# Field Evaluation of an Innovative Stormwater Treatment System in a Tropical Environment

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## ABSTRACT
The StormFilter® EnviroPod® (SFEP) stormwater treatment system is a self-contained treatment train that had been designed to treat runoff water from elevated road ways, underwent a field evaluation at Kuranda in Queensland's Wet Tropics. The field evaluation followed on from a study performed on the same device by James Cook University. Data were collected from six storm events, predominantly during the dry seasons of 2008 and 2009. Data analysis from these events showed that the system captured a substantial proportion of the suspended solids, nutrients and total metals load. Dissolved copper capture was moderate, whereas the use of galvanised structural elements caused an addition of dissolved zinc. Median effluent concentrations were comparable with traditional stormwater best management approaches.

## INTRODUCTION
The StormFilter ®EnviroPod® (SFEP) treatment train is a compact implementation of multiple stormwater treatment elements (Figure 1). It is comprised of an EnviroPod® (EnviroPod) gully pit insert pre-treatment filter, a wet-sump sedimentation chamber with a floatables control baffle and a Stormwater Management StormFilter® (StormFilter) radial cartridge filter with ZPG™media. The SFEP is designed to provide stormwater treatment on elevated bridge deck structures, by treating runoff at, or near, the road level. By treating as close to source as possible, it offers an alternative to large end-of-pipe solutions.

Field evaluation of the SFEP had been undertaken near Kuranda, on the Kuranda Range Road,which is a main arterial route from Cairns to the Atherton Tablelands in Northern Queensland, Australia. It traverses the ecologically sensitive Wet Tropics World Heritage Area.

### Background
This study follows a previous field study performed by the School of Earth and Environmental Sciences, James Cook University (JCU), as part of a wider investigation into the impacts of road runoff on the Kuranda Range Road watershed (Munksgaard, 2008).JCU reported on the quality of the watershed's receiving waters, the chemistry of the road runoff and the performance of the SFEP over four runoff events. In addition, they performed laboratory investigations into the effect of contact time on the retention of metals, by components of the SFEP's ZPG cartridge media(Munksgaard, 2008).

This paper uses combined data sets from both studies. This is done in order to provide more appreciation of the range of water quality data, than might otherwise be evident in two relatively small datasets. (Munksgaard, 2008 & Vigar, 2011). In addition, JCU identified that the SFEP was, in fact, responsible for a significant net export of zinc. Total nitrogen (TN) and total phosphorus (TP) were also part of JCU's analytical suite. On the basis of their data, nutrient levels in the road runoff were low, such that they do not constitute a water quality concern at Streets Creek. Interestingly, however, JCU reported significant retention of both TN and TP.

The limited JCU study, found the SFEP gave substantial removal of total nitrogen (45%), total phosphorus (70%), total aluminum (71%), total nickel (73%), total lead (60%) and total copper (58%). On the other hand, it identified potential release of suspended solids under 500 micron, as well as dissolved zinc and copper. It was largely to address these issues that Stormwater360 continued with further field evaluation of the SFEP thereby expanding the dataset.

**SFEP Treatment Train**
A broad description of the SFEP has been given, above. The structures and functions of the SFEP are now described with reference to the schematic of the unit displayed in **Figure 1**. which shows the SFEP in function.

