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IMPACT ON STORMWATER RUNOFF QUALITY BY THE CONCRETE DRAINAGE SYSTEM

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Abstract

A major source of pollution of urban waterways is from urban runoff. Research over the past 20 years has lead to a greater understanding of the source and how to control many pollutants. However, recent investigations by the authors has identified that concrete, being the dominant material for public drainage systems including gutters and pipes, has a significant impact on the chemistry of urban water runoff. This in turn is influencing the water quality within urban creeks. Across the Northern suburbs of Sydney, reference or undisturbed natural creeks are acidic and characterised by their low alkalinity and electrical conductivity. Urban creeks, located with similar geology and soil, are mildly acidic to mildly alkaline with much higher alkalinity and electrical conductivity. To ascertain what may be a causal factor for this difference in water chemistry, rainwater collected within the catchment was pumped through various concrete pipes and along gutters. The results identify that the dissolution of cement products changes a range of analytes particularly calcium, bicarbonate, potassium and pH. There are significant changes to urban water quality as a result of the in-transport processes associated with the concrete drainage system. This should be factored into the design of urban drainage schemes particularly if they discharge into naturally acidic or minerally poor waterways.

Introduction

Urbanisation has lead to many changes to the natural environment. Research into the impacts on waterway health from urban development commenced in Australia with a review of the water quality and biota up and downstream of a sewerage treatment plant in Lithgow by Jolly and Chapman (1966). This and other work focused on point source pollution that informed the development and introduction of a pollution licencing and regulatory system with the *Clean Waters Act (NSW) 1971.*

Non-point source or diffuse pollution is the other major contributor to the decline in urban water quality. From a regulatory perspective this is much harder to address and in part was identified in NSW through the stormwater management planning process in the 1990's. However as Meyer et al (2005), Breen and Lawrence (2003) and others have noted the causal factors for the decline in urban stream health is multi facetted and interrelated. Consequently the policy and regulatory response is much more challenging.

In undeveloped catchments the geology and soils play a major role in determining the chemistry of the water in streams. For urban catchments runoff is significantly influenced by new materials imported into the catchment, which effectively recalibrate the natural geochemistry. For example Bridgman (1992) and Garnaud et al (1999) investigated the changes in rainwater passing over various roof materials and Sartor and Boyd 1972, Ball *et al.* 1998, Shinya *et al.* 2000 and others have reported the effects of rainwater passing over concrete footpaths, bitumen roads and related transport surfaces. Others, such as Prowse (1978), Hayes and Buckney (1995) and Rose (2007), have looked at the changes in stream hydrochemistry (primarily baseflow) due to urbanisation. These investigations discuss the role of non point source urban pollutants such as leaking sewers, construction activity, impervious surface build-up, road and highway runoff, industrial pollution fertilisers and building materials amongst other anthropogenic impacts. More recently, Setunge et al (2009) reported that the pH of water changes significantly when in contact with freshly poured cement particularly within the first few days.

Looking at other factors influencing urban water chemistry, Novotny and Kincaid (1981) considered the effect of in transport process as part of their investigations into the buffering capacity of pavements to neutralised acid rain. Their conclusions supported the use of materials such as concrete due to their effectiveness in buffering the acid rain experienced in Milwaukee.

An interesting omission from the research to date has been an detailed analysis of the impact that the materials that make up the drainage system have on urban water quality. This is what we refer to as the in-transport drainage process.

This paper draws from the findings of previous studies by the authors and reports the most recent study on the impact of concrete gutters on urban water chemistry.

Previous research

Past studies on the waterways in the northern suburbs of Sydney identified major differences in base flow water chemistry between urban and naturally vegetated non-urban ‘reference’ waterways (Wright et al 2007). Dry weather sampling of the urban streams reported mildly acidic to slightly alkaline water while reference streams were about 1 pH unit more acidic. Urban waterways had an approximate 10-fold higher alkalinity and twice the electrical conductivity of reference waterways (Wright et al. 2007).

