Guiding BMP adoption to improve water quality in various estuarine ecosystems in Western Australia

N. Keipert, D. Weaver, R. Summers, M. Clarke and S. Neville

ABSTRACT

The Australian Government's Coastal Catchment Initiative (CCI) seeks to achieve targeted reductions in nutrient pollution to key coastal water quality hotspots, reducing algal blooms and fish kills. Under the CCI a Water Quality Improvement Plan (WQIP) is being prepared for targeted estuaries (Swan–Canning, near Perth, and the Vasse–Geographe, 140 km south of Perth) to address nutrient pollution issues. A range of projects are developing, testing and implementing agricultural Best Management Practices (BMPs) to reduce excessive loads of nutrients reaching the receiving waters. This work builds on progress-to-date achieved in a similar project in the Peel–Harvey Catchment (70 km south of Perth). It deals with the necessary steps of identifying the applicability of BMPs for nutrient attenuation, developing and promoting BMPs in the context of nutrient use and attenuation on farm and through catchments and estimating the degree to which BMP implementation can protect receiving waters.

With a range of BMPs available with varying costs and effectiveness, a Decision Support System (DSS) to guide development of the WQIP and implementation of BMPs to protect receiving waters, is under development. As new information becomes available the DSS will be updated to ensure relevance and accuracy for decision-making and planning purposes. The DSS, calibrated for application in the catchments, will play a critical role in adaptive implementation of the WQIP by assessing the effect of land use change and management interventions on pollutant load generation and by providing a tool to guide priority setting and investment planning to achieve agreed WQIP load targets.

Key words | best management practice (BMP), catchment management, modelling, nutrient management, water quality

N. Keipert
R. Summers
M. Clarke
Department of Agriculture and Food,
Western Australia, Waroona District Office,
120 South West Hwy,
Waroona, WA, 6215,
Australia
E-mail: *nkeipert@agric.wa.gov.au*;
rsummers@agric.wa.gov.au;
mfclarke@agric.wa.gov.au

N. Keipert
D. Weaver
R. Summers
M. Clarke
Centre for Ecohydrology, University of Western Australia,
Crawley Campus,
Perth, WA, 6009
Australia

D. Weaver
Department of Agriculture and Food,
444 Albany Hwy,
Albany, WA, 6330,
Australia
E-mail: *dweaver@agric.wa.gov.au*

S. Neville
Ecotones and Associates,
RMB 1050 South Coast Highway,
Denmark Western Australia, 6333,
Australia
E-mail: *ecotones@westnet.com.au*

INTRODUCTION

Water quality deterioration in Western Australia (WA) has resulted in algal blooms as a result of nutrient inputs to aquatic systems. Nutrient and sediment transport are attributed to large-scale land clearing for agricultural and urban development, both of which are supported by regular inputs of nutrients from fertilizers and feed. In particular, agricultural development in the south-west of WA over the latter half of the 20th century has contributed to increased nutrient export to waterways mainly because of its extent. A number of catchments in south western WA have been subject to investigations and management proposals around the issue of eutrophication (Figure 1, Hodgkin & Hamilton 1993; Weaver & Prout 1993).

Since the 1950s, for example, waterways of the Peel–Harvey Estuary in WA have experienced severe nutrient enrichment as earlier settlement, based on agriculture, cleared and drained the majority of the catchment (Bradby 1997). Unfortunately even the poorest (sandiest), low

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nutrient retention soils were cleared and brought into production with post war migration and availability of new farming technology. For these reasons, along with the large scale application of fertilisers with high water solubility (superphosphate) since the 1950s, the waterways within the Peel–Harvey catchment began to dramatically deteriorate and by 1968, the area was a eutrophic ecological disaster with massive toxic algal blooms (Cross 1974). Algal growth has mainly been stimulated by phosphorus (P) which was identified as the limiting nutrient, most (90%) of which entered waterways from sandy soils in the coastal portion of the catchment (Bradby 1997).

Most catchments are unique and complex, encompassing a variety of land uses, landscape characteristics, soils, climate and vegetation. As a result, some parts of landscapes are more predisposed to nutrient and sediment transport than others. By identifying these critical source areas (Gburek *et al.* 2000), future management plans can be targeted to hotspots to minimise offsite impacts and maximise the cost effectiveness of remedial actions.