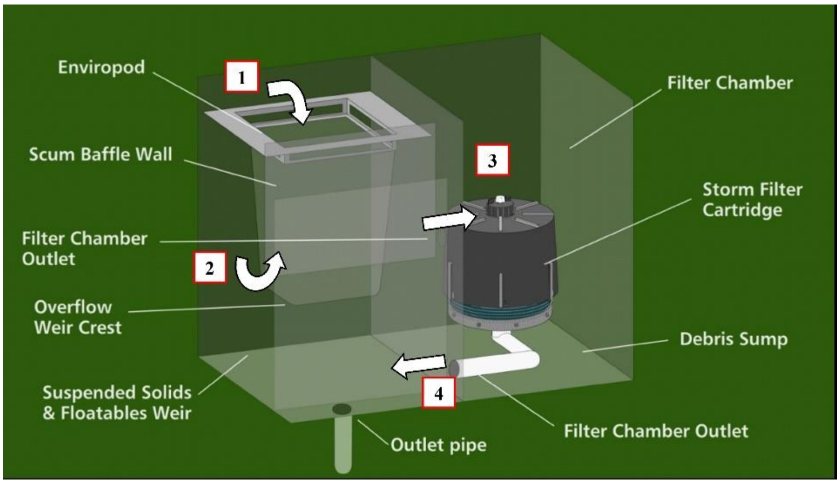


**Figure 1**. Schematic of the SFEP treatment train.

Inflow is directed into the EnviroPod pre-treatment filter [1] by the device's deflector flaps. The EnviroPod screens the inflow through a precision-woven polyester fabric insert. At Kuranda, the EnviroPod was configured with an insert of nominal 200 micron aperture and retained solids captured by the fabric insert were held dry in between events. After treatment by the EnviroPod, flow passes into the wet-sump sedimentation chamber of the inlet bay. The function of the wet-sump is two-fold. Firstly, it is designed to maximize settling prior to the StormFilter and thus to reduce the sediment load experienced by the cartridge. Secondly it provides a mechanism for retaining free oil on the surface of the standing water. Flow must travel under a floatables baffle [2], before exiting the inlet bay via a circular orifice. Treatable flow now proceeds into the cartridge bay [3]. The theoretical volume of oil that may be retained by the floatables baffle is *ca.* 50 L. In the cartridge bay, water is filtered radially through the StormFilter cartridge. It flows via the cartridge center column and the underdrain in the floor of the cartridge bay. In this manner treated flow reaches the outlet bay [4] for discharge.

**Streets Creek Field Evaluation Site**

The SFEP field evaluation took place at Streets Creek, *ca.* 2 km from Kuranda Township, on the Kuranda Range Road, within the World Heritage Wet Tropics Rain forest. This road experiences significant traffic flow, being the main arterial route between the coastal city of Cairns and the tablelands. For the SFEP field evaluation, a *ca.* 250 m$^2$ catchment of the road at Streets Creek was kerbed and channeled to direct all flow to the SFEP unit

**Figure 2.** The Streets Creek catchment.

## PROCEDURE

**Sampling Equipment Specifications and Installation**

Figure 3 is a schematic of the sampling equipment layout. Influent and effluent samples were collected using individual ISCO 6712 portable automated samplers with integrated flow modules.An ISCO low profile area velocity flow sensor was mounted in the downstream 90° v-notch weir. Flow data were used to trigger the sampling program and then to provide flow proportional sampling. The effluent sampler was configured as a slave, such that it was triggered to take a sample by the influent sampling algorithm. Discrete samples were collected in each automated sampler. Bypass events were registered by a float-switch mounted in the inlet bay, each sampler was connected to its own ISCO SPA 1563 GSM cellular modem for remote communication and data access. Samples were collected, composited and analysed by Cairns Water, a NATA accredited laboratory. For full detail of analytical procedures and method please see the full project report. (Vigar, 2011)

