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David Weaver

Adrian Reed

John Grant

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## Relationships Between Stream Order and Management Priority: a Water Quality Case Study

*David Weaver<sup>1</sup>, Adrian Reed<sup>2</sup> and John Grant<sup>1</sup>*

**SUMMARY:** Seagrass, which once dominated the habitat of Oyster Harbour on the south coast of Western Australia has been replaced by macroalgae because of increased nutrient and sediment discharge from the rural dominated catchment. Total Phosphorus (TP), Total Nitrogen (TN), Suspended Sediment (SS) and Electrical Conductivity (EC) concentrations from a catchment – wide (168 sites), event-driven snapshot, water quality monitoring program conducted from 1994 to 1996, were analysed in relation to stream order and published survey data on riparian zone condition. This analysis was performed to examine relationships between stream order, riparian zone condition and water quality, and implications for the allocation of limited resources for stream fencing, rehabilitation and stock exclusion towards the moderation of nutrient loss for the benefit of the harbour at the catchment exit. Eighty percent of the stream length was in low order streams (stream order 1 and 2) and the remainder in order 3 and above. Riparian zone condition worsened as stream order decreased. Total Phosphorus, and to a lesser degree TN and SS, decreased with increasing stream order, whilst EC increased with increasing stream order. Amongst many factors, one factor influencing the change in water quality is that low order streams exhibit the poorest riparian zone condition and therefore have little capacity to moderate paddock nutrient runoff. The systematic change in EC implies that low order streams are dominated proportionally more by surface runoff than groundwater, and hence represent a greater relative opportunity to moderate surface derived nutrients and sediment. In summary, low order streams in this case study represent the greatest length, have the poorest condition, show the highest nutrient and sediment concentrations, have greater surface runoff, and therefore are priority candidates for the purpose of minimising the downstream impacts of nutrients when limited funds are available.

### THE MAIN POINTS OF THIS PAPER

- This paper presents a case study assessing the prioritisation of stream management for water quality improvement, where the primary objective is to protect a downstream waterbody, Oyster Harbour, Western Australia.
- About three quarters of the length of the stream network is represented by low order streams (order 1 and 2)
- Riparian zone condition worsens as stream order decreases.
- Low order streams tend to have the highest nutrient and sediment concentrations and are more dominated by surface runoff, and therefore represent the best opportunity to moderate surface derived nutrients and sediment.
- Managing low order streams by fencing, stock exclusion and revegetation imposes a small burden on the rural community by removing less than 0.7% of privately managed land in the catchment from agricultural production

### 1. INTRODUCTION

Increased macroalgal and epiphytic growth promoted by excessive nutrients, along with increased turbidity have reduced light for seagrass photosynthesis in Oyster Harbour on the south coast of Western Australia (EPA, 1990a). As a result, more than eighty percent of the seagrass cover has been lost and management recommendations have been made (EPA, 1990b). The Oyster Harbour catchment drains an agricultural landscape and a range of options, including stream management (Weaver and Prout, 1993) have been recommended to achieve nutrient load targets (EPA, 1990b). Stream fencing and rehabilitation are important components of catchment management, and the subsequent loss of nutrients and sediment to Oyster Harbour (Weaver et al., 1994). In contrast to the objectives of ecological stream rehabilitation (Rutherford et al., 1999), the primary objective for this catchment is to rehabilitate streams in order to protect a downstream waterbody from the impact of nutrients, rather than the purpose of stream ecological health

itself. With limited resources, it is important to give priority to those parts of the catchment or stream network where the greatest moderation of nutrient loss can be realised through the application of this best management practice.

Until recently, stream restoration efforts have focused mainly on high order streams (main channels) in the south coast region of Western Australia. To their credit, groups like the Oyster Harbour Catchment Group have successfully commissioned surveys (Pen, 1994) to map riparian zone condition and restoration requirements of high order streams, and subsequently secured funds to subsidise restorative efforts identified in the survey. Whilst this resulted in 95% of the main river channel being fenced, these high order streams typically represent less than 5% of the entire stream channel length, and therefore provide little buffering against nutrients and sediment discharged from much of the catchment.

