Stormwater Treatment Devices — How Effective Are They? A case study — Golden Pond, Calamvale, Brisbane

Margaret Greenway and Nicole Le Muth
School of Environmental Engineering and CRC for Catchment Hydrology
Griffith University, Nathan Qld 4111 AUSTRALIA
Email: M.Greenway@mailbox.gu.edu.au

Summary

Urban stormwater is now recognised as a pollution source to waterways with impacts on aquatic ecosystem health. In urbanised residential areas major pollutants are sediment and nutrients and to a lesser extent heavy metals and hydrocarbons. Stormwater best management practice is aimed at reducing potential downstream impacts. Stormwater treatment devices to control or reduce trash, sediment and nutrients include gross pollutant traps (trash tracks, CDS and ECOSOL units); sediment basins, vegetated buffer strips, wetlands and ponds and biofiltration systems. A crucial question is "How effective are these stormwater treatment devices in improving water quality?" A case study was undertaken to evaluate the performance of several devices in a 'treatment train' including a sediment basin, constructed wetland, pond, CDS unit, ECOSOL unit, natural riparian wetland and a 600 m length of natural stream channel. Our study showed that during a storm event there was no reduction in total suspended solids or nutrients throughout the treatment train, but within 24 hours TSS concentrations were at background concentrations or lower, but nutrients increased. During dry weather small amounts of NH_4-N and NO_3-N were produced in the sediment basin but the wetland and pond effectively removed soluble nutrients. Stormwater via the CDS and ECOSOL units produced higher soluble nutrients, however these were removed by the pond and riparian wetland vegetation respectively. The existing natural stream, lagoons and associated vegetation was the most effective "treatment" at removing sediment and nutrients.

1. Introduction

1.1 Pollutants in urban stormwater

The amount and types of pollutants carried in stormwater runoff will vary according to land use, the intensity and duration of rainfall events and the time between rainfall events. Land use can be indicative of types and concentrations of pollutants. In agricultural areas sediment, nutrients and pesticides are likely to be major pollutants in runoff. In urbanised residential areas major pollutants are sediment and nutrients; in industrial areas other major pollutants may include heavy metals, oil and grease. Rainfall intensity can influence the quantity of pollutants carried in stormwater. Both intensity and duration of rainfall events aid in dislodging and transporting pollutants into water courses. The time between rainfall events also affects the quality and quantity of stormwater runoff due to the build up of contaminants on impervious surfaces between events. As time between events increases, more pollutants accumulate that can be potentially dislodged.

Urbanisation has led to an increase in impervious surfaces resulting in increased volumes of stormwater runoff. Modification of natural streams into concrete, trapezoidal channels has also increased volumes and peak flow rates of stormwater. Urban stormwater runoff is now recognised as a pollution source to downstream waterways and aquatic ecosystems. Major pollutants include suspended solids (sediment and organic particles) and nutrients, (ammonium, nitrite, nitrate; organic nitrogen; orthophosphate; organic phosphorus; and organic carbon), these can impact aquatic ecosystem health. Suspended solids increase water turbidity which reduces light penetration and photosynthesis, if there is a high proportion of organic particles then biochemical oxygen demand (BOD) increases. These organic particles provide a food source for micro-organisms which use up oxygen in aerobic respiration, this may lead to oxygen depletion. Nutrients are essential for plant (and animal) growth however excess nutrients in particular soluble inorganic nitrogen and phosphorus can increase the growth of unicellular algae and cyanobacteria causing algal blooms. Dense blooms can also increase turbidity and BOD, some cyanobacteria are toxic. Other potential stormwater pollutants include heavy metals, pesticides/herbicides, oils/grease and microbial pathogens, these substances are often more localised and their impacts on aquatic ecosystems is usually not acute. Microbial pathogens are a human health problem if the water is consumed.

1.2 Stormwater best management practice

Given the potential detrimental impacts of increased suspended solids and nutrients on aquatic ecosystems it is not surprising that stormwater management strategies relate to sediment and nutrient control (NSW Dept Housing 1993, IEAust 1996, Qld EPA 1998, NSW EPA 1998). Stormwater best management practice (BMP) is aimed at reducing potential downstream impacts on aquatic ecosystem health. BMP can be categorised into structural and non-structural mechanisms (Urbonas 1994).