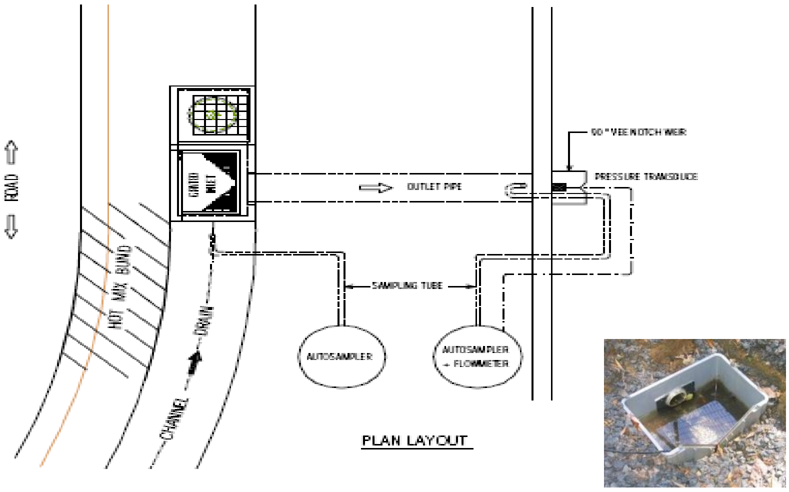


**Figure 3**. Experimental schematic (v-notch weir inset)

### Wet-Sump Grab Samples

In an effort to better understand the soluble species being generated in the wet-sump of the inlet bay, routine grab samples of the standing water were also taken. Samples were taken after antecedent dry periods of varying durations.

## RESULTS

Water quality results from qualifying storm events are summarized in **Table 1.**Table 2 summarises the results from the wet-sump grab samples. Table 3 displays the nitrogen species analytical suite for Storm 6.

| Analyte | n | Range Influent EMCs (mg/L) | Median Influent EMC (mg/L) | Range Effluent EMCs (mg/L) | Median Effluent EMC (mg/L) | Mean Removal Efficiency (Sum of Loads) |
|---|---|---|---|---|---|---|
| SSC | 6 | 75 to 4384 | 1181 | 8 to 63 | 20 | 99% |
| SSC < 500 micron | 6 | 48 to 180 | 105 | 8 to 62 | 20 | 78% |
| TP | 6 | 0.08 to 0.19 | 0.123 | 0.02 to 0.15 | 0.055 | 47% |
| TN | 6 | 0.6 to 1.5 | 1.045 | 0.2 to 0.9 | 0.615 | 44% |
| TKN | 6 | 0.6 to 1.2 | 1.007 | 0.175 to 0.800 | 0.515 | 49% |
| $NH_3$-N | 6 | 0.05 to 0.15 | 0.050 | 0.05 to 0.07 | 0.050 | 31% |
| TOC | 6 | 3 to 16 | 7 | 3 to 10 | 5 | 32% |
| DOC | 6 | 3 to 12 | 7 | 3 to 11 | 6 | 21% |
| Tot. Cu | 6 | 0.008 to 0.045 | 0.016 | 0.006 to 0.016 | 0.008 | 49% |
| Tot. Pb | 6 | 0.002 to 0.040 | 0.006 | 0.001 to 0.006 | 0.001 | 67% |
| Tot. Zn | 6 | 0.056 to 0.190 | 0.088 | 0.044 to 0.120 | 0.066 | 25% |
| Diss. Cu | 6 | 0.002 to 0.037 | 0.007 | 0.002 to 0.009 | 0.005 | 41% |
| Diss. Zn | 6 | 0.011 to 0.032 | 0.016 | 0.028 to 0.066 | 0.037 | -171% |

**Table 1.** Summary of water quality results

| Date | Antecedent Dry Period (days) | Diss. Cu (mg/L) | Diss. Zn (mg/L) | DOC (mg/L) | Diss. N (mg/L) | Diss. $NH_3$-N (mg/L) | Diss. $NO_x^-$-N (mg/L) |
|---|---|---|---|---|---|---|---|
| 07/07/2008 | 8 | 0.011 | 0.053 | 17 | - | - | - |
| 20/02/2009 | 6 | 0.001 | 0.016 | - | 2.4 | 2.39 | <0.01 |
| 06/05/2009 | 19 | 0.005 | 0.082 | 16 | 7.2 | 5.85 | 0.72 |
| 21/07/2009 | 79 | 0.004 | 0.083 | 20 | 3.4 | 2.24 | 0.025 |

