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BETTER PRACTICE CATCHMENT WATER QUALITY PLANNING FOR AUSTRALIA

A perspective on the National Water Quality Management Strategy

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ABSTRACT

Although catchment-based water quality planning is common in Australia, the quality and robustness of the approaches varies enormously. Insights are offered into more efficient and effective catchment-based water quality planning for Australia. These are based around the systematic approach provided by 'Water Quality Management Framework' promoted by the National Water Quality Management Strategy. Although treated separately for convenience, water quality planning should be an integral part of broader water resource planning.

Crucial elements include:

- An explicit statement of the strategic management goals. Failure of high profile water quality management initiatives can, in part, be traced back to vague and ambiguous management goals.
- Development of water quality targets aligned to the management goals using appropriate scientifically valid water quality guidelines.
- Systematic development of an effective and efficient 'program of measures' designed to reach the water quality targets.
- Recognition of the likely need for trade-off when considering social and economic impacts, and a transparent approach to do this.
- Better recognition of uncertainty, and the necessary support of a robust monitoring and evaluation program.

The discussion also briefly identifies some important areas requiring policy decisions.

Key words: water quality, planning, management, National Water Quality Management Strategy

INTRODUCTION

On-going water quality protection is aided by a systematic approach to catchment-based water quality planning and management. This paper describes a process to do this, emphasising those areas where, despite the many examples of good practice, a number of current efforts can commonly fall down. It is based on a synthesis of my experience derived over many years in the area of water quality management.

All commonly recognised 'uses' of the water resource are considered, although in the case of drinking water quality planning, only the source water protection element is relevant. This paper does not address the major governance and accountability issues, including stakeholder engagement. These are worthy of a separate discussion. Emphasis in this discussion is on the technical elements. It is not a comprehensive 'recipe' or review of methodologies, but provides guidance on the main issues to address, and common shortcomings.

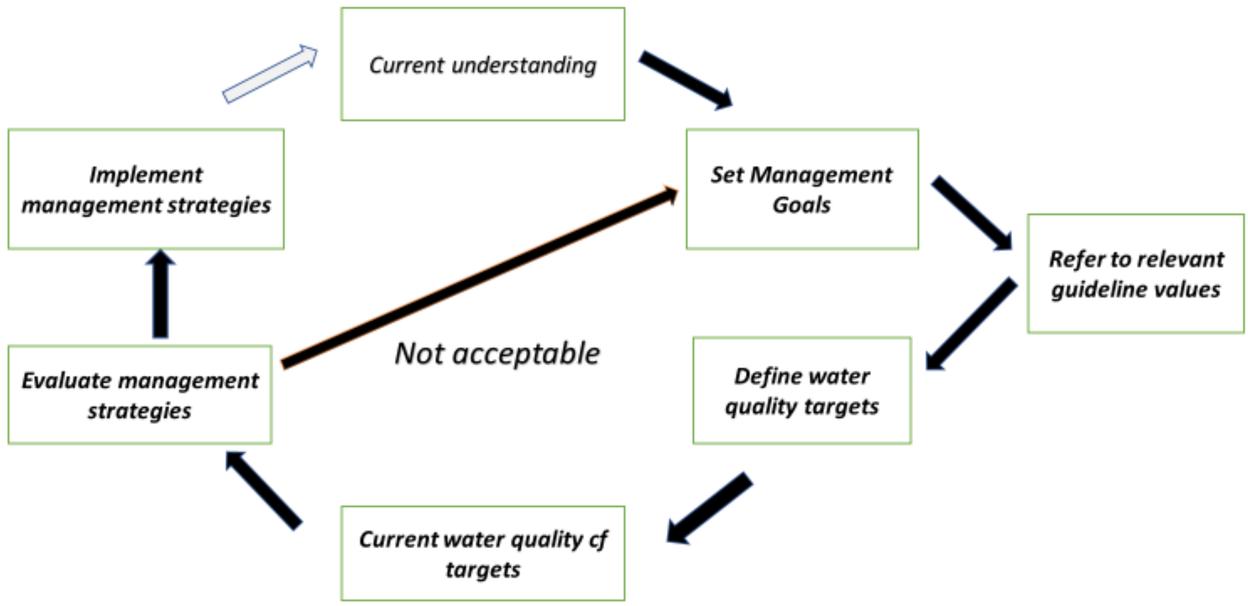

Figure 1. Simplified NWQMS Water Quality Management Framework

A useful framework for organising catchment water quality planning and management is the water quality management framework (Bennett 2008, p7) part of the Australia's 'National Water Quality Management Strategy' (NWQMS) A simplified version of the framework is outlined in Figure 1.