To reduce the discharge of nitrogen (N) and P to waterways of the Swan–Canning and the Vasse–Geographe catchments (Figure 1), a range of projects were funded within the CCI, and include activities to develop, test and implement agricultural BMPs for the control of nutrient export from point and nonpoint sources. These activities build on progress-to-date in the nearby Peel–Harvey catchment, which was also a CCI funded project (Figure 1).

In the past, various management programmes have been proposed, and implemented to control algal blooms. For example, in the Peel–Harvey an extensive fertiliser management programme designed and implemented by state government agencies to change landholder attitudes and practices was initiated. The Landcare movement also began during this period and this empowered community groups to take action and tackle the problems in their districts (Bradby 1997). Despite these attempts that relied on the voluntary adoption to improve management practices by landholders, water quality within the catchments did not improve. Other costly ($50M AUD) symptomatic treatments were tried, such as the Dawesville Channel constructed in 1992. The channel was constructed to increase flushing to the ocean whilst altering the salinity regime so that the aquatic environment would no longer be suitable for toxic algae to flourish.

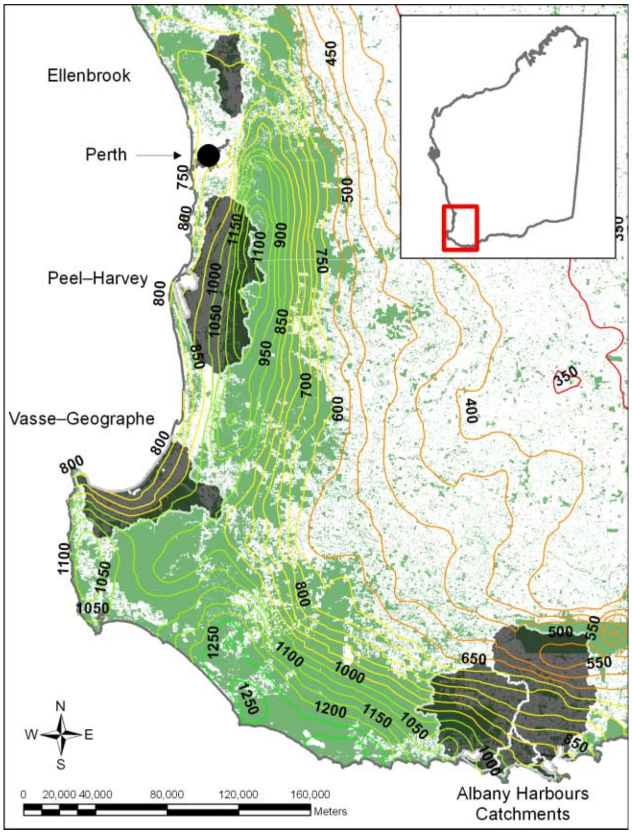

Figure 1 | Vegetation (light green), rainfall isohyets (mm), location and catchment boundaries (dark green) of Swan–Canning (Ellenbrook catchment), Peel–Harvey, Vasse–Geographe and Albany Harbours catchments which have been the focus of nutrient management issues in WA Swan–Canning (Ellenbrook catchment), Peel-Harvey, and Vasse–Geographe have been part of the CCI program.

Despite these efforts nutrients continue to be lost from the catchment into the rivers and estuaries today. Algal blooms and fish kills occur in lower river reaches and closure of river tributaries to recreation activities is more common, and beneficial uses continue to decline. It is clear from this history of management effort that voluntary approaches have not resulted in required outcomes (Weaver *et al.* 2004), and engineering solutions alone have not been able to achieve outcomes. A mix of measures is more likely needed, including regulation and certification schemes, and a more considered approach to the adoption of BMPs, including better guidance to the cost effective placement of these actions.

This paper introduces the CCI funded activities currently being undertaken in the Swan–Canning and the Vasse–Geographe catchments, and uses the Peel–Harvey as a case study to highlight the some activities, relevant findings and approach.

METHODS

Catchment management environment

The south west of WA has a Mediterranean climate, with cool wet winters and dry, temperate summers. Coastal annual rainfall varies between 700 mm and 1,100 mm and average daily temperatures range from 17 to 30 degrees C in summer and 6 to17 degrees C in winter. Ninety percent of the average annual rainfall falls between May and October. The growing season usually commences mid April to mid May and typically lasts for about seven months. There are three main landform types within these catchments – the Swan Coastal Plain, the Darling Plateau and the Dandaragan Plateau. The soil types vary throughout the landform types, but all have a strong association with vegetation and hydrology. The soils include limestones, sandstones, sands, silts and clays; however, much of the CCI study area is dominated with sands. From the coast, the vegetation associations include grasslands, shrublands and, less commonly, woodlands (Tuart forest) to open woodlands (Govt. of WA 2000).