**Table 2.** Grab samples from wet sump

| Phase | Analyte | Influent EMC (mg/L) | Effluent EMC (mg/L) | Mean Removal Efficiency (Sum of Loads) |
|---|---|---|---|---|
| Total (dissolved and particulate) | TN | 0.8 | 0.4 | 50% |
| | TKN | 0.8 | 0.34 | 58% |
| | $NH_3$-N | 0.15 | 0.07 | 53% |
| | Org-N | 0.65 | 0.27 | 58% |
| | $NO_3^-/NO_2^-$-N | 0.01 | 0.06 | -500% |
| Dissolved | TN | 0.4 | 0.3 | 25% |
| | TKN | 0.39 | 0.23 | 41% |
| | $NH_3$-N | 0.16 | 0.073 | 54% |
| | Org-N | 0.23 | 0.157 | 32% |
| | $NO_3^-/NO_2^-$-N | 0.01 | 0.07 | -600% |
| Particulate (by calculation) | TN | 0.4 | 0.1 | 75% |
| | TKN | 0.41 | 0.11 | 73% |
| | $NH_3$-N | 0 | 0 | N/A |
| | Org-N | 0.41 | 0.11 | 73% |
| | $NO_3^-/NO_2^-$-N | 0 | 0 | N/A |

**Table 3**. Nitrogen species from Storm 6

# DISCUSSION

## Suspended Solids

Retention of suspended solids is the fundamental treatment process for any stormwater treatment practice. In this experimental protocol $SSC_{<500\ micron}$ represents what is commonly understood by the term 'suspended solids'. Over the 6 storms analyzed, the influent EMC of suspended solids had a range of 48 to 180 mg/L, as per Table 3. The median influent EMC was 105 mg/L, which could be regarded as typical of other published international and Australian data (Duncan, 1999& Fletcher 2004).The median effluent EMC was 20 mg/L. Mean removal efficiency for suspended solids, calculated by sum of loads, was 78%. The scatter plot in Figure 4 shows effluent EMCas a function of influent EMC, for each event. Note that the two datasets are in relative agreement with each other, and are fairly tightly clustered, with one exception. We have treated this storm as an outlier and removed it from further analysis. Linear regression is shown for the remaining 9 data points in this plot. It indicates an irreducible concentration of 21 mg/L, beyond which 96% removal is achieved. The 95% confidence intervals are plotted for this regression. They indicate that there is no statistical significance to the slope calculated for the regression, however it is useful to visualise the trends in the data. Whilst there is a range of influent EMCs, from *ca.* 30 mg/L to *ca.* 180 mg/L, the effluent EMCs are clustered around 20 mg/L. The box plot in Figure 4illustrates this further.

