The effect of the in-transport process on urban water chemistry – an examination of the contribution of concrete pipes and gutters on urban water quality

Impact du processus de transport en réseaux sur la chimie des eaux urbaines : étude de la contribution des canalisations et caniveaux en béton sur la qualité des eaux urbaines

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RÉSUMÉ

L'objectif de cette étude était d'évaluer l'impact des canalisations en béton sur les caractéristiques chimiques de l'eau et sur la qualité des cours d'eau urbains. Alors que la gestion des eaux urbaines permet aujourd'hui de mieux comprendre les impacts environnementaux du développement, peu de recherches portent sur les processus pendant le transport des eaux de pluie dans les réseaux d'assainissement. Les systèmes conçus pour les eaux pluviales sont essentiellement destinés à gérer l'impact des inondations et des écoulements de surface. Pour ce faire, ils font surtout appel à des matériaux robustes et à haute efficience hydraulique tels que les canalisations en béton. Lors des études sur la qualité de l'eau dans les banlieues nord de Sydney, des niveaux de pH et de bicarbonates statistiquement plus élevés ont été observés dans les bassins versants des zones d'aménagement par rapport à ceux notés dans les bassins versants de zones non aménagées ou de friches. Ceci a conduit les chercheurs à étudier le rôle éventuel du béton, matériau dominant dans les systèmes d'assainissement, dans cette différence. On a fait circuler de l'eau de pluie dans des canalisations en béton pendant 120 minutes, puis on a mesuré différents composants chimiques. Les résultats indiquent qu'indépendamment de l'ancienneté de la conduite en béton, les caractéristiques chimiques de l'eau changent significativement en comparaison avec l'eau circulée dans des canalisations en plastique (utilisées comme contrôle), avec le plus fort changement constaté sur les nouvelles conduites. La dissolution dans l'eau des produits de ciment en est la principale cause. Ces observations sont particulièrement pertinentes si les eaux réceptrices et leurs écosystèmes sont naturellement acides et sensibles aux changements des niveaux d'alcalinité et de bicarbonate.

ABSTRACT

The objective of this study was to test the impact of concrete pipes on the chemistry of water and how this may be a factor that influences water quality in urban streams. While contemporary urban water management is increasing its understanding of the impacts of urban catchment development on the environment, little research has been undertaken on in-transport processes associated with the stormwater drainage network. Stormwater systems are designed primarily to manage the impacts of flooding and overland flow. Robust and hydraulically efficient materials, such as concrete pipes, have been the favoured to achieve these outcomes. An investigation of water quality in the northern suburbs of Sydney showed pH and bicarbonate levels were statistically higher in the developed catchments compared to the undeveloped or bushland catchments. This prompted the researchers to investigate if concrete, being the dominate material of the stormwater drainage system, may be contributing to this difference. Rainwater collected from the catchment was passed through various concrete pipes over a period of 120 minutes and measured for a range of analytes. The results reported that irrespective of the age of the concrete pipe there was a significant change in water chemistry when compared with the flows through a plastic stormwater pipe (used as a control). Newer pipes reported the greatest degree of change. The principal cause was the dissolution of cement products into the water. These findings are particularly relevant where the buffering of naturally acidic rain, primarily achieved through the dissolution of calcium from concrete drainage structures, alters the chemistry of natural water bodies. These ecosystems are naturally acidic and sensitive to changes in alkalinity and bicarbonate levels.

KEYWORDS

Concrete pipes, urban water drainage, water chemistry, water sensitive urban design

1 INTRODUCTION

Urban drainage systems are dominated by a series of connected concrete pipes and culverts to convey stormwater runoff away from developed areas. The design philosophy behind this engineering has been to mitigate the impacts of local flooding and overland flow. In Australia, this has led to numerous design guidelines such as '*Australian Rainfall and Runoff*', by the Institute of Engineers Australia (O'Loughlin and Robinson 2001) and '*Flood Plain Development Manual*' (DIPNR 2005) that have informed hydrology, civil design and urban planning.