As a result of these observations, an initial investigation was undertaken to explore if there was a link between the water chemistry in urban streams and the materials comprising the urban drainage system (Davies et al 2009 and Davies et al 2010b).

This research project examined the changes in three water types (rain, urban stream and reference stream) when exposed to two commonly used drainage materials, concrete and PVC. This study found roof water and water from the undeveloped catchment reported a significant increase across a range of analytes: bicarbonate levels increased steeply when passed through the concrete pipe, while water from the urban creek (that had been exposed to concrete influence runoff) changed a lesser amount.

Following from these results, a further study was undertaken to assess if the changes could be attributed the dissolution of concrete products across pipes of various types and ages (Davies et al 2010a). In this study, rainwater was circulated through two new pipes (a steel reinforced concrete pipe and a fibre reinforced concrete pipe) and two old pipes (steel reinforced with visible pitting and hairline fractures). This study reported clear differences in water chemistry conveyed through new and old concrete pipes (when compared to a PVC pipe as a control), particularly for bicarbonate and calcium levels. The most sudden increase was recorded for pH which displayed a rise of two (2) pH units within the first 20 minutes of exposure to new (steel and fibre reinforced) concrete pipe. Electrical conductivity did not start to increase for ten minutes, and for new concrete pipes, rose at a steady gradient for the entire experiment. Similar trends were also evident for hardness, bicarbonate and calcium for the newer concrete pipes. The changes in water chemistry in the two older concrete pipes was generally around 40% to 60% lower than that recorded in the new pipes, though there were substantial increases in ionic levels (calcium, bicarbonate, hardness, total anions, total cations) through the experiment.

The other major part of the urban drainage system is gutter network. This study, and the subject of this paper, extended on the controlled experiments to investigate if rainwater passing over concrete gutters of varying lengths, age and condition produced similar changes in water chemistry.

Methods

Study area

Research was conducted primarily in the Ku-ring-gai Local Government Area (LGA) in Sydney's northern suburbs (at 33°45'20"S and 151°9'0"E) with some urban sites located in the adjacent Ryde LGA.

The natural geology is characterised as Wianamatta Shale overlying Hawkesbury Sandstone on ridges with the deeply incised valleys and streambeds dominated by exposed Hawkesbury sandstone (NSW Department Mineral Resources 1983). The soil type is generally described as poor in both structure and geochemistry and is closely related to the underlying shale/sandstone geology (Herbert and Helby 1980).

Development across the Ku-ring-gai LGA, is dominated by low density residential housing on block sizes around 940 m^2 with little commercial and no industrial development. The majority of the development occurred between the 1940's to 1970's and for the last 30 years the population has been relatively stable at approximately 100,000.

A notable characteristic of the northern suburbs of Sydney is that development has occurred on the upper and flatter sections of the catchment while the steeper incised valleys contain remnant bushland and modified streams (this is generally inverse to traditional development patterns were the upper catchment remains forested or less developed while the lower flatter slopes contain the development). Within the urban area, approximately 40% of the local roads are constructed with concrete curb and guttering. The average total surface imperviousness is between 20-40% (Ku-ring-gai Council 2004) while the connected impervious area is approximately 29% (Davies et al 2010a).

Study design

Methods

Rainwater was collected from a zincalume roof in South Turramurra into a 3000 litre plastic rainwater tank. The water was then transferred into 20 litre plastic jerry cans for the experiment. The water from the rainwater tank had been stored for up to two weeks and the water in the jerry cans was used on the day of sampling.

Twenty-three (23) sections of gutter across 12 different streets chosen for this study comprising 17 sites in the Lane Cove River catchment and 6 sites in Cowan Creek catchment (refer to Table 1). This included 6 gutters less than 10 years old, 8 gutters between 20 and 35 years old and 4 gutters that were 45 years old. The older gutters had a greater the amount of exposed aggregate, while the newer gutters still retained the finer cement covering (refer to Figure 1).

