THE TREATMENT OF STORMWATER FOR DISSOLVED METALS IN TROPICAL AND SUBTROPICAL ENVIRONMENTS

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Abstract

There are many different contaminants in stormwater runoff. Of particular concern to sensitive environments is the toxicity of the dissolved fraction of heavy metal contaminants. The characterization and partitioning of metals in stormwater is complex and dynamic with many factors affecting it.

The majority of stormwater investigations have occurred in the temperate climates of the USA, Europe and Australia. Temperate climates have 4 distinct seasons (summer, autumn, winter and spring) while tropical climates tend to have two; dry and wet. A tropical climate is typically associated with the tropics and is typically between latitudes 23.4° N and 23.4° S. A tropical climate is defined as having a mean temperature of over 18° C (64.4°F). The term 'subtropical' describes the area found adjacent to the tropics. The definition of a subtropical climate is one that has at least eight months with a mean temperature of 10° C (50°F) or above. Tropical and sub tropical environments have higher temperatures, higher intensity rainfall and generally faster growing flora. These climatic conditions greatly influence the characterization of stormwater pollutants.

The paper draws on research and results from 3 field studies. One on a highly trafficked arterial road in the world heritage wet tropics rainforest near Cairns in Northern Queensland, Australia (latitude 16°51 south) and two industrial sites is Auckland, New Zealand (latitude 36°52 south)

This paper investigates the effect of climate conditions on the relationship between solids and dissolved metals, the effect of organic carbon and dissolved metal concentration and the effect of temperature on contaminant removal. The paper also discusses sizing of a treatment system in a 2 season environment as well as treatment train mechanisms suitable for these climates.

Key Words: Total Metals, Dissolved Metals, Treatment, Climatic Conditions

1. INTRODUCTION

Aside from suspended solids, the primary contaminants of concern from highly trafficked roads are copper and zinc, from brake pad and tyre wear, respectively. In terms of protecting the receiving environment from the effects of these metals, there are two issues that require consideration. The first issue concerns the total metal load reaching the receiving waters. Generally speaking this can be effectively managed with efficient suspended solids removal. Most of the metals load is carried in the sediment fraction below 100 microns[1]. Efficient suspended solids removal in this particle size range will, generally speaking, result in effective reduction of total metals. The second issue concerns the dissolved (*i.e.* soluble) metals concentrations entering the receiving waters. This paper considers the effect of treatment train design on the downstream dissolved metals concentrations. In particular, we consider the effect of standing water in the treatment train and how, in a tropical or subtropical environment there is evidence that substantial dissolved metals concentrations may be released downstream.

2. CASE STUDIES

Below are descriptions of three field studies. The most comprehensive of these involves a treatment train in the Australian wet tropics. One of the implications of the results from this study is that the standing water in the sedimentation chamber amplifies dissolved metal concentrations. With this in mind, we also present results from two more limited field studies that look solely at the effect of standing water on dissolved metals concentrations in the subtropical climate of Auckland, New Zealand.

2.1 SFEP Treatment Train

The StormFilter EnviroPod Treatment Device (SFEP) is a complete self-contained ‘treatment train in a box’. The main components of the train are a gully pit sedimentation chamber with a downstream filtration device. This rather conventional design is augmented with a 200 micron pre-treatment screening device, which is effective at capturing the bulk of sediments down to 100 microns diameter. The SFEP is designed to be installed in a modular fashion on elevated bridge deck structures. The layout of the SFEP treatment train is illustrated in Figure 1. Despite its’ compact nature, the components of the SFEP treatment train are very conventional.