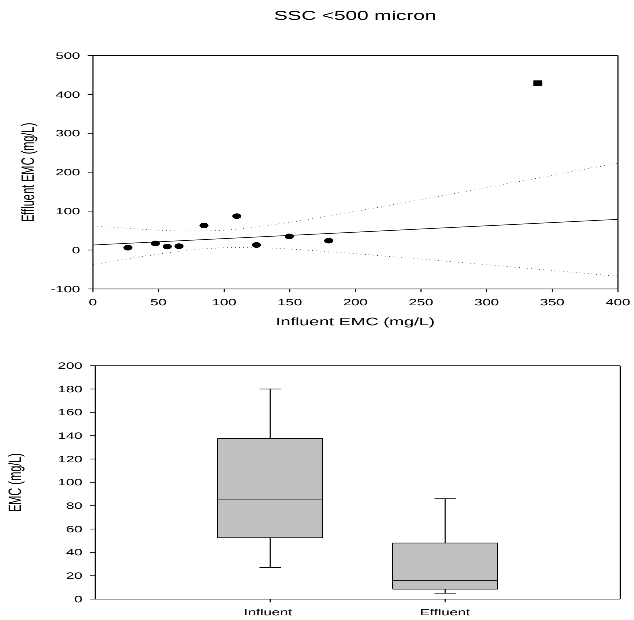


**Figure 4**. SSC<500 micron data (SW360 & JCU combined)

**Metals**

In terms of total metals, the median influent concentrations at Streets Creek were moderate for copper (0.016 mg/L) and lead (0.006 mg/L) and relatively high in terms of total zinc (0.088 mg/L), compared with international data(BMP Database, 2008).Median removal efficiency of total lead (67%) is lower, but still comparable to that for suspended solids (78%). Total lead exists predominantly as particulate lead and its removal might be expected to be closely related.Median removal efficiency of total copper (49%) must be understood in the context that the median influent dissolved copper concentration (0.007 mg/L) was *ca.* 50% of the total. With reference to the fact that the median removal efficiency of dissolved copper (41%) was lower than for total copper, by inference the removal rate for particulate copper was *ca.* 60%. This is more in keeping with the removal rate for particulate lead.

Median removal efficiency of total zinc (25%) must be understood in two contexts. Firstly, the median influent dissolved zinc concentration (0.016 mg/L) was *ca.* 20% of the total influent zinc concentration (0.088 mg/L). Also, there was an almost threefold increase in median effluent dissolved zinc concentrations as water passed through the SFEP. As such the indications are that removal of particulate zinc is comparable to the other results for particulate metals. It is evident from the results that, in terms of dissolved zinc concentrations, there was a significant issue with operation of the SFEP at Streets Creek. Grab samples from the wet sump indicate that the concentrations of dissolved zinc here were routinely up to five times higher than the median influent concentration. This observation makes it fairly clear that the standing water is significantly involved in the addition of dissolved zinc, given that the vault was constructed from galvanised mild steel, and with an unknown powder coating, it is most likely that this was the source of additional dissolved zinc in the sump water

It is important to point out that, in any normal context, the median influent and effluent dissolved zinc concentrations are *both* exceedingly low at Streets Creek with reference to international BMP Database figures (BMP Database, 2008) As the influent concentration becomes lower and lower, it becomes progressively more difficult to achieve good removal rates, since the concentration gradients driving any ion-exchange become less, reducing dissolved action removal from the water column, The median effluent dissolved zinc and copper concentration at Streets Creek (0.005 mg/L) is lower than the lowest recorded value for *any* bio-filter or media/ sand filter recorded on the database. In other words, whilst there has certainly been addition of dissolved zinc during operation of the unit, the median effluent concentration of dissolved zinc is still lower than would normally be found on most major roads. Figure 5 below plots influent and effluent EMCs for total copper and total zinc.