More recently the management of urban water drainage has broadened its focus from hydrology and hydraulics to encapsulate considerations of the broader water cycle such as water quality, riparian systems, potable water supply, wastewater disposal and stormwater drainage. The terms integrated water cycle management, water sensitive urban design (WSUD) (Wong 2006) and low impact development (LID) (Coffman 2002) are often used to describe this shift in philosophy, which has been encapsulated in broader urban water planning and local government policy (e.g. Ku-ring-gai Council 2008). These contemporary engineering and urban planning themes are consistent with the work of environmental scientists such as Dunne and Leopold (1978) Klein (1979), Hall and Ellis (1985) and Walsh et al (2001) that identified various impacts subsequently described by Meyer et al (2005) as the 'urban stream syndrome'.

In Australia, regulation of the pollution of waterways has traditionally been the domain of state governments through their environmental protection agencies. The point source regulatory regime introduced in the 1970s has evolved to the present day approach where diffuse pollution from stormwater runoff is also considered, although largely within a broader policy framework. The challenge for regulators, urban planners, environmental scientists and engineers is to identify the most influential factors and also interrelationships that impact on the health of the environment. For example, Breen and Lawrence (2006) identified nine major factors that contribute to waterway health (including: biology; geology; in-stream habitat; hydrology; hydraulics; water quality; sediment quality; riparian habitat; and continuity and barriers), although these are rarely considered in totality in the design and maintenance of urban drainage networks particularly in infill or already developed areas. Added to these considerations are other factors such as acidic deposition and pollution from urban building materials.

In seeking to understand the contribution of non-point source pollution, researchers have brought together water quality findings from various land uses (eg residential or industrial) or urban materials (eg roads and roofs) to estimate pollution generation across urban catchments (eg: Novotny et al 1985 and Wong 2006). Common to many of these studies has been the attempt to describe the accumulation of pollutants to help inform pollution generation models such as MUSIC (Fletcher et al 2001). For example Sartor and Boyd (1972) concluded most pollutants could be found within 1 metre of the kerb thus supporting a conclusion of pollutant load as an expression of the total length of kerb. Ladson et al (2006) and Conway (2007) suggested catchment imperviousness or connected imperviousness (generally be defined by the area linked by urban drainage systems) as a proportion of the catchment areas to be a surrogate indicator of total pollution generation and in turn waterway health. Most attempts to determine the sources and contribution of non-point source pollution in urban areas is recognition of the importance of the urban drainage network, be it length or proportion linking the impervious areas of the catchment. Research to date in this field has largely ignored the contribtion of in-transport processes of the urban drainage network to water quality, water chemistry and subsequent ecological implications, particularly given the widespread use of concrete (eg Clark et al 2005).

Leung and Jiao (2006) touched on this area where they reported groundwater downstream of concrete basements had a high pH and high levels of bicarbonate, calcium and other ions when compared to groundwater in the undeveloped catchment upslope. However they did not draw any strong conclusions as to the environmental impact. Conway (2007) reported a positive correlation between pH and catchment imperviousness, though did not suggest drainage materials to be causal factor.

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 materials such as concrete due to their effectiveness in buffering very low pH levels associated with acid rain in Milwaukee.

Low pH, salinity and buffering values are natural characteristics for the coastal, sandstone dominated water bodies in the Sydney region, as identified by Hayes and Buckney (1995). Thus, the benefit of highly buffered run-off (pH 7+) containing elevated levels of bicarbonate and calcium ions in an environment usually devoid of such elements is questioned.

This paper seeks to provide supportive evidence of the impact of concrete (the most commonly used stormwater drainage material) on in-stream water quality and suggests that its effect should be considered as a significant contributor to changes in urban water chemistry that can affect urban waterway health.

1.1 Water chemistry and the urban environment

Gibbs (1970) identified three major mechanisms controlling world surface water chemistry: atmospheric precipitation, that is often but not always related to the proximity to the coast; rock dominance, where waters are often in equilibrium with the geology of their area; and the evaporation-crystallisation process that dominate in hot arid regions. He also concluded that second order factors such as composition of materials had a minor influence at a catchment scale. Building on this work, Hart and McKelvie (1986) looked at the natural ionic balance of waterways of inland Australian waters and similarly concluded the composition and relative proportion of the major ions (Na, Ca, Mg, K, HCO_3, Cl, SO_4) responded to the atmospheric and catchment geological sources of ions.