In this case the SFEP was installed on the Kuranda Range Road in Northern Queensland, Australia. The Kuranda Range Road is the major arterial route from Cairns to the Atherton Tablelands. The latter represent the major area of population growth in the region. Currently the Kuranda Range Road is a two lane highway and carries *ca.* 10 000 cars/ day, but it is estimated that this will more than double in the next 10 years. The proposed Kuranda Range Road Upgrade involves replacing the existing road with 12 km of 4 lane highway predominantly constructed with elevated bridge deck. It is proposed that the SFEP treatment device, or a variant thereof, will be installed to treat stormwater at the road surface before discharging directly to one of several streams in the region. Discharge to land, in this case, is unfeasible due to the potential for scouring of the topsoil, especially during intense wet-season rainfall. The area traversed by the Kuranda Range Road is a World Heritage Area and contains numerous endangered wildlife species. In particular, the streams into which it is planned to discharge road runoff contain several species of fish and amphibians that are considered to be particularly at risk from elevated metals levels. The crucial period is considered to be during the dry season (winter months), during which the stream levels are very low. In extreme dry periods these streams may, in fact, revert to isolated pools with little or no flow between them. It is considered that runoff from the road in this scenario might have sufficiently high dissolved copper and zinc concentrations that the receiving waters could become acutely toxic to the various sensitive species therein. Runoff, in these circumstances, is unlikely to be substantially diluted because in these dry conditions the initial abstraction of rainfall from adjacent pervious surfaces is complete and the latter areas will not contribute runoff to the streams. Taking into account all of the above, the design brief for the SFEP was to provide sufficient attenuation of dissolved metal concentrations that sensitive aquatic life would be afforded maximum protection. As such, the Kuranda SFEP was configured with ZPG® media, a proprietary blend containing perlite, zeolite and granular activated carbon that has previously proven effective at removing *ca.* 50% of dissolved copper and zinc from road runoff [2, 3].

2.1.1 SFEP Treatment Train Experimental

The SFEP treatment train was installed in ground beside a section of the existing Kuranda Range Road. A portion of the road with an approximate catchment area of 320 m^2 was kerbed and channeled into the device. Figure 2 shows a schematic of the sampling set-up. ISCO 6712 auto-samplers were used, with flow data being recorded as stage data in a v-notch weir downstream of the outlet pipe. Influent samples were taken via a low-profile strainer sitting in a grooved channel where runoff flows into the SFEP. Outlet samples were taken via a strainer mounted in the invert of the outlet pipe. Flow weighted samples were taken. The pacing for this was 1 sample per 400 L where wet-season rainfall patterns were expected and 1 sample per 200 L where dry-season rainfall patterns were expected. Following a qualifying storm event, samples were collected within 24 hours by Cairns Water Analytical Laboratory. Influent and effluent Event Mean Concentration (EMC) composites were prepared in a 14 L polyethylene USGS approved churn splitter. Sub-samples were then drawn off for further analysis. Duplicate analysis was performed on at least 20% of all samples. Maximum allowable RPD = 20%, in all cases.

2.1.2 SFEP Treatment Train Results

James Cook University performed an independent study on the SFEP train; monitoring 4 storms over 2006/ 07, predominantly throughout the wet-season. Their full report should be consulted for experimental detail.

Stormwater360 continued the study over 2008/ 09, monitoring 6 storms, predominantly throughout the winter dry-season.

Results from both studies are summarized in Table 1.

2.1.3 SFEP Treatment Train Discussion

The overall performance of the SFEP treatment train proves to be excellent for most analytical parameters across both studies, particularly in terms of suspended solids and nutrients. The notable exception to this rule is that dissolved zinc and, to some extent, total zinc results are poor. Specifically, the most curious result is that during both studies the treatment train, as a whole, exported dissolved zinc, when the ZPG media has proven in numerous other field trials to be capable of significant dissolved metal reduction.