Much of the vegetation consisting of melaleuca swamps inland of coastal heath and woodlands has been cleared in the last 50 years and enabled agricultural practices to develop. These practices mainly include broad scale grazing (cattle and sheep) of annual pasture (Trifolium subterraneum L. and ryegrass) in higher rainfall coastal areas, with increased cropping in lower rainfall inland areas. Small areas of intensive agriculture are located close to coastal regional centres. Fertiliser management practices have continued from those developed when the land was first cleared, and include annual fertiliser application to maintain the productivity of pastures on naturally infertile soils.

Overview of BMPs

For nutrient management plans to be effective at a farm level and in a watershed context, BMPs should first be assessed and developed at a small scale in the watersheds of concern. This assessment is underway as part of the Swan – Canning and Vasse – Geographe CCI programs. Previously, typical BMPs considered for adoption or having undergone field assessment at a small scale in south-west WA include soil amendments (Summers *et al.* 2004), effective fertiliser management (Summers *et al.* 2000), riparian management (McKergow *et al.* 2003), perennial pastures, irrigation and effluent management. In addition, the relative costs and water quality benefits of BMP implementation were assessed to identify the most cost effective BMPs and whether they can be spatially optimised (Weaver *et al.* 2005).

The effectiveness of BMPs can vary for different locations and conditions as indicated by riparian management research in the Peel – Harvey which showed P reductions of 30 – 60% (Cronin 1998), and research in the Albany Harbours catchments which showed no P reduction, but large (90%) suspended sediment reduction (McKergow *et al.* 2003). Therefore, where possible locally derived data on costs and effectiveness should be used to evaluate BMPs in a watershed context.

An alkaline residue from bauxite processing (Alkaloam™) has significant P retention capacity and provides production benefits (Summers *et al.* 2001). The capacity of Alkaloam™ to reduce P loss ranges between 30 and 60% depending on application rate and is expected to require replacement about every 10 years.

Perennial pastures appear to offer an opportunity to reduce nutrient loss whilst increasing farm productivity through high water use, deeper rooting systems and lower nutrient requirements (Knight 1990). Previous research has compared perennial systems and their attendant nutrient losses (Ridley *et al.* 2003), however no research has compared nutrient losses from annual and perennial pasture based systems. Productivity returns are more certain, but nutrient export reductions of around 20-30% are expected.

Effective fertiliser use considers the lowest and the most effective use of nutrients in farming. It includes soil and tissue testing to determine nutrient requirements (e.g. deficiencies and suitable fertiliser usage) and helps with the management of nutrients including rates, timing and locations (eg use of fertiliser buffers). Some alternative fertilisers that are more suited to the sandy leaching soils on the coastal plains of south-west WA have been assessed for productivity and water quality benefits (Summers 2000).

BMP audits, farm-gate nutrient balance and stakeholder opinions

The CCI programme offered an opportunity through a range of projects, two of which focussed on agricultural nutrient sources, to guide the development of a WQIP. The agricultural projects included an assessment of current levels of adoption of BMPs by farmers and their attitudes towards water quality problems (Lavell *et al.* 2004), along with assessments of farm-gate nutrient balance (Neville *et al.* 2004). Identification of the current levels of BMP adoption allowed an assessment of the impact of BMPs to date on water quality, in comparison to what might occur with full adoption. This BMP audit also sets the scene for what scope there is for further works in the catchment, and establishes a link between water quality trends and levels of management implementation.

Farm-gate nutrient budgets provide an opportunity to assess farm nutrient use efficiency (NUE) and surplus, and to compare the differences in efficiency and surplus within and between various enterprises. This simple approach of assessing nutrient inputs (fertiliser and feed), and nutrient outputs (products) can provide landholders with a business context within which they can improve their nutrient use, and also compare amongst peers running the same enterprise. A statistical approach (US EPA 1997) was used in gathering farm-gate nutrient budget information for different enterprises, and median values calculated for each. The values of nutrient surplus were then used to support the DSS, as one component of a risk based approach in DSS development (Weaver *et al.* 2004). An incidental outcome of the farm-gate nutrient budgets was the construction of a catchment perspective of annual nutrient flows by way of a Sankey diagram (Figure 3).