Non-structural BMPs include a variety of educational and regulatory practices for both land developers and the public. Structural BMPs for sediment and nutrient control include: Gross Pollutant Traps (to catch coarse sediment and trash), Retention Sediment Basins (to capture coarse and fine sediment), Vegetation Buffer Strips (sediment and nutrient removal by sheet flow across wide natural vegetation strips), Infiltration and Bioretention Systems (sediment and nutrient removal by filtration and biological processes), Vegetation Filter Strips/Grass Swales (sediment and nutrient removal along concentrated flow paths), Water Quality Control Ponds/Wet Basins/Wetlands (effective sediment and nutrient removal by aquatic ecosystems dominated by wetland plants). It is therefore possible with new subdivisions and urban developments to minimise the amount of suspended solids and nutrients entering downstream aquatic environments by incorporating some of these techniques. It is also possible to install Gross Pollutant Traps, Sediment Basins, Grass Swales, Wetlands and Ponds into established urban infrastructure however the constraints are greater.

In Queensland the Environmental Protection Act (1994) and the Environmental Protection (Water) Policy (1997), require Local Authorities to manage the impacts of stormwater on receiving waters. The Brisbane City Council and private land developers have constructed several different stormwater quality improvement devices (SQIDs) in order to improve the quality of stormwater runoff which ultimately flows into Moreton Bay. SQIDs currently constructed in Brisbane include – Gross Pollutant Traps (trash racks, floating booms, CDS units, ECOSOL units); Sediment Basins; Bioretention Systems; Grass Swales; Constructed Wetlands and Ponds (BCC, 2000; 2001).

1.3 Effectiveness of stormwater quality improvement devices

A crucial question is "How effective are these stormwater treatment devices in improving water quality". In order to answer this question the evaluation of the performance of stormwater treatment devices for a range of conditions – catchment size, land use (percentage urban, industrial, rural), pollutant characteristics, climate in particular rainfall; under both wet weather and dry weather conditions is essential. Although literature and case studies have documented the performance of various SQIDs (Lawrence et al, 1996, 1997; 1996; Shutes et al, 1997; Bartone and Uchrin, 1999; Mehler and Ostrowski, 1999; Braune and Wood, 1999, Carleton et al, 2001; Mazer et al, 2001). Very limited stormwater and SQID performance data is available for Queensland's climatic conditions which are characterised by high intensity summer/autumn rainfall events.

In 1994 BCC established a Stormwater Quality Monitoring program to characterise pollutants from different land use activities and in 1998 established a Stormwater Quality Improvement Device Monitoring Program. To date the following SQIDs have been monitored ECOSOL Units, CDS Units, a Grass Swale, a Sediment basin (site construction phase monitoring), a Constructed Wetland (BCC, 2000; 2001).

The purpose of the Griffith University CRC Catchment Hydrology study was to gain a greater understanding of the effectiveness of several SQIDs in a "treatment train" in the South East Queensland region, in particular focusing on a constructed stormwater wetland in a residential development in Calamvale.

This paper will present data from a 12-month monitoring program of a Sediment Basin, Constructed Wetland, Pond, Natural Riparian Wetland, 600 m length of natural Stream Channel and Lagoons, and Stormwater from a CDS unit and ECOSOL unit.

2. Case study

2.1 Study area

The location for this case study was the suburb of Calamvale, 24 km south west from the Brisbane Central Business District. Urbanisation of this outer suburb occurred in the early 1990s. The area bounded by Compton road to the north; Honeysuckle Way to the south, Beaudesert Road to the west and Gowan Road to the east; is within the upper catchment of a tributary of Scrubby Creek which flows into the Logan River and Moreton Bay. The catchment size is 235 ha consisting predominantly of residential land use and about 70% impervious surface.

Prior to development three stream channels fed into a series of lagoons with fringing riparian Melaleuca wetlands – known as the Kameruka Wetlands. The main north-south flowing stream tributary had a catchment of 160 ha, whereas the two smaller west-east flowing stream tributaries had a combined catchment of approximately 50 ha.

As a consequence of residential development the drainage infrastructure is underground drainage pipes. The lower section (650 m) of the main (north-south flowing) stream has been modified into a concrete lined trapezoidal channel with a bed width of 4 m (12.2 m bank to bank). This flows into a series of structural BMPs or SQIDs – a small sediment basin, a constructed wetland and a pond, before entering the original natural stream channel in parkland.