On a smaller scale, such as an urban catchment, the secondary impacts as described by Gibbs (1970) would seem to have greater dominance over water chemistry. As naturally acidic precipitation, pH 5.6 (AEC 1989), passes through the atmosphere and over the ground, buffering mechanisms neutralise the acids through a variety of cation exchanges, expressed broadly in terms of alkalinity (primarily carbonate and bi-carbonate levels).The composition of catchment surfaces is altered by urbanisation through the introduction of built structures and the extent of this buffering process is largely dependant upon catchment materials.

Past studies on the waterways in the northern suburbs of Sydney have identified major differences in base flow water chemistry between urban and non-urban 'reference' waterways (Wright et al 2007). These studies found dry weather sampling indicated a significantly different chemical signature across the major anions and cations with urban streams varying between mildly acidic to slightly alkaline while reference streams were about 1 pH unit more acidic, suggesting a different level of buffering. In addition, the urban waterways had a 20-fold higher alkalinity and twice the electrical conductivity of reference waterways.

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). This research examined the changes in three water types (rain, urban stream and reference stream) when exposed to two commonly used drainage materials, concrete and PVC. Rainwater collected from rainwater tanks in the study area was acidic (pH 4.79) and had low bicarbonate concentrations (0.5mg/L). A composite water sample from two urban streams was mildly alkaline (pH 7.35) with bicarbonate concentrations of 36.3 mg/L. A composite water sample from two reference streams in close proximity to the urban area and with similar geology was mildly acidic (pH 5.5) with bicarbonate concentrations of 1.7 mg/L.

A 20 L sample from each of three water types (rain, urban stream and reference stream) was then circulated through a new concrete pipe and a new PVC pipe for 100 minutes. Roof water and stream water from the non-urban 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 changed a lesser amount. When passed through the PVC pipe the changes in water chemistry were significantly less for all water types (Davies et al 2009).

This study concluded, similar to Novotny and Kincaid (1981), that the elevated calcium ions are attributed to concrete and that in spite of the low pH of the rain, runoff from urban areas was always well above neutral indicating a high buffering capacity of the urban overland flow process.

1.2 Impact and degradation of concrete

The process of carbonation is a major factor in the degradation of concrete. It is the result of chemical reactions between carbon dioxide and concrete hydrates, such as calcium hydroxide ($Ca(OH)_2$) or portlanidite and calcium silicate hydrates (CSH) producing calcium carbonate ($CaCO_3$) and water. The mechanism is well described and understood in material science literature (eg: Clifton 1993). A number of factors have been classified as affecting the chemical attack of concrete including: acidic attack, alkaline attack, carbonation, chloride attach, leaching and sulphate attack (ACI 1982).

In urban areas and where cement pipes are used to convey stormwater, the acidic attack associated with the lower pH of the acidic rain reacts with the alkaline hydration products of cement as part of the buffering process. This results in calcium salts as well as other changes to water chemistry (Zivica and Bajza 2001). This process is evident in past research by the authors (Davies et al 2009) and other such as Novotny and Kincaid (1981) and Leung and Jiao (2006) that reported a higher concentration in alkalinity-bicarbonate, calcium concentrations and potassium in runoff or ground water flow that has had a prolonged contact with concrete surfaces

As the reinforced concrete pipe used in the earlier study by the authors was new, there was a need to explore if the age or degradation of the pipe resulted in any difference to the water chemistry as urban catchment typically contain drainage systems of a variety of ages reflecting their development pattern. The surface of new pipes can be described as smooth with no visible aggregate and can often have a fine film of dry cement material that is removed once flushed. These characteristics suggests a higher concentration of finer cement (concrete hydrates) at the surface than would be representative if the pipe has been in use and this “skin” or surface material had eroded or dissolved, consequently having a greater impact on water chemistry. It would therefore be expected that as pipes and other concrete drainage structures (such as gutters and culverts) degrade, their impact on water chemistry should lessen. This research was initiated to test this hypothesis.

2 METHODS

Two new (without the fine film described above) and two old pipes were used for this study in conjunction with a PVC pipe to provide a control. The two new pipes were selected as representative of the drainage materials used by local government: a steel reinforced concrete pipe and a fibre reinforced concrete pipe. Each was 1600mm in length and 375mm diameter. The two old pipes were sourced from a material stockpile having been retired from the drainage network and were visibly pitted with aggregate showing and contained hairline fractures visible once water had been passed through them. The first was a steel reinforced pipe 1800mm in length and 300mm in diameter; the second was a steel reinforced half pipe 800mm in length and approximately 225 mm in diameter. The concrete pipes and PVC pipe (as a control) were set at a grade of approximately 7.5%.