Once it became apparent that there was a dissolved metals issue it was decided to sample the wet-sump to compare the concentrations of dissolved metals in the standing water with the influent EMCs during storm events. This was performed on a limited number of occasions and does not constitute a quantitative analysis. Having said this, Figure 3 shows the relationship between the dissolved zinc in the standing water, sampled during dry periods, and the influent EMC during the following storm event. On the occasions where sampling the standing water was followed, within 5 days, by a storm event (A,B,C Figure 3) the dissolved zinc concentrations in the wet sump were between 95% and 440% of the influent EMC. The mean dissolved zinc concentration across 5 occasions that the wet sump was sampled was 36 µg/L, compared with a mean dissolved zinc EMC of 19 µg/L across all storms. Clearly the dissolved zinc levels present in the standing water are, in large part, responsible for the poor performance of the SFEP treatment train for dissolved zinc. The potential influence of this can be understood by considering Figures 5 & 6. Figure 5 shows the typical tropical rainfall pattern experienced in the Queensland wet tropics. Most of the sampling during the Stormwater360 study at this site took place during the dry season; the flat part of the graph in Figure 5 from early June to late December. This is the rainfall pattern that the SFEP system was sized to treat. A typical storm event during this period is illustrated in Figure 6. In this case a storm event of *ca.* 4 mm of rainfall gives rise to just short of 800 L of runoff. Given that the volume of the standing water is *ca.* 600 L, it is clear that the dissolved zinc levels in the sedimentation bay are compromising the removal efficiency of the entire treatment train, even if the zeolite based media downstream is achieving significant removal.

Inspection of figure 4, which compares dissolved copper influent EMCs with that found in the catchpit suggests that this same effect may not be so marked as was the case with dissolved zinc. The mean dissolved copper concentration across 5 occasions that the wet sump was sampled was 4 µg/L, compared with a mean dissolved zinc EMC of 13 µg/L across all storms. This is supported by the observation that, at least during the Stormwater360 phase of testing, dissolved zinc performance was reasonable across all storms.

It is pertinent to note that other authors have remarked on the correlation between dissolved metals and organic carbon[4]. Mean value for dissolved organic carbon (DOC) in the wet sump was a fairly elevated 15 mg/L. It may suggest that in the tropical environment, with a high organic load entering the unit, there is a tendency for high DOC, with a correlated high dissolved zinc concentration.

2.2 Galvanizing Facility Sedimentation Chamber

With the results from Kuranda in mind, as a first stage of designing a treatment train to cope with high total and dissolved zinc levels coming from an Auckland galvanizing facility, we set out to investigate the effect of the standing water in a conventional sedimentation chamber treating the roof runoff.

2.2.1 Galvanizing Facility Sedimentation Chamber: Experimental

Mid-storm dissolved zinc samples were compared with dissolved zinc samples in the sedimentation chamber prior to that storm.

2.2.2 Galvanizing Facility Sedimentation Chamber: Results

See Figure 6.

2.2.3 Galvanizing Facility Sedimentation Chamber: Discussion

Inspection of Figure 6 indicates, very anecdotally, that, whilst the dissolved zinc levels were typically elevated in the wet sump, they were not observed to be more than 30% more than the concentration of mid-storm runoff.

2.3 North Shore Catchpits

An brief study was conducted to measure the dissolved metals levels present in 4 roadside catchpits on Auckland's North Shore. This was compared with typical mid-storm dissolved metals values.

2.3.1 North Shore Catchpits: Experimental

Dissolved metals levels were measured from 4 catchpits, with an antecedent dry period of 5 days. Mid-storm grab samples were collected prior to each catchpit 3 days after the initial catchpit sampling. Samples were tested for dissolved copper and zinc.

2.3.2 North Shore Catchpits: Results

See Figures 8 (dissolved zinc) & 9 (dissolved copper)

2.3.3 North Shore Catchpits: Discussion

This does not constitute an in-depth study, however results tend to indicate that, in general in these catchpits the dissolved metals concentrations were significantly lower than during mid-storm samples.

3. Conclusions

It is clear from the study in Kuranda, in the wet tropics, that the standing water in the treatment train is amplifying dissolved zinc concentrations as runoff passes through it. This may be, in part due to the relatively high DOC concentrations, due to organic matter decomposing in the standing water, in the comparatively high temperatures. Future designs of the SFEP in this location will have the wet-sump removed. It seems likely that in a full drain-down configuration the performance of the SFEP for removal of dissolved metals, and zinc in particular, should be significantly improved.

