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### Riparian Conundra

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# Riparian conundra

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**Abstract:** Riparian vegetation is established or restored on the basis that it physically filters and traps hillslope derived particulate nutrients in surface runoff. Whilst many studies support this conventional model of riparian function, few test this models embedded assumptions. The assumptions are that catchments are surface runoff dominated, that most surface derived nutrients are transported in particulate form, and that riparian management targets locations that will result in the greatest change in water quality. This paper reviews studies in south west Western Australia that challenge these assumptions.

Plots measuring leaching and runoff of nutrients showed that 20 times more water and 2 to 3 orders of magnitude more Phosphorus (P) was transported through leaching than runoff processes. Along with soluble leachate P, most runoff samples were >75% Filterable Reactive P (FRP).

A before and after riparian restoration experiment in a small catchment reduced Suspended Sediment (SS) by 90%, had no impact on Total P (TP), increased FRP by 70 % and reduced TN exports by 25%. Prior to restoration FRP leached through sandy soils and entered streams via subsurface pathways, combining with SS to give particulate P signals. Restoring riparian vegetation stabilised streambanks and exhausted SS supply and limited FRP sorption. Whilst SS transport had been stopped, FRP continued downstream. Implications arise for catchments dominated by sub-surface transport pathways through increased bio-availability of P, as well as changes in the N:P ratio of discharging waters.

Hillslope experiments measuring the trapping efficiency of sediment and nutrients by grass and trees shows that trapping efficiency of 54% of surface derived TP was trapped by grass buffers compares well with other studies, however, this is discounted to 10% when considering both surface and subsurface transported nutrients.

Riparian condition studies show systematic changes in condition with stream order. High order streams (<10% of the total stream length) have good condition riparian cover. Low order streams (~80% of the stream length) have poor riparian condition. Snapshot water quality programs show systematic changes in water quality with stream order, whereby low order streams have higher nutrient concentrations than high order streams. Despite the poor condition, greater representative length and poor water quality of low order streams, riparian management programs focus on high order iconic streams in good condition.

These studies show riparian management is unlikely to be effective for P management in these catchments. Most P delivered to streams is soluble and travels via subsurface pathways and the restoration effort is not directed to areas that would make a significant change to water quality.

**Keywords:** Riparian management, phosphorus, soluble, leaching, subsurface flow, sediment

## Introduction

Phosphorus (P) and Nitrogen (N) loss from landscapes to waterways has been identified as a key influence over the frequency and intensity of algal blooms in waterways. In response, a range of nutrient management practices have been proposed, tested, modelled and implemented in order to reduce nutrient loss from landscapes, so that the threat of algal blooms can be minimised. Nutrient management practices and tools include fertiliser management (timing, solubility, soil testing), effluent management (land disposal, artificial fertiliser substitution), soil amendment (increase P retention for sandy soils), perennial pastures and riparian management (fencing, stock exclusion, off-stream stock watering, stock and vehicle crossings). The conventional model under which riparian management (buffer strips) functions to improve water quality is by physically filtering and trapping hillslope derived particulate P in surface runoff. Riparian management can also reduce stream bank erosion, and hence reduce P delivery from the erosion of high P subsoils. Some studies suggest that riparian management can reduce P loss by 90% (Line et al., 2000), whilst others suggest buffer strips may offer a temporary solution as sinks in some

years and sources in others (Omernik et al., 1981), and others have shown no impact of riparian management on P delivery (McKergow et al., 2003). Despite these differences, riparian management is considered a universal nutrient management solution and is often subsidised for implementation by land management groups. It can also be an expensive practice to implement, when other more cost beneficial nutrient management practices are available (Weaver et al., 2005). In order for practices such as riparian management to be advocated, scientists and managers need to be sure that the practice satisfies the embedded assumptions required for its function. For riparian management this means surface runoff domination, surface derived particulate nutrients, targetting locations that will result large water quality changes, implementation in nutrient source areas and to the extent necessary to improve water quality, and that the practice has limited adverse impacts either for the issue being addressed, or any other issue. This paper explores the aforementioned in relation to riparian management in a catchment context, and points to some paradoxes for this practice in particular environments.

