# An Economic Analysis of Improved Water Quality

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***Abstract***
The research reported in this paper is focused on the cost-effectiveness of intervention strategies to reduce pollution loads and improve water quality in South-east Queensland. Strategies considered include point and non-point source interventions. Predicted reductions in pollution levels were calculated for each action based on the expected population growth. The costs of the interventions included the full investment and annual running costs as well as planned public investment by the state agencies. The results show that the cost-effectiveness of strategies is likely to vary according to whether suspended sediments, nitrogen or phosphorus loads are being targeted.

*Key words:* catchment modelling, cost-effectiveness analysis, environmental assets, water quality objectives

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## 1. Introduction

Increasing scale of economic activities together with rising populations has led to large increases in consumption and waste outputs in many Australian watersheds. The latter includes wastes discharged into waterways, which reduce levels of water quality and has subsequent economic, social (including public health) and environmental impacts. To address this issue, public investments in water quality improvement have increased substantially at all levels in Australia in recent years. Under the *National Action Plan for Salinity and Water Quality*, nationally $1.4 billion has been committed over the period of 2002-09 with $162 million (M) to be spent in Queensland to address salinity and water quality issues. The *Reef Water Quality Protection Plan*, a joint initiative of the Australian and Queensland Governments, is now in operational to halt and reverse the decline in water quality by reducing land-sourced pollutants entering the Great Barrier Reef (GBR) lagoon and by rehabilitating and conserving wetlands, riparian zones and floodplain areas. In addition, there are substantial investments in public infrastructure such as sewerage treatment plants, and tighter controls over emissions from private industry.

Increasing commitments of public funding can generate questions about the economic efficiency of such investments. Queensland Treasury (1997) requires strategies and options in addressing significant environmental concerns to be identified and valued to assist in the ranking of alternative investment options. Considering the constraint and competing uses of resources, optimality in resource allocation is important. Economic analysis plays an important role in assessing the desirability of public investment.

An economic analysis of water quality improvement requires proper estimation of costs and benefits of different mitigation strategies to assess the desirability of particular interventions. Estimation of mitigation costs is often a comparatively easy task as information is available either within relevant public agencies or from market transactions. However, estimation of mitigation benefits tends to be more difficult, mainly due to the fact that many of the benefits are not directly included in market transactions. Improved or maintained water quality can generate direct use benefits (e.g. direct recreation), indirect use benefits (e.g. impact on health risks) and non-use benefits (e.g. protection of biodiversity and cultural heritage). These may not be priced in markets.

Many improvements in water quality (or avoidance of deterioration) are not included in market transactions because they have non-rival and non-excludable characteristics. One consequence is that Government intervention is typically needed to address water quality issues. Another consequence is that information about the costs and benefits of such intervention are difficult to assess, and therefore can be difficult to include in an economic analysis.

The standard economic assessment tool used to evaluate the net benefits of an intervention measure in an economic welfare framework is cost benefit analysis (CBA). CBA operates by identifying, valuing, discounting and then comparing the costs and benefits that flow from a particular intervention strategy. Where a desired outcome has already been established, then cost-effectiveness analysis (CEA) may be employed. CEA determines the least-cost option of achieving a given target, and focuses on identifying the most cost-efficient ways of achieving set outcomes.

In assessing investments for water quality improvement, CBA is the most appropriate methodology to evaluate different policy options and the desirability of investment. However, in some situations CBA is difficult to apply because of issues involved in identifying and valuing different impacts (Gerasidi *et al*. 2003), and the difficulty of linking particular mitigation actions with community benefits. Where there is incomplete knowledge and high levels of uncertainty, decisions about resource allocation are often made through political processes. In these cases, the key policy question often becomes one of how to most efficiently meet the objectives that have been set by other processes. A CEA can be appropriate for this purpose, because it can avoid the difficulties of measuring benefits of environmental improvements by "focusing on the costs of achieving a quantified non-economic objective" (Keplinger and Santhi, 2002: 206).

CEA is being widely used in resource allocation decision-making. The technique is used extensively in the health industry to evaluate the most efficient ways of achieving certain health outcomes, where health-related benefits are usually expressed in a single measure, such as life years saved or quality-adjusted life-years (Abelson, 2003), or disability adjusted life years (Fox-Rushby and Hanson, 2001). The advantages of this approach are that the benefits of programs do not have to be measured (because the goals are already set), meaning that the analytical focus is on measuring and evaluating costs.