<sup>1</sup> Department of Agriculture, 444 Albany Hwy, Albany, WA, 6330. dweaver@agric.wa.gov.au

<sup>2</sup> Formerly Department of Agriculture, 444 Albany Hwy, Albany, WA, 6330.

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This paper examines the connection between stream order, riparian zone condition, water quality and some other aspects of riparian management, using data from independent sources (1) riparian zone condition in three surveys (Pen, 1994; APACE Greenskills and Pen, 1997; Wilson Inlet Management Authority, 1998) and (2) a catchment - wide, event-driven snapshot water quality monitoring program.

## 2. METHODS

### 2.1 Catchment Environment

The study area has a Mediterranean climate, with cool wet winters and dry, temperate summers. Rainfall varies along a strong gradient from 400 mm in the north east of the region to 1000 mm near the coast (Figure 1). Most rain falls from April to October and supports agriculture based around broad scale grazing in the south, with increased cropping in the north. Land use trends show increases in areas under cereal crops, and tree crops where annual rainfall exceeds 600mm. Fertiliser management is based on annual applications of phosphorus fertilisers (Weaver and Reed, 1998) to naturally infertile soils. The catchment consists of gently undulating plains developed mainly on tertiary sediments with occasional granitic hills (Churchward et al., 1988). Duplex soils are common, often comprised of shallow grey acidic siliceous sands overlying laterite and clay higher in the landscape, with sands and sandy gravels at lower elevations, and deep sands in the valleys. The natural coastal vegetation consisted of small treed swamps inland of coastal heath, with pockets of tall to medium level forest and woodland (Beard, 1979).

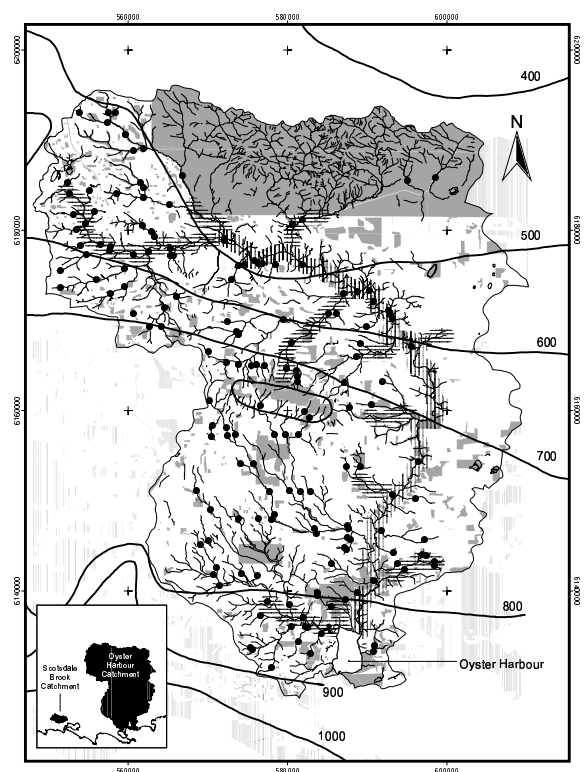
### 2.2 Riparian Zone Surveys and Stream Order

Whilst assessing the condition of the Kalgan River main channel, Pen (1994) characterised riparian zones into four classes from pristine ("A"), degraded ("B"), eroded or erosion prone ("C"), through to ditch ("D"). These classifications were also used in surveys done by APACE Greenskills and Pen (1997) in a survey of major tributaries entering the Kalgan River and the Wilson Inlet Management Authority (1998) in a survey of the Scotsdale Brook catchment discharging into Wilson Inlet (Figure 1).

Order	Stream Order Class/Survey		
	High <sup>1</sup>	Middle <sup>2</sup>	Low <sup>3</sup>
	Kalgan River Main Channel	Kalgan River Major Tributaries	Scotsdale Brook Streams
1		4.3	61.6
2		8.7	23.4
3		30.2	14.9
4		27.5	
5		26.4	
6	14.3	2.95	
7	85.7		

**Table 1.** Stream order distributions for each riparian zone condition survey. <sup>1</sup>High (Pen, 1994), <sup>2</sup>Middle (APACE Greenskills and Pen, 1997), <sup>3</sup>Low (Wilson Inlet Management Authority, 1998)

In this study these published surveys were used to compare riparian zone condition for streams of different order classes. Based on the numeric stream ordering method of Strahler (1952), streams in the riparian zone condition surveys were further classified as low, middle or high order streams (Table 1). The boundaries of these classifications overlap to some degree, but provides three distinct stream order groups to compare riparian zone condition. Figure 1 shows the location of the "high" and "middle" stream order surveys in the Oyster Harbour catchment, and the Scotsdale Brook catchment where "low" order streams were surveyed.