The framework and the individual steps can be used as the basis of developing a catchment-based 'water quality management plan'. (The framework can also be applied in other contexts which are not dealt with here). Ideally, the water quality management plan will be imbedded in a 'Catchment Action Plan' or similar, which deals in a coherent fashion with a broader range of water resource management issues. Water quality is dealt with here as a separate issue for convenience and illustrative purposes only.

From its beginning, the NWQMS had an expectation that jurisdictions would develop catchment-based management plans to meet agreed water quality objectives (Agriculture & Resource Management Council of Australia & New Zealand and Australian and New Zealand Environment and Conservation Council, 1998). Most Australian jurisdictions have planning instruments that incorporate water quality management planning in various forms, e.g., 'Catchment Action Plans' (NSW), 'Healthy Waterway Plans' (Queensland). However, the quality of individual plans varies enormously.

Although for the purposes of this discussion the framework is illustrated as a series of steps, the water quality planning process need not necessarily be followed sequentially; many of the steps are inter-related and the information and analysis is often undertaken in parallel in an iterative fashion.

METHOD

Major steps in the framework are discussed in more detail, with emphasis on those areas that are often currently poorly done, and ways in which they can be improved.

Need for Clearly-defined Management Goals

Good planning is 'outcome-based'. The most common mistake in conservation planning is said to be trying to solve an ill-defined problem; to be usable in decision making, broad, ill-defined goals need to be translated into definable and measurable objectives (Game et al., 2013). Similarly, Baldwin & Hamstead (2015, p. 137) in a review of water resource (quantity) planning concluded: '...planning process is more effective if the objectives are explicitly and clearly stated...'.

Thus, before considering how to undertake water quality management, it is necessary to have clear and unambiguous overall management goals[1] or objectives for the particular water resources under consideration. Unfortunately, all too often the management goals are vague and ill-defined. The management goals should describe precisely and in detail what is to be protected or restored. This may include the acceptable level of risk to achievement of the management goal. The management goals should reflect the key assets and values of the water resource, and thus may be not only ecological but also incorporate other uses/ values, such as drinking water supply, for recreation, for irrigation. In the case of planning for drinking water quality, the management goal in this instance will reflect only the role 'source protection' will play in drinking water quality management. Although the overall planning is done on a catchment basis, it is likely that many of the management goals will vary regionally.

Although this discussion is focussed on water quality, the management goal itself is not explicitly a water quality one, but a value of the water resource that could be impacted by poor water quality, e.g.,

> *the water is swimmable in the lower reaches of Clear River*

> *maintain seagrass to a depth of 5m in Hopeful Bay*

The management goal should be described in sufficient detail to ensure there is no confusion about what 'success' would entail. Moreover, the management goals should:

- be consistent with the management goals of other types of plans that cover the same water resource, such as Water Resource Plans or natural resource management plans. Ideally, this would reflect a common water resource policy and planning framework.
- be selected after consideration of all possible environmental or 'community' values (ecological, as well as social such as recreation)
- be 'ambitious, but feasible' (Roberts & Craig, 2014, p.111). If, on analysis (see below), a proposed management goal proves to not be feasible, perhaps on economic or equity grounds, it should be modified. This is amplified further below.

There has been an increasing unfortunate tendency to propose 'aspirational goals' that are clearly not feasible. This is counter-productive:

> *'It encourages a disconnection between target setting and assessment of technical and financial feasibility… It encourages a culture of hope in which people are encouraged to believe that, despite very limited resourcing…, and despite the absence of any technical evidence to support such hope, it will be possible to achieve extremely ambitious environmental outcomes' (Park et al., 2013, p.297)*

The development of the management goals should be developed through stakeholder engagement.