The western section of the catchment (13.6 ha) bounded by Kameruka Street, Beaudesert Road and Golden Avenue is all piped and redirected to enter the pond via a CDS unit. The piped south western section of the catchment (38.4 ha) bounded by Tupelo Street, Golden Avenue, Beaudesert Road and Honeysuckle Way enters the original natural stream channel through 3 stormwater drain outlets at the top of the parkland at Tupelo Street.

The natural stream and adjacent riparian vegetation has been retained from Tupelo Street to Gowan Road as parkland. Several lagoons occur within this 680 m length of stream.

2.2 Stormwater Quality Improvement Devices

Within the study area several structural features to improve stormwater quality and remove gross pollutants occur – these include a sediment basin, a constructed wetland, a pond, a CDS (Continuous Deflective Separation) Unit, an ECOSOL Unit; a natural vegetated riparian-wetland; natural vegetated stream channel and lagoons. The sediment basin and constructed wetland are retrofit structures incorporating the lower 120 m of the channelised main stream and adjoining parkland. Construction was completed in September 1999.

The sediment basin is a trapezoidal concrete structure (21 m long × 13.5 m width) with 1 in 3 sloping slides and a maximum centre depth of 1.5 m. It receives water from the modified stream channel. The accumulated coarse sediment is periodically (but infrequently) removed by Brisbane City Council.

The constructed wetland is 80 m long × 15-20 m wide and 20–120 cm deep. It has a surface area of 1550 m^2 with a volume of 1100 m^3 at the standing water level. Percentage cover of emergent vegetation varied between 60% (post storm event) to 90%, of which floating leaved emergent species (*Nymphoides indica, Nymphaea spp., Ludwigia peploides*) accounted for 77%. Submerged pond weed (*Elodea*) occurred in open water areas and beneath floating leaved species. The constructed wetland receives water from the sediment basin.

The pond was originally a small farm dam, it was further excavated to its current dimensions: 52 m long × 20 m wide and up to 1.2 m deep. 95% is completely covered with floating leaved emergent species. *Nymphaea* and *Nympoides* are rooted in the deeper sections, whereas the aquatic creepers *Ludwigia* and *Persicaria orientalis* extend from the banks. It receives water from the constructed wetland after it has passed through the culverts under Golden Av. It also receives a continuous flow from the piped drainage system covering the western section (13.6 ha). This water enters the pond after it has passed through a CDS unit. At the bottom of the pond, the water then flows into the natural stream channel in parkland.

The natural riparian wetland is a 90 m length of the original western tributary and associated riparian vegetation. It now receives stormwater from the ECOSOL outlet on Tupelo Street. The stream channel is poorly defined, it is permanently saturated and supports a dense cover of emergent aquatic plants including *Typha domingensis, Persicaria sp* and ferns (*Blechnum indicum, Hypoclepis muelleri,* Melaleuca (*M. quinquenervia, M. linarifolia)* fringe the landward margins.

A 600 m length of the original stream channel, lagoons and associated fringing riparian Melaleuca zone known as “Kameruka Wetlands” extends to Gowan Road.

3.0 Method

Urbanised catchments with large impervious areas respond quickly to rainfall events. This often makes it difficult to interpret/correlate (synchronise) water quality data with rainfall and runoff, unless synchronisation of sampling occurs. Furthermore, in order to produce a hydrograph, i.e. a plot of the variations in discharge, or a pollutograph, i.e. a plot of the variations of pollutant concentrations throughout the duration of the event, a minimum sampling frequency of hourly intervals is required and preferably 5-minute intervals. This requires automatic samplers. Unfortunately, given the number of sampling sites, it was only possible to take one grab sample at each site per visit. Water quality was monitored on a regular basis at 17 sites over a period of 12 months (November 2000 to November 2001). The location of the sampling sites is shown in Figure 1.

