or more sites are presented (see Appendix 5 for a full list). Correlation coefficients are presented for each of the six study sites, separated by solidi in the following order: Hedgeley Dene / Lara Street / Fairfield / Box Hill / Blackburn / Nunawading.

	Al [mg/L]	Cu [mg/L]	Fe [mg/L]	Sr [mg/L]	*E. coli* [MPN/100mL]	Flow [L/s]
Ba [mg/L]	0.88 / -- / 0.53 0.61 / 0.9 / --	0.9 / -- / -- 0.62 / 0.72 / --	0.92 / -- / -- 0.81 / 0.91 / --	0.68 / 0.95 / 0.7 0.43 / ---- / ----		
Fe [mg/L]	0.98 / 0.86 / -- 0.47 / 0.99 / --					
Mn [mg/L]			0.97 / -- / -- 0.44 / -- / 0.6			-- / -- / -- -- / -- / 0.59
Zn [mg/L]	0.99 / 0.45 / 0.54 -- / -- / --	0.95 / 0.44 / -- 0.53 / -- / --	0.98 / 0.7 / -- 0.45 / -- / --	-- / -- / 0.59 -- / 0.88 / -0.49		-- / -- / -- -- / -0.48 / --
Enterococci [MPN/100mL]					0.93 / 0.45 / 0.48 -- / 0.65 / --	
Flow [L/s]	-- / 0.46 / 0.59 -- / -- / --			-- / -- / -- -- / -0.51 / --		

A number of metals were significantly correlated with one another, indicating positive relationships between certain heavy metals. For example, aluminium was positively correlated with barium, iron and zinc, whilst zinc was also found to be significantly correlated to iron, copper and strontium at more than three of the six study sites. These correlations do provide evidence that the sources and behaviour of these metals are similar at some study sites, but these sources/behaviour are not consistent at all study sites.

While Appendix 5 indicates that some metals, at some sites, were correlated with *E. coli* or enterococci, no metal or TPH was significantly correlated to these indicators at more than three study sites (Table 5). As expected, *E. coli* and enterococci were significantly correlated, but only at four of the study sites. The lack of correlation between these two indicators at the Nunawading site could be explained by the *very* low numbers of organisms at this site (with all samples having concentrations of less than 7 MPN/100mL for both indicators). There is generally a much higher uncertainty in the estimation of these indicators at this level of concentration, and it is hypothesised that the variability in these parameters at this site is predominantly due to measurement errors. This makes it difficult to obtain good correlation results.

The absence of a significant correlation between *E. coli* and enterococci at the Box Hill site is more difficult to explain. However, when investigating the data in more detail, the significant correlation found at the only industrial site (Blackburn) between the two indicators is largely controlled by one very polluted sample (15th May, afternoon) with *E. coli* of 10000MPN/100mL and enterococci of 1600 MPN/100mL. This was atypical of what was usually found at this site, with average *E. coli* concentrations of around 2400 MPN/100mL and enterococci never being higher than 100 MPN/100mL. As displayed in Appendix 3, this sample was noted to have a brownish colour, not dissimilar to that of diluted sewage. The removal of this 'outlier' reduces the correlation between *E. coli* and enterococci at the Blackburn site to just 0.4 (p>0.05).

Taking the above into consideration, it can be concluded that none of the industrial sites have a true significant correlation between *E. coli* and enterococci, whilst all three of the residential sites showed significant positive relationships. This could indicate that, except for the one sample at the Blackburn site, the sources and behaviour of *E. coli* are not the same as that for enterococci at the industrial sites, whereas the opposite is true for the residential sites. It could also be because all industrial sites had low enterococci levels (which generally have higher associated uncertainties) causing these correlations to be unidentifiable at these sites.

3.1.4 Errors in weekly loads using just one sample per day

The boxplots shown in Figure 14 display the accuracy in using one sample per day to estimate weekly loading rates of different pollutants at the six study sites. The boxplots were created using the results of the 500 iterations whereby one sample was randomly selected from each of the three available (per day) for the seven day monitoring period. Each randomly selected sample concentration was multiplied by the daily stormwater volume to get a daily load estimation, and the sum of these seven daily load estimations was the estimated weekly load.

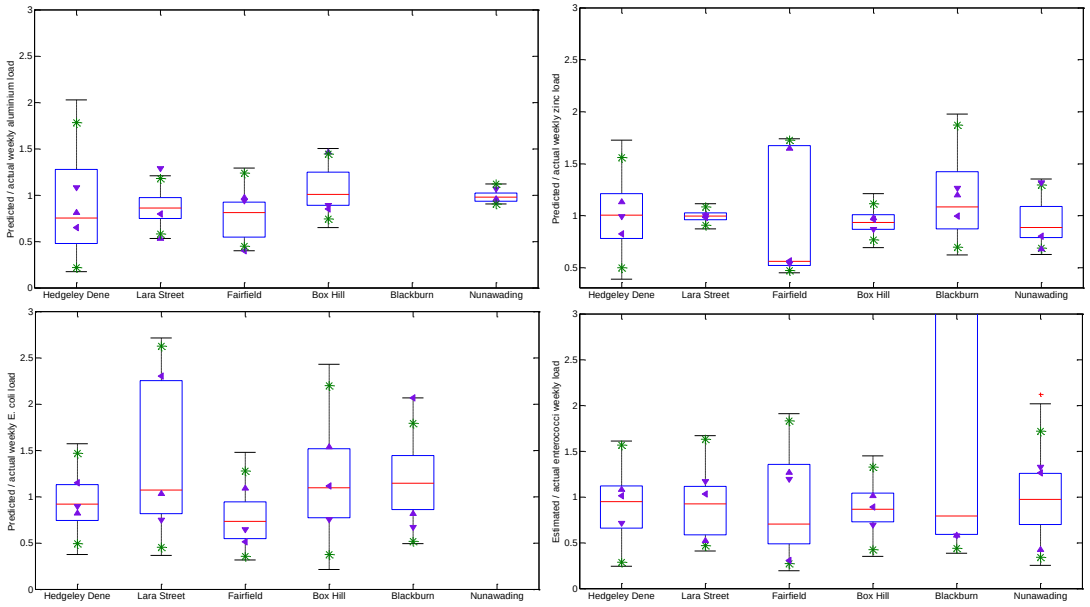

Figure 14. Boxplots showing the accuracy of using just one sample per day (randomly selected from each of the three taken each day) to estimate weekly loads for aluminium (top left), zinc (top right), *E. coli* (bottom left) and enterococci (bottom right). Green stars indicate upper and lower points in 95% confidence boundaries. Purple triangles which point down represent the weekly load if only morning samples were used to estimate the weekly load, while those that point left and up are similar but for afternoon and evening samples, respectively.

Figure 14 indicates that while using one sample per day for weekly load estimations can be accurate for some pollutants at some sites, for other pollutants the error in the weekly load is large. Furthermore, there seems to be no real agreement between catchments, with some sites having very narrow boxplots (indicating high accuracy, such as for aluminium at Nunawading), and other sites having broad boxplots for the same pollutant (indicating high uncertainty, such as for aluminium at the Hedgeley Dene site). In general, it is shown that the error when using one sample per week to estimate weekly loads is higher for the indicator organisms than for the two heavy metals (Figure 14).

To investigate this for all pollutants, the 95% confidence interval (and upper and lower bounds) are presented in Table 6. This table reiterates that shown in Figure 14, demonstrating that for some heavy metals (aluminium, barium, zinc, etc) the accuracy of using just one sample per day to estimate weekly loads varies between the study sites. This table also reinforces the fact that the

error when using one sample per week to estimate weekly indicator organism loads is consistently high (and most often higher than those found for heavy metals).

Table 6. 95% confidence intervals for estimating a pollutant's weekly load using just one sample per day (randomly selected from the three taken for each day). Values in parentheses indicates the 2.5 and the 97.5 percentile values for the 500 combinations tested. Superscript values indicate the number of samples used in the analysis which were above the detection limit. Missing pollutants and blanks indicate that the analysis could not be conducted due to too many non detects.

Pollutant	Hedgeley Dene	Lara Street	Fairfield	Box Hill	Blackburn	Nunawading
Al [mg/L]	1.57 (0.22,1.78)[16]	0.6 (0.58,1.18)[20]	0.78 (0.45,1.24)[20]	0.7 (0.74,1.45)[20]		0.22 (0.9,1.12)
Ba [mg/L]	0.62 (0.68,1.3)	0.32 (0.84,1.16)	0.19 (0.88,1.06)	0.47 (0.85,1.32)	1.75 (0.62,2.38)	0.05 (0.98,1.03)
Cu [mg/L]		0.41 (0.79,1.19)		1.36 (0.3,1.66)[17]		
Fe [mg/L]		0.32 (0.77,1.1)[20]		0.66 (0.72,1.38)		0.18 (0.88,1.07)
Mn [mg/L]				0.61 (0.69,1.3)		0.11 (0.94,1.05)
Ni [mg/L]				0.98 (0.51,1.49)		
Sr [mg/L]	0.42 (0.77,1.19)	0.28 (0.87,1.15)	0.17 (0.92,1.09)	0.16 (0.95,1.11)	0.06 (0.99,1.05)	0.01 (0.99,1.01)
Ti [mg/L]		0.87 (0.39,1.26)[15]				
Zn [mg/L]	1.06 (0.5,1.56)	0.18 (0.91,1.09)	1.25 (0.48,1.73)	0.35 (0.77,1.12)	1.17 (0.7,1.87)	0.61 (0.69,1.3)
E. coli [org/100mL]	0.98 (0.49,1.47)	2.17 (0.45,2.62)	0.92 (0.35,1.28)	1.82 (0.38,2.2)	1.27 (0.52,1.79)	
Enterococci [org/100mL]	1.28 (0.29,1.56)	1.16 (0.47,1.63)	1.56 (0.27,1.83)	0.9 (0.42,1.32)[19]	3.14 (0.44,3.58)	1.38 (0.34,1.72)17
TPHs [mg/L]				1.67 (0.32,1.99)[16]		

After further investigation, a general trend became apparent that for the pollutants in Table 3 which have high variability (i.e. their RSD value is high), the 95% confidence interval presented in Table 6 (representing the accuracy of using just one sample per week) becomes broader. This means that as the variability of a pollutant in the dry weather samples increases, the accuracy in using one sample per week to estimate that pollutant's weekly load decreases. This finding is logical, since the weekly load for a pollutant which has concentrations which do not vary (i.e. its RSD is close to zero) will be estimated well using any combination of pollutant concentrations. Conversely, a pollutant which varies significantly throughout the day, and week, will require more samples to be taken to achieve a similar level of accuracy. These results are simply a product of the central limit theorem.

From the above findings, it was decided to determine whether there would be any quantifiable relationship between a pollutant's variability and the accuracy of the weekly load estimation using one sample per week. As such, the RSD of a pollutant (from Table 3) were plotted against the 95% confidence intervals (from Table 6) and this plot is shown in Figure 15. This figure displays a clear positive linear relationship (very close to 1:1) between these two variables. This type of information

can be used to guide future sampling regimes by providing evidence that the sampling regime should be designed specifically based on the pollutant's variability.

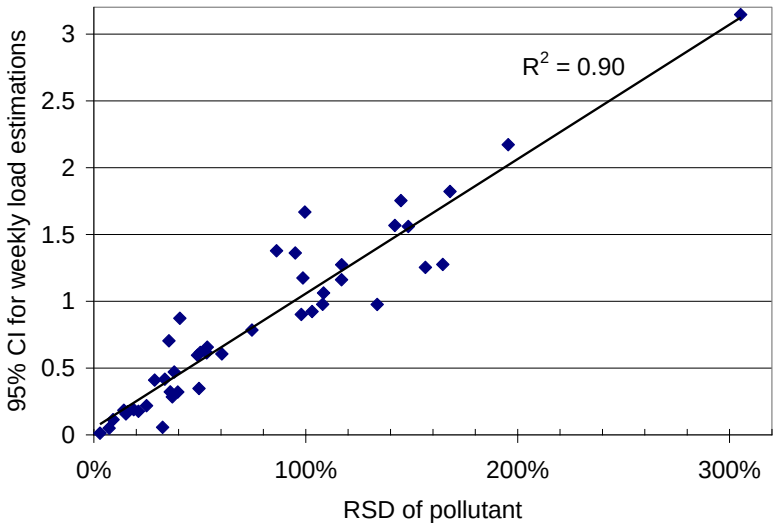

Figure 15. Relationship between the overall variability of the pollutant during dry weather (represented by Relative Standard Deviations from Table 3) and the accuracy of using one random sample per day to estimate weekly loads (represented by the 95% Confidence Interval of the pollutant, obtained from Table 6).

3.2 Wet weather data

In total, eight wet weather events were monitored from Hedgeley Dene and Nunawading (four from each site). Each event varied in the number of samples withdrawn, since sample spacing was flow weighted. In total, 43 samples were taken from Hedgeley Dene and 33 samples from Nunawading (Table 7). Summary statistics of each event for each site is provided in Table 7, including maximum flow rates, maximum rainfall intensities, total event volumes and total rainfall depths. Comparing the flow rates leaving the two sites indicates that the Hedgeley Dene site has a much larger impervious area, with this site having maximum runoff rates and total runoff volumes much larger than that observed at the Nunawading site. However, impervious area is not the only factor controlling these flows, with an obvious difference in the magnitude and intensity of the rainfall events monitored at each site (Table 7).

It is interesting to note that the runoff coefficients presented in Table 7 (which represent the effective imperviousness of the catchment) vary quite considerably between the four events at the Hedgeley Dene site. There are many reasons why these values vary between events, especially since the effective impervious area is often controlled by the intensity and size of the rainfall event. Tree canopy interception is also thought to be a factor in controlling the effective impervious area, with small events being largely affected by canopy interception and larger events being less impacted (especially after canopy saturation). However, the two largest events at the Hedgeley Dene site had the lowest runoff coefficients, which does not follow that described above. A possible reason for this is related to the uncertainties in the measurements of rainfall and flow rates. For example, spatial errors in rainfall measurements using tipping bucket rainfall gauges could help explain this result.

Table 7. Summary of event data for the eight wet weather events collected at the Hedgeley Dene and Nunawading sites.

	Hedgeley Dene	Nunawading
Number of samples per event		
Event 1	10	4
Event 2	6	6
Event 3	11	6
Event 4	16	17
Total Event Rainfall Depth (mm)		
Event 1	4.8	4.8
Event 2	4.4	2.6
Event 3	23.8	5.6
Event 4	23.6	17.8
Maximum Event Rainfall Intensity (mm/6min)		
Event 1	0.6	1.4
Event 2	0.6	0.4
Event 3	2.6	0.4
Event 4	3.6	0.8
Total Event Runoff (kL)		
Event 1	3346	191
Event 2	2038	114
Event 3	6165	209
Event 4	5523	689
Maximum Runoff rate (L/s)		
Event 1	499	80
Event 2	316	24
Event 3	1297	29
Event 4	1645	72
Runoff Coefficient		
Event 1	0.44	0.36
Event 2	0.29	0.40
Event 3	0.16	0.34
Event 4	0.15	0.35

The wet weather events are presented in Figure 16 and Figure 17 for Hedgeley Dene and Nunawading, respectively. These graphs indicate the runoff rate [L/s] and rainfall intensities [mm/6min] for each of the four events collected at each site. The coverage of the samples over each event is also indicated, with sampling times included on these graphs. The water quality characteristics of these samples are presented in the following sections, but all results are provided in Appendix 4.

The following sections will be divided into four separate sections, each addressing one of the key questions outlined in Section 1.2:

1. Between- and within-site variability – to attempt to provide details about how each pollutant is varying between, and within, each different site
2. Within-event variability – to provide information about how each pollutant varies within the events, and whether first flushes exist at the monitored sites
3. Correlation analysis – to determine the relationship between pollutant concentrations and other pollutants and flow rates
4. Errors in load estimations – to assess the accuracy of random grab sampling methodologies during wet weather events to estimate total wet weather loads.

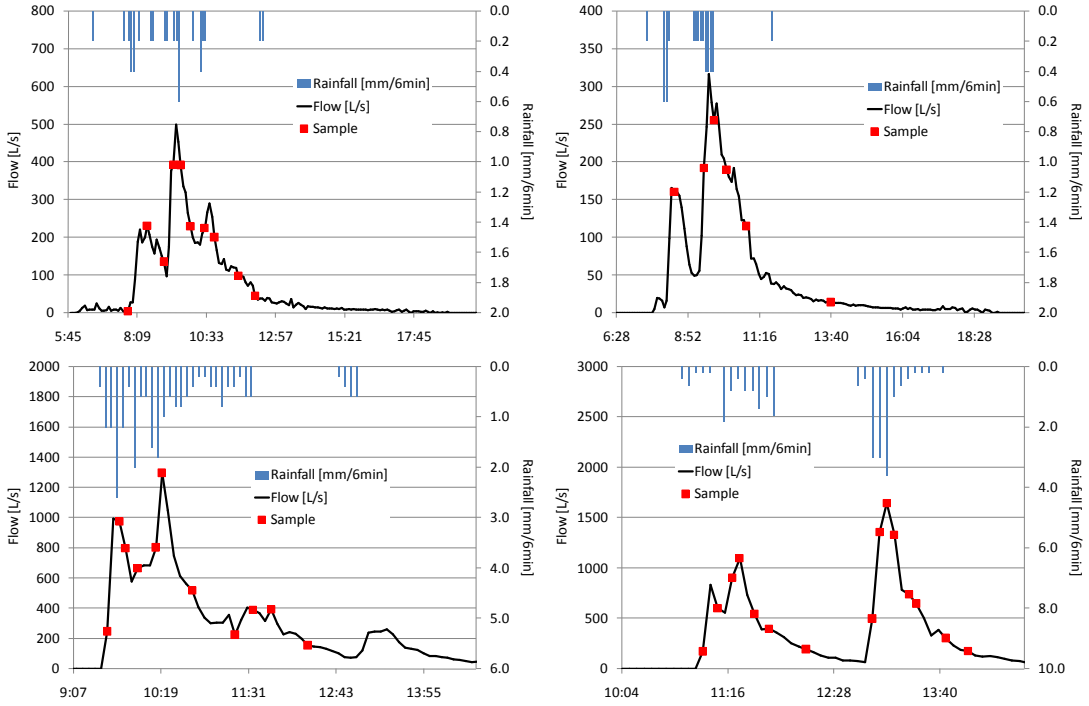

Figure 16. Flow rates, rainfall intensities and sampling times for the four events monitored at the Hedgeley Dene catchment. Top left – 5th March 2009, top right – 12th March 2009, bottom left – 14th March 2009, bottom right – 3rd April 2009.

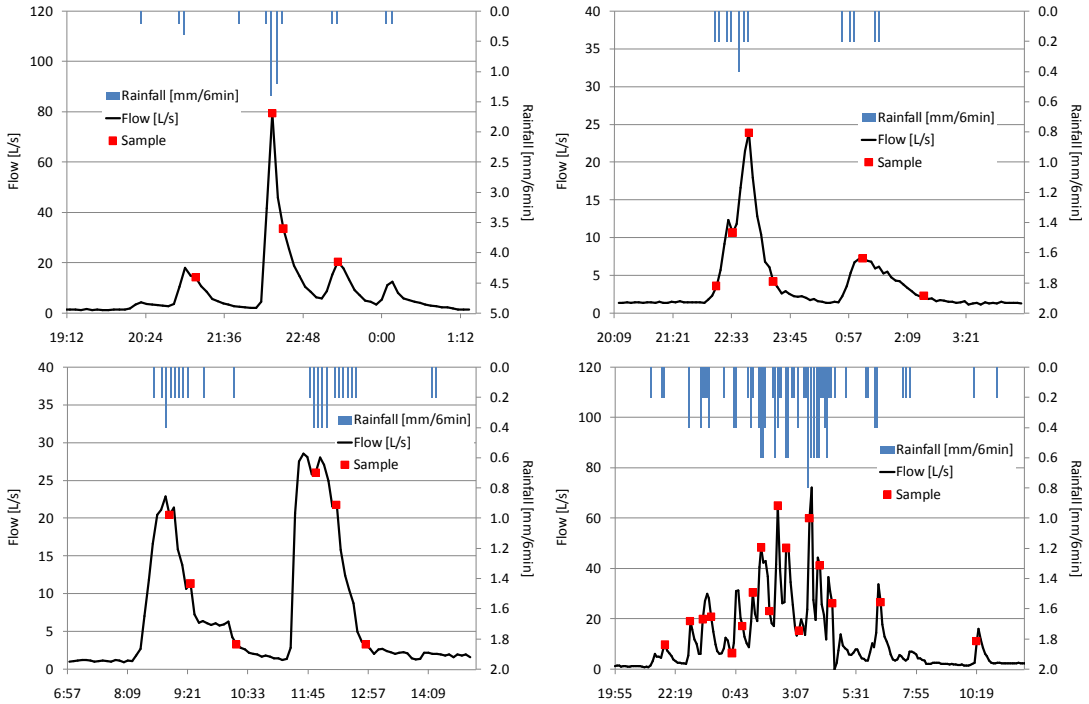

Figure 17. Flow rates, rainfall intensities and sampling times for the four events monitored at the Nunawading catchment. Top left – 27th-28th May 2009, top right – 2nd-3rd June 2009, bottom left – 9th June 2009, bottom right – 9th-10th June 2009.

3.2.1 Between- and within-site variability

Table 8 provides a summary of the water quality constituents found in the wet weather samples taken from Hedgeley Dene and Nunawading. The mean and RSD for each pollutant was calculated using all 43 and 33 samples collected from these two sites, respectively. The boxplots in Figure 18 displays how select pollutants vary both within each study site and between the two sites.

Table 8. Mean and Relative Standard Deviations (RSD = standard deviation divided by mean, expressed as a percentage) of detected constituents in the 4 wet weather events monitored at each site (76 samples collected in total – 43 at HD and 33 at NW). A superscript indicates the number of samples used to calculate the mean and RSD, with all other samples not detected. Absent superscripts indicate all samples were above detection. Heavy metals and TPHs are measured in mg/L, *E. coli* and enterococci are both measured in MPN/100mL.

	Hedgeley Dene	Nunawading
Aluminium	1.36 (88%)	0.28 (64%)
Barium	0.03 (73%)^{42}	0.02 (61%)^{32}
Copper	0.03 (51%)^{38}	0.02 (78%)^{5}
Iron	1.71 (88%)	0.52 (109%)^{21}
Lead	0.04 (92%)^{34}	0.02 (38%)^{4}
Manganese	0.05 (80%)	0.02 (56%)
Nickel	0.01 (0%)^{3}	ND
Strontium	0.04 (64%)	0.03 (46%)
Titanium	0.05 (73%)^{42}	0.01 (52%)^{9}
Zinc	0.30 (47%)	1.24 (49%)
E. coli	26688 (77%)	340 (118%)
Enterococci	20212 (52%)	668 (111%)
TPHs	0.34 (60%)^{17}	ND

antimony was not detected at any site; arsenic was always under detection limit; beryllium was not detected at any site; boron was always under detection limit; cadmium was not detected at any site; chromium was only detected in 3 samples at Hedgeley Dene (0.01mg/L); cobalt was not detected at any site; mercury was not detected at any site; molybdenum was not detected at any site; selenium was not detected at any site; silver was not detected at any site; thallium was not detected at any site; tin was not detected at any site; vanadium was only detected once at Hedgeley Dene (0.01mg/L).

Many of the pollutants measured were either detected only in a select number of wet weather events, or were never detected during wet weather flows. Antimony, beryllium, boron, cadmium, cobalt, mercury, molybdenum, selenium, silver, thallium and tin were never detected at either Hedgeley Dene or Nunawading during wet weather flows. Furthermore, at the Nunawading site, the wet weather samples never contained detectable levels of TPHs or nickel.

Many other constituents were only present in a select number of samples (e.g. barium, copper, iron, lead and titanium). In general, detection of these pollutants was more common at the Hedgeley Dene site in preference to the industrial site (Nunawading). Moreover, for all constituents, except for zinc, the average pollutant concentration found at the Hedgeley Dene site was higher than that for the Nunawading site. This is an interesting finding, considering that the industrial site was hypothesised to have higher, and more consistent, heavy metal and hydrocarbon levels than the residential site. The higher zinc levels in the industrial catchment are not surprising since the proportion of roofs (often comprised of zinc components) which make up the impervious area in this catchment is likely to be much higher than that of the residential catchment.

Out of the heavy metals analysed, iron seemed to vary the greatest (with RSD of 88% and 109%, for Hedgeley Dene and Nunawading, respectively) while zinc varied the least and had RSD of less than 50% for both sites (Table 8 and Figure 18). The following section will investigate within-event variations in more detail.