Many Possible Ecological End-points

For ecologically based management goals, it needs to be recognised in a formal sense that not all systems can be returned to a pristine state. Thus, management goals may relate to possible end-points which reflect impacted systems.

In the NWQMS, there is guidance given for establishing three possible end-points (levels of protection/ risk) for aquatic ecosystem protection:

- High ecological value systems
- Slightly to moderately disturbed systems
- Highly disturbed systems

This bears some resemblance to the idea of a 'healthy, working river' as a possible end-point:

> *'a managed river in which there is a sustainable compromise, agreed to by the community, between the condition of the natural ecosystem and the level of human use' (Whittington, 2002)*

1. Terminology varies widely! For the purposes of this discussion, the term 'management goals' has been adopted, consistent with the National Water Quality Management Strategy'

For high value ecosystems, we might expect adoption of the highest level of protection (lowest risk), whilst in other instances (e.g. urban areas) a lower level of protection may be appropriate (i.e., greater level of human use). However, ultimately, these are policy issues to be resolved by the decision maker.

Understand the System – Situational Analysis

An early step in making decisions about how to acheve your management goals requires a good understanding of how the system 'works'. This allows logical linkages to be made between:

- proximate stressor (water quality) and the management goal
- underlying key causes/ pressures or drivers and water quality.

(Bennett, 2008, p 39)

These high level linkages form the basis for the development of a more detailed conceptual model or models for the water resource.

An initial stage in the development of the conceptual model is an analysis of any available relevant data and information. Moreover, a good conceptual model does not attempt to explain all possible relationships, but should highlight those that contribute the greatest risk to achievement of the management goals. Thus, the model developed should focus on the proposed management goals, and as well reflect current condition, water quality attributes of significance, and the possible key causes and drivers of water quality degradation for the water resource. That is, *inter alia,* a good conceptual model should identify the most important water quality attributes which will need management and monitoring. The conceptual model can be described as 'the hypothesis' of the water quality management plan.

Conceptual models can represent the system in many ways, including descriptive text, tables, box-and-arrow diagrams and pictorial conceptual models. Each of these kinds of models works well for some applications and not so well, or even poorly, for others (Queensland Department of Environment and Heritage Protection, 2012).

Pressure/ Threat Identification

An important component of the conceptual model development requires a good understanding of the major pressures or threats in the catchment. There is generally a wide range of existing information on the various pressures and threats in individual catchments. This could be supported by quantitative modelling tools such as eWater's 'Source Catchments'. It is important to capture not only existing pressures, but also incorporate risk from possible future activities.

The US EPA provides a useful comprehensive approach to identify the most significant pressures in a catchment (Cormier *et al.*, 2000). There are also several good case studies undertaken in the Australian context (e.g., Walker *et al.*, 2001).

Assessments that are more comprehensive will also consider interactions among various stressors. See for example, Van den Brink et al. (2016). Whatever the model, 'some misconceptions and errors arise from narrowing the focus, but … (the model) can be refined as new information is collected.' (Maddox et al., 1999, p.565). This requires the support of a robust monitoring and evaluation program (see below).

Setting Water Quality Targets

The conceptual model developed above should identify the water quality attributes/ parameters that will be most critical in achieving the management goals for the water resource. For example, based on the management goal *to maintain seagrass to a depth of 5m in Hopeful Bay,* our conceptual model is likely to identify turbidity as a key water quality attribute.

One needs to set a water quality target that will tell us, in a quantitative sense, the water quality necessary to achieve the management goal. These targets should reflect the best available science. For various ('environmental') values of the water resource, there is, in Australia, published guidance material which will contain default water quality target values, or a methodology for determining local targets (Table 1).

Note that the water quality target in this context is equivalent to a 'limit of acceptable change' or a 'threshold'; i.e., the level beyond which there is an unacceptable risk the management goal might not be achieved. As part of the management process, we may well set lower water quality triggers to indicate where a change of strategy might be necessary, before we have reached the threshold level – i.e., early warning signals.