## Materials and Methods

Data and findings from disparate studies in south-western Western Australia (WA) were used to explore the embedded assumptions required for P control using riparian management. These studies include measurements of runoff, leaching and water quality from runoff plots, before and after riparian management impacts on water quality in a small catchment, surface and subsurface hydrology and water quality measurements on a hillslope with grass and tree riparian buffers, a monitoring program that examined water quality in relation to stream order, and published surveys of riparian condition.

### *Runoff Plots*

Runoff plots were established in 3 locations on sandy soils in the Oyster Harbour catchment on the south coast of WA to assess nutrient leaching and runoff losses over 2 years. The plots had been used for sheep or cattle grazing on annual pastures (subterranean clover), for around 30 years. Uniform slopes (0.6 - 1.9%) were analysed for Bicarbonate extractable P (Colwell, 1965), Phosphorus Retention Index (PRI) (Bolland and Windsor, 2007), Phosphorus Saturation Ratio (PSR) (Chrysostome et al., 2007) (Table 1).

**Table 1. Soil chemical and physical characteristics of the 0-10 cm layer at each site.**

Parameter	Site 1	Site 2	Site 3
Bicarbonate extractable P (ppm)	54	32	13
PRI (mL/g)	64	-1.1	-0.9
P Saturation Ratio (PSR)	0.02	0.09	0.07

Surface runoff from 6 hydrologically isolated plots (2m wide and 40m long) at each location was directed into drums and volumes measured. Lysimeters were installed in the centre of each plot to determine volumes and quality of water leaching below 10 cm. Three plots at each location received applications of 10 kg P ha<sup>-1</sup> in mid June each year as Superphosphate, whilst the other 3 plots were controls. Volumes were measured and converted to mm of rainfall equivalents for analysis and subsamples of runoff and leachate waters were retained for analysis. Runoff samples were analysed for Total P, Total N and a filtered (<0.45µm) subsample analysed for Filterable Reactive P (FRP), whilst leachate samples were filtered (<0.45µm), and analysed for FRP. Water volumes and concentrations of analytes were used to compute loads of nutrients lost (kg ha<sup>-1</sup>) on an event basis, or aggregated as required.

### *Before and after riparian management*

A small 600 ha catchment near Albany, WA was monitored before (1991-1996) and after (1996-2000) riparian management. The catchment drains grazed pasture on duplex sand over clay soils with deeper sands in riparian areas. Discharge was determined from compound sharp crested and broad crested weirs using depth measurements captured with capacitance probes and pressure transducers (McKergow et al., 2003). Samples for water quality analysis were collected manually, with rising stage samplers (Guy and Norman, 1970) and automatically using ISCO samplers. Sub-samples were filtered for FRP determination whilst unfiltered samples were analysed for suspended sediment (SS, APHA, 1989; with 1.2 µm GF/C filter paper), total persulfate N (TN, APHA, 1989) and total persulfate P (APHA, 1989).

### ***Hillslope riparian hydrology and water quality***

Surface runoff and subsurface flow volumes and nutrient and sediment concentrations were measured over a three year period (1998-2000) from two adjacent planar hillslopes based on duplex soils (McKergow et al., 2006a, 2006b). One hillslope drained towards a grass riparian buffer, and the other drained to an adjacent *E. globulus* buffer. The buffers were evaluated over a ten metre width, measured perpendicular to the stream. Soils were characterised by dark grey loamy sands gradually changing to a light brown sandy gravel A-horizon (8 to 40 cm depth), scattered with roots, small gravel (1-3 cm) and macropores (4-16 mm). The B-horizon (40 to 80 cm depth) is yellowish gravelly clay with pockets of lateritic gravels (3-8 cm).

Surface runoff was measured at 20 locations in the riparian buffers, with five runoff troughs positioned to capture input from paddock to each riparian buffer as grass or trees, and five plots placed 10 m into each riparian buffer. Runoff flowing into troughs was directed through a splitter and 10% was diverted to storage drums where volumes were measured. The remaining 90% of runoff was returned to the buffer as dispersed flow. Subsurface flow was measured at two depths (A- and B-horizons) in both the grass and *E. globulus* buffers using six metre wide Whipkey-style troughs. Collected subsurface flow travelled under gravity to a 50 mm RBC flume, where water levels were measured and converted to discharge. Water was collected either as grab samples or with automatic samplers for analysis from all flumes and storage drums on each site visit. Surface runoff samples were a composite of single or multiple events, whilst subsurface water samples were collected from troughs daily. Whole samples and filtered subsamples (<0.45µm) were refrigerated prior to analysis for TP, TN, EC, SS and FRP.