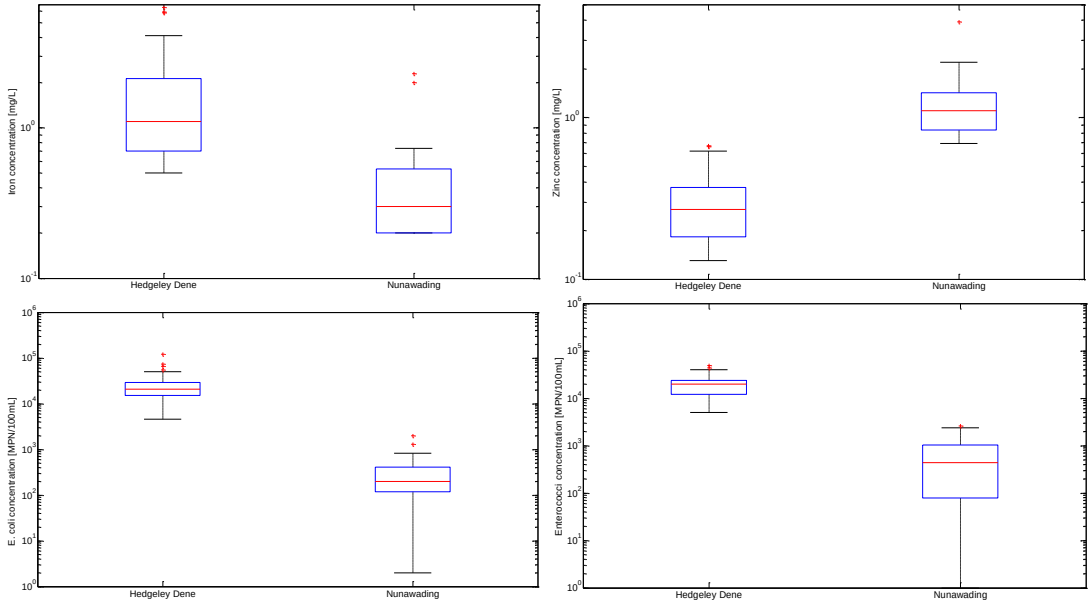

Figure 18. Boxplots showing the distribution of iron (top left), zinc (top right), *E. coli* (bottom left) and enterococci (bottom right) concentrations found during the four wet weather events at Hedgeley Dene and Nunawading.

3.2.2 Within-event variability

The first flush phenomenon has been noted in urban stormwater runoff for many years. However, whilst the first flush does occur for many stormwater quality pollutants, its presence is not consistent between wet weather events, between different pollutants and between different sites. However, it is often interesting to investigate whether there is a general trend for pollutant concentrations to decrease as the event progresses.

As a result, Figure 19 is shown to help identify trends between cumulative runoff depth of wet weather events (x-axis) and pollutant concentrations. It is evident that for zinc, and to a lesser extent iron, the concentrations decrease as the event progresses (i.e. the concentrations are higher at the start of the event as compared to the end of the event). To determine whether or not concentrations for other pollutants follow a similar trend (i.e. concentrations decrease as event runoff depth increases), a correlation analysis was conducted for each pollutant's concentrations and the cumulative runoff depth (see Table 9). The results indicate that there are a number of significant correlations present at the Hedgeley Dene site, with eight heavy metals' concentrations decreasing as events progress. However, only two metals followed that same trend at the Nunawading site, possibly because many more of the samples contained levels below detection, making it not possible to conduct these correlation analyses (i.e. correlations could have been seen, but because of the low levels, these could not be identified due to non detection). This was especially true for copper, lead and titanium.

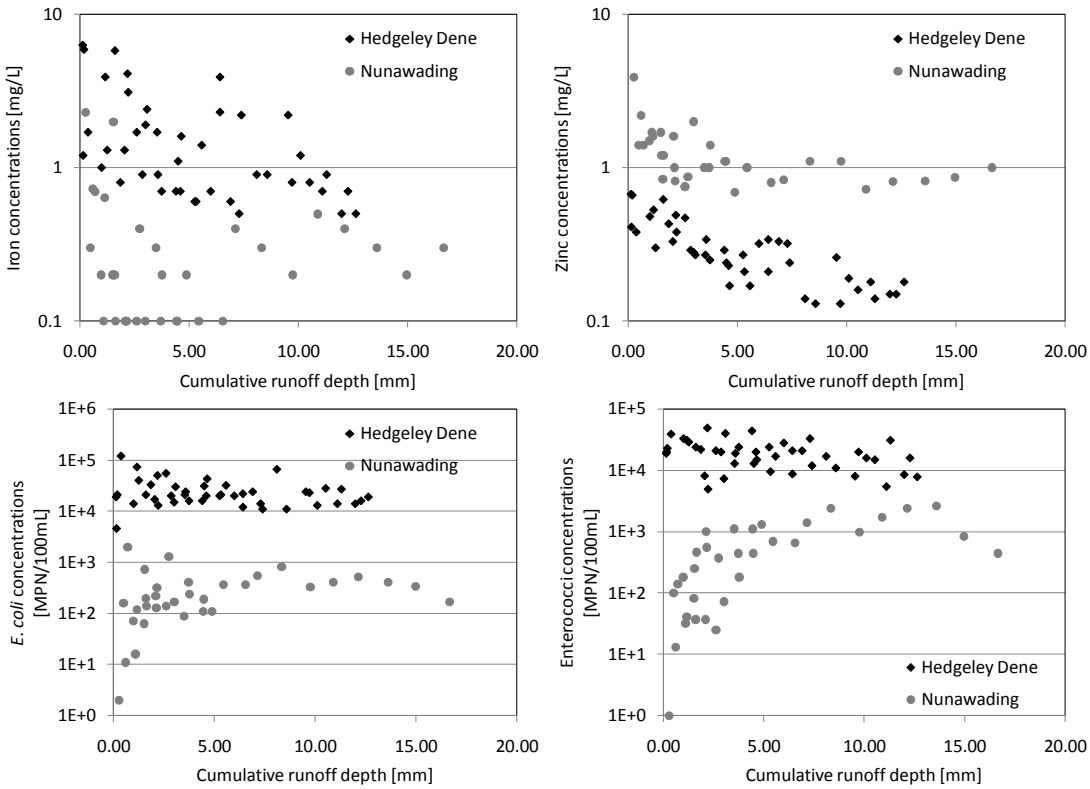

Figure 19. Pollutant concentrations found in the four wet weather events at the Hedgeley Dene and Nunawading sites plotted against cumulative runoff depth [mm] for iron (top left), zinc (top right), *E. coli* (bottom left) and enterococci (bottom right).

These results indicate that a slight first flush might be present for heavy metals and the sources of these pollutants are being depleted during wet weather events (whether by rainfall drop impact or runoff shear forces). For copper, this finding is especially prevalent at the residential site, with a strong negative trend. The main source of copper in urban stormwater is thought to be from the wearing of tyres and brake linings (Makepeace *et al*., 1995). Copper deposited on the roads in the catchment could be effectively conveyed to the catchment's outlet during rainfall/runoff events. If these events are large enough (in intensity and volume) the deposited copper could be effectively depleted, thus causing a first flush effect. As mentioned above, a similar correlation was not detected at the Nunawading site because there were insufficient samples above detection to perform statistical testing.

For the microbial indicators, different trends were observed. Figure 19 shows that for the Hedgeley Dene site, the concentrations of *E. coli* generally stay constant, and high, throughout the events. However, for enterococci at this site, there is a slight decrease in concentrations with cumulative runoff depth and this trend is also reported by Table 9 as being significant at the 95% level. Whilst this is inline with other studies which have shown little first flush effects for microorganisms, it should be noted the presence of a first flush for microorganisms in urban stormwater is still under debate (Makepeace *et al.*, 1995; McCarthy *et al*., *in press*).

Table 9. Linear correlation coefficients between cumulative runoff depths [mm] and pollutant concentrations taken from the four wet weather events at each study site. Only correlations which were significant at the 95% level were reported below.

	Hedgeley Dene	Nunawading
Al [mg/L]	-0.43	
Ba [mg/L]	-0.57	
Cu [mg/L]	-0.73	
Fe [mg/L]	-0.48	
Pb [mg/L]	-0.36	
Mn [mg/L]	-0.55	-0.39
Ti [mg/L]	-0.45	
Zn [mg/L]	-0.76	-0.45
Enterococci [MPN/100mL]	-0.38	0.67

3.2.3 Correlations between water quality pollutants and flow rates

Many of the heavy metals found at the Hedgeley Dene site, and to a lesser degree at the Nunawading site, were positively correlated with one another (Table 10). In fact, most of these relationships were very strong, with correlation coefficients of greater than 0.90 (these trends were plotted to ensure they were not being skewed by one outlier). These strong correlations indicate that the majority of these metals most probably originate from similar sources at both study sites and that their behaviour in urban stormwater wet weather flows are similar. Again, the lack in correlation for the Nunawading site can partly be explained by the low level of heavy metals found at this site, which resulted in a number of samples having metal concentrations less than their detection limit (Table 8), thus making it difficult to perform a correlation analysis.

Few heavy metals were significantly correlated with flow rates, with aluminium being the only metal increasing in concentration with flow rate. Strontium concentrations decreased significantly with flow rate at both sites, possibly indicating that this pollutant is being diluted in stormwater flows. The negative correlation between flow rates and zinc concentrations at the Nunawading site also indicates a dilution effect for zinc at this site. However, in such an industrial estate it was hypothesised that there should be a positive correlation with flow rates. This is because shear forces associated with runoff would increase with increasing flow rates, thus allowing more of the catchment's zinc load to be transported to the outlet. Inspecting these trends further showed that, unlike the other correlations presented in Table 10, this correlation was being skewed by one outlier. Whilst the trend is still generally negative, the removal of this point reduced the correlation coefficient to less than -0.33, which is no longer significant at the 95% level.

Only one correlation was found which significantly explained TPH concentrations, maybe as a result of the non detects observed for the majority of wet weather TPH samples. The positive correlation found with copper indicates that these two pollutants may share a similar source of contamination. Copper in stormwater has often been highly correlated to vehicular traffic (Dannecker *et al*., 1990) because it is sourced from the wear of brake linings, tires and other moving parts located in cars. TPHs are also often associated with vehicular traffic because of the use of petroleum and diesel products for combustion engines (Fam *et al*., 1987). As such, it is logical that these pollutants are positively correlated.

Table 10. Correlation coefficients between wet weather pollutant concentrations and flow rates measured at Hedgeley Dene and Nunawading (presented in that order separated by a solidus). Only statistically significant correlation coefficients are reported (i.e. p<0.05). Dashes or empty cells indicate non significant or absent correlations (due to detection limit problems).

	Ba [mg/L]	Cu [mg/L]	Fe [mg/L]	Pb [mg/L]	Mn [mg/L]	Sr [mg/L]	Ti [mg/L]	Zn [mg/L]	*E. coli* [MPN/ 100mL]	Flow rate [L/s]
Al [mg/L]	0.93 / 0.47	0.77 / --	0.99 / 0.69	0.96 / --	0.97 / 0.38		0.98 / 0.86	0.73 / --	-- / 0.43	-- / 0.47
Ba [mg/L]		0.86 / --	0.95 / 0.64	0.93 / --	0.96 / 0.47		0.94 / --	0.85 / 0.44		
Cu [mg/L]			0.80 / --	0.72 / --	0.85 / --		0.78 / --	0.92 / --		
Fe [mg/L]				0.97 / --	0.97 / 0.90		0.98 / --	0.76 / 0.68		
Pb [mg/L]					0.95 / --		0.95 / --	0.70 / --		
Mn [mg/L]						-- / 0.68	0.96 / --	0.85 / 0.60		
Sr [mg/L]								0.30 / 0.40		-0.50/-0.73
Ti [mg/L]								0.73 / --		
Zn [mg/L]										-- / -0.39
TPHs [mg/L]		0.61 / --								
Ent. [MPN/100 mL]						-- / -0.48		0.35/ -0.46	0.40 / --	-- / 0.47

Correlations between heavy metals and indicator organisms occur on three occasions, with *E. coli* and aluminium positively correlated (Nunawading), strontium and enterococci negatively correlated (Nunawading) and enterococci and zinc being positively correlated at Hedgeley Dene and negatively correlated at Nunawading. The correlation between strontium and enterococci could have been a product of the strong negative correlation between flow and strontium, and the positive correlation between enterococci and flow at this site (i.e. because strontium is negatively correlated with flow rates, and enterococci are positively correlated with flow rates, strontium and enterococci are hence positively correlated). A similar explanation could be made for the negative correlation between zinc and enterococci at the Nunawading site. The positive correlation between *E. coli* and enterococci at the Hedgeley Dene site means that these two indicators have very similar sources, and behave similarly in wet weather flows. This is similar to what was found for the dry weather data, with positive correlations between *E. coli* and enterococci at this site. However, again as with the dry weather data, there was no correlation between *E. coli* and enterococci at the industrial site, once again iterating that the sources and behaviour of these indicator organisms at industrial sites may not be related.

3.2.4 Errors in loads using a small number of samples per event

To understand the impact of taking just one, two, three or four 'grab' samples from a wet weather event to estimate downstream loads, a boot strapping methodology was adopted. Figure 20 shows the results of this, and indicates that as the number of samples used per event to estimate wet weather loads increases from 1 to four the spread of the boxplots tends to decrease. This is logical since more samples are being used to estimate the load, hence capturing more of the likely variability in the pollutant.

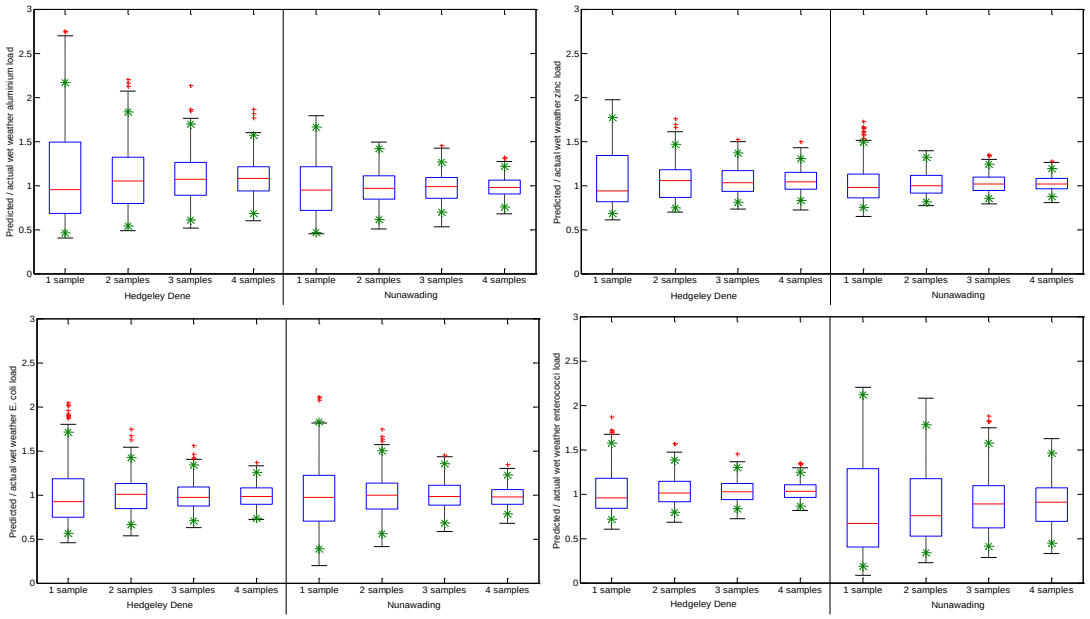

Figure 20. Boxplots showing the accuracy of using one, two, three and four samples randomly selected from each wet weather event to estimate total wet weather loads at each site. Green stars indicate 95% confidence interval.

Figure 20 shows that for some pollutants taking just one or two samples during an event produces reasonable estimates of the total wet weather load (to within 50% of the actual value, e.g. zinc at Nunawading). However, for other pollutants, even taking four samples from each event does not produce accurate wet weather event load estimates (e.g. enterococci at Nunawading).

Table 11 shows the 95% confidence interval for estimating total wet weather event load for each site and each pollutant using one, two, three and four samples from each of the available events. There is an amount of variability in these 95% confidence intervals. The intervals were always greater at the Hedgeley Dene site for heavy metals, but the opposite was true for microbial indicators (with Nunawading producing the larger confidence intervals).

Similarly as in Section 3.1.4 it was expected that the accuracy of using a few samples from each event to estimate wet weather loads was related to the variability of the pollutant at each site. As such, a plot of the confidence intervals obtained from Table 11 and the relative standard deviations from Table 8 is provided in Figure 21. Four plots are presented in this figure, each representing a different number of samples used to estimate the wet weather load. Although not as significant as that shown in Figure 15, the trends in this graph still indicate the direct relationship between a pollutants variability and the accuracy of using, for example, just one sample from each event to estimate pollutant loads.

Table 11. 95% confidence intervals for estimating a pollutant's wet weather load using just one, two, three or four samples randomly selected from each event. Superscript values indicate the number of samples used in the analysis which were above the detection limit. Missing pollutants and blanks indicate that the analysis could not be conducted due to too many non detects.

	Hedgeley Dene				Nunawading			
	1 sample	2 samples	3 samples	4 samples	1 sample	2 samples	3 samples	4 samples
Al [mg/L]	1.70	1.29	1.09	0.88	1.20	0.80	0.57	0.46
Ba [mg/L]	1.63[42]	1.14[42]	1.02[42]	0.83[42]	1.18[32]	0.67[32]	0.48[32]	0.36[32]
Cu [mg/L]	1.34[38]	0.96[38]	0.82[38]	0.70[38]				
Fe [mg/L]	1.83	1.33	1.04	0.83				
Pb [mg/L]	2.23[34]	1.62[34]	1.30[34]	1.02[34]				
Mn [mg/L]	1.66	1.26	0.99	0.79	0.78	0.51	0.36	0.26
Sr [mg/L]	0.89	0.64	0.49	0.39	0.87	0.57	0.41	0.36
Ti [mg/L]	1.54[42]	1.14[42]	0.88[42]	0.72[42]				
Zn [mg/L]	1.09	0.72	0.56	0.48	0.74	0.51	0.39	0.32
E. coli [MPN/100mL]	1.15	0.76	0.63	0.52	1.44	0.94	0.67	0.44
Enterococci [MPN/100mL]	0.86	0.59	0.47	0.38	1.93	1.44	1.16	1.02

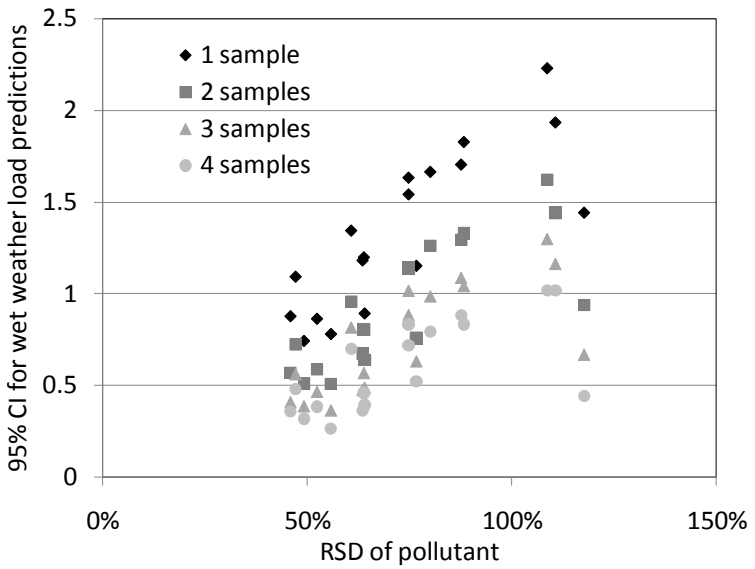

Figure 21. Relationship between the overall variability of a pollutant during wet weather (represented by Relative Standard Deviations given in Table 8) and the accuracy of using one, two, three and four random samples per event to estimate total wet weather loads (represented by the 95% Confidence Interval of the pollutant, obtained from Table 11).

This section has presented information which can be used to help identify the number of samples required to be collected during events to accurately estimate wet weather loads. It clearly demonstrates that it is possible to obtain accurate total wet weather loads from taking just one random sample from each event. However, it also illustrates that there are definitely different wet weather sampling regime requirements for different pollutants at different sites. Whilst many of the heavy metals at a site could be assumed to share similar sampling requirements, some heavy metals are clear outliers (e.g. strontium at Hedgeley Dene). This is similar for indicator organisms. Whilst these general within-site assumptions of equality may be sufficient enough for load estimations, from the results presented here it is not possible to assume that the sampling requirements of a

pollutant at one site is the same as for the same pollutant at a different site. In any case, further collection and subsequent analysis of the data will help us understand the true underlying distributions (i.e. true population variability) for different pollutants. This could then be used to obtain 'minimum' sampling requirements to meet the likely maximum variability of a pollutant.

3.3 Comparison between wet weather and dry weather concentrations & loads

Comparison of concentrations. Comparing the concentrations of the pollutants measured during dry and wet weather periods can help explain sources and the behaviour of pollutants in stormwater. It can also help determine whether efforts should concentrate on treating rainfall events, or whether treatment of dry weather flows is more important. Figure 22 provides boxplots which allows a comparison between dry weather and wet weather concentrations of select pollutants. While iron concentrations are relatively similar during dry and wet weather periods, zinc concentrations at both sites are generally higher during wet weather periods.

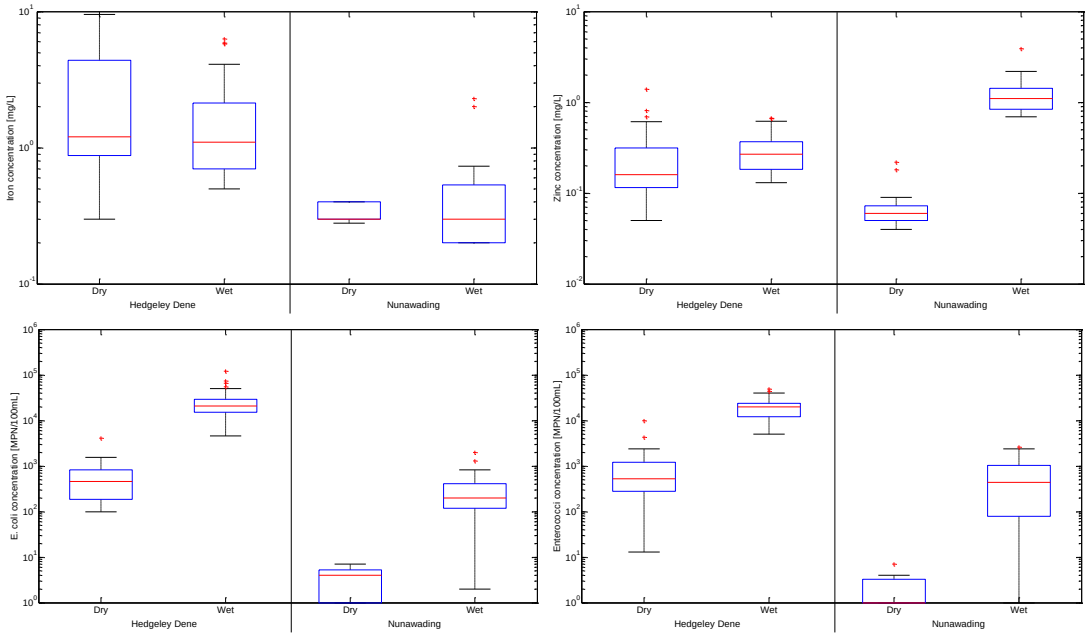

Figure 22. Boxplots comparing the concentrations of iron, zinc, *E. coli* and enterococci during dry weather and wet weather at Hedgeley Dene and Nunawading.

Table 12 provides a summary of Table 3 and Table 8 to provide easy comparisons between pollutant concentrations during dry and wet weather periods. Heavy metal concentrations at the Hedgeley Dene site are generally higher during dry weather periods, with the exception of aluminium and zinc. There is no such trend at the Nunawading site, with some pollutants having higher concentrations in wet weather, and others vice-versa. Variability of these heavy metals also changes between dry and wet weather, but no general trends are obvious.