Figure 1. Photo of the concrete surfaces at St Columbans Green constructed in 2008 (left) and Currong Place constructed in 1981 (right).

A leaf blower was used to remove the visible debris and the gutter was then flushed with rainwater prior sampling at a rate of approximately 10 litres for gutters of 15 to 25 meters and 20 litres for gutters between 50 and 100 metres.

Rainwater from the jerry cans was pumped at a rate of approximately 0.26 l/s using a 3060 LPH Bilge pump. Three (3) consecutive samples were collected at 5-10s intervals 10 seconds after the initial flush of water had passed the sample point. The sampling was repeated 3 times at each site with an interval of approximately 10 minutes between each run. Water used for the preparation flush was also sampled on random occasions.

Conductivity, pH and temperature were recorded for each batch of initial rainwater and every sample using a hand held water chemistry meter (Model 611 – Intelligent Water Quality Analyser - Yeo-Kal Electronics Pty. Ltd. Australia). Random samples from 1 of the 3 repeat runs at random sites were analysed at a NATA accredited laboratory for Potassium, Calcium, Sodium, Magnesium, Bicarbonate Alkalinity, Chloride, Sulphate, Total Anions and Total Cations. Results are all reported to a limit of 1 mg/L and ionic balance (Total Anions and Total Cations) are reported to a level of 0.01 meq/L.

Results

The chemistry from water sourced from the rainwater tank prior to its release into the concrete gutters was strongly acidic (mean pH 4.8) with a very low concentration of dissolved salts (EC 24 µS/cm) (Table 2). The major mineral constituents of (alkalinity) bicarbonate, calcium and potassium were also very low (2.0, 0.5 and 0.5 mg/L respectively).

There was a highly significant relationship (ANOVA: $F_{8,955} = 1297.5$, $p<0.0001$) between pH levels and the exposure of tankwater samples to different length of concrete road gutter (15 to 200m) (Table 3). The mean pH level rose (from mean 4.8) with progressive lengths of exposure to the concrete gutters. This was measured over relatively short distances rising from 5.3 at 15 m, 5.9 at 25 m and 6.7 at 50 m (Figure 2). Mean pH levels were elevated within a band of 6.9 to 7.6 at distances varying from 75 to 200 m of gutter.

The concentration of anions in water samples increased highly significantly (ANOVA: $F_{5,22} = 14.5$, $p<0.0001$) according to the length of gutter, rising from 0.11 (meq/L) to a mean of 0.54 (meq/L) after 200 metres of travel in the concrete gutter (Table 2 and 3). A similar relationship was observed for cations which also increased highly significantly (ANOVA: $F_{5,22} = 10.4$, $p<0.0001$), rising from 0.08 to a mean of 0.47 (meq/L) after 200 metres (Table 2 and 3). There was a highly significant relationship for changes to bicarbonate (ANOVA: $F_{5,22} = 17.35$, $p<0.0001$) and potassium (ANOVA: $F_{5,22} = 9.33$, $p<0.0001$) levels with exposure of tankwater samples to different lengths of concrete road gutter (50 to 200m) (Table 2 and Table 3). Calcium levels also had a significant relationship (ANOVA: $F_{5,22} = 4.99$, $p=0.003$) with exposure to concrete gutters (Table 2 and 3). Mean mineral levels rose steeply over progressive exposure of lengths of gutter (50 to 200m) (Figure 3-5). The mean levels of bicarbonate, calcium and potassium had all doubled at the 50 m length. The largest increase was observed for bicarbonate rising more than eight times, from 2 mg/L at the start to 16.3 mg/L at 200m (Figure 3). Mean potassium levels also increased more than eight fold, from 0.5 mg/L at the outset to a mean of 4.3 mg/L at 100 m (Figure 4). A similar trend was also observed for calcium, rising from 0.5 mg/L to a mean of 2.7 mg/L at 200 m (Figure 5).