The water quality target will depend on the level of risk adopted as part of the management goal (see above). Obviously, the higher the level of risk agreed to, the less stringent the water quality target (and management measures required will be less intrusive).

Table 1. Source of Australian guideline material to determine water quality targets

Value/ use of water resource	Guideline Material
ecological	'Australian and New Zealand Guidelines for Fresh and Marine Water Quality' (ANZECC & ARMCANZ, 2000) and/or regional guidelines, for example: 'Queensland Water Quality Guidelines' (Queensland Department of Environment and Heritage Protection, 2013)
irrigation	'Australian and New Zealand Guidelines for Fresh and Marine Water Quality' (ANZECC & ARMCANZ, 2000)
drinking water	'Australian Drinking Water Guidelines' (NHMRC & NRMMC, 2011). 'Guidelines for Health Based Targets', (Water Services Association of Australia, 2015) Although health-based targets are not currently covered in the ADWG, they are becoming increasingly adopted.
recreational use	'Guidelines for Managing Risk in Recreational Waters' (NHMRC, 2008)

An example of varying water quality targets in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality is shown below (Table 2):

Evaluate Current Water Quality

This step is necessary, in conjunction with information on the key causes of water quality degradation and the conceptual model, to inform the identification and prioritisation of possible management measures.

Ideally, evaluation of existing water quality would be on the basis of a comprehensive and well-designed water quality monitoring program; this is not always the case. In the absence of comprehensive data, a 'weight of evidence' approach could be used to evaluate current water quality. This may include predictive models to infer the likely current water quality, supported by a comprehensive risk assessment. A systematic approach to the use of 'weight of evidence' is currently being developed as part of the revision of the Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Although restricted to drinking water quality risks, there are also good approaches adopted in the Australian Drinking Water Guidelines (ADWGs).

Table 2. Water quality targets for As (III) in freshwater (ANZECC & ARMCANZ 2000, p. 3.4-5)

Minimum level of protection	Water quality target, As(III) µg/L
99% of species at low risk	1
95% of species at low risk	24
80% of species at low risk	360

When evaluating the existing water quality against the water quality targets, it is important for 'like' to be compared to 'like'; that is, you need to have a good understanding of the context in which the water quality target should be applied. This is often done badly. Factors to address include:

- What water quality target do I use? In addition to geographic considerations, you will need to be aware of the level of protection (risk) that has been incorporated in the management goal.
- How do I compare monitoring data with the target value? Relevant characteristics of the target value can include (Royal Commission on Environmental Pollution, 1998):

    A statistic – i.e., how often the limit can be exceeded. For example, for a number of parameters in the Australian water quality guidelines, the median of monitoring data, not individual values, should be compared against the target values.

    The period for time of which the statistic applies. For example, for the Australian guideline values referred to above, an annual median, based on monthly data, for the monitoring data is an appropriate comparison.

- There is an additional policy decision to make regarding the level of certainty that is appropriate; it is not straight-forward to decide if monitoring data meets a water quality target (Goudey, 1999, Department of Water, 2015).

This evaluation of existing water quality should help identify:

- Areas or aspects where water quality needs to be improved to meet the water quality targets. (The greater the deviation of current water quality from the water quality target, the greater will be the management effort required to attain the water quality required).
- Areas of good water quality where the management emphasis should be on possible risks and the prevention of degradation.

Establishment of Program of Management Measures

General

This is the most critical part of the process, yet is generally the part often done poorly. Instead of a logical and coherent program of management measures, there is all too often a haphazard collection not selected on the basis of any objective analysis.

Selection of management measures needs to be carried out in a systematic manner. Areas or issues requiring management intervention will be informed by existing water quality and the analysis of key causes, as identified through the conceptual model. All significant sources should be considered. The analysis should recognise there may be multiple interacting pressures rather than a single pressure, and there are tools available to facilitate.

It is generally usefully, for both technical and operational reasons, to split the catchment into clearly defined, geographically-based, management zones; key causes of water quality degradation are likely to vary geographically.