Comparing the mean values obtained during wet and dry weather periods can help identify the sources of these heavy metals. For instance, average zinc concentrations have increased during wet weather events at both sites (more significantly at the Nunawading site), clearly indicating the presence of zinc sources during rainfall periods. On the other side, the significant reduction in strontium levels during wet weather at Hedgeley Dene (i.e. Table 12 shows the wet weather levels are almost six times lower than in dry weather) indicates that this heavy metal might not have significant sources during rainfall events, and it is really only being diluted during high flow rates. In fact, this is exactly what is shown in Table 5 and Table 10, where strontium concentrations were

negatively correlated with flow rates, verifying that as flow rates increase, the concentration of strontium decreases.

Table 12. Average and relative standard deviations (shown in parentheses) of pollutants in dry weather and wet weather flows at the Hedgeley Dene and Nunawading sites. ND indicates the pollutant was not detected, superscript numbers indicate the number of samples which were above detection, absent superscripts indicates all samples were used.

	Hedgeley Dene		Nunawading	
	Dry weather	Wet weather	Dry weather	Wet weather
Aluminium	1.09 (142%)[16]	1.36 (88%)	0.17 (25%)	0.28 (64%)
Barium	0.06 (50%)	0.03 (73%)[42]	0.03 (7%)	0.02 (61%)[32]
Copper	0.03 (74%)[14]	0.03 (51%)[38]	ND	0.02 (78%)[5]
Iron	2.65 (108%)[11]	1.71 (88%)	0.33 (14%)	0.52 (109%)[21]
Lead	0.05 (90%)[7]	0.04 (92%)[34]	0.01 (0%)[1]	0.02 (38%)[4]
Manganese	0.16 (129%)[11]	0.05 (80%)	0.06 (9%)	0.02 (56%)
Nickel	0.01 (43%)[3]	0.01 (0%)[3]	ND	ND
Strontium	0.22 (33%)	0.04 (64%)	0.08 (3%)	0.03 (46%)
Titanium	0.04 (106%)[10]	0.05 (73%)[42]	ND	0.01 (52%)[9]
Zinc	0.30 (108%)	0.30 (47%)	0.07 (60%)	1.24 (49%)
E. coli	655 (134%)	26688 (77%)	3 (71%)[9]	340 (118%)
Enterococci	1331 (165%)	20212 (52%)	2 (86%)[17]	668 (111%)
TPHs	0.15 (0%)[1]	0.34 (60%)[17]	ND	ND

For TPHs, the number of detections at the Hedgeley Dene site grew from just one in dry weather flows, to 17 in wet weather flows, truly indicating that the main source of hydrocarbons in this catchment is only prevalent during rainfall events. This is logical since sources of hydrocarbons during dry weather flows should not be high in residential areas, and if present would be highly intermittent (i.e. someone washing their engine over a stormwater grate may create detectable levels). However, oil and petroleum products which are deposited onto the surfaces of the catchment during dry weather periods are effectively washed to the catchment's outlet by the kinetic energy of rainfall and shear forces of runoff. It is very interesting that Nunawading's samples never had detectable levels of TPHs, especially since many of the businesses in this catchment are focused on motor repairs. Dry weather levels could have been diluted in this sites high flow rates, but non detectable levels in wet weather flows is difficult to explain.

Referring to Table 12 and Figure 22, *E. coli* and enterococci concentrations tend to increase in wet weather events, generally by several orders of magnitude at each site. The Hedgeley Dene site sees a decrease in the variability of these microbes in wet weather periods while the Nunawading site has a large increase in variability during wet weather. This indicates that the sources of *E. coli* and enterococci at the Hedgeley Dene site are more constant during wet weather than during dry weather. The opposite can be said for the Nunawading site.

Comparison of loads. Table 13 provides an overview of the dry weather and wet weather annual loads for each pollutant at Hedgeley Dene and Nunawading. It is interesting to note the large amount of aluminium, iron and zinc which are delivered to downstream systems from both sites, but more notably from the residential site. Furthermore, over $4.3x10^{13}$ *E. coli* come from the residential catchment each year, which is equivalent to that found in around 1200kg of human faeces (calculated using a human faecal concentration of $3.6x10^{7}$/g; Leeming *et al*., 1998). The total loads from the industrial catchment were always much lower than that from the residential catchment, mainly due to its smaller size and therefore lower runoff volumes.

However, Nunawading's heavy metal dry weather loads were always greater than that of Hedgeley Dene, even though the concentrations at the industrial site during dry weather were generally much lower than those found at the residential site (Table 12). A logical reason for these higher loads is the high dry weather flows at the Nunawading site, with average flow rates exceeding 1L/s during dry weather (compared to less than 0.2L/s for Hedgeley Dene). This is an interesting finding considering the sizes of each catchment. If only stormwater runoff was being discharged to the stormwater pipe system, then baseflow rates should be relative to the catchment's area (or more specifically to its pervious area, assuming groundwater infiltration is negligible in these areas). This data clearly shows that dry weather flows, and hence a certain portion of wet weather flows, are comprised of anthropogenic sources of water.

Table 13. Total annual loads sourced from wet and dry weather periods for select pollutants at Hedgeley Dene and Nunawading. Blank cells indicates pollutant has too many non detects for the analysis.

	Hedgeley Dene			Nunawading		
	Wet weather load	Dry weather load	% wet weather	Wet weather load	Dry weather load	% wet weather
Al [kg/yr]	197.2	5.0	98%	7.2	8.1	47%
Ba [kg/yr]	4.6	0.4	93%	0.6	1.4	29%
Cu [kg/yr]	3.4	0.1	96%			
Fe [kg/yr]	247.0	8.7	97%	8.5	15.4	36%
Mn [kg/yr]	7.0	0.5	93%	0.5	3.0	15%
Sr [kg/yr]	6.4	1.5	81%	0.6	3.6	14%
Zn [kg/yr]	43.4	1.7	96%	28.5	3.5	89%
E. coli [MPN/yr]	4.3 E13	4.9 E10	100%	9.6 E10	6.0 E8	99%
Enterococci [MPN/yr]	3.1 E13	9.0 E10	100%	2.0 E11	8.7 E8	100%

At Hedgeley Dene, the loads contributed by wet weather events dominate the total load being delivered to downstream systems from this catchment. This holds true for all pollutants, with 90% of most pollutant loads being sourced from wet weather. This is partially due to the very low flows found at this catchment during the dry weather monitoring period. At the Nunawading site a different trend was observed for the heavy metals. Again, this is partially due to the quite high and consistent flows found at the Nunawading site during the dry weather monitoring period.

These results demonstrate the differences which can occur between different catchments, and that management decisions need to take into account all variables when deciding to implement certain mitigation options. The results suggest that the treatment of Hedgeley Dene's dry weather flows is not going to drastically reduce loads going to downstream systems. In fact, in order to reduce a large percentage of the total pollutant load, wet weather flows need to be mitigated. However, this

may require large amounts of money and infrastructure to achieve, since the volume of water would require a large treatment system. On the other hand, treatment of Nunawading's dry weather flows has the potential to remove a large proportion of the annual pollutant load being delivered to downstream systems. In fact, the treatment of this water would be relatively straight forward since treating 1L/s is easily achievable using a small Water Sensitive Urban Design system.

3.4 Analytical uncertainty of laboratory methodologies

During the dry weather period, triplicate samples were taken on one occasion at each site to help assess the analytical uncertainty of the laboratory methods. However, some heavy metals were never detected in these triplicate samples, making it impossible to assess this uncertainty for the following: antimony, arsenic, beryllium, boron, cadmium, chromium, cobalt, lead, mercury, molybdenum, selenium, silver, thallium, tin, titanium, vanadium.

For the other heavy metals, the triplicate results were all very close indicating that the analytical uncertainty of heavy metals is generally very low, with most heavy metals being identical in all three replicate samples. One large difference was observed at the Box Hill site for nickel concentrations, which varied by more than 50% between replicates (0.14mg/L, 0.07mg/L, 0.07mg/L).

The analytical uncertainty for microbes was much more substantial than that of heavy metals, with samples often varying by over 50% within triplicates (Figure 23). For example, the concentrations in the triplicate samples obtained from the Box Hill site were: 1400, 1900 and 3000MPN/100mL. This shows that while the error in the laboratory method is far less than an order of magnitude (which is often considered to be the accuracy of microbial measurements), the uncertainty is still considerable.

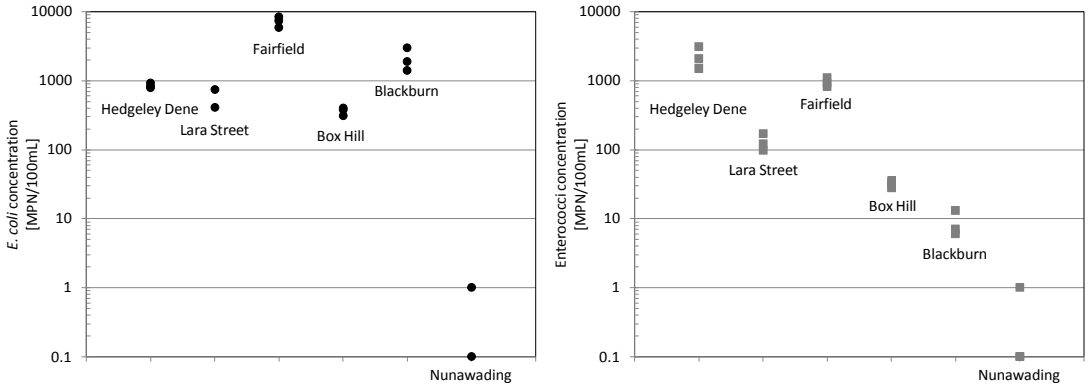

Figure 23. Triplicate results for *E. coli* (left) and enterococci (right). Each point on these graph indicates the concentration of one of the triplicate samples. At Nunawading, two of the triplicate samples had non detectable *E. coli* and enterococci concentrations, while one had a concentration of 1 MPN/100mL for both indicators.

TPHs were only detected in the triplicate samples collected from the Box Hill site. However, only one of the three samples had detectable levels of TPHs (0.36mg/L), with the other two samples having non detectable TPH concentrations. This translates into a very high level of uncertainty, considering the detection limit for TPH analysis is around 0.01mg/L (over 36 times lower than that detected in one of the samples). This could have been caused by a number of different uncertainty sources: sampling, laboratory, transportation, etc.

For the majority of pollutants measured during the sampling regime, there were only a few which had high associated analytical uncertainties. It is unlikely that the analytical uncertainties in the pollutants investigated are causing all of the variability seen between or within each of the study sites. Hence, there are actual bio-physical processes (e.g. rainfall kinetic energy, flow shear stress, human behaviour, etc) which are controlling these variations (i.e. not just random/systematic

uncertainties in their measurements causing these variations). However, these uncertainties are definitely contributing to the observed variability, and should not be ignored, especially for the indicator organisms. For example, while the RSD of *E. coli* at the Blackburn site was high during dry weather (at 117%), the RSD of the triplicate samples taken from the same site was over 38%, indicating that a significant proportion of the variability in *E. coli* observed at this site could have been caused by analytical uncertainties, and not the actual variation in pollutant levels.

4 Conclusions and recommendations from the results

The results presented in Section 3 answer the related questions presented in the Aims/Objective section at the start of this document. These results revealed the intermittent and variable nature of urban stormwater systems, with flow rates and pollutant concentrations varying by a large degree in both dry weather and wet weather events. Moreover, the magnitude and variability of a pollutant was rarely consistent between study sites, and rarely consistent among land-use types. It was also determined that the variability for some pollutants between catchments and within sites is not just caused by the actual fluctuation of the pollutant's concentrations, but is also due to the inherent analytical uncertainty in the laboratory method used to quantify the pollutant. This is especially the case for *E. coli* and enterococci which had large analytical uncertainties, but generally not the case for heavy metals.

The variability of the pollutants has a large influence on the accuracy of certain sampling strategies on pollutant load estimations. For example, a pollutant which has concentrations that vary quite considerably during dry weather flows cannot have its weekly loading accurately estimated by one random sample per day. On the other hand, a pollutant which is fairly constant during dry weather periods could have its load accurately estimated using the same sampling regime. This argument holds true for wet weather as well, with the variability in the pollutant's concentrations governing how many samples are required to be taken during each event for accurate wet weather pollutant load estimations.

While this dataset has helped us to understand the variability of these pollutants between and within each study site, there is insufficient data to extrapolate these findings directly to other catchments. More data collection is required to understand the underlying population distribution of each pollutant at a range of different sites. This population distribution can then be used to estimate the likely pollutant load coming from an unmonitored catchment. However, until this is completed, it will be necessary to monitor catchments to understand their pollutant levels and their associated variability.

This dataset can help future studies to develop these sampling strategies. For example, if a pollutant's variability at a site can somehow be estimated accurately, then the information presented within this report can help estimate the likely sampling regime requirements to adequately assess this pollutant's loads. However, without an accurate estimate of the pollutant's variability, it is very hard to specify an adequate sampling strategy which is both cost effective and produces accurate results. Estimating this pollutant's variability is a difficult task, mainly because it is so pollutant and site dependent. There are several solutions which could be employed to obtain the required sampling regime for a pollutant. Firstly, a 'safe' sampling regime could be adopted, where it is assumed that the variability of the pollutant is in the upper range identified within this report. From this variability, it would be possible to estimate the required number of samples needed for accurate load estimates using a boot strapping methodology as presented in this report. This first method has the advantage of probably producing very accurate load estimations, but is associated with increased sampling costs because of the high variability assumption. The second option would be to employ a dynamic sampling strategy, where the number of samples taken is adopted based on previous sample information. For instance, a sampling method may start out similar to that of the 'safe' method presented above, but after a certain number of days, weeks or months, this sampling strategy is adapted to suit the variability which has been seen in the previously collected data. This type of sampling method has the advantage of reducing costs quite considerably, whilst still ensuring accurate load estimates are obtained. However, the demand on management and the alteration of sampling strategies during a sampling regime may introduce a number of barriers for implementation of this strategy. This method could be employed for both dry and wet weather load estimations. In either case, if the monitoring regime is required to

characterise a number of pollutants, it is more than probable that one of these pollutants are going to govern the sampling regime. For example, if strontium and *E. coli* are to be monitored, then it is likely that the variability of these pollutants is such that the number of samples required for accurate *E. coli* load estimations are much higher than that for strontium. As such, since sampling has to occur more regularly for *E. coli*, and considering that sending sampling teams is often the major cost, it would make little difference to the overall budget to analyse all samples for strontium as well.

In any case, more data collection will help us to fully understand the variability of these pollutants in urban stormwater, and thus provide us with appropriate datasets to base these future sampling designs. In fact, more data could start to help us understand the behaviour of these pollutants at a physical level so that accurate water quality models could be developed. These models (which would have to be partly stochastic) could use certain inputs to identify the likely magnitude and variability of each pollutant, and hence could not only help with designing sampling strategies, but could help avoid these in the future.

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Appendix 1 – raw data collected during project

Please note that several Excel spreadsheets have been included as an electronic appendix for the raw data collected during the project. This is because it is simply impossible, and not practical to display this information in a report format. This appendix includes the following information:

1. Measured flow rates for each study site
2. Measured physical water quality parameters (i.e. data from Greenspan and Hydrolab water quality probes): temperature, dissolved oxygen, pH, turbidity, electric conductivity
3. Dry weather sampling times, comments and concentrations of water quality pollutants (heavy metals, *E. coli*, enterococci, TPHs and nutrients)
4. Wet weather sampling times, comments and concentrations of water quality pollutants (heavy metals, *E. coli*, enterococci, TPHs and nutrients)

Appendix 2 – Determination of dry weather sampling times

Introduction

In order to estimate the dry weather sampling times for each site, water quality probe data collected during a two week dry weather period was analysed to determine peak flow rates and peaks in physical/chemical water parameters (temperature, dissolved oxygen, pH, electric conductivity, turbidity and ammonia). The data used for this Appendix has been provided in Appendix 1 in an electronic format.

Methods

The data collected from each of the six sites was analysed using standard statistical techniques and box and whisker plots. Box and whisker plots were created in a way to help identify the most appropriate dry weather sampling times. Ratio plots were created in which each value in the data was first converted into a ratio of the current parameter's value to its respective daily average. These ratios were then grouped in 24 columns according to the hour at which the data was collected. 24 box and whisker plots were created using these 24 columns.

Results

Figures 2.1 to 2.6 shows the results of the above analysis for each study site.

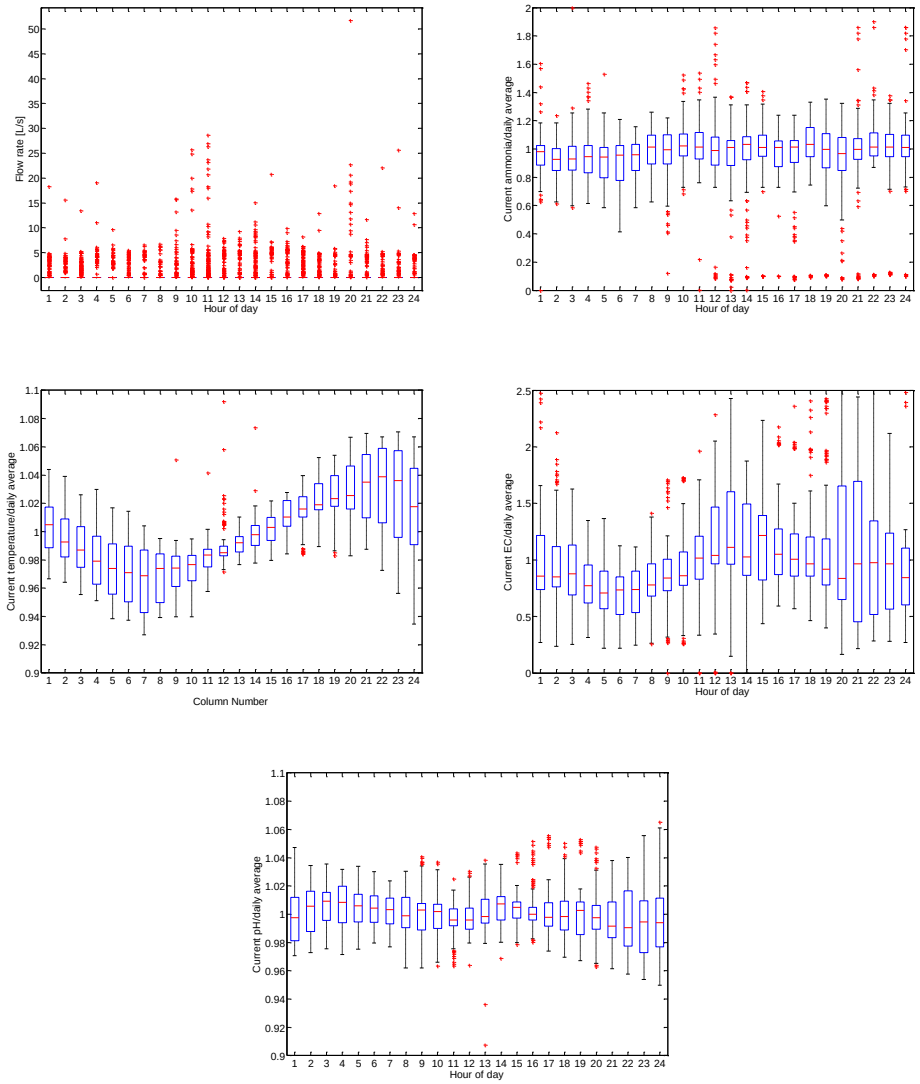

Figure 2.1. The flow and water quality data for the Hedgeley Dene site.

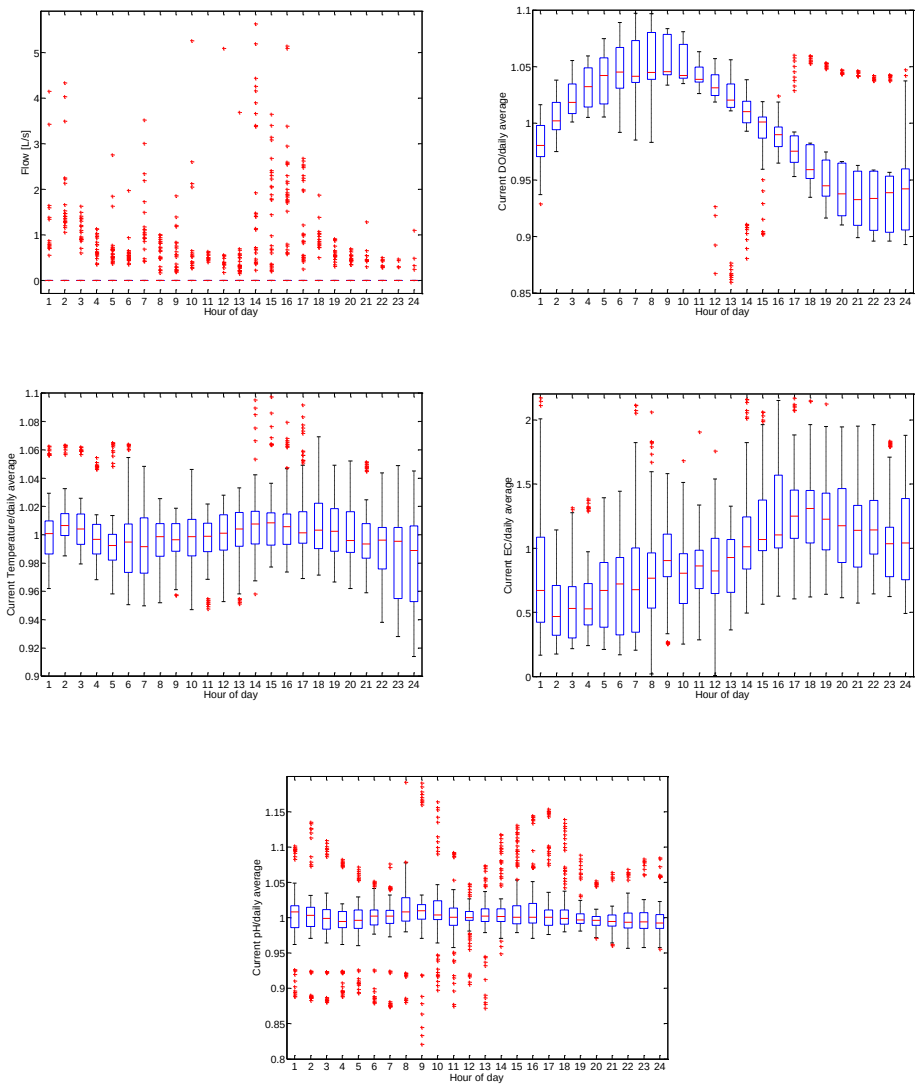

Figure 2.2. The flow and water quality data for the Lara Street site.

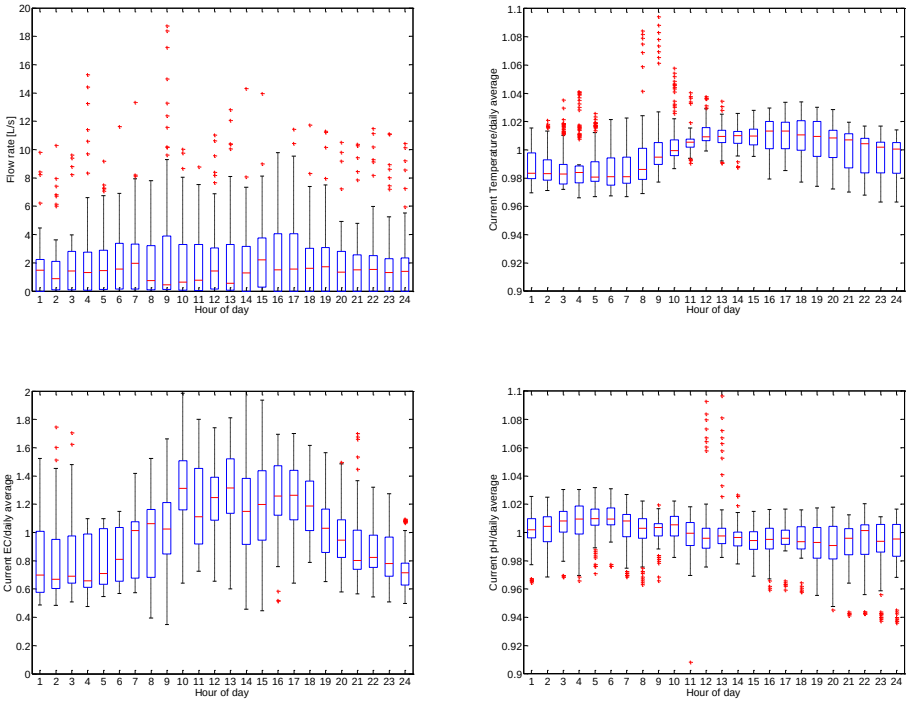

Figure 2.3. The flow and water quality data for the Fairfield site.