### ***Stream order and riparian condition***

Riparian zones were classified into four classes from pristine ("A"), degraded ("B"), eroded or erosion prone ("C"), through to ditch ("D") on the high order main channel of the Kalgan River (Pen, 1994), middle order major tributaries of the Kalgan River (APACE Greenskills and Pen, 1997), and low order streams of the Scotsdale Brook catchment (Wilson Inlet Management Authority, 1998). These surveys were used to compare riparian zone condition for streams of different order classes based on the numeric stream ordering method of Strahler (1952), but further classified as low, middle or high order streams.

### ***Stream order and water quality***

A catchment-wide, event-driven snapshot water quality monitoring program was carried out in the Oyster Harbour catchment from 1994 to 1996. The 168 sampling sites, representing catchments of differing stream order were located at road and stream intersections. Stormflow was sampled using rising stage height samplers (Guy and Norman, 1970) and ambient flow by grab samples. Samples were analysed for TP, TN, EC and SS.

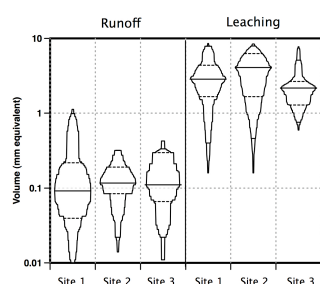
## **Results and Discussion**

### ***Runoff Plots***

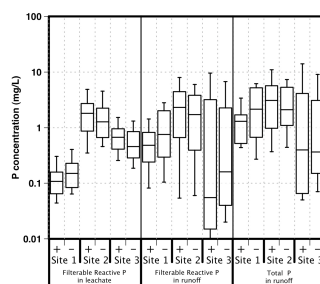
Across all events, sites and treatments, 23 times more water was leached than was delivered as surface runoff (Fig 1). This is consistent with high winter rainfall acceptance of sandy textured soils in this environment. Nutrient transport processes at the hillslope-scale are therefore more likely to be dominated by soluble fractions favoured by leaching, and this will limit the effectiveness of riparian management. Despite the consistent water yield data across all sites, there were some site and hydrological vector-specific differences in the concentrations of P in runoff or leachate (Fig 2), and these differences can to some degree be explained by differences in soil characteristics (Table 1). Figure 2 indicates that collectively, FRP concentrations in leachate and runoff were similar, except perhaps for Site 1, probably due to the high PRI and low PSR. There were not large differences between FRP and TP concentrations in surface runoff, suggesting that most of the surface runoff P was also in a soluble form. Site 1 did show some difference between FRP and TP in surface runoff, again due to higher PRI and soil P content measures (Table 1). Therefore, if Site 1 was to discharge particulate matter in surface runoff, and particulate P to contribute to TP, it should show the largest difference in FRP and TP of all of the sites.

Given that there are major differences in the volumes of leachate and runoff at each site (Figure 1), and little overall difference in FRP concentrations in leachate and runoff (Fig 2), the loads of FRP lost via leaching and runoff vectors are driven by volume. This has implications for riparian management since

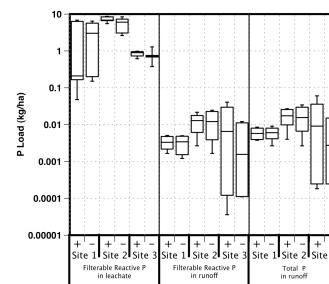
most of the P is being transported in a soluble form, and most likely via subsurface transport pathways (McKergow et al, 2006a, 2006b). The physical filtering opportunities provided by riparian buffers would therefore be bypassed, and even where surface runoff was occasionally a more dominant process (Site 1), significant amounts of the transported P was in a soluble form which would not be filtered by the buffers.