**Figure 1.** Oyster Harbour catchment, vegetation (shaded), streams, rainfall isohyets, water quality sampling sites (dots) and location of high (vertical line shade) and middle (horizontal line shade) order riparian zone condition surveys. Inset - location of low order riparian zone condition survey (Scotsdale).

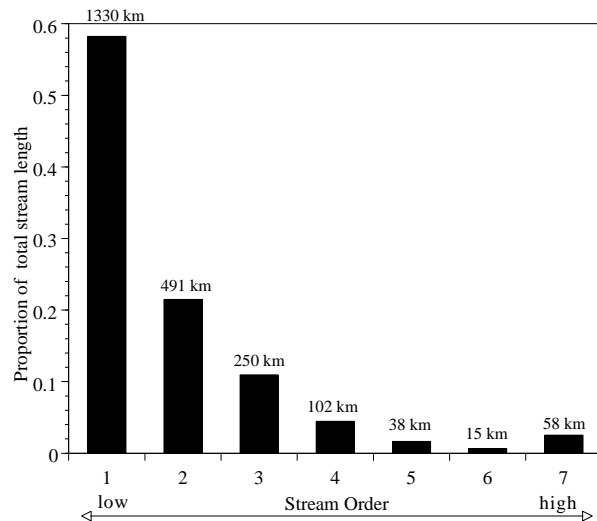
### 2.3 Water Quality

Using standard methods described by George et al., 1996 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 characteristics, including stream order, catchment size, land use, slope and amount of vegetative cover were located at the intersections of roads and streams (Figure 1). Stormflow was sampled using rising stage height samplers (Guy and Norman, 1970) and ambient flow by grab samples. We measured Total Phosphorus (TP) (Murphy and Riley, 1962) and Total Nitrogen (TN) concentrations simultaneously after persulphate digestion, using Flow Injection Analysis, and Electrical

Conductivity (EC) and Suspended Sediment (SS) concentrations (APHA, 1978). Relationships between stream order and log transformed data were examined using ANOVA and box and whisker plots.

### 3. RESULTS AND DISCUSSION

There was a systematic change in the proportion of total stream length represented by each stream order in the Oyster Harbour catchment (Figure 2). About 60% or 1330 km of streams are first order streams and about 80% or 1820 km streams are low order streams (stream order 1 and 2). Stream order 3 and above represented about 20% of streams and these in the main have been the focus of surveys of riparian zone condition in the Oyster Harbour catchment (Table 1, Figure 1).