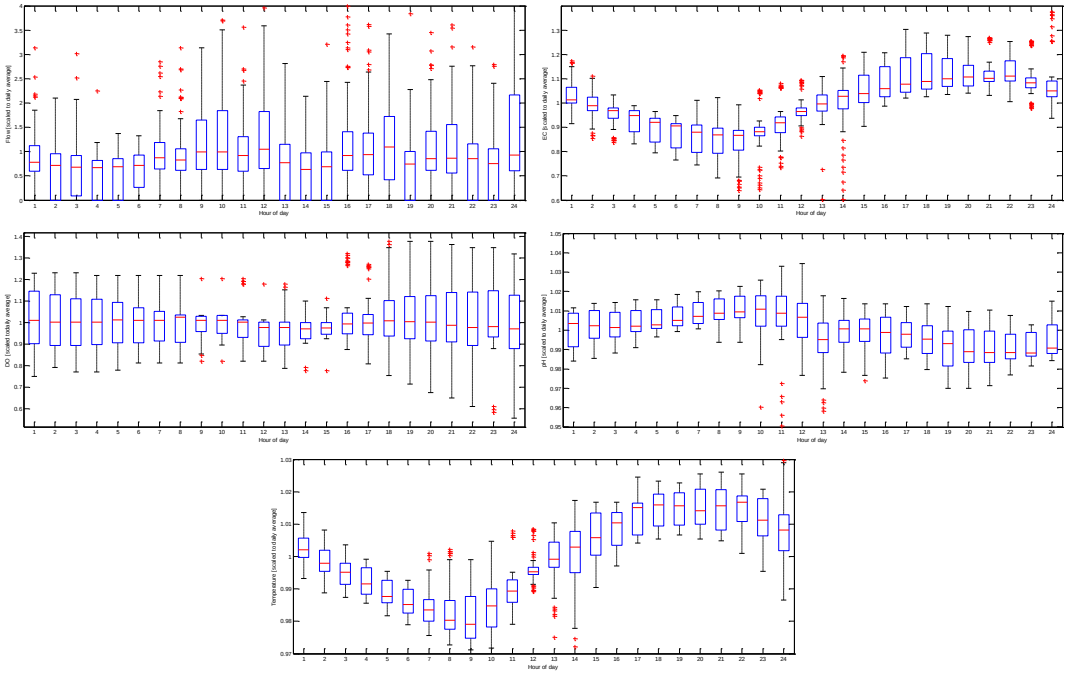

Figure 2.4. The flow and water quality data for the Box Hill site.

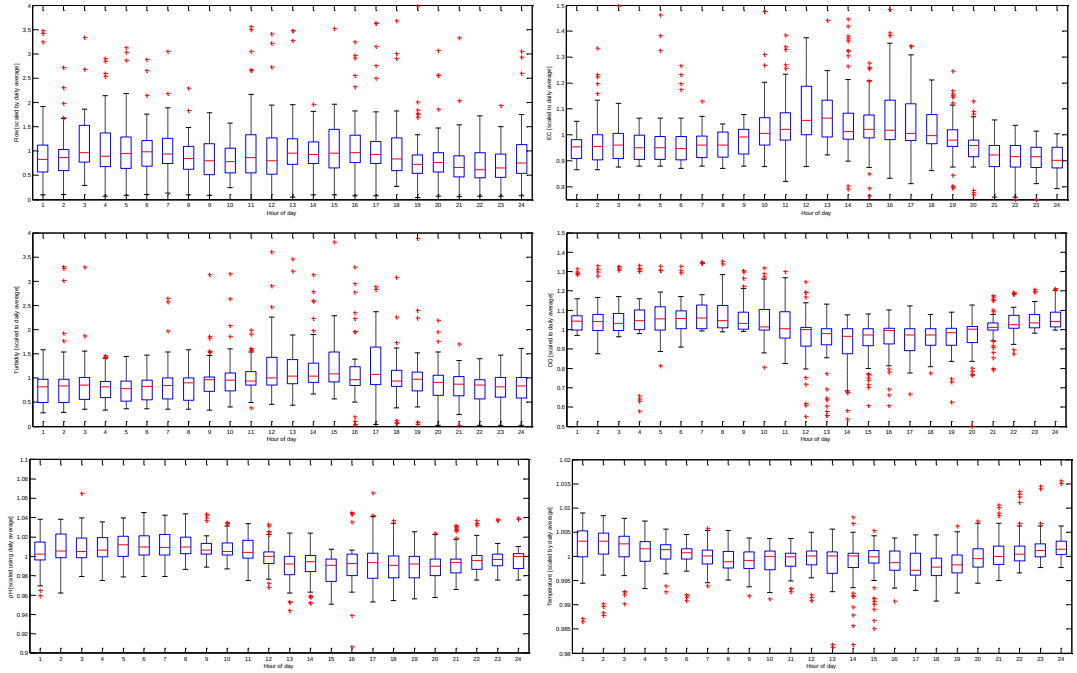

Figure 2.5. The flow and water quality data for the Blackburn site.

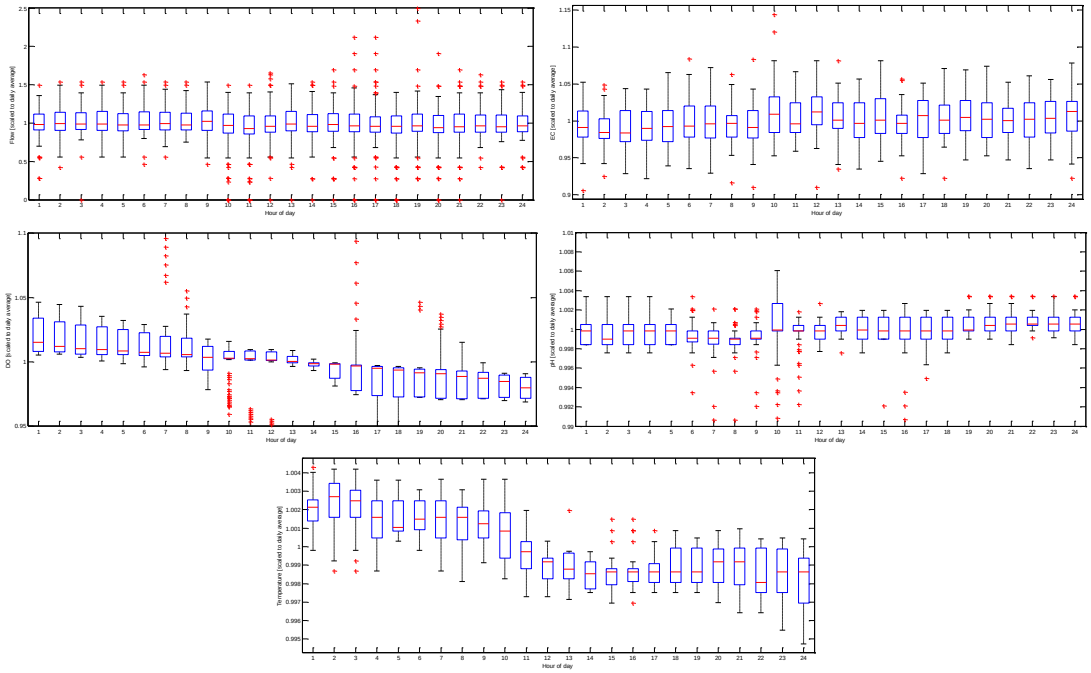

Figure 2.6. The flow and water quality data for the Nunawading site.

Appendix 3 – Dry weather data

Table 3.1. Dry weather sampling results – Residential sites: Hedgeley Dean (part 1). Note: Samples for nitrogen species were only collected on the last 3 days of the sampling week.

Sample name	Date / Time	Comments	Flow (L/s) - approx on site	MICROORGANISMS		TPH					NITROGEN SPECIES			
				E.coli (org/100mL)	Enterococci (org/100mL)	C6-C9 (mg/L)	C10-C14 (mg/L)	C15-C28 (mg/L)	C29-C36 (mg/L)	Total C6-C36 (mg/L)	TN (mg/L)	TDN (mg/L)	NH3 (mg/L)	NOx (mg/L)
HD 1	10/02/2009 7:13	Yellow	N/A	820	520	nd	nd	nd	nd	nd				
HD 2	10/02/2009 13:18	VERY low flow	N/A	110	270	nd	nd	nd	nd	nd				
HD 3	10/02/2009 20:15	Really slow	0.005	290	330	nd	nd	nd	nd	nd				
HD 1	11/02/2009 6:55	Yellow, bit of sediment	0.007	220	1000	nd	nd	nd	nd	nd				
HD 2	11/02/2009 13:15	Very low flow, odourous	0.003	550	980	nd	nd	nd	nd	nd				
HD 3	11/02/2009 20:06	Almost no flow	0.002	200	2400	nd	nd	nd	nd	nd				
HD 1	12/02/2009 6:55	Virtually no flow, bottom sediments came in	0.003	350	490	nd	nd	nd	nd	nd				
HD 2	12/02/2009 13:27	A lot more flow than usual	0.101	4100	9900	nd	nd	nd	nd	nd				
HD 3 *	12/02/2009 20:00	_	0.023	1550	4263	nd	nd	nd	nd	nd				
HD 1	13/02/2009 6:55	Almost no flow	0.009	870	1100	nd	nd	nd	nd	nd				
HD 2	13/02/2009 13:25	No flow	0.002	460	960	nd	nd	nd	nd	nd				
HD 3	13/02/2009 20:03	Very smelly, no flow	0.004	99	690	nd	nd	nd	nd	nd				
HD 1	14/02/2009 6:50	"High" flow, no smell	0.032	820	1600	nd	nd	nd	nd	nd	1.40	1.40	0.005	0.890
HD 2	14/02/2009 13:27	Smelly	0.010	490	13	nd	nd	nd	nd	nd	2.10	2.00	0.010	1.300
HD 3	14/02/2009 19:50	Standard	0.013	1100	1700	nd	nd	nd	nd	nd	2.90	2.70	0.019	1.700
HD 1	15/02/2009 6:52	Odourless	0.016	690	410	nd	nd	nd	nd	nd	2.00	1.70	0.013	1.000
HD 2	15/02/2009 13:23	Smelly, very low flow	0.002	460	240	nd	nd	nd	nd	nd	2.20	1.90	0.033	1.000
HD 3	15/02/2009 19:55	Smelly, very low flow	0.005	150	160	nd	nd	nd	nd	nd	2.40	2.10	0.034	1.700
HD 1	16/02/2009 6:55	_	0.008	110	130	nd	nd	nd	nd	nd	2.90	2.90	0.009	2.000
HD 2	16/02/2009 13:25	Virtually no flow, bottom sediments came in	0.002	110	510	nd	0.02	0.09	nd	0.15	5.90	3.00	0.033	1.900
HD 3	16/02/2009 20:00	Stinks	0.013	210	280	nd	nd	nd	nd	nd	2.40	2.20	0.005	1.500

* Triplicates taken on this round, **N/A** = not available (flow was either too low or too high to capture), **nd** = not detected

Table 3.2. Dry weather sampling results – Residential sites: Hedgeley Dean (part 2). Note: All samples taken were below detection limit for beryllium, mercury, selenium, thallium and tin.

Sample name	Date / Time	METALS																		
		Al (mg/L)	Sb (mg/L)	As (mg/L)	Ba (mg/L)	B (mg/L)	Cd (mg/L)	Cr (mg/L)	Co (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Mn (mg/L)	Mo (mg/L)	Ni (mg/L)	Ag (mg/L)	Sr (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
HD 1	10/02/2009 7:13	0.1	<0.01	<0.01	0.05	<0.2	<0.002	<0.01	<0.01	0.02	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.19	<0.01	<0.01	0.17
HD 2	10/02/2009 13:18	0.2	<0.01	<0.01	0.05	<0.2	<0.002	<0.01	<0.01	0.02	0.3	<0.01	0.01	<0.01	<0.01	<0.01	0.24	<0.01	<0.01	0.16
HD 3	10/02/2009 20:15	0.9	<0.01	0.01	0.05	<0.2	<0.002	<0.01	<0.01	0.03	1.2	0.01	0.07	<0.01	<0.01	<0.01	0.21	0.01	<0.01	0.27
HD 1	11/02/2009 6:55	0.6	<0.01	0.01	0.03	<0.2	<0.002	<0.01	<0.01	0.02	0.8	<0.01	0.02	<0.01	<0.01	<0.01	0.14	0.01	<0.01	0.16
HD 2	11/02/2009 13:15	0.8	<0.01	0.01	0.05	<0.2	<0.002	<0.01	<0.01	0.03	1.8	0.02	0.06	<0.01	<0.01	<0.01	0.18	0.03	<0.01	0.28
HD 3	11/02/2009 20:06	2.5	<0.01	0.01	0.09	<0.2	<0.002	<0.01	<0.01	0.06	5.3	0.05	0.25	<0.01	0.01	<0.01	0.27	0.06	0.01	0.61
HD 1	12/02/2009 6:55	5.9	<0.01	0.01	0.14	<0.2	<0.002	0.01	<0.01	0.09	9.5	0.12	0.70	<0.01	0.02	<0.01	0.27	0.12	0.02	1.40
HD 2	12/02/2009 13:27	0.1	<0.01	<0.01	0.01	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	0.05
HD 3 *	12/02/2009 20:00	<0.1	<0.01	<0.01	0.08	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.20	<0.01	<0.01	0.69
HD 1	13/02/2009 6:55	0.1	<0.01	<0.01	0.05	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.26	<0.01	<0.01	0.10
HD 2	13/02/2009 13:25	1.4	<0.01	<0.01	0.07	<0.2	<0.002	<0.01	<0.01	0.05	2.3	0.03	0.20	<0.01	<0.01	<0.01	0.23	0.02	<0.01	0.42
HD 3	13/02/2009 20:03	<0.1	<0.01	<0.01	0.08	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.41	<0.01	<0.01	0.12
HD 1	14/02/2009 6:50	<0.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.15	<0.01	<0.01	0.08
HD 2	14/02/2009 13:27	<0.1	<0.01	<0.01	0.05	<0.2	<0.002	<0.01	<0.01	0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.25	<0.01	<0.01	0.12
HD 3	14/02/2009 19:50	0.6	<0.01	<0.01	0.07	<0.2	<0.002	<0.01	<0.01	0.03	1.1	<0.01	0.06	<0.01	<0.01	<0.01	0.29	0.01	<0.01	0.24
HD 1	15/02/2009 6:52	0.3	<0.01	<0.01	0.04	<0.2	<0.002	<0.01	<0.01	0.01	0.5	<0.01	0.02	<0.01	<0.01	<0.01	0.17	0.01	<0.01	0.13
HD 2	15/02/2009 13:23	0.6	<0.01	<0.01	0.04	<0.2	<0.002	<0.01	<0.01	0.02	1.2	0.01	0.05	<0.01	<0.01	<0.01	0.16	0.01	<0.01	0.24
HD 3	15/02/2009 19:55	<0.1	<0.01	<0.01	0.05	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.21	<0.01	<0.01	0.09
HD 1	16/02/2009 6:55	0.1	<0.01	<0.01	0.04	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.22	<0.01	<0.01	0.10
HD 2	16/02/2009 13:25	3.1	<0.01	<0.01	0.12	<0.2	<0.002	<0.01	<0.01	0.07	5.1	0.08	0.33	<0.01	0.01	<0.01	0.31	0.07	<0.01	0.81
HD 3	16/02/2009 20:00	0.2	<0.01	<0.01	0.07	<0.2	<0.002	<0.01	<0.01	0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.30	<0.01	<0.01	0.12

* Triplicates taken on this round

Table 3.3. Dry weather sampling results – Residential sites: Lara Street (part 1). Note: Samples for nitrogen species were only collected on the last 3 days of the sampling week.

Sample name	Date / Time	Comments	Flow (L/s) - approx on site	MICROORGANISMS		TPH					NITROGEN SPECIES			
				E.coli (org/100mL)	Enterococci (org/100mL)	C6-C9 (mg/L)	C10-C14 (mg/L)	C15-C28 (mg/L)	C29-C36 (mg/L)	Total C6-C36 (mg/L)	TN (mg/L)	TDN (mg/L)	NH3 (mg/L)	NOx (mg/L)
LS 1	10/02/2009 7:31	Urine colour (cleaned weir)	N/A	3100	2400	nd	nd	nd	nd	nd				
LS 2	10/02/2009 13:40	_	N/A	1100	490	nd	nd	nd	nd	nd				
LS 3	10/02/2009 20:30	_	0.018	3500	530	nd	nd	nd	nd	nd				
LS 1	11/02/2009 7:22	Yellow, high flows	0.201	1100	1000	nd	nd	nd	nd	nd				
LS 2	11/02/2009 13:40	Bad smell, faecal/urine	0.183	2300	780	nd	nd	nd	nd	nd				
LS 3 *	11/02/2009 20:30	_	0.111	2300	770	nd	nd	nd	nd	nd				
LS 1	12/02/2009 7:22	More flow than usual at the start (cleaned weir)	0.337	740	780	nd	nd	nd	nd	nd				
LS 2	12/02/2009 14:00	"just piss", "worst smell yet"	0.303	630	450	nd	nd	nd	nd	nd				
LS 3	12/02/2009 20:30	"pure urine"	0.068	130	74	nd	nd	nd	nd	nd				
LS 1	13/02/2009 7:15	Warm, smells	0.519	450	520	nd	nd	nd	nd	nd				
LS 2	13/02/2009 13:45	Lower flow, marginally less odourous	0.073	24000	4100	nd	nd	nd	nd	nd				
LS 3	13/02/2009 20:24	Very low flow, smelly	0.073	2600	410	nd	nd	nd	nd	nd				
LS 1	14/02/2009 7:12	Extremely warm, pee smell	0.361	330	630	nd	nd	nd	nd	nd	2.40	2.30	0.018	1.200
LS 2	14/02/2009 13:45	Smelly	0.126	140	920	nd	nd	nd	nd	nd	2.70	2.40	0.014	1.600
LS 3	14/02/2009 20:09	Smell - faecal, urine	0.029	43	500	nd	nd	nd	nd	nd	4.30	3.90	0.021	3.300
LS 1	15/02/2009 7:15	Odourless, almost a pleasure	0.192	160	1300	nd	nd	nd	nd	nd	1.90	1.90	0.020	0.960
LS 2	15/02/2009 13:44	stinks like shit' - DB was KB	0.046	9900	2100	nd	nd	nd	nd	nd	9.00	9.30	2.800	3.700
LS 3	15/02/2009 20:22	Really bad smell	0.158	640	390	nd	nd	nd	nd	nd	2.50	2.30	0.038	1.900
LS 1	16/02/2009 7:20	Warm	0.172	310	310	nd	nd	nd	nd	nd	3.00	2.90	0.022	1.500
LS 2	16/02/2009 13:48	Reeks	0.128	3100	2900	nd	nd	nd	nd	nd	3.90	3.20	0.075	2.000
LS 3	16/02/2009 20:24	Urine smell	0.090	800	6500	nd	nd	nd	nd	nd	3.20	2.90	0.160	2.000

* Triplicates taken on this round, **N/A** = not available (flow was either too low or too high to capture), **nd** = not detected

Table 3.4. Dry weather sampling results – Residential sites: Lara Street (part 2). Note: All samples taken were below detection limit for beryllium, mercury, selenium, thallium and tin.

Sample name	Date / Time	METALS																		
		Al (mg/L)	Sb (mg/L)	As (mg/L)	Ba (mg/L)	B (mg/L)	Cd (mg/L)	Cr (mg/L)	Co (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Mn (mg/L)	Mo (mg/L)	Ni (mg/L)	Ag (mg/L)	Sr (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
LS 1	10/02/2009 7:31	0.8	<0.01	0.01	0.04	<0.2	<0.002	<0.01	<0.01	0.02	0.6	<0.01	<0.01	<0.01	<0.01	<0.01	0.20	0.04	<0.01	0.10
LS 2	10/02/2009 13:40	0.6	<0.01	0.01	0.04	<0.2	<0.002	<0.01	<0.01	0.01	0.4	<0.01	<0.01	<0.01	<0.01	<0.01	0.24	0.03	<0.01	0.09
LS 3	10/02/2009 20:30	0.3	<0.01	0.01	0.05	<0.2	<0.002	<0.01	<0.01	0.02	0.4	<0.01	<0.01	<0.01	<0.01	<0.01	0.25	<0.01	<0.01	0.11
LS 1	11/02/2009 7:22	0.9	<0.01	0.02	0.03	<0.2	<0.002	<0.01	<0.01	0.02	0.7	<0.01	<0.01	<0.01	<0.01	<0.01	0.15	0.04	<0.01	0.10
LS 2	11/02/2009 13:40	0.7	<0.01	0.01	0.04	<0.2	<0.002	<0.01	<0.01	0.03	0.7	0.01	0.01	<0.01	<0.01	<0.01	0.15	0.02	<0.01	0.12
LS 3 *	11/02/2009 20:30	0.6	<0.01	<0.01	0.04	<0.2	<0.002	<0.01	<0.01	0.02	0.6	<0.01	<0.01	<0.01	<0.01	<0.01	0.18	<0.01	<0.01	0.11
LS 1	12/02/2009 7:22	0.6	<0.01	<0.01	0.04	<0.2	<0.002	<0.01	<0.01	0.02	0.4	<0.01	<0.01	<0.01	<0.01	<0.01	0.19	0.01	<0.01	0.08
LS 2	12/02/2009 14:00	0.2	<0.01	<0.01	0.02	<0.2	<0.002	<0.01	<0.01	0.02	0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.14	<0.01	<0.01	0.05
LS 3	12/02/2009 20:30	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	0.02	0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.21	<0.01	<0.01	0.07
LS 1	13/02/2009 7:15	0.6	<0.01	0.01	0.06	<0.2	<0.002	<0.01	<0.01	0.02	0.5	<0.01	<0.01	<0.01	<0.01	<0.01	0.26	0.02	<0.01	0.08
LS 2	13/02/2009 13:45	0.2	<0.01	<0.01	0.05	<0.2	<0.002	<0.01	<0.01	0.03	0.3	<0.01	<0.01	<0.01	<0.01	<0.01	0.26	<0.01	<0.01	0.09
LS 3	13/02/2009 20:24	<0.1	<0.01	<0.01	0.10	<0.2	<0.002	<0.01	<0.01	0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.50	0.02	<0.01	0.07
LS 1	14/02/2009 7:12	1.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	0.02	0.6	<0.01	<0.01	<0.01	<0.01	<0.01	0.15	0.04	<0.01	0.08
LS 2	14/02/2009 13:45	0.5	<0.01	0.01	0.04	<0.2	<0.002	<0.01	<0.01	0.03	0.4	<0.01	<0.01	<0.01	<0.01	<0.01	0.21	0.02	<0.01	0.09
LS 3	14/02/2009 20:09	0.3	<0.01	<0.01	0.04	<0.2	<0.002	<0.01	<0.01	0.02	0.3	<0.01	<0.01	<0.01	<0.01	<0.01	0.19	0.02	<0.01	0.07
LS 1	15/02/2009 7:15	0.7	<0.01	0.01	0.02	<0.2	<0.002	<0.01	<0.01	0.02	0.6	<0.01	<0.01	<0.01	<0.01	<0.01	0.12	0.03	<0.01	0.08
LS 2	15/02/2009 13:44	0.6	<0.01	0.01	0.04	<0.2	<0.002	<0.01	<0.01	0.03	0.5	<0.01	<0.01	<0.01	<0.01	<0.01	0.21	0.03	<0.01	0.09
LS 3	15/02/2009 20:22	0.4	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	0.01	0.3	<0.01	<0.01	<0.01	<0.01	<0.01	0.15	0.02	<0.01	0.06
LS 1	16/02/2009 7:20	0.6	<0.01	<0.01	0.04	<0.2	<0.002	<0.01	<0.01	0.02	0.6	<0.01	<0.01	<0.01	<0.01	<0.01	0.20	0.04	<0.01	0.09
LS 2	16/02/2009 13:48	0.2	<0.01	<0.01	0.05	<0.2	<0.002	<0.01	<0.01	0.02	0.3	<0.01	<0.01	<0.01	<0.01	<0.01	0.26	0.01	<0.01	0.06
LS 3	16/02/2009 20:24	0.3	<0.01	<0.01	0.05	<0.2	<0.002	<0.01	<0.01	0.02	0.3	<0.01	<0.01	0.01	<0.01	<0.01	0.26	<0.01	<0.01	0.08

* Triplicates taken on this round

Table 3.5. Dry weather sampling results – Residential sites: Fairfield (part 1). Note: Samples for nitrogen species were only collected on the last 3 days of the sampling week.