A brief, non-comprehensive study of standing water in Auckland catchpits and sedimentation devices did not show the same tendency for amplification of dissolved metals. Whether these differences are related to differences between Auckland's (sub-tropical) and Kuranda's (tropical) climate remains to be seen. This may warrant further investigation.

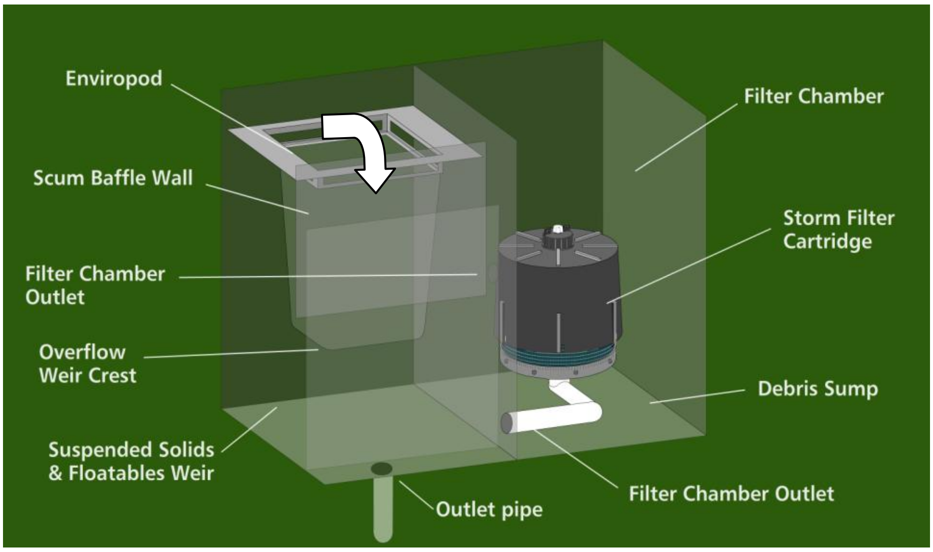


Fig 1. Kuranda SFEP: Treatment train layout.