Rainwater was collected from two roof rainwater tanks within the Ku-ring-gai local government area, situated 14 km north of Sydney City at 33°45’20”S and 151°9’0”E. The first drained from a zincalume roof located in South Turramurra and the other from a slate (75%) and vitrified clay tile (25%) roof in Wahroonga. Both water samples were stored in a plastic rainwater tank for approximately two weeks prior to sampling. Equal portions of the rainwater were mixed to make a composite sample. These were divided into five batches, each with a volume of 20 litres.

A Rule 800GPH bilge pump operating off a 12 volt 5 amp fuse was used to pump the rainwater at a rate of approximately 0.5 L/s for 120 minutes. Prior to the commencement of sampling, each pipe was swept then flushed with surplus rainwater to remove any residual particulate or chemical matter. Samples were collected at time zero then at 5, 10, 20, 30, 40, 60, 90 and 120 minutes. The samples were analysed at a commercial NATA (National Association of Testing Authorities) accredited laboratory for Potassium, Bicarbonate Alkalinity, Carbonate, Hydroxide, Calcium, Sodium, Chloride, Sulphate, Magnesium, Total Anions and Total Cations. Bicarbonate Alkalinity (Alkalinity PC Titrator), dissolved major cations (Calcium, Sodium, Magnesium, Potassium) Chloride (Chloride discrete analyser) and Sulfate as SO4 (Turbidimetric) are all reported to a limit of 1 mg/L. Ionic balance (Total Anions and Total Cations) are reported to a level of 0.01 meq/L.

In addition to the laboratory analyses of conductivity, pH and temperature readings were collected every minute for the first 10 minutes then at five minute intervals using a hand held water chemistry meter (Yeo-Kal 615 Water Quality Analyser, Yeo-Kal Pty Ltd, Brookvale NSW).

3 RESULTS

The rainwater collected from the roofs in the urban catchment was acidic (pH 4.74-5.2) with an electrical conductivity of 12-25 µS/cm (Table 1). The low acidity of rainwater collected is likely to be caused by a combination of proximity to the coast and urban atmospheric pollutants (acid rain). The potential for acid rain has not been fully investigated in this study, however Chapman et al (2006) found that although Sydney’s tank rainwater is slightly acidic it wasn’t regarded as acid rain. The rainwater also had much lower levels of major anions and cations than had been previously recorded in urban streams in the northern Sydney area (Davies et al 2009).

Results from the field measurement and laboratory analysis are summarised in Table 1. Figure 1 shows the change in pH and conductivity for each of the different material type. Figure 2 shows the results of the laboratory analysis for Total Hardness; Bicarbonate alkalinity (as $CaCO_3$); Total Anions; Total Cations and Dissolved Major Cations – Calcium.

The rise in pH and conductivity over the experimental exposure period was greatest for the water conveyed in the new (steel-reinforced and fibre reinforced) concrete pipes, which had an average increase of 2.46 pH units and salinity increased by 43.5 µS/cm (Table 1). Water conveyed within the two older concrete pipes had lesser increases (average rise of 1.56 pH units and 9.5 µS/cm) (Table 1).

Bicarbonate and calcium levels both increased steeply after recirculation in both types of new concrete pipe, compared to old concrete pipes (Table 1). In comparison, bicarbonate levels also increased to a lesser magnitude in the PVC pipe, but calcium levels were unchanged (Table 1).

The PVC pipe recorded a negligible change in most water attributes over the same period (Table 1). The only notable increase was pH (average rise of 1.17 pH units) and bicarbonate (rise of 1.5 mg/L). (Table 1 and Figures 1 and 2).