Sample name	Date / Time	Comments	Flow (L/s) - approx on site	MICROORGANISMS		TPH					NITROGEN SPECIES			
				E.coli (org/100mL)	Enterococci (org/100mL)	C6-C9 (mg/L)	C10-C14 (mg/L)	C15-C28 (mg/L)	C29-C36 (mg/L)	Total C6-C36 (mg/L)	TN (mg/L)	TDN (mg/L)	NH3 (mg/L)	NOx (mg/L)
FF 1	10/02/2009 8:15	(cleaned weir)	N/A	13000	8800	nd	nd	nd	nd	nd				
FF 2 *	10/02/2009 14:17	Really clean water	N/A	7233	947	nd	nd	nd	nd	nd				
FF 3	10/02/2009 21:03	Yellowish	1.296	31000	29000	nd	0.08	0.11	nd	0.19				
FF 1	11/02/2009 8:11	Very clean	0.773	16000	5000	nd	nd	nd	nd	nd				
FF 2	11/02/2009 14:20	Very clean, odourless	0.332	3700	2200	nd	nd	nd	nd	nd				
FF 3	11/02/2009 21:05	Smelly at opening	0.483	4600	1100	nd	nd	nd	nd	nd				
FF 1	12/02/2009 8:12	Clear, WARM water	0.629	9300	4000	nd	nd	nd	nd	nd				
FF 2	12/02/2009 14:45	clear	0.542	5100	1900	nd	nd	nd	nd	nd				
FF 3	12/02/2009 21:00	High flow, no smell, water sound upstream	0.915	46000	1500	nd	nd	nd	nd	nd				
FF 1	13/02/2009 7:58	Warm, VERY high flow	N/A	4100	3700	nd	nd	nd	nd	nd				
FF 2	13/02/2009 14:25	Clear water, "a pleasure to be here"	0.607	15000	2600	nd	nd	nd	nd	nd				
FF 3	13/02/2009 20:52	Low flow	1.183	3500	1300	nd	nd	nd	nd	nd				
FF 1	14/02/2009 7:52	Standard	2.033	44000	13000	nd	nd	nd	nd	nd	3.00	3.00	0.270	2.000
FF 2	14/02/2009 14:20	Standard	1.833	10000	1700	nd	nd	nd	nd	nd	2.60	2.50	0.025	2.000
FF 3	14/02/2009 20:47	Odourless, low flow	0.632	2000	370	nd	nd	nd	nd	nd	2.60	2.60	0.026	1.900
FF 1	15/02/2009 7:54	_	0.252	920	330	nd	nd	nd	nd	nd	3.20	2.70	0.074	2.000
FF 2	15/02/2009 14:25	Standard, low flow	0.297	9100	2400	nd	nd	nd	nd	nd	2.90	2.00	0.007	1.500
FF 3	15/02/2009 20:53	Clear	1.033	2200	500	nd	nd	nd	nd	nd	2.80	2.40	0.110	2.200
FF 1	16/02/2009 8:17	_	1.550	10000	17000	nd	nd	nd	nd	nd	3.40	3.30	0.220	2.300
FF 2	16/02/2009 14:25	Not whole flow! Too large to capture	0.616	13000	520	nd	nd	nd	nd	nd	4.20	4.00	0.370	2.500
FF 3	16/02/2009 20:53	_	2.067	9800	1800	nd	nd	nd	nd	nd	4.40	4.30	0.170	2.900

* Triplicates taken on this round, **N/A** = not available (flow was either too low or too high to capture), **nd** = not detected

Table 3.6. Dry weather sampling results – Residential sites: Fairfield (part 2). Note: All samples taken were below detection limit for beryllium, mercury, selenium, thallium and tin.

Sample name	Date / Time	METALS																		
		Al (mg/L)	Sb (mg/L)	As (mg/L)	Ba (mg/L)	B (mg/L)	Cd (mg/L)	Cr (mg/L)	Co (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Mn (mg/L)	Mo (mg/L)	Ni (mg/L)	Ag (mg/L)	Sr (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
FF 1	10/02/2009 8:15	0.2	<0.01	<0.01	0.04	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.06	<0.01	<0.01	0.07
FF 2 *	10/02/2009 14:17	0.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	0.08
FF 3	10/02/2009 21:03	0.6	<0.01	<0.01	0.05	<0.2	<0.002	<0.01	<0.01	0.03	0.6	<0.01	0.05	<0.01	<0.01	<0.01	0.07	0.01	<0.01	0.78
FF 1	11/02/2009 8:11	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.06	<0.01	<0.01	0.10
FF 2	11/02/2009 14:20	0.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	0.09
FF 3	11/02/2009 21:05	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	0.06
FF 1	12/02/2009 8:12	0.2	<0.01	<0.01	0.03	<0.2	0.003	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	0.08
FF 2	12/02/2009 14:45	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.06	<0.01	<0.01	0.08
FF 3	12/02/2009 21:00	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	0.06
FF 1	13/02/2009 7:58	0.7	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.6	<0.01	0.01	<0.01	<0.01	<0.01	0.04	0.02	<0.01	0.06
FF 2	13/02/2009 14:25	<0.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	0.06
FF 3	13/02/2009 20:52	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	0.01	<0.01	0.05
FF 1	14/02/2009 7:52	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	0.05
FF 2	14/02/2009 14:20	0.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	0.05
FF 3	14/02/2009 20:47	0.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	0.06
FF 1	15/02/2009 7:54	0.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	0.05
FF 2	15/02/2009 14:25	0.1	<0.01	<0.01	0.02	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	0.06
FF 3	15/02/2009 20:53	0.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	0.06
FF 1	16/02/2009 8:17	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	0.05
FF 2	16/02/2009 14:25	0.2	<0.01	<0.01	0.04	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	0.07
FF 3	16/02/2009 20:53	0.4	<0.01	<0.01	0.04	<0.2	<0.002	<0.01	<0.01	0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.06	<0.01	<0.01	0.08

* Triplicates taken on this round

Table 3.7. Dry weather sampling results – Industrial sites: Box Hill (part 1).

Sample name	Date / Time	Comments	Flow (L/s) - approx on site	MICROORGANISMS		TPH					NITROGEN SPECIES			
				E.coli (org/100mL)	Enterococci (org/100mL)	C6-C9 (mg/L)	C10-C14 (mg/L)	C15-C28 (mg/L)	C29-C36 (mg/L)	Total C6-C36 (mg/L)	TN (mg/L)	TDN (mg/L)	NH3 (mg/L)	NOx (mg/L)
BH 1	12/05/2009 7:11	Used 4 filters!! Seems clean, removed weir	0.037	99	130	nd	0.08	nd	nd	0.08	0.90	0.86	0.170	0.280
BH 2	12/05/2009 11:50	Used 4 filters (lots of fines, but not visually detectable)	0.084	56	120	nd	nd	nd	nd	nd	0.66	0.55	0.055	0.220
BH 3	12/05/2009 16:26	lots of fines in the water (4 filters used)	0.070	2000	<1	0.01	0.25	0.38	nd	0.64	2.30	1.90	0.042	0.100
BH 1	13/05/2009 7:01	3 filters only -> higher flow rate, probably diluted with runoff	0.218	2400	110	nd	0.22	0.17	nd	0.39	1.30	1.00	0.075	0.710
BH 2	13/05/2009 11:40		0.042	270	58	nd	nd	0.07	nd	0.07	0.45	0.32	0.001	0.060
BH 3	13/05/2009 16:35	Less flow	0.044	490	12	nd	0.06	0.22	nd	0.29	1.00	0.86	0.008	0.017
BH 1	14/05/2009 7:00		0.034	6500	29	nd	nd	nd	nd	nd	0.40	0.32	0.013	0.022
BH 2	14/05/2009 11:45		0.071	14000	25	nd	0.04	0.27	nd	0.31	0.64	0.47	0.005	0.024
BH 3	14/05/2009 16:32	Very high flow?	0.067	2800	310	0.02	0.13	0.40	nd	0.54	1.40	1.10	0.007	0.007
BH 1 *	15/05/2009 6:58	Low flow, smelt better	0.029	363	32	0.01	0.12	0.19	0.05	0.36	0.60	0.36	0.016	0.018
BH 2	15/05/2009 11:45	More flow than in the morning	0.086	910	170	nd	0.09	0.25	nd	0.34	1.90	1.60	0.011	0.040
BH 3	16/05/2009 16:42	Very low flow, ponding from last rain event?	0.037	13000	200	0.06	0.86	nd	nd	0.95	0.63	0.47	0.060	0.070
BH 1	17/05/2009 7:05	Only one filter used, ponding from previous rainfall?	0.033	400	82	nd	nd	nd	nd	nd	0.41	0.35	0.036	0.083
BH 2	17/05/2009 11:41	1 filter only, higher flows, rain?	0.049	290	64	nd	0.18	nd	nd	0.18	0.97	0.53	0.033	0.240
BH 3	17/05/2009 16:36	Low flow	0.029	230	39	nd	0.05	nd	nd	0.05	0.50	0.39	0.032	0.110
BH 1	18/05/2009 7:05	Smelly	0.052	1400	17	nd	nd	nd	nd	nd	0.63	0.57	0.046	0.320
BH 2	18/05/2009 11:43		0.181	1100	32	nd	nd	nd	nd	nd	0.90	0.77	0.021	0.350
BH 3	18/05/2009 16:33		0.058	21	41	nd	0.03	0.15	nd	0.18	0.73	0.57	0.014	0.010
BH 1	19/05/2009 7:11	Stinks, 1 filter only	0.090	63	21	nd	0.11	nd	nd	0.11	1.80	1.70	0.046	1.100
BH 2	19/05/2009 11:50	Smells	0.052	870	24	0.01	0.10	0.35	0.05	0.52	0.71	0.59	0.014	0.056
BH 3	19/05/2009 16:30	Very strong hydrocarbon odour, possibly diesel	0.049	2600	<1	0.03	0.20	1.10	0.35	1.7	0.94	0.67	0.011	0.011

* Triplicates taken on this round, **N/A** = not available (flow was either too low or too high to capture), **nd** = not detected

Table 3.8. Dry weather sampling results – Industrial sites: Box Hill (part 2). Note: All samples taken were below detection limit for beryllium, mercury, selenium, thallium and tin.

Sample name	Date / Time	METALS																		
		Al (mg/L)	Sb (mg/L)	As (mg/L)	Ba (mg/L)	B (mg/L)	Cd (mg/L)	Cr (mg/L)	Co (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Mn (mg/L)	Mo (mg/L)	Ni (mg/L)	Ag (mg/L)	Sr (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
BH 1	12/05/2009 7:11	0.1	<0.01	<0.01	0.07	<0.2	<0.002	<0.01	<0.01	0.01	0.6	<0.01	0.06	<0.01	0.05	<0.01	0.11	<0.01	<0.01	0.79
BH 2	12/05/2009 11:50	0.2	<0.01	<0.01	0.04	<0.2	<0.002	<0.01	<0.01	0.03	0.5	<0.01	0.03	<0.01	0.03	<0.01	0.08	<0.01	<0.01	0.57
BH 3	12/05/2009 16:26	0.2	0.01	<0.01	0.10	0.6	<0.002	<0.01	0.01	0.24	2.0	0.03	0.10	0.08	0.33	<0.01	0.11	<0.01	<0.01	2.40
BH 1	13/05/2009 7:01	0.2	<0.01	<0.01	0.05	<0.2	<0.002	<0.01	<0.01	0.02	0.7	<0.01	0.06	<0.01	0.05	<0.01	0.05	<0.01	<0.01	2.00
BH 2	13/05/2009 11:40	0.1	<0.01	<0.01	0.05	<0.2	<0.002	<0.01	<0.01	0.02	0.9	<0.01	0.09	<0.01	0.05	<0.01	0.07	<0.01	<0.01	1.10
BH 3	13/05/2009 16:35	0.3	0.01	<0.01	0.15	<0.2	<0.002	<0.01	0.01	0.10	2.3	<0.01	0.11	0.01	0.27	<0.01	0.10	0.03	<0.01	1.80
BH 1	14/05/2009 7:00	0.2	<0.01	<0.01	0.07	<0.2	<0.002	<0.01	<0.01	0.01	0.9	<0.01	0.06	<0.01	0.07	<0.01	0.10	<0.01	<0.01	0.53
BH 2	14/05/2009 11:45	0.3	<0.01	<0.01	0.11	<0.2	<0.002	<0.01	<0.01	0.08	1.0	<0.01	0.07	0.01	0.07	<0.01	0.09	0.02	<0.01	0.74
BH 3	14/05/2009 16:32	0.2	<0.01	<0.01	0.08	<0.2	<0.002	<0.01	0.01	0.10	1.9	<0.01	0.09	0.01	0.29	<0.01	0.09	0.01	<0.01	1.30
BH 1 *	15/05/2009 6:58	0.3	<0.01	<0.01	0.07	<0.2	<0.002	<0.01	<0.01	0.02	1.2	<0.01	0.07	<0.01	0.09	<0.01	0.10	<0.01	<0.01	0.52
BH 2	15/05/2009 11:45	0.2	<0.01	<0.01	0.09	<0.2	<0.002	<0.01	0.01	0.16	1.5	<0.01	0.07	0.02	0.33	<0.01	0.10	<0.01	<0.01	1.60
BH 3	16/05/2009 16:42	0.3	<0.01	<0.01	0.06	<0.2	<0.002	<0.01	0.05	0.02	1.1	<0.01	0.23	<0.01	0.08	<0.01	0.08	<0.01	<0.01	0.89
BH 1	17/05/2009 7:05	0.2	<0.01	<0.01	0.05	<0.2	<0.002	<0.01	0.01	<0.01	0.7	<0.01	0.07	<0.01	0.03	<0.01	0.09	<0.01	<0.01	0.41
BH 2	17/05/2009 11:41	0.2	<0.01	<0.01	0.06	<0.2	<0.002	<0.01	0.01	<0.01	0.5	<0.01	0.07	<0.01	0.03	<0.01	0.09	<0.01	<0.01	0.95
BH 3	17/05/2009 16:36	0.2	<0.01	<0.01	0.06	<0.2	<0.002	<0.01	<0.01	<0.01	0.6	<0.01	0.06	<0.01	0.03	<0.01	0.09	<0.01	<0.01	0.49
BH 1	18/05/2009 7:05	0.2	<0.01	<0.01	0.06	<0.2	<0.002	<0.01	<0.01	<0.01	0.5	<0.01	0.04	<0.01	0.02	<0.01	0.10	<0.01	<0.01	0.91
BH 2	18/05/2009 11:43	0.1	<0.01	<0.01	0.06	<0.2	<0.002	<0.01	<0.01	0.03	0.8	<0.01	0.04	0.01	0.08	<0.01	0.09	<0.01	<0.01	1.10
BH 3	18/05/2009 16:33	0.2	<0.01	<0.01	0.07	<0.2	<0.002	<0.01	0.01	0.13	0.8	<0.01	0.07	0.04	0.04	<0.01	0.08	<0.01	<0.01	1.20
BH 1	19/05/2009 7:11	<0.1	<0.01	<0.01	0.05	<0.2	<0.002	<0.01	<0.01	0.02	0.4	<0.01	0.04	<0.01	0.03	<0.01	0.08	<0.01	<0.01	2.00
BH 2	19/05/2009 11:50	0.2	0.01	<0.01	0.07	<0.2	<0.002	<0.01	0.01	0.06	1.0	<0.01	0.10	0.05	0.04	<0.01	0.09	<0.01	<0.01	1.80
BH 3	19/05/2009 16:30	0.4	0.02	<0.01	0.13	<0.2	<0.002	<0.01	<0.01	0.15	1.8	<0.01	0.10	0.02	0.04	<0.01	0.09	0.05	<0.01	1.40

* Triplicates taken on this round

Table 3.9. Dry weather sampling results – Industrial sites: Blackburn (part 1).

Sample name	Date / Time	Comments	Flow (L/s) - approx on site	MICROORGANISMS		TPH					NITROGEN SPECIES			
				E.coli (org/100mL)	Enterococci (org/100mL)	C6-C9 (mg/L)	C10-C14 (mg/L)	C15-C28 (mg/L)	C29-C36 (mg/L)	Total C6-C36 (mg/L)	TN (mg/L)	TDN (mg/L)	NH3 (mg/L)	NOx (mg/L)
BB 1	12/05/2009 8:42	Warm water	0.952	980	23	nd	nd	nd	nd	nd	0.36	0.31	<0.001	0.160
BB 2	12/05/2009 12:21		0.418	5000	46	nd	nd	nd	nd	nd	2.70	2.50	1.200	0.420
BB 3	12/05/2009 16:50	Cold water	0.845	1300	15	0.01	0.17	0.08	nd	0.27	1.20	1.20	0.480	0.420
BB 1	13/05/2009 7:22	Higher flow rate than usual… some runoff probably	1.188	2400	46	nd	nd	nd	nd	nd	1.10	0.99	0.048	0.770
BB 2	13/05/2009 12:10		0.818	8200	99	nd	nd	0.19	nd	0.19	1.20	1.00	0.093	0.500
BB 3	13/05/2009 16:50		0.806	5200	53	nd	nd	nd	nd	nd	1.20	1.10	0.290	0.460
BB 1	14/05/2009 7:20		0.781	2800	45	nd	nd	nd	nd	nd	0.40	0.35	0.011	0.170
BB 2	14/05/2009 12:10		0.914	4900	13	nd	nd	nd	nd	nd	0.93	0.87	0.150	0.440
BB 3	14/05/2009 16:48	NO. Sensor was dirty	0.840	1400	24	nd	0.03	0.49	nd	0.53	0.97	0.89	0.099	0.390
BB 1 *	15/05/2009 7:25	Normal	0.554	2100	9	nd	nd	nd	nd	nd	0.30	0.26	0.002	0.153
BB 2	15/05/2009 12:10	Coffee coloured discharge, no odour. Not good	0.386	10000	1600	0.01	0.05	0.11	nd	0.17	5.00	2.00	0.140	0.720
BB 3	16/05/2009 17:06	Low flow, Rat in pipe	0.223	800	74	nd	nd	nd	nd	nd	0.33	0.26	<0.001	0.027
BB 1	17/05/2009 7:26	Very low flow, Ponding from last rain event?	0.200	990	50	nd	nd	nd	nd	nd	0.37	0.32	<0.001	0.130
BB 2	17/05/2009 12:00		0.240	550	30	nd	nd	nd	nd	nd	0.54	0.47	<0.001	0.250
BB 3	17/05/2009 16:56	Clean, warm water	0.203	400	18	nd	nd	nd	nd	nd	0.35	0.33	<0.001	0.120
BB 1	18/05/2009 7:26	High LEL on gas detector	0.224	230	53	nd	nd	nd	nd	nd	0.81	0.53	0.046	0.310
BB 2	18/05/2009 12:07		0.345	130	76	0.06	0.15	nd	nd	0.21	3.00	2.90	0.530	1.600
BB 3	18/05/2009 16:53	No rat	0.200	700	23	nd	0.04	0.13	nd	0.17	2.00	1.80	0.036	0.850
BB 1	19/05/2009 7:30	Warm, low flows?	0.415	320	40	0.05	0.01	nd	nd	0.06	2.00	1.90	0.035	1.500
BB 2	19/05/2009 12:10		0.294	960	14	0.08	0.27	0.06	nd	0.41	2.70	2.60	0.540	1.400
BB 3	19/05/2009 16:50	Dirty, urine coloured	0.350	220	1	0.34	0.58	0.86	0.07	1.80	12.00	11.00	5.200	0.960

* Triplicates taken on this round, **N/A** = not available (flow was either too low or too high to capture), **nd** = not detected

Table 3.10. Dry weather sampling results – Industrial sites: Blackburn (part 2). Note: All samples taken were below detection limit for beryllium, mercury, selenium, thallium and tin.

Sample name	Date / Time	METALS																		
		Al (mg/L)	Sb (mg/L)	As (mg/L)	Ba (mg/L)	B (mg/L)	Cd (mg/L)	Cr (mg/L)	Co (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Mn (mg/L)	Mo (mg/L)	Ni (mg/L)	Ag (mg/L)	Sr (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
BB 1	12/05/2009 8:42	<0.1	<0.01	<0.01	0.01	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	0.12
BB 2	12/05/2009 12:21	0.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	0.02	1.1	<0.01	0.01	<0.01	<0.01	0.07	0.03	<0.01	<0.01	0.33
BB 3	12/05/2009 16:50	0.1	<0.01	<0.01	0.02	<0.2	<0.002	<0.01	<0.01	0.01	0.3	<0.01	<0.01	<0.01	<0.01	0.02	0.03	<0.01	<0.01	0.20
BB 1	13/05/2009 7:22	0.1	<0.01	<0.01	0.02	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	0.78
BB 2	13/05/2009 12:10	<0.1	<0.01	<0.01	0.02	<0.2	<0.002	<0.01	<0.01	<0.01	0.3	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	0.27
BB 3	13/05/2009 16:50	<0.1	<0.01	<0.01	0.02	<0.2	<0.002	<0.01	<0.01	<0.01	0.4	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	0.23
BB 1	14/05/2009 7:20	0.1	<0.01	<0.01	0.01	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	0.11
BB 2	14/05/2009 12:10	0.1	<0.01	<0.01	0.02	<0.2	<0.002	<0.01	<0.01	<0.01	0.3	<0.01	<0.01	<0.01	<0.01	0.01	0.03	<0.01	<0.01	0.15
BB 3	14/05/2009 16:48	0.2	<0.01	<0.01	0.04	<0.2	<0.002	<0.01	<0.01	0.02	0.3	<0.01	0.01	<0.01	<0.01	0.01	0.03	<0.01	<0.01	0.39
BB 1 *	15/05/2009 7:25	0.1	<0.01	<0.01	0.02	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	0.10
BB 2	15/05/2009 12:10	22.0	<0.01	<0.01	0.29	<0.2	<0.002	0.04	0.02	0.08	18.0	0.08	0.18	<0.01	0.03	<0.01	0.03	0.03	0.02	0.32
BB 3	16/05/2009 17:06	<0.1	<0.01	<0.01	0.02	<0.2	<0.002	<0.01	<0.01	<0.01	0.2	<0.01	0.02	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	0.52
BB 1	17/05/2009 7:26	<0.1	<0.01	<0.01	0.02	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	0.01	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	0.37
BB 2	17/05/2009 12:00	<0.1	<0.01	<0.01	0.02	<0.2	<0.002	<0.01	<0.01	<0.01	0.2	<0.01	0.02	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	0.98
BB 3	17/05/2009 16:56	<0.1	<0.01	<0.01	0.02	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	0.01	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	0.51
BB 1	18/05/2009 7:26	<0.1	<0.01	<0.01	0.02	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	0.01	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	0.65
BB 2	18/05/2009 12:07	<0.1	<0.01	<0.01	0.04	<0.2	<0.002	<0.01	<0.01	0.02	0.6	<0.01	0.03	<0.01	<0.01	0.05	0.06	<0.01	<0.01	1.00
BB 3	18/05/2009 16:53	0.2	<0.01	<0.01	0.07	<0.2	<0.002	<0.01	<0.01	0.05	0.7	<0.01	0.03	<0.01	<0.01	0.03	0.04	0.01	<0.01	0.88
BB 1	19/05/2009 7:30	<0.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	0.01	0.2	<0.01	0.02	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	1.40
BB 2	19/05/2009 12:10	<0.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	0.01	0.6	<0.01	0.02	<0.01	<0.01	0.03	0.04	<0.01	<0.01	1.30
BB 3	19/05/2009 16:50	0.5	<0.01	<0.01	0.14	0.5	<0.002	<0.01	<0.01	0.13	1.1	0.01	0.42	0.19	0.01	0.16	0.08	0.03	<0.01	2.80

* Triplicates taken on this round

Table 3.11. Dry weather sampling results – Industrial sites: Nunawading (part 1).