Table 1. Sample site locations

Suburb	**Street Name**	**Distance (m)**	**Date constructed**
South Turramurra	Ashburton Ave	150	˜1981
South Turramurra	Ashburton Ave (near cul-de-sac)	15	˜1981
South Turramurra	Ashburton Ave (near cul-de-sac)	25	˜1981
South Turramurra	Currong Place	15 & 50	1981
South Turramurra	Currong Place	25 & 50	1981
South Turramurra	Eden Avenue	200	1965
South Turramurra	Maxwell Street	100	1977
South Turramurra	Benning Avenue	75	1965
South Turramurra	Robin Avenue	25	1965
South Turramurra	Robin Avenue	50	1965
South Turramurra	Holmes Street	50	1978
North Turramurra	St Columbans Green	25 & 50	2008
North Turramurra	St Columbans Green	15	2008
North Turramurra	Sir Frederick Scherger Drive	75	2003/2004
North Turramurra	Beaufort Close	75	2003/2004
North Turramurra	Du Faur Street	100	˜1990
North Ryde	Long Road, Macquarie University	150	1999
North Ryde	Long Road, Macquarie University	15 & 100	1999

Table 2 Summary of gutter sampling results

Site	Kerb side	Distance (m)	K (mg/L)	Total Alk-Bicarb (mg/L)	Ca (mg/L)	Na (mg/L)	Cl (mg/L)	Total Anions (meq/L)	Total Cations (meq/L)
Initial Rainwater	N/A	0	0.5	2	0.5	2	3	0.11	0.08
Currong Place	Left	50	1	7	2	3	4	0.29	0.25
Currong Place	Left	50	1	5	1	3	4	0.24	0.24
Currong Place	Left	50	1	3	1	3	4	0.2	0.22
Currong Place	Right	50	2	6	1	4	6	0.31	0.26
Currong Place	Right	50	2	6	1	3	5	0.29	0.24
Currong Place	Right	50	1	5	1	3	4	0.25	0.21
Holmes Street	Left	50	4	7	1	4	4	0.28	0.31
Holmes Street	Left	50	3	3	0.5	3	4	0.16	0.2
Holmes Street	Left	50	2	5	0.5	2	4	0.22	0.17
The Landings	Right	75	0.5	5	2	3	6	0.29	0.23
The Landings	Right	75	0.5	4	2	3	7	0.31	0.23
The Landings	Right	75	0.5	8	2	3	5	0.32	0.2
Beaufort Close	Right	75	2	8	3	4	6	0.38	0.4
Beaufort Close	Right	75	2	8	3	4	7	0.38	0.38
Beaufort Close	Right	75	2	8	3	4	6	0.35	0.33
Benning Avenue	Right	75	3	9	2	4	6	0.38	0.37
Benning Avenue	Right	75	2	7	1	3	5	0.29	0.27
Benning Avenue	Right	75	2	7	1	3	5	0.29	0.24
Du Faur Street	Left	100	5	10	1	4	6	0.39	0.37
Du Faur Street	Left	100	4	8	2	4	6	0.34	0.36
Du Faur Street	Left	100	4	6	1	3	5	0.3	0.3
Long Road	Right	150	4	9	3	5	9	0.48	0.51
Long Road	Right	150	4	7	2	5	8	0.4	0.43
Long Road	Right	150	4	4	2	4	8	0.32	0.37
Eden Place	Left	200	4	20	4	7	7	0.67	0.59
Eden Place	Left	200	4	14	2	6	5	0.48	0.45
Eden Place	Left	200	3	15	2	4	4	0.46	0.36

Table 3. ANOVA results. *F statistics and associated probabilities from analysis of variance of water chemical attributes (pH, anions, cations, calcium, bicarbonate potassium, sodium and chloride) varying according to distance travelled in concrete gutters.*