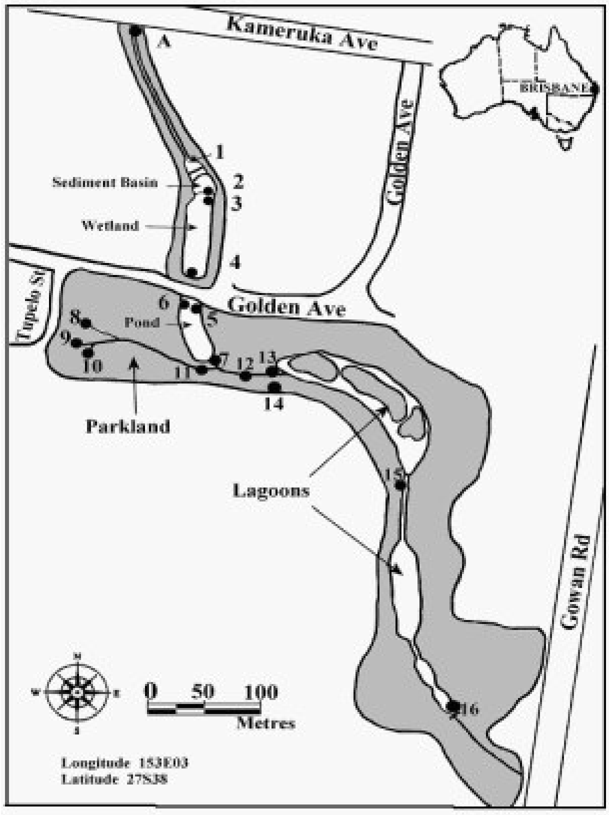


Figure 1. Location Map Golden Pond and Kameruka Wetlands, Calamvale

Only two rainfall events were actually sampled on the same day as the storm 18 January 01 (11 mm + 21 mm previous day) and 17 October 01 (28 mm), whereas six samples were collected 24 hours after an event. The 1-in-100-year storm event of Friday 9 March was not sampled until 12 March.

Water samples were analysed for the following parameters: total suspended solids (TSS) and total volatile solids (TVS); total nitrogen, ammonium-N, nitrate-N, nitrite-N; total phosphorus, soluble reactive phosphate-P.

Results

4.1 Total Suspended Solids

Water quality data for total suspended solids (TSS) is shown in Figure 2 for sites 1, 2, 3, 4, 6, (CDS outlet), 7, 11, 16.

During storm events (i.e. within 12 hours) TSS increased and concentrations throughout the treatment train were fairly constant indicting limited effectiveness of either man-made treatment devices or natural features. Lower TSS at the end of the densely vegetated riparian wetland was partly due to the lower TSS in receiving waters from the ECOSOL unit and some natural filtration and settlement. Within 24 hours TSS was similar to dry weather concentrations and consistently below the Brisbane City Council water quality objective of 15 mg/L. During storm events inorganic particles made up 70% of TSS, whereas during dry weather, inorganic particles composed 40-50% TSS. The bottom of the wetland and pond always had higher TVS than in the upstream waters and sediment basin indicating the addition of organic particulates to the water column. The 600 m length of natural stream channel was effective at removing these additional particulates. The CDS unit was effective in reducing TSS under both wet and dry conditions.

Upstream Channel (1): TSS entering the sediment basin ranged from < 1 mg/L to 34 mg/L. The maximum of 34 mg/L was recorded during a storm event of which 71% was inorganic, however by the following day TSS was only 4 mg/L. For samples collected between 21 November and 26 July 01 TSS remained consistently low between 1-8 mg/L, however samples collected in August, September and October were higher 10-16 mg/L despite the lack of rain, this may have been due to over watering of gardens and lawns.

Sediment Basin (2): TSS leaving the sediment basin was similar to the water entering indicating little or no settlement of finer particulates, an exception was for the August, September and October samples where TSS was reduced to < 5 mg/L.

Top (3) and Bottom (4) of Wetland: A comparison between top and bottom shows that TSS is consistently higher at the bottom indicating an increase in fine particulates even during dry weather.

Top (5) and Bottom (7) of Pond: A comparison between the top and bottom of the pond shows that TSS is generally reduced during dry weather but increases during wet weather, probably due to resuspension of particles. The samples from the top of the pond were taken after the water from the wetland flows through the culverts under Golden Av. TSS was often higher in these samples than those taken at the bottom of the wetland (4), probably due to resuspension of accumulated sediment in the culverts.