	New Steel Reinforced Pipe			**New Fibre Reinforced Pipe**			**Old Steel Reinforced Pipe**			**Old Steel Reinforced Half-Pipe**			**PVC Pipe**		
	S	**F**	**D**	**S**	**F**	**D**	**S**	**F**	**D**	**S**	**F**	**D**	**S**	**F**	**D**
pH	4.9	7.59	2.69	5	7.22	2.22	5.07	6.32	1.25	4.74	6.61	1.87	5.2	6.37	1.17
Conductivity µS/cm	16	59	43	19	63	44	17	23	6	25	38	13	12	12	0
Bicarbonate alkalinity (mg/L)	0.5	22	21.5	0.5	16	15.5	0.5	3	2.5	0.5	5.3	4.8	0.5	2	1.5
Total hardness (mg/L)	0.5	17.7	17.2	0.5	17.0	16.5	0.5	4.7	4.2	0.5	6.0	5.5	0.5	0.5	0
Total Calcium (mg/L)	0.5	7.0	6.5	0.5	7	6.5	0.5	2	1.5	0.5	2.0	1.5	0.5	0.5	0
Total anions (meq/L)	0.18	0.71	0.53	0.18	0.53	0.35	0.2	0.3	0.1	0.20	0.26	0.06	0.20	0.19	-0.01
Total cations (meq/L)	0.13	0.6	0.47	0.13	0.49	0.36	0.13	0.24	0.11	0.13	0.25	0.12	0.13	0.14	0.01

Table 1. Concentration of water chemistry attributes before (S – Start) and after (F – Finish) 120 minutes of recirculation through the pipes. The difference between the start and finish is represented by the values listed in column "D".

4 DISCUSSION

The results from this study confirm the previous research (Davies et al 2009 and Novotny and Kincaid 1981) that supports the hypothesis that concrete drainage materials influence the chemistry of water during conveyance or overland flow. We suggest that buffering rainwater will primarily occur when exposed to concrete hydrates. The degree of this impact lessens as the concrete pipes degrade.

As previously reported (Davies et al 2009), the change in pH in all pipes, including PVC, can in part be attributed to the circulation of water resulting in aeration. This causes carbon dioxide gas to be released from the water, which is part of the normal buffering process. The results for the PVC pipe also show that as pH increases, the level of bicarbonate ions also rise, due to the disassociation of carbonic acid (e.g. Boulton and Brock, 1999), with bicarbonate levels increasing four-fold after recirculation within the PVC pipe . The level of bicarbonate increase was considerably higher for all concrete pipes, with a 6 to 44 fold increase (Table 1).

Levels of pH appear to asymptote at different units as time of contact increases for the various pipes. This would suggest the buffering is nearing equilibrium. While the study circulated the water for only 120 minutes the flattening of the curves suggest a probable maximum pH change as reflected by the

Langeiler saturation pH value (Langelier 1936). This needs to be explored further and would be expected to be directly related to the molar concentration of calcium (as reflected by the composition of the pipe) and total alkalinity of the solution.

While pH can be used as an approximate measure of the level of influence the bicarbonate alkalinity, hardness and major cations provide the best indication as to the degree and extent of the dissolution of cement products into the water.

The circulation time of 120 minutes is roughly representative of the average time a given volume of base-flow interacts with the piped drainage network in Ku-ring-gai local government area. It should be noted that the impact on water chemistry as a result of contact with a concrete pipe would be more profound in low flows (base flow) than during storm flows, due to the relative ratio between wetted perimeter and flow during low flows. For the receiving waterways, low flows make up most of the volume of water found in permanent pools that occur between rain events and comprise the major habitat (by time) for aquatic plants and animals. Storm flows will typically pass through ephemeral and intermittent waterways as hydraulic peaks. For aquatic ecosystem health the water chemistry of base flow is therefore considered to be of high importance in urban creeks.