Comparison	Degrees Freedom (treatment, error)	F values	*P values*
pH	8, 955	1297.7	*<0.0001*
Anions	5,22	14.49	*<0.0001*
Cations	5,22	10.38	*<0.0001*
Calcium	5,22	4.99	*0.003*
Bicarbonate (alkalinity)	5,22	17.35	*<0.0001*
Potassium	*5,22*	*9.33*	*<0.0001*
Sodium	*5,22*	*8.31*	*<0.0001*
Chloride	*5,22*	*13.03*	*<0.0001*

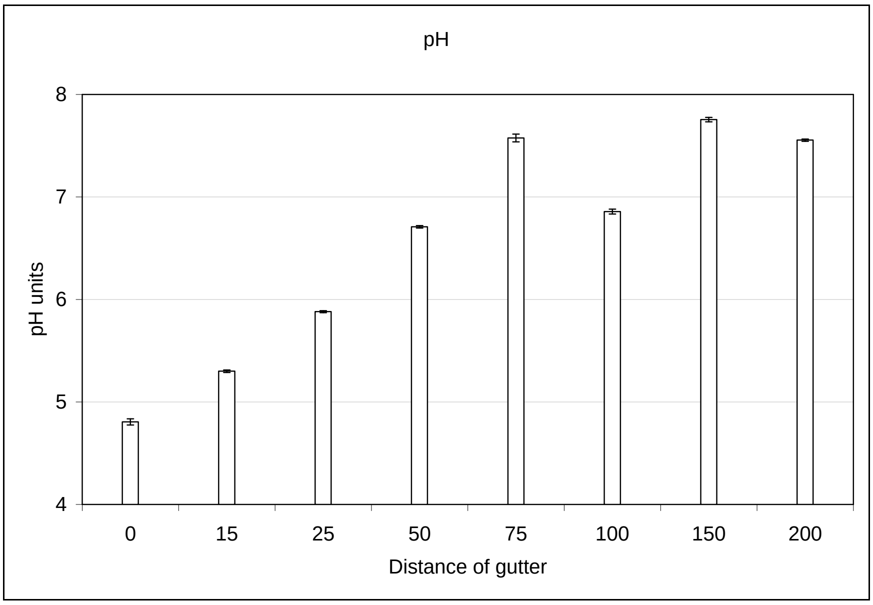

Figure 2. Mean pH levels (plus/minus standard error) in water samples, measured prior to the sample release (distance 0) and after running down different lengths of concrete gutter (15m, 25 m, 50m, 75m, 100m, 150m and 200m).

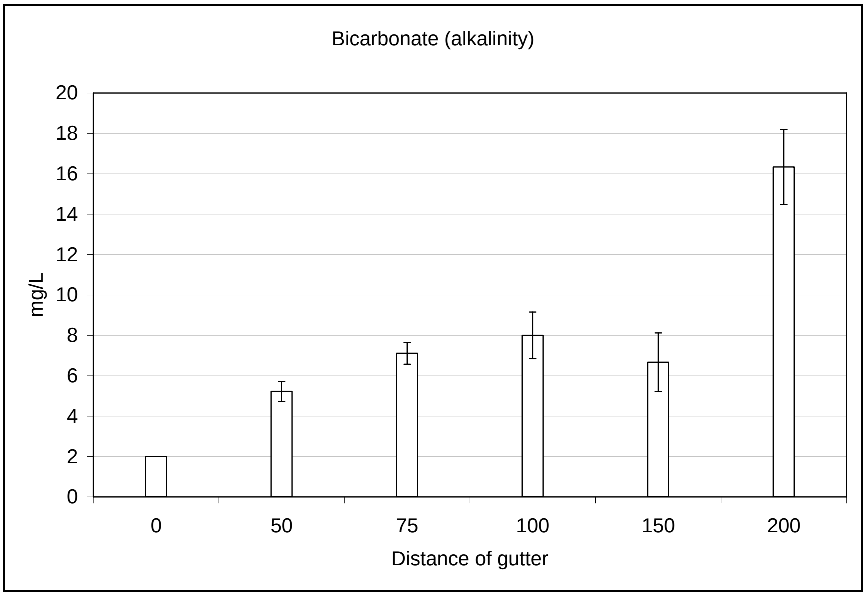

Figure 3. Mean bicarbonate (total alkalinity) levels (plus/minus standard error) in water samples, measured prior to the sample release (distance 0) and after running down different lengths of concrete gutter (50m, 75m, 100m, 150m and 200m).