Nitrogen

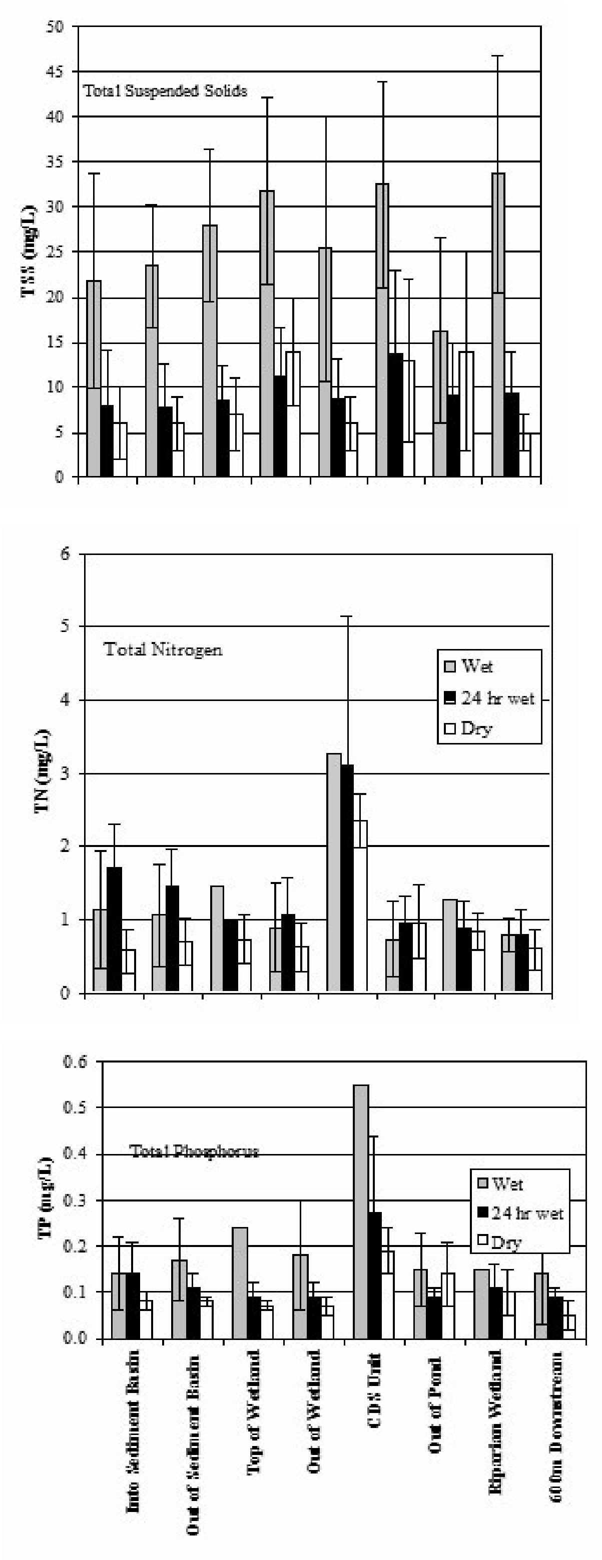
Water quality data for TN is shown in Figure 2 and NH_4-N and NO_3-N in Figure 3. Nitrate was the major component of stormwater entering the treatment train in both wet and dry weather samples, accounting for up to 70% TN. During a storm event organic N remained fairly constant throughout the treatment train (0.5 ± 0.1 mg N/L) but concentrations varied temporarily and spatially in 24 hour wet and dry samples ranging from 0.2-0.5 mg/L at most sites. In dry weather samples, higher organic N was always found at the pond outlet (7) due to a combination of high input from the CDS unit (6) and the export of organic particulates from within the pond itself. Nutrient concentrations of NH_4-N and NO_3-N were higher in the 24 hour wet than dry weather samples. The 24 hour samples showed that ammonium was highest at the bottom of the pond suggesting ammonification, however at the downstream site (16) concentrations were almost undetectable. Nitrate was substantially reduced in the wetland suggesting removal by plants and autotrophic micro-organisms. During dry weather higher NH_4-N (0.08 ± 0.09 mg/L) at the pond outlet compared with the wetland (0.03 ± 0.03 mg/L) was probably due to additional contributions from the CDS unit (0.07 ± 0.06 mg/L) and some ammonification in the pond. The densely vegetated riparian wetland also generated high ammonium.

NO_3-N concentrations were highest in the discharges from the stormwater outlets from the CDS (1.76 ± 0.78 mg/L) (6) and ECOSOL (1.10 ± 0.81 mg/L) (10) units, however concentrations were reduced as the stormwater passed through the pond and riparian wetland respectively. The 600 m length of natural stream channel was effective in removing both ammonium and nitrate. BCC Water Quality Objective of 0.65 mg/L N was most frequently achieved in the wetland and downstream natural channel.

Phosphorus

Water quality data for TP is shown in Figure 2 and PO_4-P in Figure 3 for sites 1, 2, 3, 4, 6 (CDS outlet), 7, 11, 16.