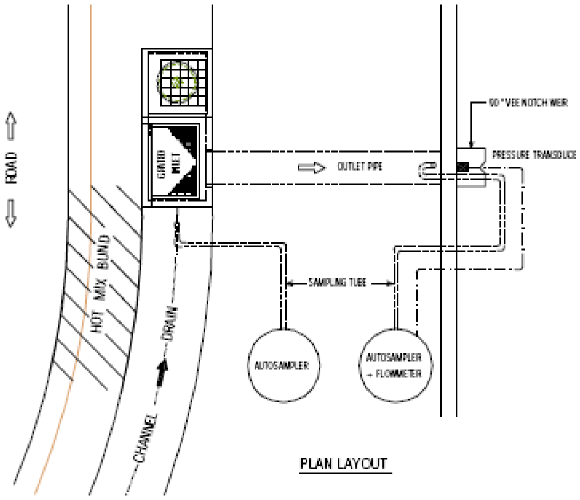


Fig 2. Kuranda SFEP: Experimental set-up

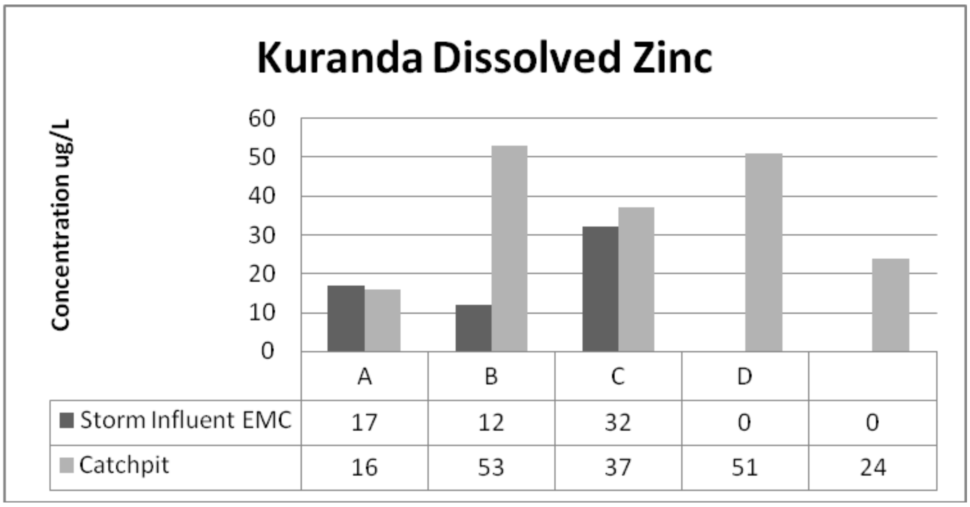
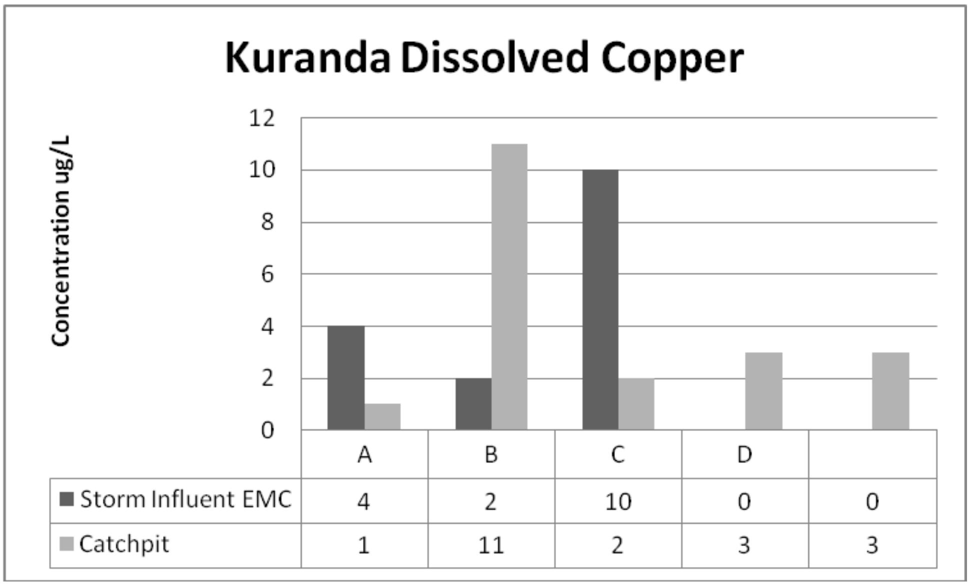