Information on farmers' opinions was used to help understand what is needed to encourage the adoption of BMPs in the catchment (Lavell *et al.* 2004). Iles (1996) states that evaluation of alternative BMP adoption strategies is an important component of an adaptive management approach where strategies are to be refined over time through focussed experimentation and feedback monitoring. This feedback monitoring was a missing element in the Peel–Harvey CCI programme, but has now been implemented in the Swan–Canning and Vasse–Geographe programmes.

Decision support system

It is important to evaluate what nutrient reductions are possible, and at what cost, so that limited funds can be targeted to realise the greatest moderation of nutrient loss for the least cost. Modelling offers some short-term catchment scale insights not available through long-term implementation and monitoring approaches. Numerous DSS tools, varying in computational complexity, data, parameterisation and calibration requirements are available to estimate nutrient losses from catchments as the first step in a management programme. Few of these couple this with simple cost benefit analyses, and fewer still bring the scientific complexity of these tools into a manageable form for interrogation by land managers and responsible authorities.

A risk based DSS described by Weaver *et al.* (2005), based on tools previously developed by Young *et al.*, was adapted for the Peel–Harvey catchment to examine nutrient management scenarios. The DSS framework (Figure 2) is an adaptation of the P indicators approach of Heathwaite *et al.* (2003) which combines source factors (nutrient inputs and soil mineralisation), transfer factors (effective rainfall and erosion risk), and delivery factors (land drainage or hydrological connectivity). Source factors were represented by P surplus data sourced from farm-gate nutrient balances for agricultural land uses (Neville *et al.* 2005), or derived from published work for urban land uses (Gerritse *et al.* 1990; Kelsey & Zammit 2003). Transfer factors were represented by an existing framework for P loss risk for WA soils (Van Gool *et al.* 2001). Delivery factors were described by nutrient assimilation functions (Simmons & Cheng 1985) and considerered both assimilation *within* each sub-catchment where nutrients are generated, as well as subsequent assimilation as nutrients *pass through* downstream catchments and other significant hydrological features.

The risk based DSS was then used to estimate how different BMPs, particularly perennial pastures, soil amendment (Alkaloam™), fertiliser management, riparian management and effluent management compared in terms