Soluble reactive phosphate was always higher in the stormwater wet weather samples entering the sediment basin (0.01 ± 0.10 mg/L) (2) and from the CDS unit (0.24 ± 0.19 mg/L) (6) and ECOSOL unit (0.10 ± 0.09 mg P/L) (10). The pond was particularly effective at removing the high PO_4 entering from the CDS unit. The downstream site (16) always had the lowest concentrations again indicting the effectiveness of the natural stream channel, lagoons and aquatic vegetation in removing soluble nutrients. High total P leaving the pond in dry weather was due to organic particulates. BCC Water Quality Objective of 0.07 mg/L TP was most frequently achieved in the wetland and downstream natural channel.



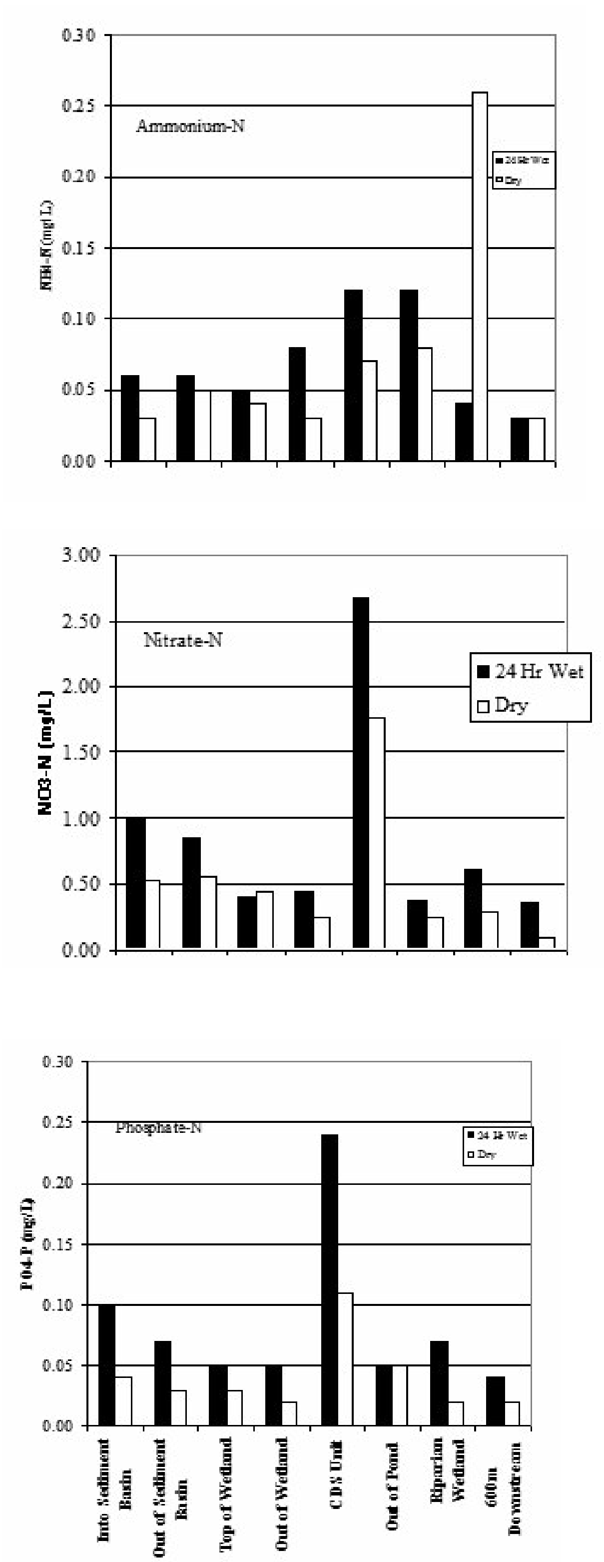


Figure 2. A comparison of TSS, TN and TP for samples collected within 12 hours of a storm, 24 hours of a storm and during dry weather (mean ± SD).

Figure 3. A comparison of mean nutrient concentration of ammonium, nitrate and phosphate for samples collected within 24 hours of a storm event and during dry weather.

5. Discussion

5.1 Stormwater quality (Sites A, 1, 8, 9, 10)

Mean TSS was higher in wet periods indicating mobilisation of sediment and organic particulates in response to runoff. TN concentrations are higher in wet periods (due to higher NO_3-N and organic N) but of similar magnitude for both wet and dry periods due to the large proportion of soluble N (NO_3-N) components. TP concentrations are higher in wet periods, a large component of TP is probably associated with particulate matter and suspended sediment.