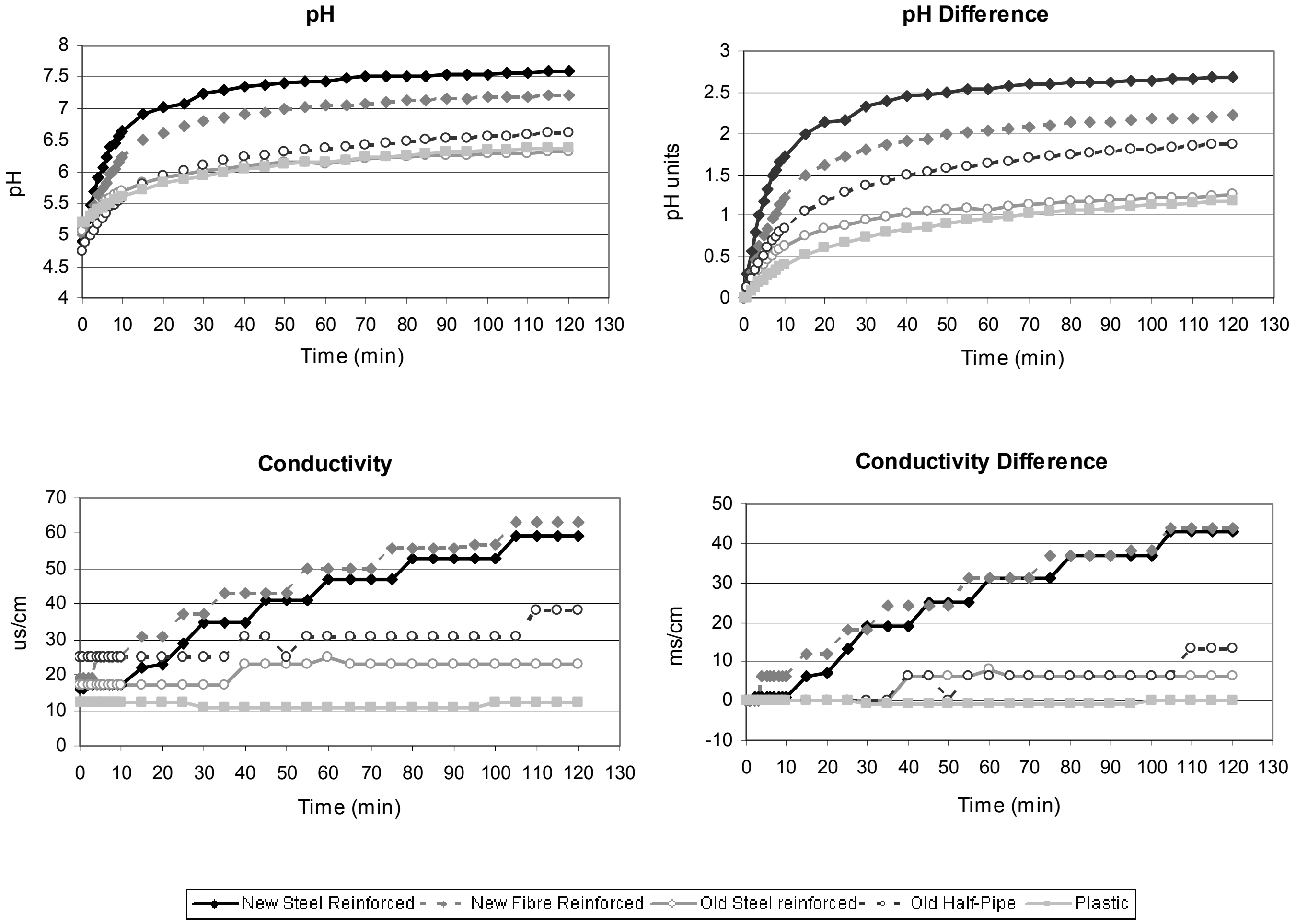

Figure 1. Field collected data graphs for pH and conductivity. Both the actual records and the difference from the start of circulation for each pipe are shown here. The different start points for the samples are due to a slight discrepancy in the meters (despite rigorous attempts to calibrate together) and the different batches of water.