A review by Zanou *et al.* (2003) revealed that the majority (approximately 80%) of the applications of CEA,were in the area of health care. CEA is also used in other areas including water quality improvement. Using a linear programing model, Schleich *et al.* (1996) calculated the total cost of achieving a 50% phosphorus load reduction target established in various locations throughout the Fox-Wolf River basin in North-east Wisconsin. Gren *et al.* (1997) calculated cost-effective nutrient reductions to the Baltic Sea. Lise and van der Veeren (2002) assessed cost-effective nutrient emission reductions in the Rhine River Basin. They calculated the cost-effective joint nitrogen and phosphorus emission reduction to achieve a desired load to the North Sea. Yuan *et al.* (2002) applied CEA to evaluate the cost-effectiveness of alternative agricultural best management practices (BMPs) for sediment reduction in the Mississippi Delta. Using the Annualized Agricultural Non-point Source pollutant loading model (AnnAGNPS), the impacts of several BMP combinations on sediment yield were assessed and the most cost-effective BMPs were identified.

Previous studies on water quality improvement have focused mainly on nutrient reduction issues (Gren *et al.*, 1997; Schleich *et al.*, 1996). However, there has been little work done in Australia to determine the economic efficiency of locally specific water quality objectives. The focus of this study was to explore the economic case for improving water quality in South-east Queensland by using cost-effectiveness analysis to determine the most cost-effective mitigation strategy for achieving a new set of water quality objectives.

This paper is organised in the following way. Section 2 contains a brief description of water quality policy issues in Queensland and the study area. An overview of the cost-effectiveness analysis technique is provided in Section 3. The results of the case study analysis on intervention strategies, estimates of costs and cost-effective pollutant load reductions are presented in Section 4. Section 5 concludes the paper.

## 2. Case Study Background

### 2.1 Water Quality Policy Issues in Queensland

Water quality in Queensland is protected by the *Environmental Protection (Water) Policy 1997 (EPWP 1997).* The management framework for achieving sustainable development of Queensland's water resources under this legislation, with respect to water quality, includes:

- identifying environmental values for Queensland waters to be protected in consultation with industry, government and the community;
- deciding and stating water quality guidelines and objectives to protect environmental values; and
- integrating environmental values into the management of natural resources and making decisions about Queensland waters that promote efficient use of resources and best practice environmental management.

Environmental values (EVs) are the categories and aspects of water use that communities think are important[1]. EVs can be thought of as some measure of the differing impacts on society. These impacts are related to the qualities of waters that need to be protected from the effects of pollution and waste discharges to ensure healthy aquatic ecosystems and waters that are safe for recreation and productive use. Water quality objectives (WQOs) are measures of water quality indicators (including physical, chemical or biological measures) that protect the environmental values of the water. WQOs are measures of water quality needed to protect or improve environmental values.

*The EPWP* provides uniform water quality standards for all water bodies throughout the State. It covers a range of issues including the setting of environmental values for water quality and the establishment of water quality objectives for all waterbodies in Queensland. However, water quality varies naturally due to location-specific variation in rainfall and runoff pattern, river discharge, landuse, geology and soil type, topography (slope length and gradient) and land cover conditions. Therefore, irrespective of the level of pollutant load entering into a specific water body, the *EPWP* provides the same environmental controls as throughout the State. Against this backdrop, the Queensland Environmental Protection Agency (EPA) has developed draft environmental values and water quality objectives for fresh, estuarine and coastal/marine waters of the Moreton Bay in South-east Queensland along with two other regions in Queensland (EPA, 2004b). The aim of this initiative is to determine locally specific EVs and WQOs and integrate these values and objectives into existing legislation. For this, Schedule 1 (Environmental Values and Water Quality Objectives for Waters) of the *Environmental Protection (Water) Policy 1997* is proposed to change. When the proposed EVs and WQOs are integrated into the existing legislation, it will have a strict standard for waters in

[1] This is how the term 'environmental values' has been described by the Queensland Environmental Protection Agency (EPA, 2004c). However, the economic concept of value is different in that it reflects the net change in the welfare of society. Such values can be revealed by an individual's willingness to pay to obtain a specific good or service or willingness to accept compensation for a loss of that good or service. The terms 'environmental value' and 'environmental asset' are used interchangeably throughout this paper to indicate the environmental resources such as water.

Queensland. This will provide better protection to environmental assets through achieving higher water quality standards.