**Figure 1.** Distribution plots showing volumes (mm equivalent) delivered via runoff or leaching vectors for sampling events at each site.



**Figure 2.** Box and whisker plots of P concentrations (FRP and TP) for samples collected as leachate or runoff at each site over the 2 year monitoring period with (+) or without (-) P added. Whiskers show 5th and 95th percentiles, and box shows 25th, 50th and 75th percentiles.



**Figure 3.** Box and whisker plots showing the variation in loads ( $\text{kg ha}^{-1}$ ) of FRP delivered through leaching and runoff processes, and Total P through runoff processes for each site in the presence (+) or absence (-) of P additions

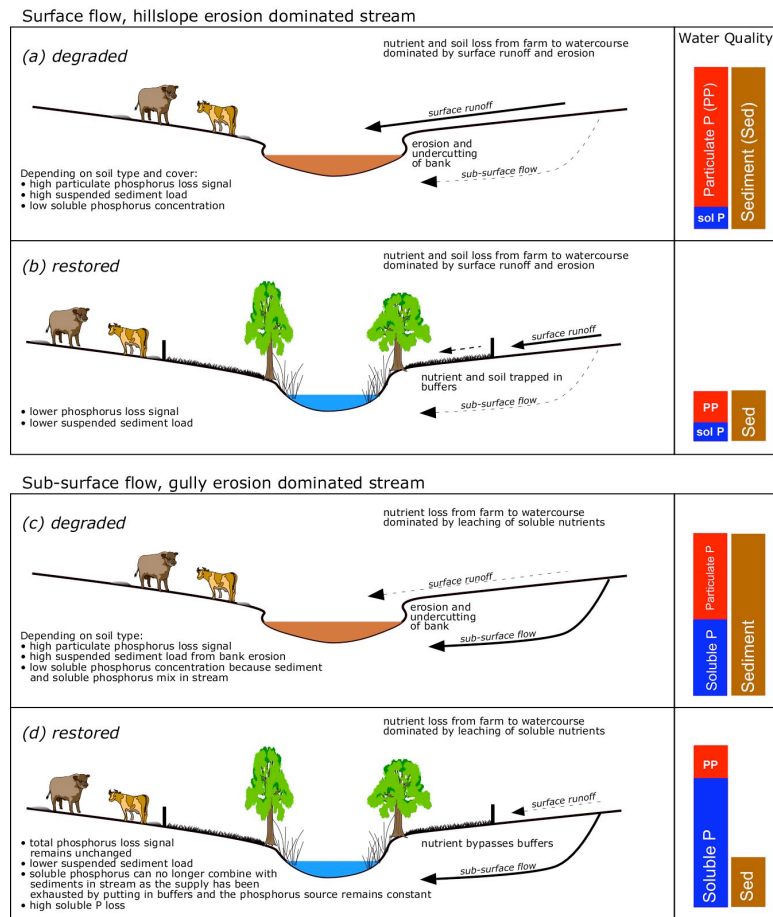
The data in Figure 3 shows that FRP loads in leachate were on average 2 orders of magnitude higher than FRP or TP in runoff. This is largely a function of much greater volumes delivered via leaching pathways. The similarity between FRP and TP loads in surface runoff is due to the dominance of soluble P forms in surface runoff. The implications of these findings are that these systems under the measured conditions are predisposed to deliver largely soluble forms of nutrients mainly through leaching. Losses via surface runoff are also dominated by soluble forms, but these are moderated where some P retention capacity remains. Over the life of the experiment, Site 1 delivered 56% of P in surface runoff in soluble form whilst Sites 2 and 3 delivered 75%. Riparian management in this environment will therefore do little to filter soluble nutrients delivered via surface runoff, and will also be unable to moderate most of the P load which is being transported via leaching pathways (Fig 3).

#### ***Before and after riparian management***

After improved riparian management catchment SS exports fell from a mean of  $150 \text{ kg ha}^{-1} \text{ yr}^{-1}$  to less than  $10 \text{ kg ha}^{-1} \text{ yr}^{-1}$  due to reduced stream bank erosion from stock exclusion. Riparian management had no impact on TP, but contributed to a 70% increase in FRP. Additionally, TN exports fell by 25%.