Sample name	Date / Time	Comments	Flow (L/s) - approx on site	MICROORGANISMS		TPH					NITROGEN SPECIES			
				E.coli (org/100mL)	Enterococci (org/100mL)	C6-C9 (mg/L)	C10-C14 (mg/L)	C15-C28 (mg/L)	C29-C36 (mg/L)	Total C6-C36 (mg/L)	TN (mg/L)	TDN (mg/L)	NH3 (mg/L)	NOx (mg/L)
NW 1	12/05/2009 8:10	Clean, warm	1.143	<1	4	nd	nd	nd	nd	nd	0.28	0.28	0.013	0.17
NW 2	12/05/2009 12:47	Hard to get all the flow	1.221	<1	1	nd	nd	nd	nd	nd	0.26	0.23	0.013	0.17
NW 3	12/05/2009 17:20	Leaf on flow sensor	0.733	<1	1	nd	nd	nd	nd	nd	0.26	0.24	0.016	0.14
NW 1	13/05/2009 7:56	Leaf blocking sensor from 5am onwards	1.276	<1	7	nd	nd	nd	nd	nd	0.37	0.33	0.015	0.19
NW 2	13/05/2009 12:35		1.708	<1	1	nd	nd	nd	nd	nd	0.24	0.23	0.011	0.15
NW 3	13/05/2009 17:20	High flow, hard to measure	1.552	<1	<1	nd	nd	nd	nd	nd	0.31	0.29	0.019	0.14
NW 1	14/05/2009 7:48	Too high to measure	N/A	<1	<1	nd	nd	nd	nd	nd	0.23	0.22	0.012	0.13
NW 2	14/05/2009 12:35	Blocked sensor	1.474	6	7	nd	nd	nd	nd	nd	0.22	0.21	0.011	0.14
NW 3	14/05/2009 17:15	Too much flow, Low alarm went off	N/A	4	1	nd	nd	nd	nd	nd	0.25	0.23	0.014	0.13
NW 1	15/05/2009 8:02	Too high, flow sensor working	N/A	<1	1	nd	nd	nd	nd	nd	0.23	0.22	0.011	0.140
NW 2 *	15/05/2009 12:40	Normal, High flows	N/A	1	1	nd	nd	nd	nd	nd	0.24	0.19	0.011	0.108
NW 3	16/05/2009 17:30	Leaf blocking sensor	1.333	<1	1	nd	nd	nd	nd	nd	0.24	0.22	0.011	0.14
NW 1	17/05/2009 7:50		1.300	1	2	nd	nd	nd	nd	nd	0.23	0.24	0.012	0.150
NW 2	17/05/2009 12:40	Stuff over sensor	2.000	1	4	nd	nd	nd	nd	nd	0.24	0.23	0.012	0.140
NW 3	17/05/2009 17:19	Lower flow	2.080	<1	<1	nd	nd	nd	nd	nd	0.25	0.24	0.012	0.150
NW 1	18/05/2009 7:53		0.714	5	1	nd	nd	nd	nd	nd	0.25	0.23	0.012	0.150
NW 2	18/05/2009 12:26		0.773	7	3	nd	nd	nd	nd	nd	0.25	0.23	0.011	0.150
NW 3	18/05/2009 17:17	No leaf	1.915	1	1	nd	nd	nd	nd	nd	0.22	0.15	0.009	0.087
NW 1	19/05/2009 7:52	Flow is working	1.800	5	2	nd	nd	nd	nd	nd	0.32	0.29	0.015	0.180
NW 2	19/05/2009 12:40	No rat	1.840	<1	<1	nd	nd	nd	nd	nd	0.25	0.24	0.013	0.150
NW 3	19/05/2009 17:20		1.574	<1	2	nd	nd	nd	nd	nd	0.21	0.21	0.012	0.130

* Triplicates taken on this round, **N/A** = not available (flow was either too low or too high to capture), **nd** = not detected

Table 3.12. Dry weather sampling results – Industrial sites: Nunawading (part 2). Note: All samples taken were below detection limit for beryllium, mercury, selenium, thallium and tin.

Sample name	Date / Time	METALS																		
		Al (mg/L)	Sb (mg/L)	As (mg/L)	Ba (mg/L)	B (mg/L)	Cd (mg/L)	Cr (mg/L)	Co (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Mn (mg/L)	Mo (mg/L)	Ni (mg/L)	Ag (mg/L)	Sr (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
NW 1	12/05/2009 8:10	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.4	<0.01	0.07	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.07
NW 2	12/05/2009 12:47	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.3	<0.01	0.07	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.06
NW 3	12/05/2009 17:20	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.3	<0.01	0.07	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.05
NW 1	13/05/2009 7:56	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.4	<0.01	0.07	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.22
NW 2	13/05/2009 12:35	0.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.3	<0.01	0.06	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.06
NW 3	13/05/2009 17:20	0.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.3	<0.01	0.06	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.05
NW 1	14/05/2009 7:48	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.4	<0.01	0.06	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.04
NW 2	14/05/2009 12:35	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.3	<0.01	0.06	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.06
NW 3	14/05/2009 17:15	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.4	<0.01	0.07	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.05
NW 1	15/05/2009 8:02	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.4	<0.01	0.08	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.05
NW 2 *	15/05/2009 12:40	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.3	<0.01	0.06	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.04
NW 3	16/05/2009 17:30	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.3	<0.01	0.06	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.06
NW 1	17/05/2009 7:50	0.2	<0.01	<0.01	0.04	<0.2	<0.002	<0.01	<0.01	<0.01	0.3	<0.01	0.07	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.09
NW 2	17/05/2009 12:40	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.3	<0.01	0.06	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.08
NW 3	17/05/2009 17:19	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.3	<0.01	0.06	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.05
NW 1	18/05/2009 7:53	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.4	<0.01	0.07	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.09
NW 2	18/05/2009 12:26	0.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.3	<0.01	0.06	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.07
NW 3	18/05/2009 17:17	0.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.3	<0.01	0.06	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.05
NW 1	19/05/2009 7:52	0.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.3	<0.01	0.06	<0.01	<0.01	<0.01	0.07	<0.01	<0.01	0.18
NW 2	19/05/2009 12:40	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.3	<0.01	0.06	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.07
NW 3	19/05/2009 17:20	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.3	<0.01	0.06	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.06

* Triplicates taken on this round

Table 3.13. Dry weather sampling results – Triplicates and average value for all sites. Note: Samples for nitrogen species were only collected on the last 3 days of the first sampling week (residential sites).

Sample name	Date / Time	Flow (L/s) - approx on site	MICROORGANISMS		TPH					NITROGEN SPECIES			
			E.coli (org/100mL)	Enterococci (org/100mL)	C6-C9 (mg/L)	C10-C14 (mg/L)	C15-C28 (mg/L)	C29-C36 (mg/L)	Total C6-C36 (mg/L)	TN (mg/L)	TDN (mg/L)	NH3 (mg/L)	NOx (mg/L)
HD 3a	12/02/2009 20:00	0.023	790	1500	nd	nd	nd	nd	nd				
HD 3b	12/02/2009 20:00	0.023	830	3100	nd	nd	nd	nd	nd				
HD 3c	12/02/2009 20:00	0.023	930	2100	nd	nd	nd	nd	nd				
HD 3	**12/02/2009 20:00**	**0.023**	**850**	**2233**	**nd**	**nd**	**nd**	**nd**	**nd**				
LS 3a	11/02/2009 20:30	0.110	740	120	nd	nd	nd	nd	nd				
LS 3b	11/02/2009 20:30	0.110	410	170	nd	nd	nd	nd	nd				
LS 3c	11/02/2009 20:30	0.110	410	98	nd	nd	nd	nd	nd				
LS 3	**11/02/2009 20:30**	**0.111**	**520**	**129**	**nd**	**nd**	**nd**	**nd**	**nd**				
FF 2a	10/02/2009 14:17	N/A	7400	1100	nd	nd	nd	nd	nd				
FF 2b	10/02/2009 14:17	N/A	8400	920	nd	nd	nd	nd	nd				
FF 2c	10/02/2009 14:17	N/A	5900	820	nd	nd	nd	nd	nd				
FF 2	**10/02/2009 14:17**	**N/A**	**7233**	**947**	**nd**	**nd**	**nd**	**nd**	**nd**				
BH 1a	15/05/2009 6:58	0.029	310	32	0.01	0.12	0.19	0.05	0.36	0.63	0.35	0.016	0.018
BH 1b	15/05/2009 6:58	0.029	400	28	nd	nd	nd	nd	nd	0.58	0.35	0.017	0.018
BH 1c	15/05/2009 6:58	0.029	380	35	nd	nd	nd	nd	nd	0.59	0.38	0.015	0.018
BH 1	**15/05/2009 6:58**	**0.029**	**363**	**32**	**0.01**	**0.12**	**0.19**	**0.05**	**0.36**	**0.60**	**0.36**	**0.016**	**0.018**
BB 1a	15/05/2009 7:25	0.554	3000	6	nd	nd	nd	nd	nd	0.29	0.26	0.002	0.150
BB 1b	15/05/2009 7:25	0.554	1400	13	nd	nd	nd	nd	nd	0.30	0.26	0.002	0.150
BB 1c	15/05/2009 7:25	0.554	1900	7	nd	nd	nd	nd	nd	0.30	0.27	0.002	0.160
BB 1	**15/05/2009 7:25**	**0.554**	**2100**	**9**	**nd**	**nd**	**nd**	**nd**	**nd**	**0.30**	**0.26**	**0.002**	**0.153**
NW 2a	15/05/2009 12:40	N/A	<1	<1	nd	nd	nd	nd	nd	0.22	0.11	0.009	0.055
NW 2b	15/05/2009 12:40	N/A	<1	1	nd	nd	nd	nd	nd	0.24	0.23	0.012	0.130
NW 2c	15/05/2009 12:40	N/A	1	<1	nd	nd	nd	nd	nd	0.25	0.23	0.013	0.140
NW 2	**15/05/2009 12:40**	**N/A**	**1**	**1**	**nd**	**nd**	**nd**	**nd**	**nd**	**0.24**	**0.19**	**0.0113**	**0.108**

N/A = not available (flow was either too low or too high to capture), **nd** = not detected

Table 3.14. Dry weather sampling results – Triplicates taken at all sites. Note: All samples taken were below detection limit for beryllium, mercury, selenium, thallium and tin.

Sample name	Date / Time	METALS																		
		Al (mg/L)	Sb (mg/L)	As (mg/L)	Ba (mg/L)	B (mg/L)	Cd (mg/L)	Cr (mg/L)	Co (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Mn (mg/L)	Mo (mg/L)	Ni (mg/L)	Ag (mg/L)	Sr (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
HD 3a	12/02/2009 20:00	<0.1	<0.01	<0.01	0.02	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.12	<0.01	<0.01	0.08
HD 3b	12/02/2009 20:00	<0.1	<0.01	<0.01	0.02	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.12	<0.01	<0.01	0.08
HD 3c	12/02/2009 20:00	<0.1	<0.01	<0.01	0.02	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.12	<0.01	<0.01	0.08
HD 3	**12/02/2009 20:00**	**<0.1**	**<0.01**	**<0.01**	**0.02**	**<0.2**	**<0.002**	**<0.01**	**<0.01**	**<0.01**	**<0.2**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**0.12**	**<0.01**	**<0.01**	**0.08**
LS 3a	11/02/2009 20:30	0.4	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	0.02	0.4	<0.01	<0.01	<0.01	<0.01	<0.01	0.17	<0.01	<0.01	0.07
LS 3b	11/02/2009 20:30	0.4	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	0.02	0.4	<0.01	<0.01	<0.01	<0.01	<0.01	0.17	<0.01	<0.01	0.07
LS 3c	11/02/2009 20:30	0.4	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	0.02	0.4	<0.01	<0.01	<0.01	<0.01	<0.01	0.18	<0.01	<0.01	0.08
LS 3	**11/02/2009 20:30**	**0.4**	**<0.01**	**<0.01**	**0.03**	**<0.2**	**<0.002**	**<0.01**	**<0.01**	**0.02**	**0.4**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**0.17333**	**<0.01**	**<0.01**	**0.07**
FF 2a	10/02/2009 14:17	0.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	0.08
FF 2b	10/02/2009 14:17	0.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	0.08
FF 2c	10/02/2009 14:17	0.1	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	0.08
FF 2	**10/02/2009 14:17**	**0.1**	**<0.01**	**<0.01**	**0.03**	**<0.2**	**<0.002**	**<0.01**	**<0.01**	**<0.01**	**<0.2**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**0.05**	**<0.01**	**<0.01**	**0.08**
BH 1a	15/05/2009 6:58	0.3	<0.01	<0.01	0.06	<0.2	<0.002	<0.01	<0.01	0.02	1.2	<0.01	0.07	<0.01	0.14	<0.01	0.1	<0.01	<0.01	0.52
BH 1b	15/05/2009 6:58	0.3	<0.01	<0.01	0.07	<0.2	<0.002	<0.01	<0.01	0.02	1.2	<0.01	0.07	<0.01	0.07	<0.01	0.1	<0.01	<0.01	0.52
BH 1c	15/05/2009 6:58	0.2	<0.01	<0.01	0.07	<0.2	<0.002	<0.01	<0.01	0.02	1.2	<0.01	0.07	<0.01	0.07	<0.01	0.1	<0.01	<0.01	0.51
BH 1	**15/05/2009 6:58**	**0.26667**	**<0.01**	**<0.01**	**0.06667**	**<0.2**	**<0.002**	**<0.01**	**<0.01**	**0.02**	**1.2**	**<0.01**	**0.07**	**<0.01**	**0.09333**	**<0.01**	**0.1**	**<0.01**	**<0.01**	**0.52**
BB 1a	15/05/2009 7:25	0.1	<0.01	<0.01	0.02	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	0.10
BB 1b	15/05/2009 7:25	0.1	<0.01	<0.01	0.02	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	0.10
BB 1c	15/05/2009 7:25	0.1	<0.01	<0.01	0.02	<0.2	<0.002	<0.01	<0.01	<0.01	<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	0.10
BB 1	**15/05/2009 7:25**	**0.1**	**<0.01**	**<0.01**	**0.02**	**<0.2**	**<0.002**	**<0.01**	**<0.01**	**<0.01**	**<0.2**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**0.03**	**<0.01**	**<0.01**	**0.10**
NW 2a	15/05/2009 12:40	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.3	<0.01	0.06	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.04
NW 2b	15/05/2009 12:40	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.3	<0.01	0.06	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.04
NW 2c	15/05/2009 12:40	0.2	<0.01	<0.01	0.03	<0.2	<0.002	<0.01	<0.01	<0.01	0.4	<0.01	0.07	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.05
NW 2	**15/05/2009 12:40**	**0.2**	**<0.01**	**<0.01**	**0.03**	**<0.2**	**<0.002**	**<0.01**	**<0.01**	**<0.01**	**0.33333**	**<0.01**	**0.06333**	**<0.01**	**<0.01**	**<0.01**	**0.08**	**<0.01**	**<0.01**	**0.04**

Appendix 4 – Wet weather data

Table 4.1. Wet weather events collected at Hedgeley Dean. Note: All samples taken were below detection limit for antimony, arsenic, beryllium, boron, cadmium, cobalt, mercury, molybdenum, selenium, silver, thallium and tin. nd = not detected.

					MICROORGANISMS		TPH					METALS											
Event number	Sample name	Date / Time	Flow rate (L/s)	Cumulative flow (kL)	E.coli (org/100mL)	Enterococci (org/100mL)	C6-C9 (mg/L)	C10-C14 (mg/L)	C15-C28 (mg/L)	C29-C36 (mg/L)	Total C6-C36 (mg/L)	Al (mg/L)	Ba (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Mn (mg/L)	Ni (mg/L)	Sr (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)
Event 1	HD 1	5/03/2009 7:50	3.5	60	4600	20000	nd	nd	nd	nd	nd	1.0	0.04	<0.01	0.04	1.2	0.02	0.05	<0.01	0.12	0.04	<0.01	0.41
	HD 2	5/03/2009 8:30	230.7	411	14000	33000	nd	nd	nd	nd	nd	0.7	0.03	<0.01	0.03	1.0	0.01	0.05	<0.01	0.06	0.03	<0.01	0.48
	HD 3	5/03/2009 9:05	135.6	769	33000	22000	nd	nd	nd	nd	nd	0.6	0.03	<0.01	0.03	0.8	0.01	0.05	<0.01	0.06	0.03	<0.01	0.43
	HD 4	5/03/2009 9:25	393.1	1082	55000	21000	nd	nd	nd	nd	nd	1.2	0.04	<0.01	0.03	1.7	0.03	0.05	<0.01	0.03	0.04	<0.01	0.47
	HD 5	5/03/2009 9:40	392.3	1486	24000	19000	nd	nd	nd	nd	nd	0.7	0.02	<0.01	0.03	0.9	0.01	0.04	<0.01	0.03	0.03	<0.01	0.34
	HD 6	5/03/2009 10:00	229.3	1830	16000	44000	nd	nd	nd	nd	nd	0.5	0.02	<0.01	0.02	0.7	0.01	0.03	<0.01	0.04	0.02	<0.01	0.29
	HD 7	5/03/2009 10:30	225.0	2187	20000	24000	nd	nd	nd	nd	nd	0.5	0.02	<0.01	0.02	0.6	<0.01	0.03	<0.01	0.04	0.02	<0.01	0.27
	HD 8	5/03/2009 10:50	200.5	2491	20000	28000	nd	nd	nd	nd	nd	1.1	0.02	<0.01	0.02	0.7	0.01	0.04	<0.01	0.04	0.02	<0.01	0.32
	HD 9	5/03/2009 11:40	97.7	2869	24000	21000	nd	nd	nd	nd	nd	0.5	0.02	<0.01	0.02	0.6	<0.01	0.03	<0.01	0.06	0.02	<0.01	0.33
	HD 10	5/03/2009 12:15	44.8	3033	14000	33000	nd	nd	nd	nd	nd	0.5	0.02	<0.01	0.02	0.5	<0.01	0.03	<0.01	0.07	0.02	<0.01	0.32
Event 2	HD 1	12/03/2009 8:25	160.2	152	120000	39000	nd	0.06	0.23	nd	0.30	1.2	0.03	<0.01	0.04	1.7	0.02	0.05	<0.01	0.05	0.04	<0.01	0.38
	HD 2	12/03/2009 9:25	192.0	520	40000	29000	nd	0.09	0.26	nd	0.34	1.0	0.03	<0.01	0.03	1.3	0.01	0.03	<0.01	0.04	0.04	<0.01	0.30
	HD 3	12/03/2009 9:45	255.5	849	17000	8200	nd	0.12	0.30	nd	0.42	0.9	0.02	<0.01	0.03	1.3	0.02	0.04	<0.01	0.03	0.04	<0.01	0.33
	HD 4	12/03/2009 10:10	189.9	1188	20000	20000	0.01	0.12	0.26	nd	0.39	0.5	0.02	<0.01	0.03	0.9	0.01	0.02	<0.01	0.04	0.02	<0.01	0.29
	HD 5	12/03/2009 10:50	114.9	1556	16000	24000	nd	0.08	0.20	nd	0.29	0.4	0.02	<0.01	0.03	0.7	<0.01	0.02	<0.01	0.06	0.02	<0.01	0.25
	HD 6	12/03/2009 13:40	14.1	1912	20000	20000	nd	0.05	0.14	nd	0.19	0.2	0.03	<0.01	0.02	0.7	<0.01	0.01	<0.01	0.17	<0.01	<0.01	0.23
Event 3	HD 1	14/03/2009 9:35	247.5	75	21000	23000	0.05	0.21	0.37	nd	0.63	4.6	0.10	0.01	0.06	5.9	0.10	0.16	0.01	0.05	0.14	<0.01	0.66
	HD 2	14/03/2009 9:45	975.4	666	21000	24000	0.02	0.11	0.14	nd	0.27	4.2	0.11	0.01	0.06	5.8	0.12	0.15	0.01	0.05	0.13	<0.01	0.62
	HD 3	14/03/2009 9:50	797.8	905	50000	49000	0.02	0.14	0.17	nd	0.33	2.8	0.06	<0.01	0.04	4.1	0.10	0.11	<0.01	0.04	0.09	<0.01	0.49
	HD 4	14/03/2009 10:00	666.2	1278	30000	40000	nd	0.08	0.10	nd	0.18	1.8	0.04	<0.01	0.02	2.4	0.05	0.07	<0.01	0.03	0.06	<0.01	0.27
	HD 5	14/03/2009 10:15	803.5	1930	43000	15000	0.04	0.11	0.12	nd	0.27	1.4	0.03	<0.01	0.01	1.6	0.03	0.04	<0.01	0.02	0.05	<0.01	0.17
	HD 6	14/03/2009 10:20	1296.5	2319	32000	17000	nd	0.14	nd	nd	0.18	1.1	0.02	<0.01	0.02	1.4	0.03	0.04	<0.01	0.02	0.05	<0.01	0.17
	HD 7	14/03/2009 10:45	518.2	3369	66000	17000	nd	0.06	0.11	nd	0.16	0.6	0.01	<0.01	<0.01	0.9	0.01	0.02	<0.01	0.02	0.02	<0.01	0.14
	HD 8	14/03/2009 11:20	225.0	4042	23000	20000	0.05	0.17	0.78	nd	0.99	0.5	<0.01	<0.01	<0.01	0.8	<0.01	0.01	<0.01	0.02	0.02	<0.01	0.13
	HD 9	14/03/2009 11:35	390.2	4378	28000	15000	0.07	0.14	0.15	nd	0.36	0.6	0.01	<0.01	<0.01	0.8	0.01	0.02	<0.01	0.03	0.04	<0.01	0.16
	HD 10	14/03/2009 11:50	393.1	4702	27000	31000	0.02	0.10	0.12	nd	0.24	0.9	0.01	<0.01	<0.01	0.9	<0.01	0.02	<0.01	0.03	0.03	<0.01	0.14
	HD 11	14/03/2009 12:20	155.4	5108	16000	16000	0.03	0.09	0.12	nd	0.24	0.7	0.01	<0.01	<0.01	0.7	<0.01	0.02	<0.01	0.06	0.02	<0.01	0.15
Event 4	HD 1	3/04/2009 11:02	171.7	52	19000	19000	nd	nd	nd	nd	nd	5.4	0.10	0.01	0.07	6.3	0.12	0.17	0.01	0.08	0.16	0.01	0.67
	HD 2	3/04/2009 11:11	599.8	481	73000	31000	nd	nd	nd	nd	nd	3.2	0.07	<0.01	0.04	3.9	0.09	0.11	<0.01	0.05	0.09	<0.01	0.53
	HD 3	3/04/2009 11:20	903.7	919	13000	5000	nd	nd	nd	nd	nd	2.6	0.05	<0.01	0.03	3.1	0.06	0.08	<0.01	0.03	0.07	<0.01	0.38
	HD 4	3/04/2009 11:25	1099.0	1248	15000	7400	nd	nd	nd	nd	nd	1.4	0.03	<0.01	0.02	1.9	0.03	0.04	<0.01	0.03	0.04	<0.01	0.28
	HD 5	3/04/2009 11:33	737.5	1470	21000	13000	nd	nd	nd	nd	nd	1.3	0.03	<0.01	0.02	1.7	0.03	0.04	<0.01	0.03	0.04	<0.01	0.27
	HD 6	3/04/2009 11:47	396.1	1870	31000	13000	nd	nd	nd	nd	nd	0.9	0.02	<0.01	0.02	1.1	0.02	0.03	<0.01	0.03	0.03	<0.01	0.24
	HD 7	3/04/2009 12:09	219.4	2214	21000	9600	nd	nd	nd	nd	nd	0.6	0.02	<0.01	0.02	0.6	0.01	0.02	<0.01	0.04	0.03	<0.01	0.21
	HD 8	3/04/2009 12:55	498.0	2669	22000	8800	nd	nd	nd	nd	nd	3.3	0.05	<0.01	0.03	3.9	0.07	0.09	<0.01	0.03	0.10	<0.01	0.34
	HD 9	3/04/2009 12:58	498.0	2669	12000	21000	nd	nd	nd	nd	nd	1.9	0.03	<0.01	0.02	2.3	0.04	0.06	<0.01	0.03	0.05	<0.01	0.21
	HD 10	3/04/2009 13:02	1356.2	3075	11000	12000	nd	nd	nd	nd	nd	1.9	0.04	<0.01	0.02	2.2	0.06	0.06	<0.01	0.03	0.06	<0.01	0.24
	HD 11	3/04/2009 13:06	1644.5	3569	11000	11000	nd	nd	nd	nd	nd	0.8	0.02	<0.01	0.01	0.9	0.02	0.02	<0.01	0.02	0.04	<0.01	0.13
	HD 12	3/04/2009 13:11	1330.2	3968	24000	8100	nd	nd	nd	nd	nd	1.6	0.03	<0.01	0.02	2.2	0.05	0.05	<0.01	0.03	0.05	<0.01	0.26
	HD 13	3/04/2009 13:18	785.9	4204	13000	16000	nd	nd	nd	nd	nd	1.0	0.02	<0.01	0.02	1.2	0.02	0.03	<0.01	0.02	0.03	<0.01	0.19
	HD 14	3/04/2009 13:27	646.8	4619	14000	5500	nd	nd	nd	nd	nd	0.7	0.01	<0.01	0.01	0.7	0.01	0.02	<0.01	0.02	0.03	<0.01	0.18
	HD 15	3/04/2009 13:43	389.3	4987	14000	8600	nd	nd	nd	nd	nd	0.6	0.02	<0.01	0.01	0.5	0.01	0.03	<0.01	0.03	0.02	<0.01	0.15
	HD 16	3/04/2009 14:00	175.7	5258	19000	7900	nd	nd	nd	nd	nd	0.7	0.02	<0.01	0.01	0.5	<0.01	0.01	<0.01	0.05	0.03	<0.01	0.18

Table 4.2. Wet weather events collected at Nunawading. Note: All samples taken were below detection limit for TPHs, and for antimony, arsenic, beryllium, boron, cadmium, cobalt, mercury, molybdenum, nickel, selenium, silver, thallium, tin and vanadium. Only event 1 and 2 were analysed for nitrogen species.