## 2.2 The Study Area

The South-east Queensland (SEQ) region occupies 22, 415 $km^2$ or 1.3% of the area of Queensland. With an estimated resident population of 2,654,000 in 2004 (OUM, 2004), SEQ is Australia's fastest growing metropolitan region enjoying consistently high rates of intra and interstate net migration. Moreton Bay is a highly urbanised region with strong population and development growth. Moreton Bay is fed by the Brisbane River upon which is situated Brisbane, the capital city of Queensland. The Bay is of national and international environmental significance, as recognized through the *Ramsar Agreement* and the declaration of the Bay as a Marine Park by the State Government.

Moreton Bay is the receiving water body for rivers and streams of a catchment area of 21,220 $km^2$, compared to the Bay area itself of 1523 $km^2$. This represents about a 14:1 ratio of catchment to Bay area (Dennison and Abal, 1999). Land used for agriculture, grazing and private forestry accounts for 71% of the catchment area, with urban and rural residential uses occupying 11% and public lands 17% (Capelin *et al.*, 1998). In recent years, however, urban development has become the most dominant form of land use change due to economic growth and increasing population pressure.

The geographic scope of the Moreton Bay study region includes:

- estuarine waters from Noosa to the Gold Coast (including Noosa, Maroochy, Mooloolah, Caboolture, Pumicestone Passage, Pine, Brisbane, Logan, Bremer, Albert, Coomera, Nerang and Gold Coast estuaries and creeks);
- Moreton Bay, the Broadwater and Queensland coastal waters; and
- coastal catchments freshwaters (excluding the Logan, Albert, Bremer, Lockyer and Brisbane catchments).

The SEQ as a whole is characterised by high variability in water quality levels and issues. There are some areas in the region that are in close to pristine condition, while other parts have serious and declining levels of water quality. Moreton Bay receives an ever-increasing load of pollutants, principally nutrients, sediments and phosphorus chiefly due to human activities and catchment and land use changes (Neil, 1998). Abal and Rogers (1999) reported that in the last 50-80 years in the Brisbane River, nitrate had increased by 22-fold, phosphate by 11-fold and suspended sediments by 4-fold.

The threats to water quality in the Bay area come from a variety of sources, broadly categorized as point and non-point sources. Protection of environmental assets requires the effective assessment and understanding of the sources of pollution loads entering the waterways so that mitigation strategies can be targeted to achieve water quality objectives.

In order to meet the water quality standards, reductions in the discharge of nutrient and sediments into the Bay water are required from all point and non-point sources. The Moreton Bay Catchment Water Quality Management Strategy cites sediment as a major cause of water quality degradation in western and southern Moreton Bay, particularly in Bramble Bay (Healthy Waterways, 2001). The major source of sediment is stormwater runoff from urban and rural areas. The majority of nitrogen entering SEQ waterways during dry periods originate from sewerage treatment plants. During periods of rainfall, urban and rural stormwater runoff also contributes nitrogen to waterways. Excessive nutrient and phosphorus inputs in some hotspots in the region are placing pressure on regulatory authorities to adopt tighter controls over nitrogen and phosphorus discharges into waters.

Water resource assets in South-east Queensland provide a variety of important functions and uses. Some of these assets have very high water quality standards, and improved protection measures will help to maintain them. In other cases, assets are threatened by low or declining water quality levels, and improved protection measures are needed to protect or remediate assets. In many waterways, current loads are causing continued deterioration in water quality even before additional loads are considered. If water quality levels continue to decline, then a number of adverse economic and social impacts over the short, medium and longer term are expected (Rolfe *et al.* 2005).

Against this setting, the EPA has developed EVs for discrete reaches of rivers, estuaries and coastal areas, with different categorisations for the study region. At an operational level, WQOs will need to be adjusted to suit each discrete reach of river, estuary and coastal area, so there will be many water quality objectives across the region (EPA, 2004b,c). This will provide location-specific WQOs in the study region.

**3. Cost-effectiveness Analysis**

The purpose of a cost-effectiveness analysis in assessing water quality improvement is to ascertain which mitigation strategy or combination of strategies can achieve a set of environmental outcomes at the lowest cost. The underlying assumption is that different alternatives are associated with different costs and different environmental outcomes. By choosing those with the least cost for a given outcome, society can use its resources more effectively (Levin, 1995).

A cost-effectiveness analysis of improved water quality can consist of the following steps:

*(a) Identification of the water quality target to be met.* This is typically set through a political process.

*(b) Determine potential mitigation strategies:* The next step toward conducting a CEA is to identify the intervention strategies available to achieve the desired environmental outcome. The impact of different mitigation strategies can be assessed using hydrological or catchment modelling. The modelling outputs provide pollutant load reductions under different scenarios designed for a study. For example, the same level of water quality improvement may be achieved by different strategies that focus on urban, industrial or agricultural emissions.