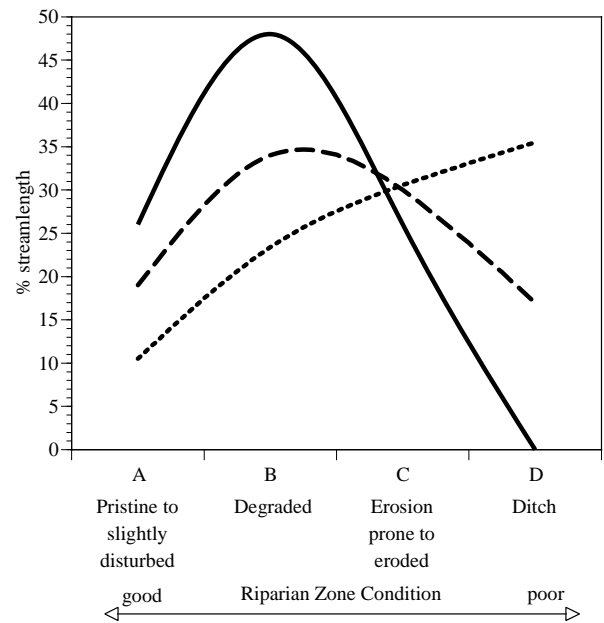


**Figure 2.** Proportional and actual stream lengths for different order streams in the Oyster Harbour catchment

There is a systematic change in riparian zone condition with stream order. High order streams (Pen, 1994) show a significant proportion of the stream surveyed (75%) as pristine ("A") or degraded ("B"). None of the stream was classed as "D" or ditch (Figure 3). Middle order streams surveyed by APACE Greenskills and Pen (1997) show less of the stream surveyed (55%) in pristine ("A") or degraded ("B") condition, and about 20% classed as "D" or ditch. The condition of streams progressively worsens as the stream order decreases. Data for low order streams from the nearby Scotsdale Brook catchment (Figure 1) (Wilson Inlet Management Authority, 1998) with order 3 or less shows a systematically poorer condition, with about 30% in pristine ("A") or degraded ("B"), and about 35% as "D" or ditch (Figure 3).

In the same way that stream length (Figure 2) and riparian zone condition (Figure 3) have varied with stream order, we can also examine water quality (Figure 1) and its variation with stream order (Figure 4). The box and whisker plots in Figure 4 show that TP, TN and SS generally decreases with increasing stream order, whilst EC increases with increasing

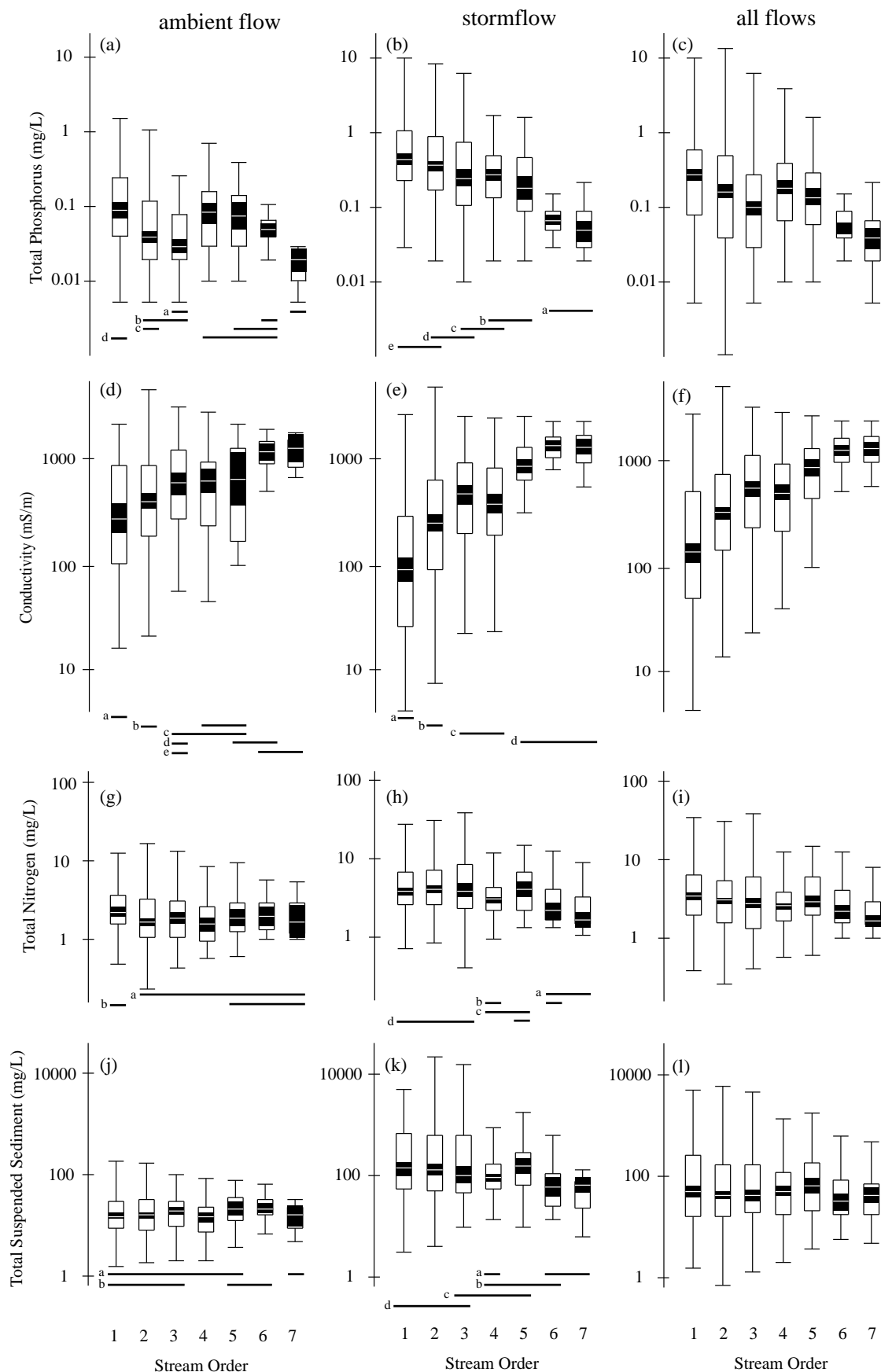
stream order. In addition, all measured water quality variables tend to show much greater variability for lower order streams than for higher order streams. Each water quality variable in Figure 4 is shown on a logarithmic scale, hence a small decline or increase in the median value can represent a significant change.