					MICROORGANISMS		NITROGEN SPECIES				METALS									
Event number	Sample name	Date / Time	Flow rate (L/s)	Cumulative flow (kL)	E.coli (org/100mL)	Enterococci (org/100mL)	TN (mg/L)	TDN (mg/L)	NH3 (mg/L)	NOx (mg/L)	Al (mg/L)	Ba (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Mn (mg/L)	Sr (mg/L)	Ti (mg/L)	Zn (mg/L)
Event 1	NW 1	27/05/2009 21:08	15.1	28	2000	140	0.66	0.55	0.070	0.270	0.5	0.02	<0.01	0.01	0.7	<0.01	0.03	0.03	0.02	1.40
	NW 2	27/05/2009 22:18	41.8	61	730	250	1.50	0.40	0.100	0.150	1.0	0.07	<0.01	0.03	2	0.02	0.05	0.02	0.03	1.20
	NW 3	27/05/2009 22:31	33.6	109	1300	370	0.49	0.33	0.036	0.190	0.3	0.02	<0.01	<0.01	0.4	<0.01	0.02	0.02	0.01	0.87
	NW 4	27/05/2009 23:20	20.5	149	240	180	0.44	0.35	0.038	0.200	0.2	0.01	<0.01	<0.01	0.2	<0.01	0.02	0.02	<0.01	1.40
Event 2	NW 1	2/06/2009 22:14	2.4	11	2	1	2.40	1.30	0.070	1.100	0.4	0.04	<0.01	0.06	2.3	0.02	0.07	0.05	0.01	3.90
	NW 2	2/06/2009 22:36	10.7	23	11	13	1.30	1.00	0.100	0.740	0.3	0.07	<0.01	0.01	0.73	<0.01	0.03	0.04	<0.01	2.20
	NW 3	2/06/2009 22:55	23.9	46	120	41	0.83	0.57	0.097	0.330	0.3	0.04	<0.01	0.01	0.64	<0.01	0.02	0.02	0.01	1.60
	NW 4	2/06/2009 23:26	4.2	63	200	37	0.63	0.42	0.024	0.240	0.2	0.02	<0.01	<0.01	0.2	<0.01	0.03	0.04	<0.01	0.84
	NW 5	3/06/2009 1:17	7.3	83	220	37	0.52	0.41	0.001	0.280	0.1	0.02	<0.01	<0.01	<0.2	<0.01	0.03	0.04	<0.01	1.60
	NW 6	3/06/2009 2:30	2.3	103	140	25	0.37	0.29	0.007	0.180	0.1	0.03	<0.01	<0.01	<0.2	<0.01	0.04	0.06	<0.01	0.75
Event 3	NW 1	9/06/2009 9:02	20.5	43	16	32					0.2	0.05	<0.01	<0.01	<0.2	<0.01	0.01	0.02	0.01	1.70
	NW 2	9/06/2009 9:26	11.4	65	140	460					0.2	0.01	<0.01	<0.01	<0.2	<0.01	0.01	0.02	<0.01	1.20
	NW 3	9/06/2009 10:21	3.3	84	130	1000					0.2	0.02	<0.01	<0.01	<0.2	<0.01	0.04	0.04	<0.01	1.00
	NW 4	9/06/2009 11:57	26.1	139	88	1100					0.3	0.02	<0.01	<0.01	0.3	<0.01	0.01	0.01	0.01	1.00
	NW 5	9/06/2009 12:22	21.8	176	110	1100					0.2	<0.01	<0.01	<0.01	<0.2	<0.01	0.01	0.01	<0.01	1.10
	NW 6	9/06/2009 12:57	3.3	194	110	1300					0.2	0.02	<0.01	<0.01	0.2	<0.01	0.02	0.03	<0.01	0.69
Event 4	NW 1	9/06/2009 21:56	9.8	19	160	100					0.3	0.02	<0.01	<0.01	0.3	<0.01	0.03	0.04	<0.01	1.40
	NW 2	9/06/2009 22:57	19.2	39	71	180					0.2	0.04	<0.01	<0.01	0.2	<0.01	0.02	0.02	<0.01	1.50
	NW 3	9/06/2009 23:25	19.9	60	63	82					0.2	0.02	<0.01	<0.01	0.2	<0.01	0.02	0.02	<0.01	1.70
	NW 4	9/06/2009 23:44	28.2	85	320	550					0.2	0.01	<0.01	<0.01	<0.2	<0.01	0.02	0.02	<0.01	0.82
	NW 5	10/06/2009 0:37	6.4	119	170	72					0.1	0.02	<0.01	<0.01	<0.2	<0.01	0.02	0.03	<0.01	2.00
	NW 6	10/06/2009 0:58	20.4	147	410	440					0.1	0.01	<0.01	<0.01	<0.2	<0.01	0.02	0.02	<0.01	1.00
	NW 7	10/06/2009 1:27	30.6	177	190	440					0.1	0.02	<0.01	<0.01	<0.2	<0.01	0.01	0.02	<0.01	1.10
	NW 8	10/06/2009 1:47	48.4	216	370	690					0.2	0.02	<0.01	<0.01	<0.2	<0.01	0.02	0.02	<0.01	1.00
	NW 9	10/06/2009 2:05	23.1	260	370	650					0.1	0.01	<0.01	<0.01	<0.2	<0.01	0.02	0.03	<0.01	0.80
	NW 10	10/06/2009 2:24	41.9	283	550	1400					0.4	0.03	<0.01	<0.01	0.4	<0.01	0.02	0.01	<0.01	0.83
	NW 11	10/06/2009 2:44	26.8	330	820	2400					0.3	0.02	<0.01	<0.01	0.3	0.01	0.02	0.01	<0.01	1.10
	NW 12	10/06/2009 3:13	13.4	387	330	980					0.2	0.02	<0.01	<0.01	0.2	<0.01	0.02	0.03	<0.01	1.10
	NW 13	10/06/2009 3:42	60.0	432	410	1700					0.5	0.02	<0.01	<0.01	0.5	0.01	0.02	0.01	0.01	0.72
	NW 14	10/06/2009 4:03	44.5	481	520	2400					0.5	0.02	<0.01	<0.01	0.4	<0.01	0.02	0.02	0.01	0.81
	NW 15	10/06/2009 4:35	26.3	539	410	2600					0.4	0.01	<0.01	<0.01	0.3	<0.01	0.01	0.02	<0.01	0.82
	NW 16	10/06/2009 6:28	33.7	593	340	840					0.3	0.01	<0.01	<0.01	0.2	<0.01	0.01	0.02	<0.01	0.86
	NW 17	10/06/2009 10:20	11.2	660	170	440					0.3	0.03	<0.01	<0.01	0.3	<0.01	0.02	0.03	<0.01	1.00

Appendix 5 – Correlation analysis using dry weather data

Table 5.1. Statistically significant (i.e. p>0.05) correlation coefficients (R) between water quality pollutants monitored during dry weather periods (part 1 of 2). Correlation coefficients are presented for each of the six study sites, separated by solidi in the following order: $\frac{\text{Hedgeley Dene / Lara Street / Fairfield}}{\text{Box Hill / Blackburn / Nunawading}}$.

	Ba (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Mn (mg/L)	Ni (mg/L)	Ag (mg/L)
Al (mg/L)	0.88 / ---- / 0.53 0.61 / 0.9 / ----	0.94 / ---- / ---- ---- / ---- / ----	0.98 / 0.86 / ---- 0.47 / 0.99 / ----	0.98 / ---- / ---- ---- / ---- / ----	0.99 / ---- / ---- ---- / ---- / 0.46	---- / ---- / ---- ---- / ---- / ----	---- / ---- / ---- ---- / 0.83 / ----
Ba (mg/L)		0.9 / ---- / ---- 0.62 / 0.72 / ----	0.92 / ---- / ---- 0.81 / 0.91 / ----	0.98 / ---- / ---- ---- / ---- / ----	0.93 / ---- / ---- ---- / 0.66 / ----	---- / ---- / ---- 0.53 / ---- / ----	---- / ---- / ---- ---- / 0.85 / ----
Co (mg/L)		---- / ---- / ---- ---- / ---- / ----	---- / ---- / ---- ---- / ---- / ----	---- / ---- / ---- ---- / ---- / ----	---- / ---- / ---- 0.95 / ---- / ----	---- / ---- / ---- ---- / ---- / ----	---- / ---- / ---- ---- / ---- / ----
Cu (mg/L)			0.95 / ---- / ---- 0.7 / ---- / ----	0.96 / ---- / ---- ---- / ---- / ----	0.94 / ---- / ---- ---- / 0.95 / ----	---- / ---- / ---- 0.67 / ---- / ----	---- / ---- / ---- ---- / 0.87 / ----
Fe (mg/L)				0.97 / ---- / ---- ---- / ---- / ----	0.97 / ---- / ---- 0.44 / ---- / 0.6	---- / ---- / ---- 0.81 / ---- / ----	---- / ---- / ---- ---- / 0.83 / ----
Pb (mg/L)					0.97 / ---- / ---- ---- / ---- / ----	---- / ---- / ---- ---- / ---- / ----	---- / ---- / ---- ---- / ---- / ----
Mn (mg/L)						---- / ---- / ---- ---- / ---- / ----	---- / ---- / ---- ---- / 0.92 / ----
Mo (mg/L)						---- / ---- / ---- ---- / ---- / ----	---- / ---- / ---- ---- / ---- / ----
Ni (mg/L)							---- / ---- / ---- ---- / ---- / ----

Table 5.2. Statistically significant (i.e. p>0.05) correlation coefficients (R) between water quality pollutants monitored during dry weather periods (part 2 of 2).

	Sr (mg/L)	Ti (mg/L)	Zn (mg/L)	*E. coli* (org/100mL)	Enterococci (org/100mL)	Total C6-C36 (mg/L)
	---- / -0.47 / ----	0.98 / 0.72 / ----	0.99 / 0.45 / 0.54	---- / ---- / ----	---- / ---- / 0.49	---- / ---- / ----
Al (mg/L)	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----	0.44 / 0.82 / ----	---- / 0.99 / ----	0.7 / ---- / ----
	0.68 / 0.95 / 0.7	0.92 / ---- / ----	0.86 / ---- / 0.7	---- / ---- / ----	---- / ---- / 0.56	---- / ---- / ----
Ba (mg/L)	0.43 / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / 0.47 / ----	---- / 0.88 / ----	---- / ---- / ----
	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----
Co (mg/L)	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----	0.97 / ---- / ----	---- / ---- / ----	0.76 / ---- / ----
	---- / ---- / ----	0.92 / ---- / ----	0.95 / 0.44 / ----	---- / 0.45 / ----	---- / ---- / ----	---- / ---- / ----
Cu (mg/L)	---- / ---- / ----	---- / ---- / ----	0.53 / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / 0.74 / ----
	---- / ---- / ----	0.98 / 0.67 / ----	0.98 / 0.7 / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----
Fe (mg/L)	---- / ---- / ----	---- / ---- / ----	0.45 / ---- / ----	---- / 0.63 / ----	---- / 0.99 / ----	0.5 / ---- / ----
	0.78 / ---- / ----	0.98 / ---- / ----	0.98 / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----
Pb (mg/L)	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----
	---- / ---- / ----	0.96 / ---- / ----	0.99 / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----
Mn (mg/L)	---- / 0.7 / ----	---- / ---- / ----	---- / 0.72 / ----	0.53 / ---- / ----	---- / ---- / ----	0.52 / 0.85 / ----
	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----
Mo (mg/L)	---- / ---- / ----	---- / ---- / ----	0.72 / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----
	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----
Ni (mg/L)	---- / ---- / ----	---- / ---- / ----	0.49 / ---- / ----	---- / ---- / ----	0.5 / ---- / ----	---- / ---- / ----
	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----
Ag (mg/L)	---- / 0.83 / ----	---- / ---- / ----	---- / 0.86 / ----	---- / ---- / ----	---- / ---- / ----	---- / 0.91 / ----
		---- / ---- / ----	---- / ---- / 0.59	-0.58 / ---- / ----	-0.5 / ---- / 0.53	---- / ---- / ----
Sr (mg/L)		---- / ---- / ----	---- / 0.88 / -0.49	---- / -0.47 / ----	---- / ---- / ----	---- / 0.76 / ----
			0.97 / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----
Ti (mg/L)			---- / ---- / ----	---- / ---- / ----	---- / ---- / ----	---- / ---- / ----
				---- / ---- / ----	---- / ---- / 0.77	---- / ---- / ----
Zn (mg/L)				---- / ---- / ----	---- / ---- / 0.5	---- / 0.77 / ----
E. coli					0.93 / 0.45 / 0.48	---- / ---- / ----
(org/100mL)					---- / 0.65 / ----	---- / ---- / ----

Appendix 6 – Analysis for number of dry weather samples required to predict weekly, monthly and yearly dry weather loads.

An in-depth analysis was conducted for this report to determine the number of samples required to accurately estimate dry weather event loads using data obtained from continuous turbidity measurements in a separate storm sewer in France. The following outlines how this data was used to determine appropriate dry weather sampling regimes. This data consisted of turbidity levels and flow rates logged at 2 minute intervals. The data was first cleaned by removing all wet weather events (since it was the aim to investigate dry weather periods only). Using this data, samples were selected using two sampling methodologies: random and systematic. These methodologies were applied to estimate the number of samples required to accurately determine: daily loads, weekly loads, monthly loads and yearly loads.

Firstly, let's use daily loads as an example. When using the random sampling method, up to 100 discrete samples were randomly selected from each day and these samples were then used to estimate the daily load using a flow-weighted approach. This was repeated for each day of the dataset (over two years). Using systematic sampling, up to 100 samples were selected with equal intervals and then used to estimate the daily load using a flow-weighted approach. The resultant 'actual' loads (calculated by using the entire continuous dataset) were then compared to the estimated load calculated using the randomly or systematically selected samples.

To present the results, ratios were calculated (estimated/'actual') and 95% confidence intervals were determined using these ratios. As such, plots were created with 'number of samples per period' on the x-axis and the ratios on the y-axis show how the estimated loads deviate from the 'actual' loads with a 95% level of confidence.

The results of the above methodology are shown in Figure 17 and Table 8. Figure 17 clearly demonstrates that in order to estimate daily loads to within 50% of their actual values (with a 95% confidence level), it is necessary to take a large number of samples per day (i.e. 21). However, as the time period of interest decreases (i.e. if we are only interested in weekly load predictions, instead of daily), then the number of samples required per day decreases with only around 9-10 being required each day (or 67 per week). This pattern continues for both monthly and yearly loads, with the latter requiring less than one sample every second week for an estimate which has a 95% probability of being within 50% of the actual load.

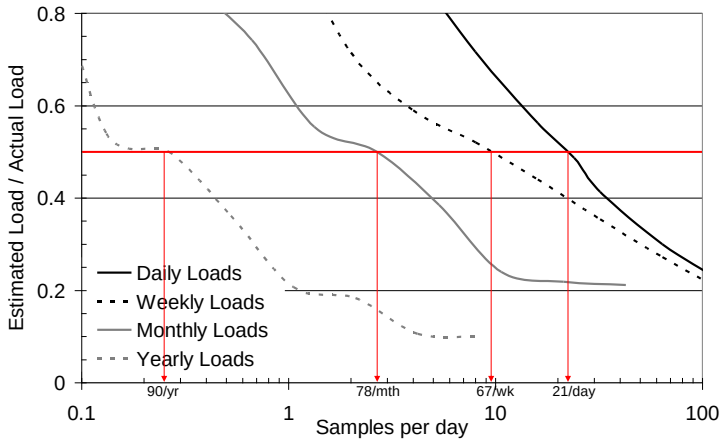

Figure 17. A graph showing the 95% deviation from the actual load as a function of the number of samples taken per day.

Table 8 compares the differences between systematically taking samples and randomly taking samples. It is evident that the number of samples required to estimate the load (to within 50% of its actual value) is decreased by at least 20% when taking samples in a systematic way (i.e. every fourth hour, etc.). This is logical since it is more likely for the sampler to capture the time period's variations when taking samples with equal intervals, as opposed to a method where all samples for a time period could be taken in a section with unusually high, or low, turbidity levels. Furthermore, it is interesting to note that as the time period of interest increases (from daily to yearly) the benefit of taking systematic samples decreases. Although there is a trend, the biggest benefit is seen for the weekly time period (not daily), and this is hypothesised to be due to the variation between days (which the weekly period needs to capture) being much greater than the variation within days (which the daily period needs to capture). In fact, when analysing the data, this is exactly what was found with an average relative standard deviation of the within-day variations in turbidity of 72% whilst the relative standard deviation of the between-day variation in turbidity was over 197%.

Table 8. The number of randomly and systematically taken samples required to estimate the load to within 50% of its actual value, with 95% confidence.

Time period	Number of samples (per time period)		Number required for random / systematic	Within / Between
	Random	Systematic		
Yearly	90	75	1.2	246 / 30
Monthly	78	62	1.3	152 / 69
Weekly	67	35	1.9	122 / 94
Daily	21	15	1.4	72 / 197

It should be noted that while the above analyses do suggest a high number of samples for the prediction of daily, weekly, monthly and yearly loads, it is possible to reduce the total number of samples analysed in the laboratory by using composite sampling methodologies. Taking daily loads as an example, while 15 samples should be taken systematically each day to achieve a load estimation to within 50% of the 'true' load, some of these samples could be combined using a flow-weighted approach. In fact, if testing for traditional pollutants, which do not experience significant die-off or alterations during an entire day's worth of sampling, then all 15 samples could be complied into just one sample. Similar reductions in samples analysed could be made for weekly sampling methodologies, however to a lesser degree because of storage issues.

Appendix 7 – Publication from research

Effective monitoring and assessment of contaminants impacting the mid to lower Yarra catchments – Temporal Scale Assessment
McCarthy, D.T., Lewis, J.F. and Bratieres, K.

Presented at the Water Sensitive Urban Design Conference

Perth, May 5 – 8, 2009

EFFECTIVE MONITORING AND ASSESSMENT OF CONTAMINANTS IMPACTING THE MID TO LOWER YARRA CATCHMENTS – TEMPORAL SCALE ASSESSMENT

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Abstract

The paper assesses the variability of a number of bacterial indicators, heavy metals and hydrocarbons in dry and wet weather urban stormwater flows. Using the collected data, several modelling techniques were employed to determine the accuracy of different sampling methodologies. The results indicate that using just one sample per day is often not enough to characterise weekly loads, however it may be sufficient for monthly estimations. The paper indicates that the number of samples required for accurate load estimations is dependent on the pollutant's variability. This was also the case for wet weather events, where pollutants with a high variability required many samples to be taken during an event, whilst a pollutant which varied only slightly required fewer samples for similar accuracies. Finally, dry and wet weather loads were compared and, as expected, the contributions from wet weather flows make up the majority of total annual loads. The estimated total annual iron load from a 160ha catchment was over 400kg, whilst the annual load of *E. coli* delivered to downstream systems was equivalent to that found in 2,500kg of human faeces. These results reiterate the need for WSUD technologies which can adequately treat traditionally monitored pollutants (such as sediment and nutrients) but also heavy metals and pathogens.

Introduction

Characterising pollutant concentrations and loads in/from urban stormwater drains during dry and wet weather periods is important for a number of reasons, including: assessing and improving WSUD treatment technologies, assessing the impacts of stormwater runoff on downstream systems and for modelling purposes. However, in order to accurately characterise pollutant loads and concentrations, accurate monitoring methodologies must be used.

The sampling of dry weather urban stormwater flows is often conducted using a 'grab' sampling methodology (e.g. Leecaster et al., 2002; Fletcher & Deletic, 2007; Francey et al, *in press*). Furthermore, 'grab' sampling of wet weather flows in urban systems is often conducted and used in the literature to characterise a site's pollution level (e.g. Eleria and Vogel, 2005; Fletcher & Deletic, 2007; Soonthornnonda and Christensen, 2008). In fact, most bacterial and toxicant sampling in rivers and drains conducted by the Victorian Environment Protection Authority is from a single sampling point using a 'grab' sample methodology. The adequacy of such a sampling methodology is dependent on a number of factors, including: the pollutant's variability, the frequency of the sampling and the corresponding time period which is being characterised (i.e. are daily, weekly, monthly or annual loads being characterised?).

The aim of this paper is to help assess the adequacy of 'grab' sampling methodologies for dry and wet weather pollutant load characterisation. The paper will determine the temporal variability of *Escherichia coli*, enterococci, heavy metals and Total Petroleum Hydrocarbons (TPHs) during dry and wet weather events. The paper will also address several minor research questions, including: (1) Can weekly dry weather pollutant loads be estimated using

one sample per day? (2) Can total wet weather pollutant loads be estimated using one, two, three or four samples per event? and (3) How important is monitoring dry weather events/wet weather events for annual load estimations?

Method

Catchments and equipment

Three residential sites around Melbourne were selected based upon previous knowledge of faecal contamination at these sites (Table 1). A Doppler based flow meter (HACH 910) and a water quality probe (Greenspan CS304) were installed in the invert of each catchment's outlet pipe and both logged at 6 minute intervals. At the Hedgeley Dene site, automatic samplers were also installed to allow the monitoring of wet weather events.

Dry weather sampling

At all sites, dry weather sampling was conducted. For seven consecutive days, three samples were withdrawn from the inverts of the outlet pipes at different times of the day (21 samples in total from each site). Sampling times were estimated from a preliminary study which used the installed water quality probe measurements and flow rates to identify times of peak pollutant levels. However, safety of water quality sampling staff and laboratory closures also had to be considered when deciding on sampling times. In summary, depending on the site, samples were withdrawn from the pipes in the morning (7-8am), in the afternoon (1-2pm) and in the evening (8-9pm) on each of the 7 days.

Table 1. Site characteristics.

Site	Land-use	Catchment area [ha]	Approx. catchment imperviousness [%]
Hedgeley Dene Main Drain	Medium density residential	160	45%
Lara Street Main Drain	Medium density residential	110	55%
Fairfield Main Drain	Medium to high density residential	337	68%

After collection, each sample was iced during transport to NATA accredited laboratories. Evening samples were refrigerated overnight and delivered to the laboratory the next morning (<12 hours after collection). Each sample was analysed for the following: *E. coli*, enterococci, aluminium, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, thallium, tin, titanium, vanadium and zinc and Total Petroleum Hydrocarbons.

On one occasion at each site, extra sample volume was collected to allow for triplicate sampling. Once the sample was withdrawn, it was decanted into three separate bottles, filling each bottle a maximum of 50mL during each rotation. This procedure ensured that each sample was a replicate of each other and these three samples could then be used to assess the uncertainty in the laboratories' analytical methodologies (McCarthy et al, 2008).

Wet weather sampling

The Hedgeley Dene site was also monitored for wet weather events and autosamplers withdrew samples using constant flow weighted intervals. Samples were collected after the storm had finished and taken to the laboratory on ice for analysis for the same constituents listed above. In total, three wet weather events were monitored during this program with 6, 10 and 11 samples taken during each event.

Analysis of results to assess research questions

Can weekly dry weather pollutant loads be estimated using one sample per day?

To answer this question, the results from the dry weather monitoring program were used from each of the three sites. One sample was randomly selected from the three available samples for each day. This was repeated for each of the seven days of the week and these seven samples were used to estimate the weekly pollutant load by multiplying the total volume each day by the corresponding sample concentration. The total of the seven loads is referred to as the 'estimated' weekly pollutant load. This process was repeated 100 times to capture most of the possible pollutant concentration combinations. These 100 'estimated' pollutant loads were compared to the pollutant load calculated when using all samples collected during the monitoring program (referred to as 'actual' weekly load). Ratios of 'estimated' to 'actual' pollutant loads were used to estimate the amount of error in the 'estimated' load. In total, 100 ratios were calculated for each pollutant at each study site and the results are presented using boxplots.