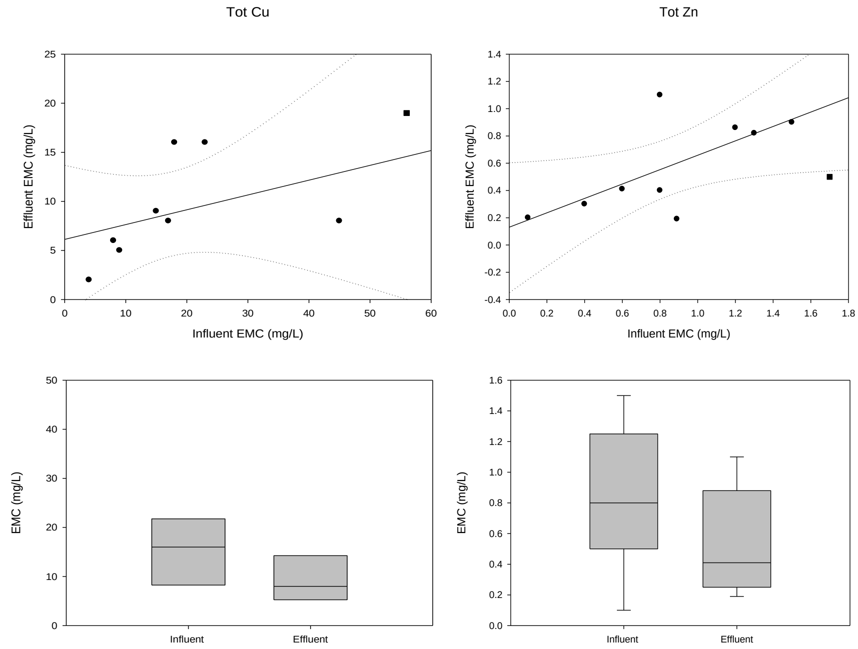


**Figure 5.** Total Cu& Zn Data (SW360 & JCU combined)

**Nutrients**

The median influent EMC for total phosphorus, during the course of the present evaluation, was 0.12 mg/L. In thecontext of Australian data (Duncan, Fletcher) it is apparent that the influent TP concentration at Kuranda is toward the very low end of published data.Over the course of the six storms analysed the SFEP achieved a sum of loads removal efficiency of 47%, with a median effluent EMC of 0.055 mg/L.Figure 6 displays the combined total phosphorus data from both studies.

With reference to Table 1, the median influent concentration of total nitrogen over the course of six storms analysed here was 1.05 mg/L, with a range of 0.6 to 1.5 mg/L. Again, this is low with respect to most other published data. The median effluent EMC of total nitrogen was 0.6 mg/L. This amounts to a sum of loads removal of 44%, which is in agreement with the 45% removal reported by JCU during their field trial.

Total nitrogen is generally considered to be a predominantly soluble contaminant that is difficult to remove, other than by biological uptake or denitrification. As such, the consistent removal exhibited by the SFEP warrants further comment. With reference to Table 1, it becomes apparent that the majority (ca. 95%) of the total nitrogen load at Kuranda is as TKN. A small proportion of this TKN load (ca. 5%) is ammonia nitrogen, which implies that ca. 90% of the total nitrogen load is present as organic nitrogen, in either soluble or particulate forms.

In order to better characterise the removal processes involved, samples were processed for the full nitrogen suite for storm 6, in order to establish whether the removal processes involved particulate removal or removal of dissolved species. As per Table 3, this storm exhibited a fairly typical TN load. Essentially, all of the TN load was present as TKN and ca. 20% of this was ammonia-N. Unsurprisingly, the entire ammonia-N load was soluble, and the SFEP achieved 54% removal of this species. The remainder (ca. 80%) of the TN/TKN load was present as organic nitrogen, and the analytical results show that ca. 35% was dissolved, whilst ca. 65% was present as particulate. The SFEP achieved 73% removal of particulate organic nitrogen and, apparently, 32% removal of dissolved organic nitrogen. Given the removal efficiency for suspended solids, the high removal for particulate organic nitrogen is understandable.

Possible removal mechanisms for dissolved organic nitrogen are less obvious. It is possible that there is some adsorption of these species to the ‘schmutzdecke’ (bio-film) that develops on the cartridge. There is another potential removal mechanism- the wet sump. In fact, all of the runoff that enters the SFEP does not pass through it during the course of one discrete storm. Rather, when runoff first enters the unit, it initially displaces the standing water in the wet-sump. As such, the contaminants in this standing water are sampled by the effluent sampler (once they have passed through the StormFilter cartridge), but not by the influent sampler. By the same token, the last runoff to enter the unit during a storm does not pass through the unit during that event. It is retained in the wet sump until the next storm event, when it is displaced. With reference to Table 2, periodic grab samples from the wet sump indicate that most of the TN load in the standing water is present as ammonia-N, and, importantly, this is present at concentrations that are two orders of magnitude higher than typical influent ammonia-N concentrations. As such, ammonia-N is, presumably, generated in the wet sump by anaerobic decomposition of organic nitrogen, in between storm events. This has two important implications. Firstly, it suggests that the load of ammonia-N passed to the StormFilter cartridge is significantly higher than is suggested by the influent EMC. This implies that the removal rates for ammonia-N removal are probably an under-estimate. Secondly, by converting organic nitrogen to ammonia-N in the wet sump, then removing this ammonia, the SFEP has a potential mechanism for removal of soluble organic-N.