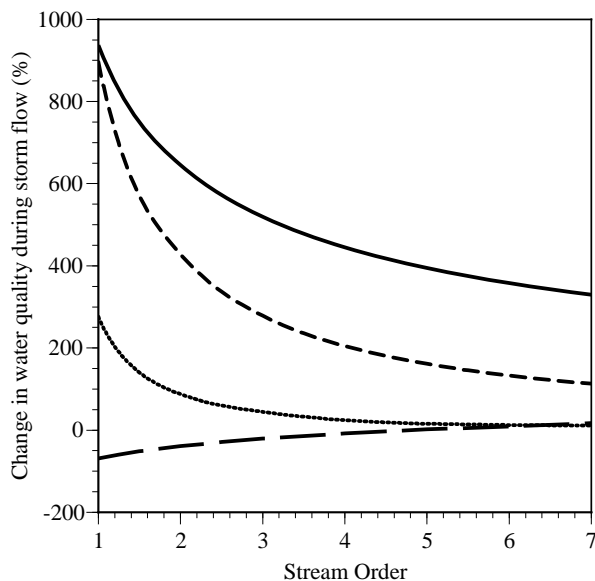
**Figure 3.** Variation in the percentage of stream lengths of different riparian zone condition for surveys of high order (line) (Pen, 1994), middle order (dash) (APACE Greenskills and Pen, 1997), and low order (dot) (Wilson Inlet Management Authority, 1998) streams

The largest decrease in water quality with increasing stream order occurs for TP across all flow regimes (Figure 4a, b, c). Stormflow samples show greater variability and significantly ( $P<0.05$ ) higher concentrations of TP, TN and SS than samples collected during ambient flows. For EC stormflow samples have significantly ( $P<0.05$ ) lower values than samples collected at ambient flows, again with greater variability for lower order streams.

Low order streams showed the greatest change in each water quality variable when the flow regime changed from ambient flow to stormflow (Figure 5). The greatest percentage changes occurred for SS and TP, and the smallest percentage changes for EC. The greater difference for lower order streams is an indication they possess the poorest buffering, which is consistent with the notion that they have the poorest quality riparian zones (Figure 3). Only part of this relationship can be attributed to riparian zone condition however, as lower order streams are more likely to have lower flow persistence (Prosser et al., 1999), and therefore have less capacity to buffer pollutants. Low order streams would therefore be inherently more prone to display greater variability in pollutant concentrations during storm events.



**Figure 4.** Box and whisker plots of TP (a, b, c), EC (d, e, f), TN (g, h, i) and SS (j, k, l) for ambient (a, d, g, j), storm (b, e, h, k) and all (c, f, i, l) flows for streams of different orders. White line shows median, black box is 95%CI of median, white box shows 25<sup>th</sup> to 75<sup>th</sup> percentile, whiskers show 5<sup>th</sup> and 95<sup>th</sup> percentile, outliers not shown. Lines beneath plots with different letters are significantly different and increase alphabetically,  $P < 0.05$



**Figure 5.** Percent change in SS (line), TP (medium dash), TN (dots) and EC (long dash) during stormflow for different stream orders. Lines are fitted to the difference between median values for ambient and stormflow for each stream order.