The data was interpreted in terms of prevailing hydrology and soil type. Prior to restoring riparian vegetation, FRP leached through the sandy soils and entered streams via subsurface pathways, and combined with SS to give particulate P signals at the catchment outlet (Fig 4c). Restoring riparian vegetation stabilised streambanks and exhausted SS supply. The FRP no longer had SS to adsorb onto, and whilst SS transport had been stopped, the more bio-available FRP continued downstream (Fig 4d). This contrasts with the accepted model of riparian function where surface derived particulate P is physically filtered (Figs 4a, b). This alternative model is consistent with the runoff plot results which suggests a leaching and sub-surface flow system dominated by soluble nutrient fractions.

Further implications arise for catchments dominated by sub-surface transport pathways in relation to the increase in bio-availability of P species, as well as changes in the N:P ratio of discharging waters. Assuming catchment wide implementation of riparian management, and uniform water quality responses seen here, undesirable ecosystem responses may result. Increased P bio-availability may increase algal blooms, and changes in the N:P ratio may force aquatic ecosystems to support undesirable N fixing algal species if N became limiting due to a reduction in catchment N exports of 25%.



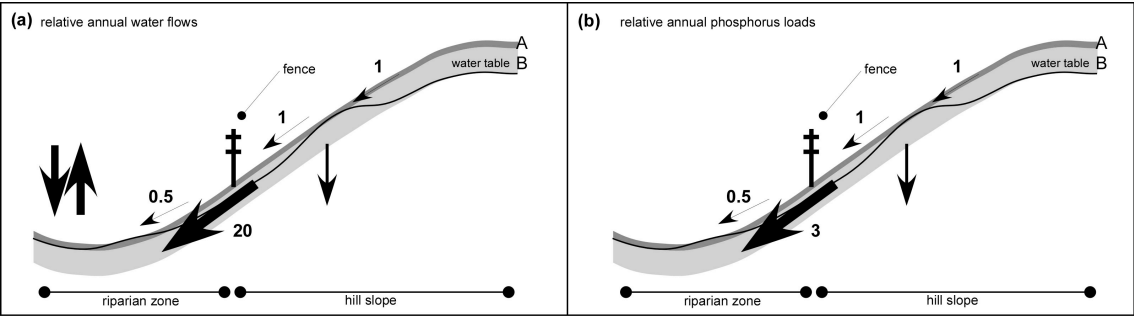
**Figure 4. Conceptual models of nutrient transport and transformations before (a, c) and after (b, d) riparian management for systems dominated by surface transport processes (a, b) and sub-surface transport processes (c, d).**

These results also question interpretation of water quality data in terms of implied transport processes embedded in that data. In this case Particulate P (PP) was around 50% of the Total P (Fig 4c) prior to implementing riparian management. It was assumed therefore that surface runoff and erosion processes were responsible for the PP, and based on other published international research demonstrating the success of riparian management that significant reductions in P transport would result. Whilst these results are positive for SS, they demonstrate the importance of understanding the prevailing hydrological processes, and nutrient transformations that can occur within streams prior to the wide-scale adoption of management practices. The results also imply that specific parts of catchments predisposed to surface transport processes would be the best candidates for riparian management if control of P was the aim.

#### **Hillslope riparian hydrology and water quality**

Hillslope experiments of riparian hydrology and water quality (McKergow et al., 2006a, 2006b) showed that surface trapping efficiency of nutrients and sediment was consistent with other published data. Grass buffers trapped 53% of runoff, 54% of TP, 50% of FRP and 64% of SS, whilst *E. Globulus* buffers trapped -3% of runoff, 37% of TP, 11% of FRP, and 21% of SS. This compares well with summarised data presented by Gitau et al., (2001) of a median removal of TP by trees of 15% and 50% by grass buffers. However, the work of McKergow et al. (2006a, 2006b) included subsurface flow and water quality measurements which showed 20 times more flow and 3 times more P was discharged in subsurface flow than surface runoff. Overall therefore whilst 54% of the surface derived TP was trapped by grass buffers, this needs to be discounted when accounting for the surface and subsurface transported nutrients. For each unit of P transported over the soil surface and reduced by 50%, a further 3 units of P are transported by subsurface pathways bypassing surface physical filtering actions, hence 3.5 out of 4 units are transported through or below the buffer (Fig 5), reducing effectiveness to around 10%. These