Can total wet weather pollutant loads be estimated using one, two, three or four samples per event?

The wet weather data collected from the three events captured at the Hedgeley Dene site was used to assess this question. Using the 'three samples per event' as an example, we randomly selected three samples from each wet weather event using a uniform distribution. These three samples were then averaged and multiplied by the total event volume to achieve a total event load. The summed loads from the three events (known as the 'estimated' total load) were then compared to the loads calculated using all of the samples collected within the events (referred to as 'actual' wet weather event load). This 'actual' event load is estimated using a flow-weighted approach. The process was repeated 500 times to ensure that most possible combinations were captured. Once again, boxplots of ratios between 'estimated' and 'actual' total wet weather loads are presented.

How important is monitoring dry weather events/wet weather events for annual load estimations?

Using the 'actual' dry weather and wet weather loads it was possible to extrapolate this data to estimate the approximate contribution of each to total annual pollutant loads. To obtain annual dry weather pollutant loads, it was assumed that the monitored week is representative of the pollutant characteristics for an entire year. As such, the weekly load was multiplied by 52 to obtain an approximate annual dry weather load. The three events were also assumed to be somewhat representative of the pollution levels found in rainfall events. As such, the total load from the three monitored events was divided by the total rainfall in these events and then this was subsequently multiplied by Melbourne's average annual rainfall to achieve an approximate annual wet weather pollutant load.

Results and discussions

Dry weather data

Analytical uncertainty of laboratory methods

It was difficult to assess the analytical uncertainty for TPH analyses, since all samples submitted for analyses were below detection. However, this was not the case for heavy metals, where the analytical uncertainty was found to be very low, with the majority of triplicate values being identical. The only time when the heavy metal sample concentrations varied between triplicates was at Lara Street where strontium concentrations varied between 0.17mg/L and 0.18mg/L and zinc concentrations varied between 0.07mg/L and 0.08mg/L. As such, it is quite clear that the analytical uncertainty (from random effects) for heavy metal analyses is quite minimal.

The analytical uncertainty for *E. coli* and enterococci were higher than that found for heavy metals. This was as expected since microorganism survival are affected by many environmental conditions (Crane and Moore, 1986) and their analytical procedure are known to have high uncertainties (see McCarthy et al, 2008 for more information). Figure 1 shows the variation between replicate samples for each site and for both *E. coli* and enterococci. The variations seen here are somewhat similar to that already reported in the literature for *E. coli* analytical uncertainties (McCarthy et al, 2008).

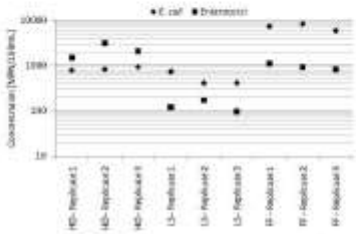

Figure 1. Assessment of the uncertainty for *E. coli* and enterococci laboratory analysis techniques. Three replicate samples are shown for each of the three sites.

Temporal variability of dry weather data

Site based variations. Table 2 provides detailed results of the between and within site variation of all detected parameters. Figure 2 also shows some of these results using boxplots. While the majority Relative Standard Deviations (standard deviation divided by mean expressed as a percentage) for heavy metals were less than 100%, all of the microorganism RSDs were above 100%, indicating that the within site variation of microorganisms are generally greater than that of heavy metals. This is also reinforced by Figure 2 which shows that both *E. coli* and enterococci vary by more than an order of magnitude within each site, while heavy metals concentrations rarely varied more than this.

Table 2. Minimum, mean, Relative Standard Deviations (standard deviation divided by mean, expressed as a percentage) and maximum of detected constituents in all 21 dry weather samples collected at each study site.

Pollutant*	Hedgeley Dene				Lara Street				Fairfield			
	Min	Mean*	RSD	Max	Min	Mean*	RSD	Max	Min	Mean*	RSD	Max
E. coli [No./100ml]	99	600	150%	4100	43	2700	200%	24000	920	12400	102%	46000
Enterococci [No./100ml]	13	1200	175%	9900	74	1300	123%	6500	330	4800	146%	29000
Aluminium [mg/L]	0.10	1.09[16]	143%	5.90	0.20	0.51[20]	50%	1.10	0.10	0.22[20]	75%	0.70
Arsenic [mg/L]	0.01	0.01[3]	0%	0.01	0.01	0.01[9]	33%	0.02				
Barium [mg/L]	0.01	0.06	52%	0.14	0.02	0.04	42%	0.10	0.02	0.03	20%	0.05
Copper [mg/L]	0.01	0.03[14]	82%	0.09	0.01	0.02	29%	0.03	0.01	0.02[7]	71%	0.03
Iron [mg/L]	0.30	2.65[11]	107%	9.50	0.20	0.44[20]	36%	0.70	0.60	0.6[2]		0.60
Lead [mg/L]	0.01	0.05[7]	82%	0.12		0.01[1]						
Manganese [mg/L]	0.01	0.16[11]	130%	0.70		0.01[1]			0.01	0.03[2]	94%	0.05
Strontium [mg/L]	0.05	0.22	36%	0.41	0.12	0.21	38%	0.50	0.04	0.05	16%	0.07
Titanium [mg/L]	0.01	0.04[10]	93%	0.12	0.01	0.03[15]	35%	0.04	0.01	0.01[3]	58%	0.02
Zinc [mg/L]	0.05	0.27	118%	1.40	0.05	0.08	21%	0.12	0.05	0.1	156%	0.78

* nickel and vanadium were detected in only a few samples at the Hedgeley Dene site at concentrations near detection, molybdenum was detected in one sample at Lara Street, Cadmium was detected once at Fairfield, chromium was detected in one sample at Hedgeley Dene and TPHs were only detected in two samples, once at Hedgeley Dene (0.15mg/L) and once at Fairfield (0.19mg/L). Antimony, beryllium, boron, cobalt, mercury, selenium, silver, thallium and tin were not detected in any sample. *superscript numbers indicate the number of samples which were above detection, if no superscript number if present, then all 21 samples were above detection.

The average RSD for the constituents listed in Table 2 for Hedgeley Dene, Lara Street and Fairfield were 97%, 61% and 82%, respectively, indicating that the average variability of pollutants at the Lara Street site was far less than that of the Hedgeley Dene site. This is

reflected in Figure 2, which shows that Lara Street's pollutant variation is usually lower than that of Hedgeley Dene (with the exception of *E. coli*). Explaining between site variability (e.g. why *E. coli* is higher in Fairfield than in Hedgeley Dene) is difficult, but is related to the sources, and their corresponding strengths, with each catchment. In order to fully understand such a dynamic, it would be necessary to conduct a source tracking technique for each pollutant. However, certain hypotheses can be made from these results, including the fact that Fairfield could have some wastewater cross-connections as opposed to Hedgeley Dene which, according to the *E. coli* results, seems to have minimal cross-connections.

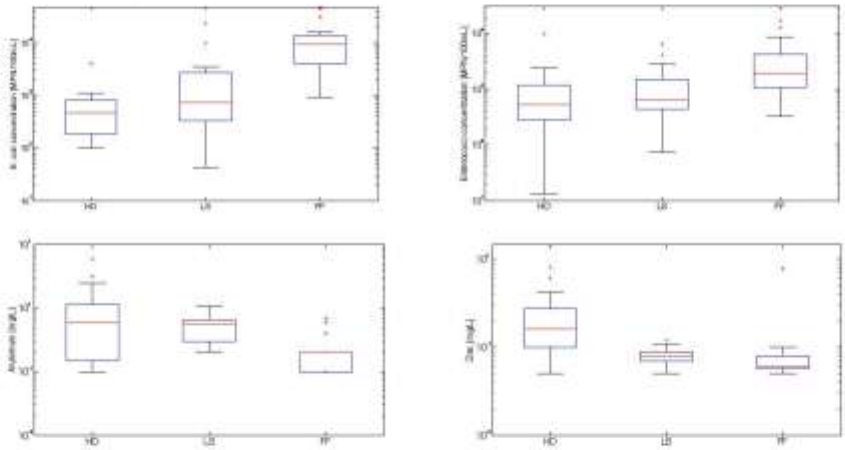

Figure 2. Boxplots of constituent concentrations for the samples analysed at each of the three study sites (top left – *E. coli*, top right – enterococci, bottom left – aluminium, bottom right – zinc).

Daily variations. Figure 3 shows boxplots which describe how several of the analysed pollutants vary during different times of the day. They are plotted using ratios on the y-axis which indicate the division between the current constituent concentration and the daily average of that constituent. All seven days of data are included in the boxplots, meaning that each box plot contains seven data points. At the Lara Street site, *E. coli* and enterococci seem to be consistently higher in the morning and afternoon periods than for evening periods. Whilst the datasets were too small to perform accurate statistical procedures, it is hypothesised that more data collection could reveal a statistically significant difference between times of day for the microorganisms at the Lara Street catchment. This trend could imply that wastewater cross connections or leakages are more prominent during the morning or afternoon periods, or alternatively that the origin of microorganisms in this pipe could be from an intermittent source (such as the small commercial area within this catchment which usually operates only during the day).

Further trends could be inferred from Figure 3, including the enterococci concentrations at the Fairfield site which decrease consistently during the day. This decrease could also be attributable to select sources of microorganisms which only contribute at different times during the day. However, the fact that *E. coli* does not show a similar trend does raise some doubt as to what is causing this decrease in daily enterococci concentrations. The data for heavy metals seen in Figure 3 show few trends, but the most notable is that of strontium at the Hedgeley Dene and Lara Street sites. Here, strontium tends to increase during the day,

indicating that sources of strontium may become stronger during the afternoon or evening periods.

It must be noted that drawing firm conclusions about the diurnal behaviour of any pollutants in these drains is difficult using just three data points per day. However, it is clear that some pollutants can vary quite considerably during each day and, as such, this should be taken into account when attempting to monitor dry weather pollutant levels.

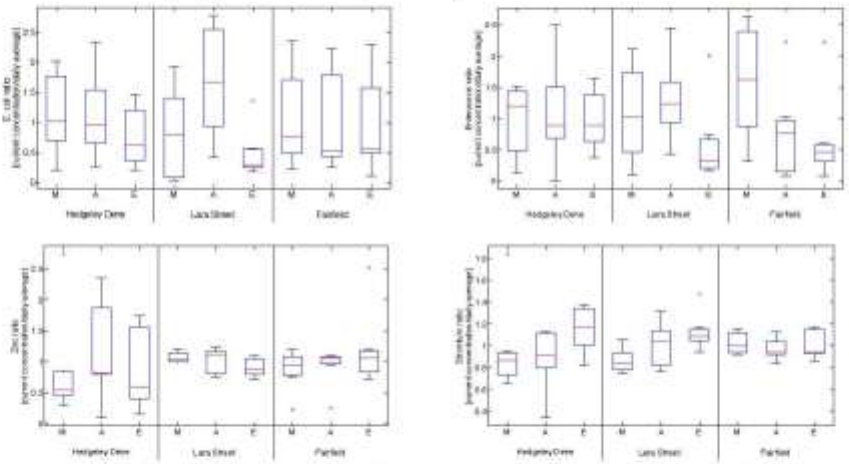

Figure 3. Boxplots showing the variation of pollutants during each day at the three sites (E. *coli* – top left, enterococci – top right, zinc – bottom left, strontium – bottom right). The y-axis shows ratios of the current concentration to the daily average and each box contains seven data points (one for each day). M – morning, A – afternoon, E – evening.

Can weekly dry weather loads be estimated using one sample per day?

Figure 4 shows that using just one water quality sample per day, with continuous flow measurements, can consistently produce adequate weekly load estimations for some pollutants (e.g. strontium), but not for others (e.g. *E. coli* and enterococci). The reason for these differences between pollutants was thought to be related to the inherent variability of the constituent in dry weather flows. In fact, the good correlation found in Figure 5 confirms this hypothesis and shows that as the variability of a pollutant's concentrations increase (represented by RSDs from Table 2), the resultant error in using just one sample per day to estimate weekly loads also increases (captured here using 95% confidence intervals from the data shown in Figure 4). These results clearly indicate that depending on the pollutant's variability in dry weather flows, the collection of just one grab sample per day to estimate weekly loads may not be advisable. However, this type of collection strategy might be adequate for estimating longer loading periods. For instance, it might be possible that taking one sample per day is adequate for the estimation of a pollutant's monthly dry weather load.

Other than for strontium, taking one sample at a regular time each day (i.e. morning, afternoon or evening) will either overestimate the weekly pollutant load (e.g. afternoon samples for *E. coli* at the Lara Street site), or, worse from a management perspective, underestimate the weekly pollutant load (e.g. afternoon and evening sampling for zinc at the Fairfield site). These types of patterns reflect the variations seen in pollutant concentrations shown in Figure 3, which indicate that some pollutants do have some diurnal variation, thus leading to over or under estimations of the true loading. More information should be gathered

in order to assess whether a systematic methodology (where samples are taken from each site at the same time of day) or a random methodology (where samples are taken from each site at random times each day). However, it is safe to suggest that pollutants which exhibit a diurnal pattern (see Figure 4) should be sampled using a random procedure, or at least a stratified systematic methodology.

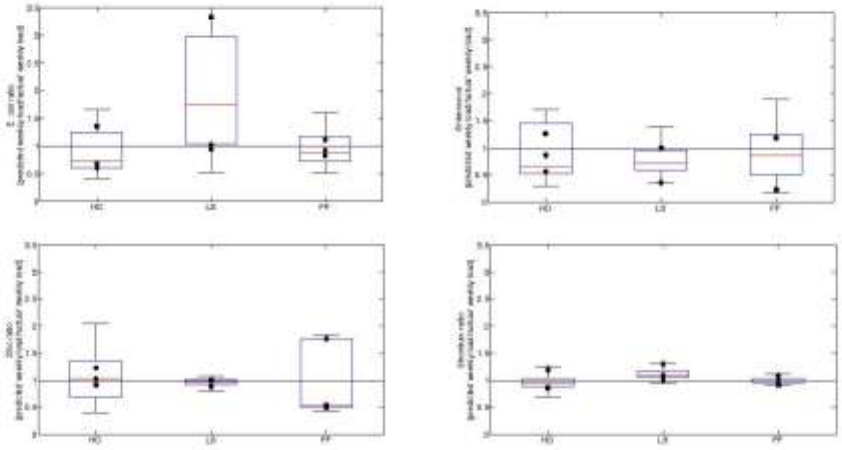

Figure 4. Boxplots showing the accuracy of using one sample per day to predict weekly loads. Y-axis shows ratios of predicted weekly loads (using one sample per day) to 'actual' weekly loads (using all collected samples). ● indicates weekly load prediction using only morning samples, ■ indicates weekly load prediction using only afternoon samples and ◆ indicates weekly load prediction using only evening samples.

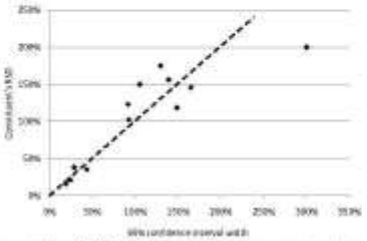

Figure 5. Correlation between dry weather RSDs (of *E. coli*, enterococci, zinc and strontium – see Table 2) and 95% confidence interval widths from data presented in Figure 4 (i.e. boxplot data was used to estimate 2.5%ile and 97.5%ile limits).

Wet weather data

Temporal variability of wet weather data

Analysing the wet weather data (Table 3), and comparing to that produced in Table 2 for dry weather flows, shows that the variability for pollutants during wet weather are usually lower than that found during dry weather flows. For example, the RSD for the *E. coli* samples taken at the Hedgeley Dene site during dry weather was 150%, while it was just 75% for wet weather periods. Similar results were found for most pollutants, with the exception of lead and strontium, both of which had higher variability during wet weather periods.

For the two indicator organisms monitored, the wet weather concentrations are much higher than that found during dry weather. This indicates that not only are dry weather sources contributing during wet weather events, but alternate sources of microorganisms are also

contributing during rainfall periods (e.g. leaking/overflowing sewer systems, animal faecal material washed from the catchment's surface, resuspension of deposited in-pipe material).

Table 3. Minimum, mean, Relative Standard Deviations (standard deviation divided by mean, expressed as a percentage) and maximum of detected constituents in all wet weather samples collected.

	Hedgeley Dene			
Pollutant*	Min	Mean^	RSD	Max
E. coli [No./100ml]	4600	30200	75%	120000
Enterococci [No./100ml]	8200	24900	39%	49000
Aluminium [mg/L]	0.2	1.14	95%	4.6
Barium [mg/L]	0.01	0.03[26]	79%	0.11
Copper [mg/L]	0.01	0.03[22]	42%	0.06
Iron [mg/L]	0.5	1.50	96%	5.9
Lead [mg/L]	0.01	0.03[19]	109%	0.12
Manganese [mg/L]	0.01	0.05	82%	0.16
Strontium [mg/L]	0.02	0.05	66%	0.17
Titanium [mg/L]	0.02	0.04[20]	77%	0.14
Zinc [mg/L]	0.13	0.32	45%	0.66
TPH [mg/L]	0.16	0.34[17]	59%	0.99

* chromium and vanadium were detected in only a few samples at the Hedgeley Dene site at concentrations near detection. Antimony, beryllium, boron, cadmium, cobalt, mercury, molybdenum, selenium, silver, thallium and tin were not detected in any wet weather sample.
^ superscript numbers indicate the number of samples which were above detection, if no superscript number if present, then all 27 samples were above detection.

TPHs and zinc also followed similar patterns to that identified for the indicator organisms. This is logical since both of these pollutants are located on the surfaces of urban catchments and are hence available for wash-off during wet weather events (e.g. zinc on roofs, TPHs on roads/car parks). The other heavy metals shown in Table 3 either do not vary significantly between wet and dry weather periods, or have higher concentrations during dry weather than during rainfall events. For example, strontium concentrations in dry weather are almost four times that found during wet weather events, indicating that some dilution effects might be occurring and that the wet weather sources of strontium are negligible.

Can total pollutant wet weather loads be estimated using one, two, three or four samples per event?
Considering the above results, it might be possible to take fewer samples during wet weather events to accurately predict total event loads. In fact, Fletcher and Deletic (2007) found that using one 'grab' sample during rainfall events could produce reliable estimates of downstream loads (i.e. within 10% of the 'actual' load).

Figure 6 shows that in order to estimate total wet weather enterococci loads within 50% of its actual load (at a 95% confidence level), around 2 samples need to be taken during each event. However, for *E. coli* at least three samples per event are required for the same level of accuracy. The values shown in Figure 6 are far greater than that predicted by Fletcher and Deletic (2007) for sediment loads. Two possible explanations for this are: (1) the variability of the pollutants in this study are large and/or (2) the small number of events used to conduct the analysis in this study are influencing the results. The latter explanation raises some concern about the validity of this analysis and current work is aiming to capture more events to help improve the robustness of this analysis.

The former explanation is also feasible and Figure 7 shows that the variability of the pollutant during wet weather periods (captured here using RSDs – Table 3) plays a crucial role in determining how many samples are required to be taken to achieve a certain level of accuracy in wet weather load predictions (captured here by the 95% confidence interval width – Figure 6). Depending on the variability of the sediment concentrations in the

catchments studied by Fletcher and Deletic (2007), this could also explain the large differences observed. In any case, the information shown in Figures 6 and 7 will help design future monitoring regimes more accurately, and also help minimise the collection and analytical costs of these new programs.

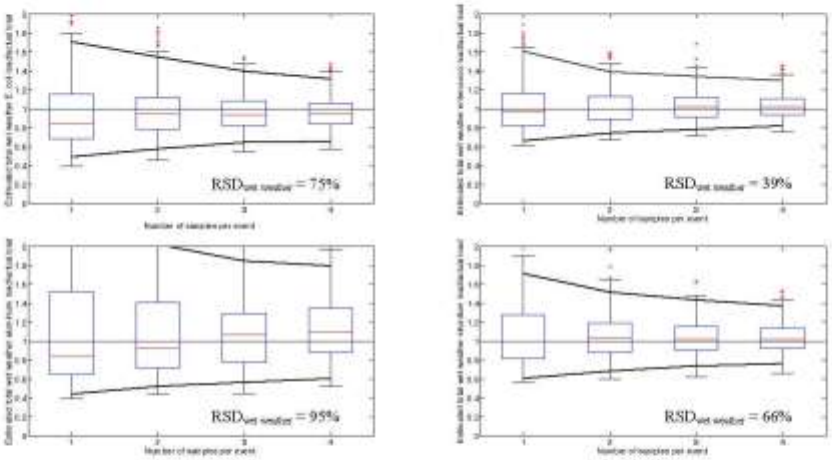

Figure 6. Boxplots showing how the ratio of estimated total wet weather pollutant to 'actual' load (estimated using all collected samples) varies with increasing number of samples taken during each event. Black lines indicate 95% confidence intervals for the ratio of estimated to 'actual' pollutant loads.

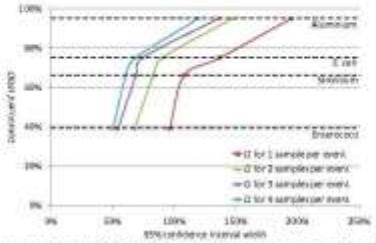

Figure 7. Correlation between wet weather RSDs (of *E. coli*, enterococci, aluminium and strontium – see Table 3) and 95% confidence interval widths from data presented in Figure 7.

How important is monitoring dry weather events/wet weather events for annual load estimations?

The high pollutant loads shown in Table 4 are quite alarming, with more than 430kg of iron and 6kg of lead being sent to downstream systems from a 160ha residential catchment. Furthermore, the high bacterial loads are also quite concerning, with more than $9x10^{13}$ *E. coli* being delivered to downstream systems per year from this catchment, this is equivalent to that found in 2,500kg of human faeces. These figures just demonstrate the importance of WSUD technologies, and that without adequate treatment, urban stormwater runoff will continue to degrade Melbourne's waterways.

Table 4 also indicates that for all monitored pollutants, the contributions during wet weather flows are the most important in terms of total annual loads. In fact, in most cases, wet weather flows contribute around 99% of the annual pollutant load. This raises the question as to the importance of monitoring dry weather loads. To address this point the specific objective of a monitoring regime must be considered. For instance, if the aim of the monitoring was to estimate total annual loads to downstream systems, then the monitoring of

dry weather flows in urban catchments is probably not required since these are never going to contribute significantly (since dry weather flows in urban systems are usually negligible compared to wet weather flows). However, if the objective of the monitoring regime was to assess whether the recreational water quality in a stream receiving inputs from a local stormwater drain could be improved, then dry weather flows might be important since most recreational activities occur during dry weather periods.

Table 4. Estimated total annual pollutant loads for some of the monitored constituents at the Hedgeley Dene site. Shown also are estimated annual dry weather and wet weather loads, and their associated proportions.

Pollutant	Annual dry weather load (% of total load)	Annual wet weather load (% of total load)	Total Annual Load
E. coli [No.]	$3x10^{10}$ (0.03%)	$9x10^{13}$ (99.97%)	$9x10^{13}$
Enterococci [No.]	$6x10^{10}$ (0.08%)	$7x10^{13}$ (99.92%)	$7x10^{13}$
Aluminium [kg]	2.95 (0.91%)	322.25 (99.09%)	325.21
Copper [kg]	0.08 (1.22%)	6.19 (98.78%)	6.27
Iron [kg]	5.11 (1.19%)	424.97 (98.81%)	430.08
Lead [kg]	0.05 (0.71%)	6.43 (99.29%)	6.48
Strontium [kg]	0.75 (5.62%)	12.55 (94.38%)	13.30
Zinc [kg]	0.94 (1.1%)	83.94 (98.9%)	84.87

Conclusion and future work

It is clear that there is considerable temporal variability for most pollutants in dry and wet weather events. The variability of these pollutants has a direct impact on the level of monitoring required for accurate load estimations. For instance, *E. coli* had quite considerable variability during both dry and wet weather flows and as such requires more samples for accurate load estimations than a pollutant that varies less (e.g. strontium). Whilst the majority of the presented work is helpful in assessing the temporal variability of certain pollutants in urban stormwater and, as such, will help the development of future monitoring campaigns, it is essential that more detailed data be collected before thorough conclusions can be made. Current work is aiming at collected more data from another three catchments in Melbourne to further characterise pollutant variations during dry and wet weather events. However, future work by the authors will focus on the collection of samples at higher frequencies than conducted in this study.

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