Fig 3. Kuranda SFEP: Dissolved zinc concentrations



	A	B	C	D	
Storm Influent EMC	4	2	10	0	0
Catchpit	1	11	2	3	3

Fig 4. Kuranda SFEP: Dissolved copper concentrations

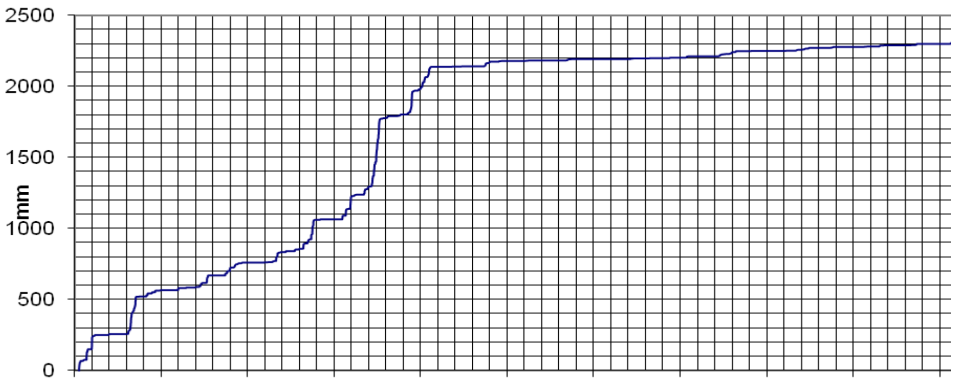


Fig 5. Kuranda SFEP: Jan to December 2008 Cumulative Rainfall

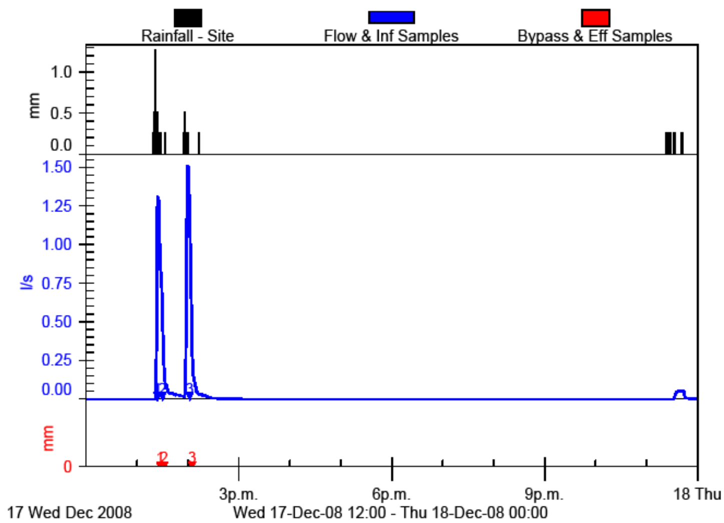


Fig 6. Kuranda SFEP: Typical dry-season storm event

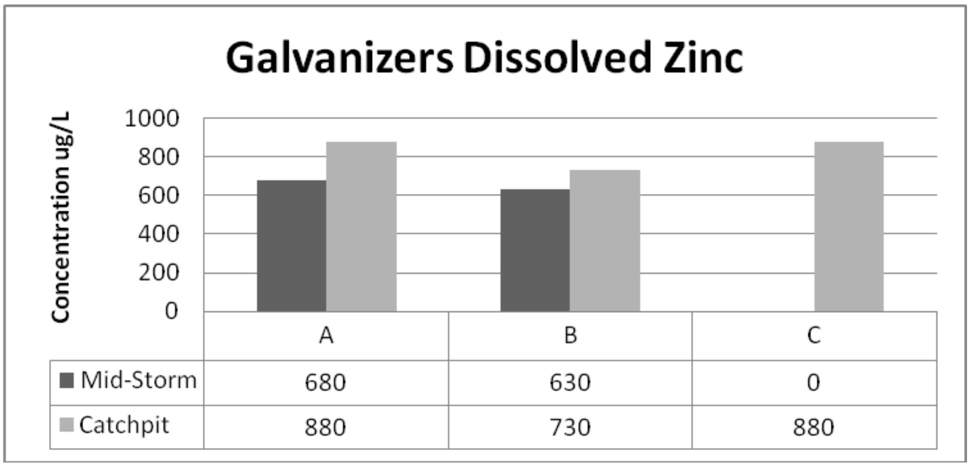


Fig 7. Galvanizing Facility Dissolved Zinc Concentrations

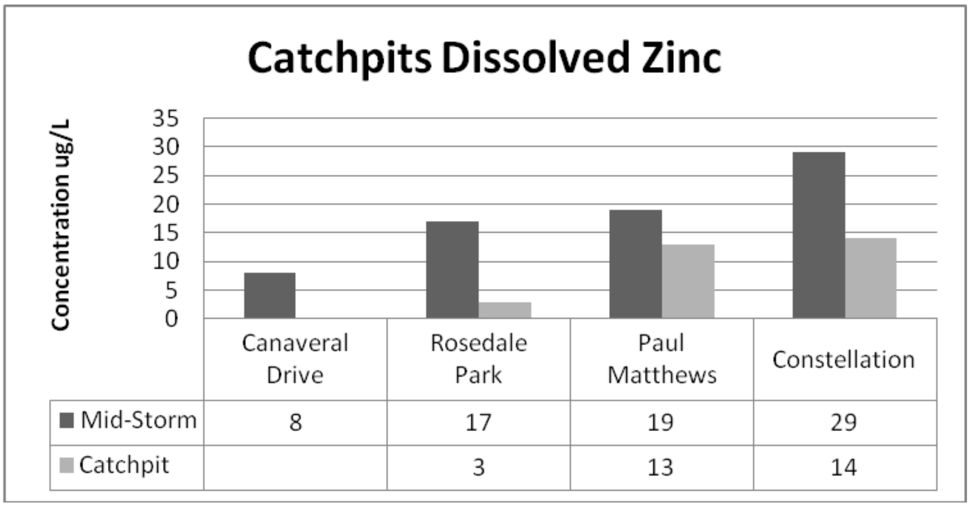


Fig 8. North Shore Catchpits Dissolved Zinc Concentrations

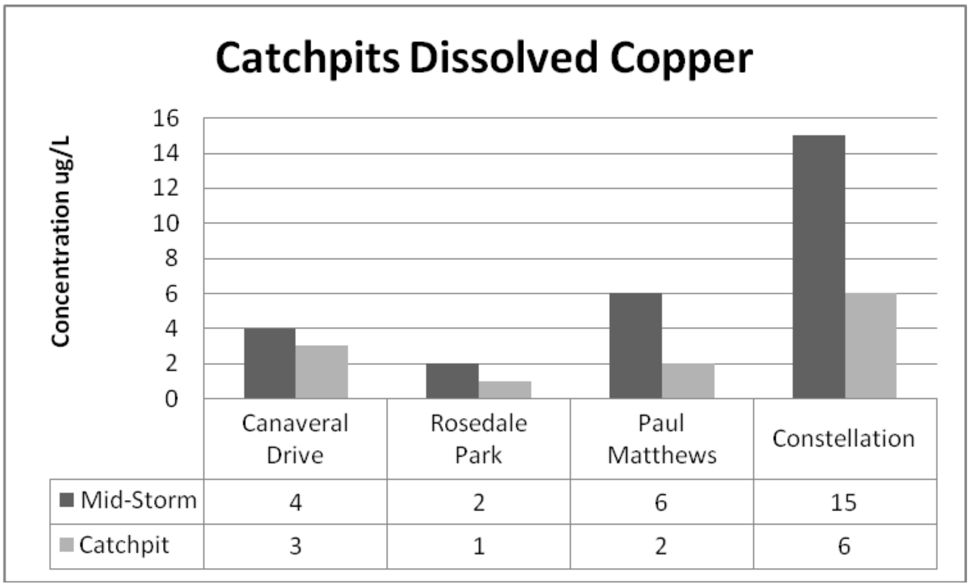


Fig 9. North Shore Catchpits Dissolved Copper Concentrations

	Removal Efficiency (Sum of Loads)	
	James Cook University Study (2006-07)	Stormwater360 Study (2008-09)
Total Suspended Sediment Concentration (Tot-SSC)	**85%**	**97%**
Below 500 micron Suspended Sediment Concentration (<500 µm SSC)	**-**	**78%**
Total Phosphorus (TP)	**70%**	**34%**
Total Nitrogen (TN)	**45%**	**42%**
Total Kjeldahl Nitrogen (TKN)	**45%**	**45%**
Total Copper (Tot-Cu)	**58%**	**49%**
Total Zinc (Tot-Zn)	**37%**	**18%**
Dissolved Copper (Diss-Cu)	**-10% (addition)**	**67%**
Dissolved Zinc (Diss-Zn)	**-302% (addition)**	**-181% (addition)**

Table 1. Kuranda SFEP: Removal efficiencies calculated by sum of loads for the SFEP treatment train

ACKNOWLEDGEMENTS

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