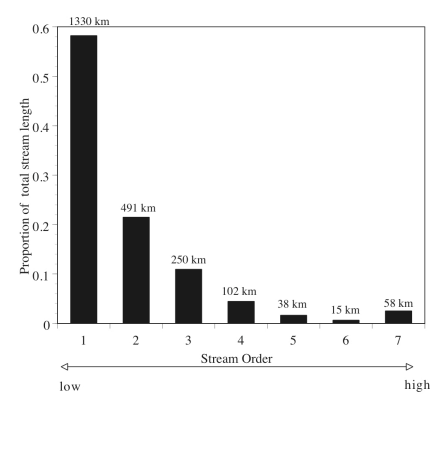
measurements reinforce the runoff plot data indicating that significant amounts of water and nutrients travel via leaching and subsurface pathways, bypassing the surface physical filtering ability of buffers.



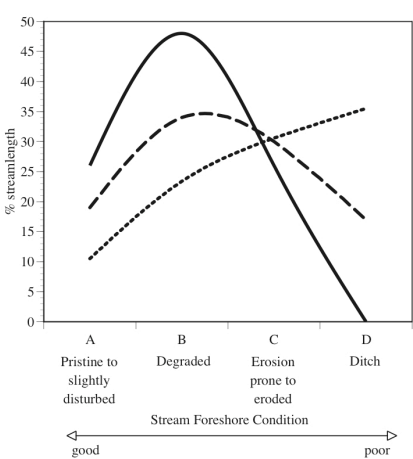
**Figure 5. Conceptual model of relative amounts of (a) discharge (a) and (b) phosphorus transport via surface and subsurface pathways (adapted from data presented by McKergow et al., 2006a, b).**

### Stream order and riparian condition

Stream length in each stream order changed systematically (Fig 6), with about 80% of the total stream length as low order streams (stream order 1 and 2). Stream order 3 and above represented about 20% of streams and these have been the focus for riparian management. Around 75% of high order streams (Pen, 1994) are classified as pristine (A) or degraded (B), reducing to 55% of middle order streams in these classes (APACE Greenskills and Pen, 1997), reducing to 30% for low order streams (Wilson Inlet Management Authority, 1998). Systematic changes in A and B classes with stream order bring an increase in class D of 0%, to 15% to 35% from high, to middle, to low order streams respectively (Fig 7). Therefore, the greatest length of stream (low orders) is in the poorest condition, the shortest length of stream is already pristine or slightly degraded, and yet the latter is mostly subject to fencing, revegetation and stock exclusion on the basis that this will improve water quality. This is unlikely to be the case since the relative change in riparian condition will be small, as will be the length of stream over which this small change in condition occurs. If it is assumed that riparian management was able to function according to the accepted conventional model (Figs 4a, 4b), the focus for restoration should be on the most degraded parts of the stream network which is the low order streams that represent the greatest length and the poorest condition. This assumption is held in these catchments, and yet the high order, iconic streams and rivers in quite good condition are the focus of attention for restoration.