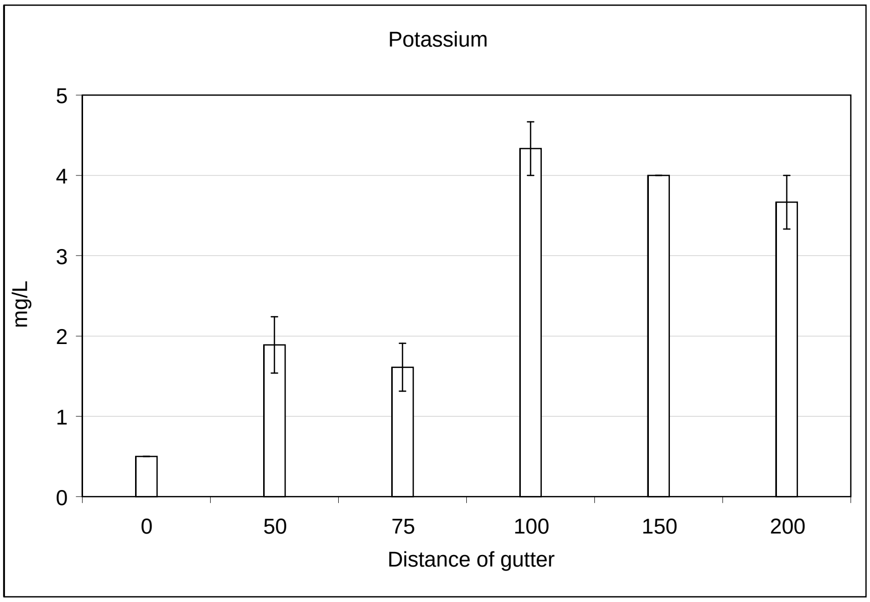

Figure 4. Mean potassium levels (plus/minus standard error) in water samples, measured prior to the sample release (distance 0) and after running down different lengths of concrete gutter (50m, 75m, 100m, 150m and 200m).

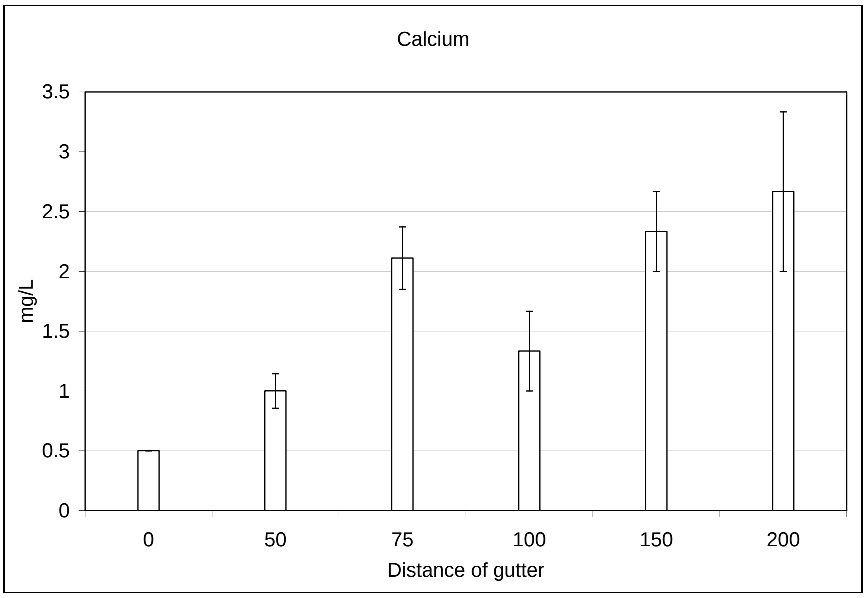

Figure 5. Mean calcium levels (plus/minus standard error) in water samples, measured prior to the sample release (distance 0) and after running down different lengths of concrete gutter (50m, 75m, 100m, 150m and 200m).