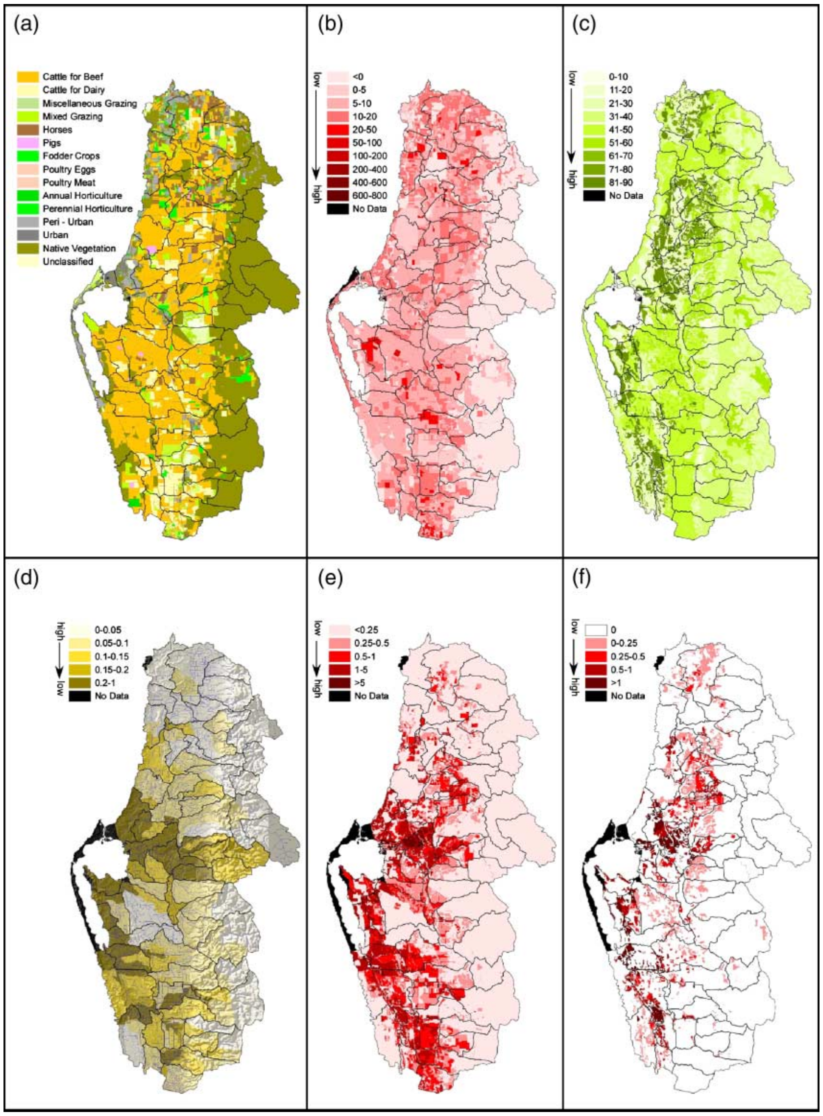

Figure 2 | Spatial data considered in the risk based DSS including (a) landuse, (b) source factors such as P surplus, (c) transport factors shown as inherent landscape risk, (d) delivery factors shown as nutrient assimilation, (e) relative P export at the catchment outlet (estuary) and (f) example of the degree and spatial extent of P reduction viewed at the catchment outlet from implementing a BMP.

of costs and water quality benefits when implemented in the DSS individually at 100% adoption, or in scenarios of different levels of adoption of each.

RESULTS AND DISCUSSION

Nutrient use efficiency

The nutrient balance information collected during the CCI programme revealed that a range of nutrient use efficiencies for different land use types exist with many showing high levels of nutrient use inefficiency. Nutrient use efficiency varied within and between land uses, with the most efficient nutrient users being the more intensive land uses such as feedlots and poultry farms that did not involve grazing activities connected with the landscape (Neville *et al.* 2005). The median P NUE for grazing systems ranged between 16% for cattle for beef and 26% for cattle for dairy. Phosphorus NUE greater than 50% were found for feedlots and poultry with annual and

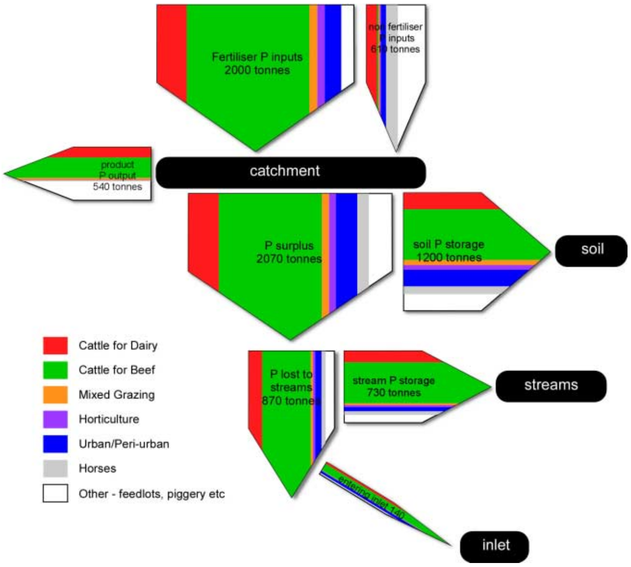

Figure 3 | Sankey diagram of the Peel-Harvey P flows and stores for various land use sectors. Width of each bar represents the relative contribution from each land use sector and flow (tonnes).

perennial horticulture, horses and viticulture recording P NUE of less than 10%. Whilst P NUE varied between and within land use, there were some statistically significant differences. When combined, these industry specific P NUE signatures provided estimates of nutrient flows and stores within the Peel–Harvey catchment by way of a Sankey diagram (Figure 3). This catchment scale analysis indicated an overall P NUE of around 20%, and that the equivalent of the annual fertiliser P inputs was surplus to production requirements each year. Whilst significant amounts of P were stored in the sandy soils of the catchment each year (~6 kgP ha^{-1} yr^{-1}), a catchment scale weighted average of 3.4 kgP ha^{-1} was lost from the edge of paddocks. Much of this was stored in the stream network so that a catchment scale weighted average of 0.5 kgP ha^{-1} was delivered to the estuarine system.