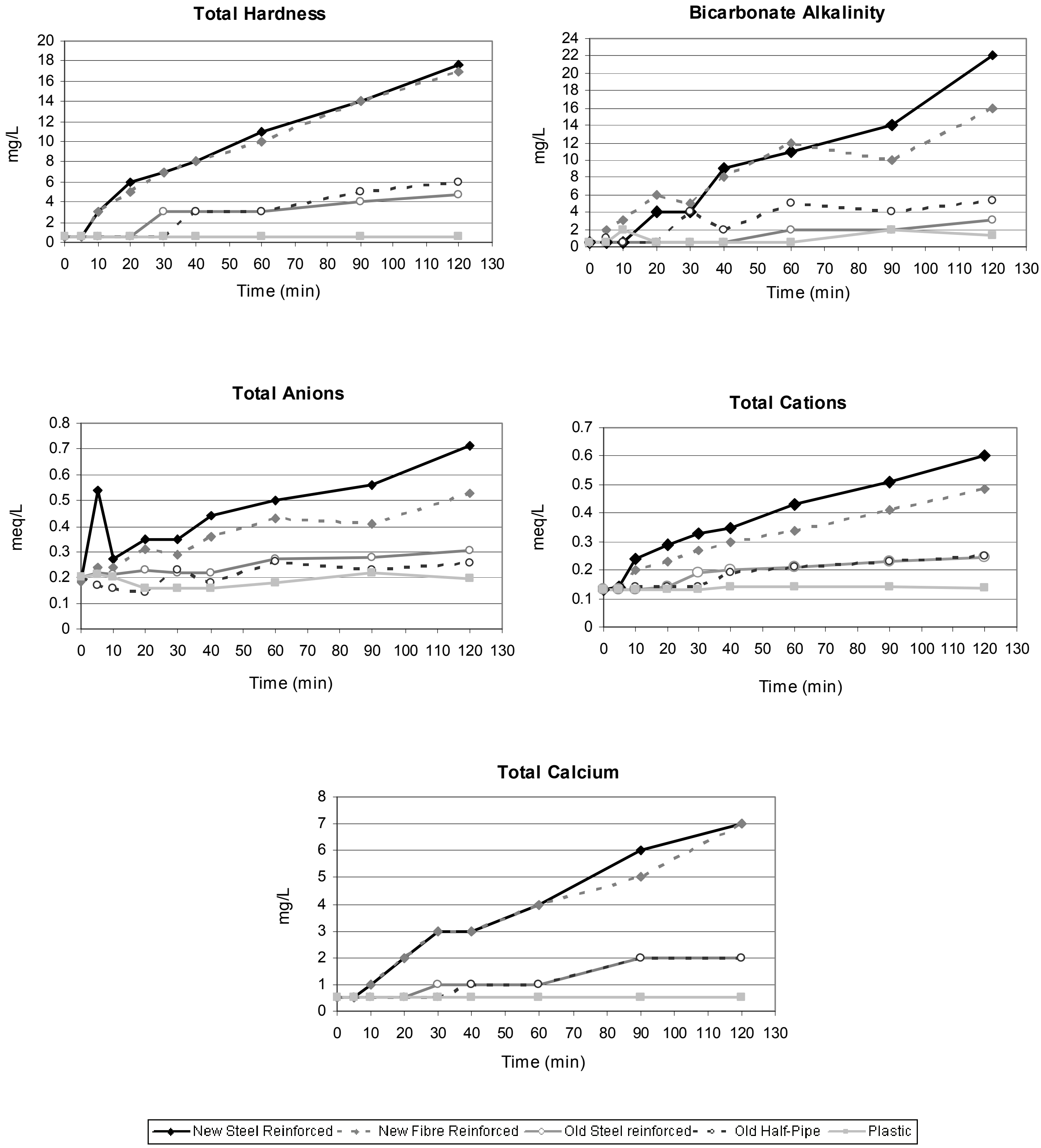

Figure 2. Graphs for Total Hardness; Bicarbonate Alkalinity; Total Anions; Total Cations and Total Calcium

4.1 Type, age and condition of concrete pipes and water chemistry effects

As reported in Table 1, this study found clear differences in the chemistry in water conveyed through new and old concrete pipes, when compared to the control. Figure 2 indicates that as circulation time increases so does the concentration of the respective anions and cations. Bicarbonate and calcium levels showed the greatest increase. We conclude that this is a result of the dissolution of the concrete. New pipes reported an increase in the concentration by over 35 times while the older pipes reported more than a four fold increase.

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 analytes when recirculated within new concrete pipes. The stepped nature of this change is likely due to the sensitivity of the hand held water chemistry meter.

The water chemistry response in the two older concrete pipes was different. It increased over the 120 minutes, but to a lesser extent than was recorded for the new concrete pipes. Electrical conductivity and pH both changed to a much lesser degree. The change in pH was similar for water recirculated within the old steel-reinforced concrete pipe to the PVC pipe than the new concrete pipes (Figure 1). The old pipes did record substantial increases in ionic levels (calcium, bicarbonate, hardness, total anions, total cations) through the experiment, but these were generally about 40 to 60% lower than the increases recorded in the new pipes.