**Figure 6. Proportional and actual stream lengths for different order streams in the Oyster Harbour catchment**

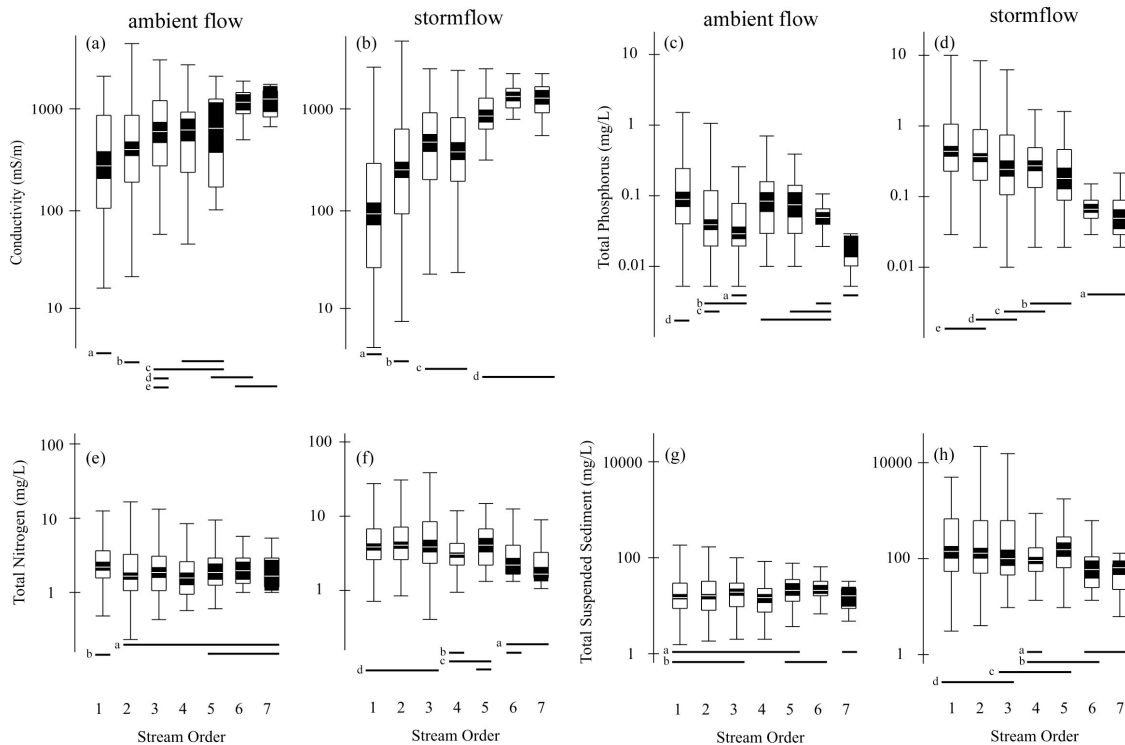


**Figure 7. Variation in the percentage of stream lengths of different riparian zone condition for surveys of high order (line) (Pen, 1994), middle order (dash) (APACE Greenskills and Pen, 1997), and low order (dot) (Wilson Inlet Management Authority, 1998) streams**



### Stream order and water quality

Total P, TN and SS generally decreased with increasing stream order, whilst EC increased with increasing stream order. All water quality variables show greater variability for low order streams than for high order streams (Fig 8). Low order streams showed the greatest change in each water quality variable when flow changed from ambient to stormflow, consistent with the poorest quality riparian zones. This can partly be attributed to riparian condition however, low order streams are more likely to have lower flow persistence (Prosser et al., 1999), and therefore have less capacity to buffer pollutants. Assuming riparian management was able to function according to the conventional model, the focus for restoration should be on the most degraded parts of the stream system, for their inherent degradation, as well as from a water quality perspective. Given that low order streams have the greatest length, the poorest condition and the poorest water quality, then these nutrient source areas should be the first target for management. Despite this, the management focus for riparian restoration is on iconic higher order streams, where pollutant concentrations tend to be lower, and potential relative changes in riparian condition to improve water quality are small.



**Figure 11.** Box and whisker plots of EC (a, b), TP (c, d), TN (e, f) and SS (g, h) for ambient (a, c, e, g), and storm (b, d, f, h) flows for different stream orders. White line shows median, black box is 95% CI of median, box shows 25th to 75th percentile, whiskers show 5th and 95th percentile. Lines beneath plots with different letters are significantly different and increase alphabetically,  $P < 0.05$

### Conclusion

This paper demonstrates the benefits of riparian management in reducing SS but suggests the capacity to reduce P exports may be limited in catchments with sandy low P sorption soils. Ignoring subsurface pathways could also lead to an over-estimation of riparian management effectiveness. It is clear in these environments that P is transported mostly in soluble form and via leaching and subsurface pathways. It is also clear that if riparian management functioned according to conventional models, the focus of that management in these catchments will have little impact on water quality as it is not directed to parts of the stream network where nutrients are derived, or where large changes in riparian condition can be attained. The finding of changes in nutrient form from particulate to soluble as a result of riparian restoration also brings into question the common interpretation of water quality data as representing the processes by which nutrients are lost.



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