Guiding priorities for BMP implementation

There are a range of criteria that could be used to provide guidance over which BMPs are implemented, and where. These criteria can include, but are not limited to:

- Water quality targets, as indicated by median concentrations and reductions in loads;
- Cost benefits of various BMPs;
- Effectiveness of BMPs in reducing nutrient loads to estuaries; or
- Combinations of these criteria.

An approach using one or more of the above criteria may help land managers to focus on activities that will provide the largest P reductions, and concurrent economic returns to land managers. In the Peel–Harvey, concentration of effort on riparian management seems to have provided little improvement in water quality (<5%), whilst overall incurring ongoing economic costs (Weaver *et al.* 2004). This small improvement in water quality is partly due

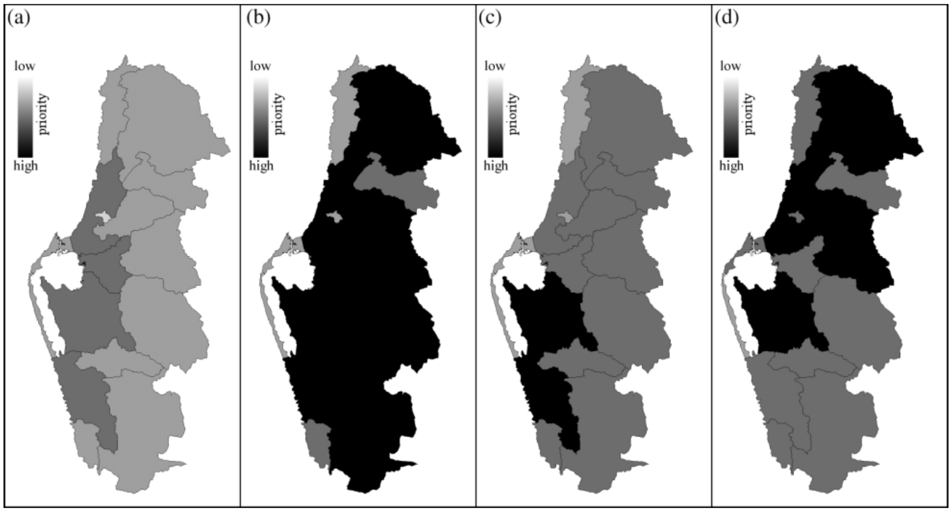

Figure 4 | Prioritisation of BMP choice (a; riparian management, b; perennial pastures, c; fertilizer management, d; soil amendment) based on cost benefit of BMPs and effectiveness of BMP to reduce P loads to the Peel–Harvey estuary.

to low adoption rates, and also because the chosen practices were relatively ineffective and costly. Simple modelling indicates that up to a 70% reduction in P discharge is possible through the use of other conventional practices including perennial pastures and the use of soil amendments, whilst improving the economic outlook for landholders implementing BMPs (Weaver *et al.* 2005). These generalisations need to be more spatially optimised so that landholders can make BMP choices informed by desired outcomes. Figure 4 shows the preferred location of different BMPs based on a combination of the cost effectiveness of each BMP type, and the degree to which each BMP in each subcatchment reduces the P load to the Peel–Harvey estuary. Choosing alternative criteria will provide a different result, and it is here where it is important to understand the motivations of landholders in making decisions, and other stakeholders' priorities for outcomes. Information of the type provided here can assist in promoting a dialogue to reconcile these priorities.

Current work

Similar approaches to that described for the Peel–Harvey work will be applied to the Swan–Canning and Vasse–Geographe areas. Local data about these catchments will be incorporated to acknowledge the differences between catchment locations and landscapes and to provide indicative or relative information to guide decisions on nutrient management. To date the Swan–Canning and Vasse–Geographe areas have been surveyed to provide information on current levels of BMP adoption and farm-gate budgets. In addition to DSS development to guide priorities for BMP implementation in these catchments, a monitoring programme of BMPs over a 2 year period will occur as part of an adaptive approach to nutrient management in these catchments.

CONCLUSIONS

The work of the Peel–Harvey CCI provides some guidance to implementing BMPs for nutrient management, dependent on different stakeholders' perspectives. Clearly where diffuse pollution dominates it is not sufficient to rely on individuals to develop management systems, and a more considered structured framework is required to achieve large scale environmental improvements. Additionally, and as is being carried out in new work, performance monitoring is required to allow for continual improvement and opportunities to adapt to appropriately monitored BMPs as they are implemented over time.

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