4.2 Implications and directions

From a water chemistry perspective, this study suggests that the second order factors such as composition of materials as described by Gibbs (1970) may have a greater level of influence on naturally acidic waterways within cities and other urban catchments. Precipitation across many cities is influenced by pollutants, particularly sulphate, sulphites and nitrates that contribute to a lowering of rainfall pH below the standard benchmark of pH 5 (AEC 1989). The impact of acidic rain on terrestrial and waterway health as well as built structures is well described in the literature (eg AEC 1989) and buffering by concrete during urban overland flow has been identified as an effective control against these negative effects (Novotny and Kincaid, 1981). However, buffering by concrete drainage systems not only elevates pH levels but also increases by many fold the concentrations of numerous cations, particularly calcium, that is not naturally prominent in all types of ecosystems.

If WSUD or low impact development is accepted as a contemporary management approach for urban development that seeks to improve the quality of the natural waterways, then recognising the impact of acidic rain and its relationship to urban building materials requires inclusion into design and maintenance considerations. These conclusions build on a long history of the impact of weathering of specific building materials such as limestone, marble and concrete (Schaffer 1932) and more recently the acceleration of this process through acid rain. Acknowledgement of this in part has been provided by the European Commission’s mandate M/366 (EC, 2005) that has sought an assessment of the release of dangerous substances from construction products such that they will not be a threat to the hygiene or health of the inhabitants or neighbours not to the environment (EC, 1989). However, research undertaken by Schiopu et al (2009) to develop a model to estimate the leaching behaviours of concrete type construction materials recognised only Cr, Cu, Zn and SO_4^{2-} as pollutants. Her research has however sought to include measure and model precipitation/dissolution reactions that could be used to quantify the effect of increasing various cations to waterways.

From a water quality perspective, variations in pH and salinity have been shown to have a strong influence on base levels of the aquatic ecosystem such as algal diatoms (Steinberg and Putz, 1991; Tibby et al. 2007). We suggest that some waterways are more susceptible to degradation from concrete-related contamination and this should be given the same level of consideration as the traditional pollutant suite such as nutrients and metals. This is particularly relevant for high conservation value waterways that are naturally acidic and have low levels of calcium and carbonate/bicarbonate.

At a practical level, the ubiquitous use of concrete as a drainage material will mean any change will be met with resistance and indeed the use of a substitute material must also undergo a similar level of investigation to determine its effect on receiving water bodies. While the rate of reactivity of calcite from acid attack has been shown to reduce with applying chemical and physical treatments (Wilkins et al 2001 and Alessandrini et al 2000), a similar approach may be possible, although there is a need to be cognisant of the abrasive forces of water and other debris that scour drainage systems during high flow. Given that the renewal of a concrete drainage system is one that is measured in decades (the useful life of drains has been estimated at 100 years and kerb and guttering at 70 years: NSW Department of Local Government 1995) and during this time the dissolution declines, the turnover of this asset to a more environmentally appropriate alternative will take time. Attention then may be best focused towards new development areas particularly at the urban fringe where discharges occur to waterways previously unaffected by concrete products particularly used in driveways, curbs and pipes.

5 CONCLUSIONS

This study has identified that rainwater collected from a major city and recirculated through different types and ages of concrete pipes can result in changes to water chemistry. This is reflected by increased levels of major anions and cations, particularity calcium, carbonates and bicarbonates. The extent of the change is greater for new pipes than old. New pipes also reported a greater level of change in pH and conductivity than old pipes and also with respect to PVC pipes that were used as a control. These findings support previous research into concrete degradation in urban areas. This research contributes to our understanding of our urban environment in that it points to a need to consider the impacts of in-transport processes from concrete structures such as drains on receiving water bodies. It also suggests that all materials across our urban landscape should be assessed for their contribution and impact on natural ecosystems. Furthermore there is a need to consider synergistic effects such as changes in pH on bioavailability of contaminants. While it is important to identify the individual contribution of pollutants in our waterways, the results of this study point to the need to look more closely at the drainage systems and their contribution beyond hydraulics and hydrology to the degradation of our aquatic ecosystems.

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