A number of studies show that catchment size also influences contaminant loads and water quality (Ekholm et al., 2000; Prairie and Kalf, 1986; Weaver et al., 1999). Not all these studies agree about effect of catchment size, in particular Ekholm et al. (2000) suggests nutrient and sediment loads increase with catchment size, whilst Prairie and Kalf (1986), and Weaver et al. (1999) suggest the reverse. Whilst stream order is a surrogate for catchment size, none of these studies, including this one have included both riparian zone condition and catchment size in their analysis. In this study, condition data, water quality data and catchment size data would be required in an attempt to separate these effects.

Amongst many factors, one factor influencing the systematic change in TP, TN and SS is riparian zone condition, and the buffering that condition provides. Low order streams in this catchment exhibit the poorest riparian zone condition and therefore have little capacity to moderate nutrient and sediment concentrations that leave in runoff from adjacent paddocks. There are other factors that could explain the changes in water quality with stream order (lower order streams are preferentially erosional and higher order preferentially depositional, catchment size, travel time, adsorption, flocculation, precipitation, biological uptake, assimilation, land use, soil type, topography etc), however the fact remains that nutrient and sediment concentrations are highest for low order streams, and therefore they present an opportunity to moderate concentrations prior to other catchment assimilation effects.

The systematic change and variation in EC with stream order (Figure 4d, e, f) implies that particular

hydrological pathways dominate for different stream orders. This is important because it gives us clues as to whether the restoration of riparian zones might have some effect on moderating surface-derived nutrients and sediment. The EC data suggest that lower order streams are at times more dominated by surface runoff than by groundwater flows. This implies that lower order streams present an opportunity to trap surface-mobilised nutrients and sediment, if good quality riparian zones existed. Of the diffuse pollution sources, surface mobilised nutrients are also most likely to exhibit the highest nutrient concentrations because enriched particulate matter is transported (Marston, 1989; Weaver and Reed, 1998; Weaver et al., 1999).

If the implied link between water quality and riparian zone condition is incorrect, and is mainly a function of catchment assimilation factors, Figure 4 still demonstrates that lower order streams are source areas for nutrients and sediment, and more dominated by surface runoff, and therefore represent good candidates for stream restoration. This assumes that the environment of these lower order streams has suitable characteristics, such as surface runoff dominance, for stream restoration to impact on water quality.

Additionally, in the Oyster Harbour and nearby catchments, land managers often propose that significant areas of land with the best productivity will be removed from production through the restoration of lower order streams. The Oyster Harbour catchment has about 50% of 1<sup>st</sup> and 2<sup>nd</sup> order streams in conservation areas, with the remainder on privately owned land that is 90% cleared. On a pro rata basis this leaves approximately 800 km of stream requiring management, and with an assumed riparian buffer of 10 metres either side of the stream, this would remove 1600 hectares from conventional agricultural production. This represents less than 0.7% of privately managed land in the catchment. Line et al. (2000) demonstrated that stock exclusion significantly reduced diffuse pollution. Many lower order streams in the Oyster Harbour catchment are used for grazing and agricultural pursuits, and this is partly influenced by topography. Exclusion of stock and traditional agricultural pursuits from lower order streams on the basis of their length alone is worthy of consideration. Whilst the task may seem large, work on individual lower order streams is less intimidating than higher order streams and is more likely to be achieved using back-of-the-ute technology (wheel barrow, spade, hand held implements) rather than expensive machinery. Restoration of meandering low order streams may also bring fretting agricultural land back into production by allowing cultivation of previously degraded areas. Because creeks meander, cultivation generally runs along a line of delineation that runs close to and usually parallel to where stream restoration works would take place. Hence the actual loss of productive land may be less than envisaged and deliver returns in agricultural production in its own right.

#### 4. CONCLUSIONS

In this case study low order streams represent 80% of total stream length, have the worst condition riparian zone, tend to have the highest nutrient and sediment concentrations, are poorly buffered against changes in water quality, are more dominated by surface runoff and therefore are good candidates as priority targets for stream fencing and restoration for the purpose of minimising the downstream impacts of nutrients when limited funds are available.

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