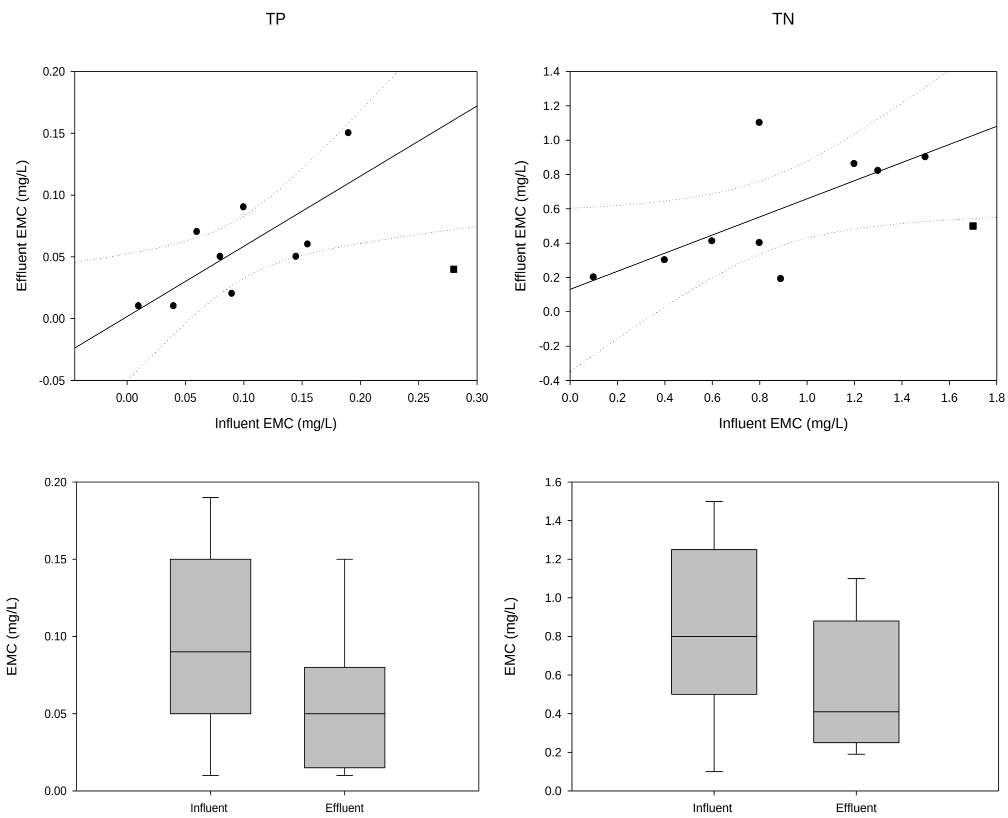


**Figure 6.**Total Phosphorous &Nitrogen Data (SW360 & JCU combined)

## CONCLUSIONS

Field evaluation of the SFEP treatment train was performed at Streets Creek, Kuranda. The size of the data set is relatively small, and the following issues contributed to this. Seasonal variations in rainfall and the sizing of the SFEP unit to cope, largely, with dry season rainfall resulted in a limited number of potentially qualifying storms. Sampling from very low flows was problematic and many potential storms were lost for this reason. The nature of the test site, on a relatively isolated section of road in dense wet tropics rain forest, also contributed to these difficulties. In spite of this, results obtained from the six qualifying storms represent a fair characterization of the performance of the SFEP. The results from this evaluation correlate well with an earlier study at this site, performed by JCU, which lends credence to the results. The SFEP achieved 78% removal for suspended solids below 500 microns. Runoff from the Streets Creek site contained moderate levels of total metals. In this context, removal of total zinc and copper provided substantial protection for receiving environments. Removal efficiency for total zinc was clearly impaired by poor performance for dissolved zinc.Runoff from the Streets Creek site contained very low levels of dissolved copper and zinc, from the perspective of international stormwater data. In this context the removal efficiency for dissolved copper of *ca.* 40% for a ZPG StormFilter is excellent and compares well with previous data. Removal efficiency for dissolved zinc was poor, probably due to leachingfrom galavanised material in the vault.

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