Categorisation of Possible Management Measures

On a process basis, management measures generally fall into one or more of the following categories:

- Reducing availability (i.e., reduce application)
- Reducing pollutants generated (e.g., erosion control)
- Slowing transport/ delivery (deposit/ capture near point of origin)
- Deposition/ treatment off-site before waterbody.

(USEPA, 2008, p. 10-3)

Broadly speaking, each of these types of management measures can be enacted via one or more of a range of different policy instruments (Gunningham & Sinclair, 2005):

- Education and information initiatives
- Voluntary instruments such as Industry Codes of Practice
- Economic instruments, including taxes and levies, tradeable nutrient quotas, subsidies, compensation
- Regulatory instruments (may be considered as 'negative incentives')
- Planning instruments.

Developing a 'program of measures'

An appropriate mix of management measures will generally be necessary. That is, a coherent, **program** of measures. There are several considerations in determining the ideal program of measures, primarily effectiveness and efficiency.

Effective Measures

The most fundamental characteristic of the program of measures is that, if implemented, it can be clearly demonstrated that the water quality targets are likely be met. That is the management measures are effective. Often, there is a logical disconnect between the management measures and the desired water quality targets. Even in high profile examples such as the Great Barrier Reef, the management measures currently adopted are recognised as insufficient to protect water quality on the Reef. (e.g., Great Barrier Reef Water Science Taskforce, 2016).

Although there is voluminous literature and experience on the performance of individual measures to manage water quality, they are not always accessible in one place. A notable exception is for urban stormwater management where there are a number of good local summaries of the performance of various management measures, or 'best management practices'. (e.g., see Department of Environment, 2004). For rural sources, overseas literature with detailed summaries of possible management measures includes the US 'National Conservation Practice Standards', available as an on-line tool. (http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/cp/ncps/?cid=nrcs143_026849). Locally, Document 9 of the NWQMS, 'Rural land uses and water quality - a community resource document' has some useful, though dated information (ARMCANZ & ANZECC, 2000).

Efficient Measures

In addition to the program of measures being effective, they also should be efficient, i.e., achieve the management goal at least cost. In recent years there have been a number of detailed approaches in Australia to identify the most 'efficent' management actions. However, often the studies have limited scope, including:

- Only one source of water quality degradation is considered, and the efficiency of measures for managing that source are evaluated.
- Resources are assumed fixed, and a set of management measures to 'maximise' the outcome then evaluated. More correctly, the outcome should be fixed, and optimum (minimum) costs determined. Tradeoffs are possible, or even likely (discussed below).

Possible Approaches

A good systematic approach to assist in the identification of the most cost-effective program of measures can be found in guidance provided under the European Union's 'Water Framework Directive' (RPA Consortium, 2005)[2]. Note the methodology is applied proportionately; i.e., in some cases effective measures are easily determined and the rigorous systematic approach is unnecessary.

Steps used by the European Union include:

- The problem is 'defined' by analysing the gap between the water quality target and current water quality (see above).
- Measures that can potentially contribute to closing the gap in water quality are identified and evaluated. This will be informed by a good conceptual understanding of how the system operates, particularly the underlying drivers of degradation (see above). Source apportionment is required so that, ideally, corrective measures can be applied at source.
- An initial, qualitative assessment of possible management measures is carried out. Even at this stage, it is often possible to screen out measures that are less effective and costlier.
- The initial screening is followed up with a detailed, quantitative prediction of the potential effectiveness of the short-listed measures, together with a preliminary assessment of costs.
- Ideally, it will be possible to develop alternative effective combinations from the measures short-listed. At this stage the detailed costs are evaluated and in-depth engagement with stakeholders to decide the ideal 'program of measures'. Considerable iteration is likely. If no combination of measures is found to be acceptable there may need to be an explicit trade-off, where management goals (and consequently water quality targets) are relaxed (see below).

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2. A 'bio-economic tool' has apparently been developed by the Great Barrier Reef Water Science Taskforce, but detail is not yet available.

Attributes which should be used to decide on the most cost-effective program of measures include:

- magnitude of effect
- characteristics such as timeliness, adaptabiity, level of intervention, certainty of effect
- practicability/ feasibility – including legal requirements, local acceptability, motivation for implementation, delivery mechanism
- side-effects: beneficial or otherwise
- 'acceptable' cost.