Discussion

One of the key differences in water quality in northern Sydney urban waterways compared to waterways in naturally vegetated non-urban catchments, was the difference in the alkalinity level. Alkalinity was typically nearly 10 times higher in urban streams (Wright et al. 2007). The current study adds to the weight of evidence that the concrete drainage system is contributing to the contamination of waterways with unnaturally high levels of alkalinity. The highest concentration and change in Bicarbonate Alkalinity was recorded at the longest stretch of gutter (200m) with longest flush time (8 minutes). This gutter was constructed in 1965. Okochi et. al. (2000) suggested that when comparing fixed quantities of rainwater with varying flow rates, carbonation or the dissolution of calcium hydrates from concrete, will increase as the period of contact between the rainwater and concrete increases. This is consistent with the results of the current gutter study and also is similar to previous studies with concrete pipes (Davies et al 2009, 2010a and 2010b). Notable is that the longest gutter was also the oldest indicating that the degradation in the concrete over time is less significant than with the pipes.

Calcium and potassium concentrations also increased according to length of travel in the concrete gutter. The scale of the increase was similar to that recorded through recirculation of rainwater in a concrete pipe (Davies et al, 2010a).

An earlier study found that all non-urban reference streams were acidic, with a mean pH of 5.8 (Wright et al. 2007). In comparison the urban streams had an average pH of 6.9. The current study confirms that concrete drainage materials are likely to make a strong contribution to the rise in urban stream pH. We found that rainwater was highly acidic (mean 4.8) (likely attributed to industrial pollution that contributes to acidic deposition), and that the level of pH rose according to distance travelled in concrete gutter. In the pipe experiments (Davies et.al. 2009) the levels of pH tended to level off at 8.0 after 100 minutes. This is equivalent to 84 metres of pipe/gutter in the current experiment. In the current study, the level of pH rose steeply, from less than 5 to average levels of 7.5 to 7.7 (Figure 1) after the water sample ran through 75 to 200 m of gutter.

Conclusions

This paper has confirmed the findings of the previous studies that the in-transport process of concrete drainage system results in the dissolution of cement products that affects the quality of urban runoff. From an urban drainage design perspective, it is the combined time of contact of both the gutter and pipe that will influence the overall changes in water chemistry. While newer gutters and pipes report a greater change in water chemistry than older ones, this of lower overall importance given the magnitude and cumulative impact associated with contact time.

Given the rapid influence of the acidic rain with the alkaline cement products it is suggested that alternative drainage materials may be necessary if an outcome of the urban design project is to minimise the impact on receiving water bodies, particularly those that are naturally acidic and minerally poor.

We suggest that protection of natural stream geochemistry from the adverse effects of urban development (urban geochemistry) deserves further attention. The ANZECC water quality guidelines endorse a process for development of regional water quality guidelines based on local studies. The south-eastern Australia guidelines recommend that pH be within the range of 6.5 to 8.5. We suggest that protection of fragile aquatic ecosystems in urban creeks actually need to retain natural pH levels that are generally below this range. Concrete drainage materials (pipes, gutters, and concrete paved areas) will react with acidic rainwater even over short distances and contact times and will quickly modify stream geochemistry.

These findings also suggest that the suite of stormwater pollutants typically associated with the runoff from urban catchments (such as dissolved oxygen, sediment and nutrients) need further attention. In particular, the analysis of urban runoff and in-transport drainage processes should examine both water quality and water chemistry. We recommend that pH, electrical conductivity and major anions and cations warrant greater attention in urban water monitoring programs.

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