5.2 Treatment train

TSS throughout the treatment train remained fairly constant during wet weather. The higher TSS out of the wetland (4) and the pond (7) was probably due to resuspension of accumulated silt.

During dry weather all sites had minimum values less than 5 mg/L. BCC Water Quality Objective of 15 mg/L was most frequently exceeded in wetland (4), the pond (7), and the riparian wetland (11). The dry weather data shows that both the wetland and to a much greater extent the pond are adding TSS to the water column.

Nutrient concentrations of NH_4-N, NO_3-N and PO_4-P were higher in the wet weather than dry weather samples with the exception of the riparian wetland (11) which exported ammonium.. Nitrate and phosphate were substantially reduced in the wetland suggesting removal by plants and autotrophic micro-organisms. Site 16 had the lowest concentrations indicating the effectiveness of the natural stream channel, lagoons and aquatic vegetation in removing soluble nutrients.

6. Conclusions

From our study the following conclusions were made about the effectiveness of SQIDs at Golden Pond, Calamvale.

The sediment basin was not effective in removing suspended solids, however coarse material is trapped. The storm event on 1 Feb 2001 deposited sandy material which completely filled the sediment basin. The 24 hour wet samples showed a reduction in NO_3-N and PO_4-P possibly due to removal by algae on the concrete walls, but in dry weather there was a slight (but not significant) increase in NH_4-N and NO_3-N possibly due to ammonification and nitrification of dead algae or organic debris.

The wetland was not effective in removing suspended solids in wet weather and generated small (but not significant) amounts of NH_4-N and NO_3-N. Reduction in all soluble nutrients occurred during dry weather indicating uptake by aquatic plants, algae and biofilms.

The silt-clogged culverts were a major source of TSS into the pond in both wet and dry weather, some removal of suspended solids occurred within the pond.

Stormwater from both the CDS and ECOSOL outlets were high in soluble nutrients, however these were removed by direct uptake by the vegetation and biofilms in the pond, and by the aquatic plants in the riparian wetland respectively.

In dry weather NH_4-N was generated in the riparian wetland due to ammonification of organic matter.

The 600 m length of remnant natural stream channel, lagoons and associated vegetation was the most effective treatment for water quality improvement.

7. References

Bartone, D.M. and Uchrin, C.G. 1999. Comparison of Pollutant removal efficiencies for two residential stormwater basins. *J. Eng. Eng.*, 125: 674-677.

BCC 2000. SQIDs Monitoring Program Stage 3. Prepared by Water and Environment City Design, for Waterways Program.

BCC 2001. SQIDs Monitoring Program Stage 4. Prepared by Water and Environment City Design, for Waterways Program.

IEAust, 1996. Soil Erosion and Sediment Control – Engineering Guidelines for Queensland Construction Sites.

Larm, T. 2000. Stormwater quantity and quality in a multiple pond-wetland system: Flemingsbergsviken case study. *Ecological Engineering*, 15: 57-75.

Lawrence, A.L., Marsalek, J. Ellis, J.B. and Urbonas, B. 1996. Stormwater detention and best management practices. *J. Hydraulic Res.*, 34.

Lawrence, A.L., Maher, W., Breen, P.F. and Baldwin, S. 1997. Urban stormwater Pollution Control Pond Research report. CRC Freshwater Ecology.

Mazer, G. Booth, D. and Ewing, K. 2001. Limitations to vegetation establishment and growth in biofiltration swales. *Ecological Engineering*, 17: 429-443.

Mehler, R. and Ostrowski, M.W. 1999. Comparison of the efficiency of best stormwater management practices in urban drainage systems. *Wat. Sci. Tech.,* 39: 267-276.

NSW Department of Housing, 1993. Soil and Water Management for Urban Development.

NSW EPA 1998. Managing Urban Stormwater: Treatment Techniques.

Qld EPA, 1998. Department of Natural Resources and Department of Quality Control Guidelines – Stormwater for Local Government.

Shutes, R.B.E., D.M. Revitt, A.S. Munger and L.N.L. Scholes 1997. The design of wetland systems for the treatment of urban runoff. *Wat. Sci.Tech.*, 35: 19-25.

Urbonas, B. 1994. Assessment of Stormwater PMPs and their technology. *Wat. Sci. Tech.*, 29: 347-353.