(RPA Consortium, 2005)

Key Considerations

It is quite legitimate for jurisdictions to decide that some possible management measures are explicitly included or excluded on policy grounds. While making such policy decisions, it remains necessary that the program of measures finally adopted have appropriate degrees of surety of success in meeting the water quality targets; i.e they will be effective.

Because of the unavoidable uncertainty, implementation of the program of measures should be linked with an on-going process of monitoring and evaluation in an adaptive management framework (see below).

The water quality management measures also should be consistent with measures for water quantity management, or the management of other related natural resource issues (e.g. biodiversity).

A risk-management approach in the selection of measures should be adopted – i.e. where risk to achievement of the management goals is high, the measures adopted should be well understood and have a high likelihood of success. For example, experience has shown that high levels of uptake of voluntary measures are extremely unlikely, and these should not be relied on in critical situations. In drinking water quality management, there are some excellent examples of careful evaluation of risk and the likelihood of success of proposed management measures. For example, the Queensland Department of Energy and Water Security provide excellent guidance on preparing a 'Drinking Water Quality Management Plan' which addresses a systematic risk-based approach to selecting management measures, https://www.dews.qld.gov.au/water/regulation/drinking/forms-guidelines.

Managing 'trade-offs'

If after consideration of the potential impact of the proposed program of measures a decision is made that the social and/ or economic cost is too high, you will need to decide on a less ambitious management goal with less stringent water quality targets that are more easily achieved. (An unfortunate widespread myth is that you are able to modify the water quality target, and leave the management goal unaffected).

This may include acceptance of a higher level of risk (see above). However, effort should continue in finding lower cost abatement measures, e.g. by market-based instruments such as advances in technology, pollution abatement payments and pollution charges which could drive innovation.

In the case of drinking water quality protection, the trade-off is often between a catchment management measure and a treatment option to achieve the same water quality.

Monitoring & Evaluation – Adaptive Management

An appropriate monitoring, evaluation and reporting program allows for timely adaptive management. Although the emphasis is often placed on the importance of 'monitoring', this is mis-directed; more correctly the emphasis should be on evaluation or assessment for which monitoring is one, albeit important, of a number of tools. In addition, an evaluation is pointless unless it leads to reflection, and if necessary, an adaption of the existing management approaches – i.e., 'adaptive management'.

Monitoring and evaluation is important at a number of stages of the water quality management framework. For example:

1. *To better understand system processes*
   This would include examination of any changes which might cause us to re-examine the dominant processes. This may mean we need to regularly and routinely evaluate predominant risk factors. We need to continually check the underlying system assumptions are still valid and reasonable.
2. *To establish relevant and most efficient indicators*
3. *To update water quality guideline values*
   This provides the link between the management goals and the water quality targets. Although the targets will be based on 'best available science' there will always remain a degree of uncertainty. If the uncertainty in the target is high, we need to ensure our decisions allow for subsequent modification as more information is gathered.
4. *To compare initial water quality with water quality targets*
   This is likely to be similar to requirements for 6), below.
5. *To check on the effectiveness of management measures*
   This will comprise the extent to which the measure was implemented, together with whether it performed as expected.
6. *To check adequate progress is being made in reaching the plan's water quality targets.*

There are significant dependencies in these programs. For instance, if an evaluation of management measures (item 5, above) identifies inadequacies in their effectiveness, it would not be surprising that there was subsequent lack of progress in reaching the plan's water quality targets (item 6). This has been described as requiring a need for inter-related 'lead' and 'lag' indicators and evaluation programs, with accompanying 'iterative' and 'transformative' planning (e.g., Eberhard *et al.*, 2009)

For each of these purposes a program will need to be properly designed, with appropriate evaluation 'questions' and objectives. The programs will vary in both spatial and temporal scales. In this summary, only item 6 is considered.

Are the Water Quality Targets Being Met?

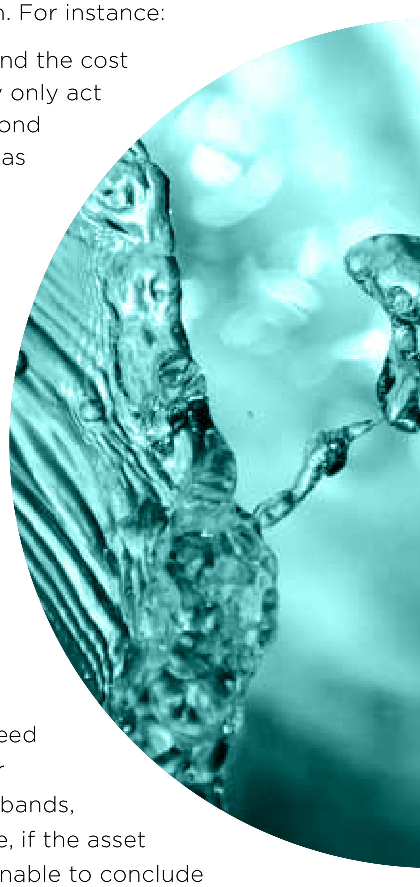
It is unlikely that with implementation of the management measures, the water quality targets will be achieved immediately; there will be a lag between implementation and the water quality achieved (Meals *et al.*, 2010). The program logic should incorporate the best estimate of the trajectory of change. This should be used in the identification of intermediate targets (milestones). In this instance evaluation of progress should be against the **expected** performance trajectory, rather than the ultimate water quality targets.

Setting of milestones will require a detailed analysis of management measures. Generally speaking, it best requires robust quantitative modelling tools, although in some circumstances expert opinion may be sufficient.

Evaluation of Monitoring Data

When we compare monitoring data against the water quality targets or milestones, the level of uncertainty needs to be taken into account. Evaluation then, does not rely on science alone; the 'burden of proof' to adopt requires a policy decision. For instance:

- If the asset is of low value, and the cost of remediation high, we may only act when we are confident (beyond reasonable doubt) a result has 'failed' to meet the target.
- If the asset is of high value, conversely we act unless we are confident (beyond reasonable doubt) the target has been achieved.
- We adopt middle ground i.e. we are 50% sure the result fails (on balance of probability).



That is, the estimated progress should recognise the uncertainty, and estimate confidence intervals, i.e., instead of, for example, 'a 17% improvement in nitrogen', we need to realise improvement is better expressed by inclusion of error bands, e.g. 17%±5%, say. In this example, if the asset is of high value, it is likely reasonable to conclude the improvement in water quality was 12%. That is, we are confident, 'beyond reasonable doubt', that the improvement in water quality is at least 12%.

This approach ('the confidence interval method') is used in Western Australia to calculate compliance with targets, where improvement is required. (Department of Water, 2015). That is, the target is only achieved '… where there is a 95 per cent probability that water quality has actually improved to better than target levels'. It follows that this approach would also be necessary in recording progress.

Use of water quality models

Increasingly water quality models are the most useful way to evaluate progress of water quality planning (SKM, 2011). High level of seasonal variability, including flow, makes it difficult to base assessment of condition purely based on monitoring data.

Appropriate models properly applied allow us to:

- Identify likely improvements in condition
- Make predictions/ projections about the impact of management measures
- Develop likely performance trajectory on which to basis progress.

Usefulness of the models relies on both a good system understanding, as well as sufficient information/ data to quantify relationships and parametise. Unfortunately, there has been little application of appropriate in-stream water quality models in the Australian context. This is an area worthy of further investigation.

CONCLUSIONS

Despite the prevalence of various catchment-level water quality management planning in Australia, there is much room for improvement. Building on the elements of good practice identified from a number of sources, this paper attempts to pull them all together.

The matters put forward in this paper are not to be seen as the last word, but an opportunity to encourage debate with the view to improve current practices and ideally promote the development of nationally applicable guidelines for water quality planning which could be used by all jurisdictions.

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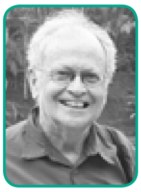
THE AUTHOR



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