*(c) Estimating investment costs:* After alternative mitigation strategies have been identified, it is important to have estimates of intervention costs. In many cases the costs, such as production losses, are assessed from market data, but there may also be non-market costs to consider in some cases. The transaction costs associated with different mitigation strategies should also be assessed.

*(d) Calculate cost-effectiveness of the alternatives being considered:* Once both the mitigation strategies and their associated costs of intervention are known, the efficiency of different actions can be assessed. This may also involve some assessment of the risks and uncertainties associated with the different mitigation strategies.

A CEA typically describes an intervention in terms of the ratio of incremental costs per unit of incremental outcome (Garber and Phelps, 1997). In these cases the output is a ratio for each intervention, with the numerator showing costs and the denominator measuring intervention outcomes. CEA translates the environmental outcomes into a common denominator, for instance, the costs per reduced ton of N and P. A simple form of CEA involves the comparison of cost-effectiveness ratios (CER).

In the case of water quality improvement, reduction of pollutant loads into waterways is defined as the target and cost-effectiveness means of achieving the most amount of load reduction per monetary unit of cost. In that case, it is necessary to convert total costs to a per ton load reduction cost figure for comparing cost-effectiveness of alternative interventions.

## 4. Case Study Results and Discussion

### 4.1 Identifying Water Quality Outcomes

The benefits of protecting environmental assets in the case study area have been assessed by catchment modelling of pollutant loads. The Environment Management Support System (EMSS) software was used for the scenario analysis within South-east Queensland catchments. Model outputs include the predicted diffuse loads to waterways in response to modelling scenarios. Point source estuary loads have also been additionally included to examine the overall predicted load impact of possible interventions. Using EMSS, estimates have been made of total point and diffuse source loads for each of the major catchments in SEQ[2]. Suspended sediment, nitrogen and phosphorous loads have been used as surrogate indicators of the characteristics needed to protect environmental assets in SEQ waterways. These objectives include a range of physical, chemical and biological parameters all of which provide a detailed description of catchment and overall water quality condition. Water quality indicators are expressed as annual loads to waterways.

Selected intervention scenarios (as surrogates for a wider range of possible management actions) include a range of planned and possible future actions by both government and the community (including industry), targeting the reduction of urban and rural point source and diffuse source loads emitted to waterways. Possible interventions focused on the setting of water quality objectives to protect the environmental assets for the waters in the project area. Such actions are aimed at initially halting the decline of aquatic ecosystems and, over time, achieving sustainable management of the water environment. Possible interventions include both existing programs, such as the upgrades of sewerage treatment plants, and projected activities such as the restoration of riparian areas.

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[2] Load modelling scenarios used in this paper are reported in Rolfe *et al.* (2005) and were estimated by WBM Oceanics Australia (2004).

Based on the identified sources of pollution load, mitigation strategies were designed. For modelling pollutant load reduction in the catchments, three broad scenarios were considered (WBM, 2004 and McMahon, 2004 reported in Rolfe *et al.*, 2005). The scenarios involved an assessment of expected annual pollutant loads for:

- *Base Case* scenario: the existing situation in 2004;
- *No Intervention* scenario: if no further management actions are implemented up until 2026; and
- *Intervention* scenario: if a range of management actions and interventions are implemented up until 2026.

The scenarios defined above vary depending on whether or not management intervention strategies are implemented to address declining water quality. In the *No Intervention* scenario water quality levels are projected to decline in line with current trends and increasing populations. This is a modelling scenario that does not include a number of current government and community initiatives. In the *Intervention* scenario, management intervention strategies are introduced that enhance or protect water quality in spite of population increases, economic development and land use changes.

The key focus is on the cost-effectiveness of protecting the environmental values by achieving the water quality objectives through investing in water quality measures under the *Intervention* scenario (including both current and future programs). These interventions will ensure two key components are achieved. The first is to avoid further reductions in water quality and the second is to enhance or protect water quality above current levels. In assessing the benefits of the intervention strategy, the appropriate comparison is between *No Intervention* and *Intervention* scenarios, as this represents the total improvement gained.

To make the modelling task more manageable, the scenarios are simplified in three important ways. First, only a select number of potential mitigation actions have been selected in each broad category of point, diffuse urban and diffuse rural sources. The actions selected are assumed to be broadly representative of the wider range of actions available within each category. Secondly, the impacts for only one level of each action have been modelled. Third, impacts have only been assessed in terms of three indicators of water quality: suspended sediments (SS), phosphorous (P) and nitrogen (N). This has the potential of understating impacts because it excludes impacts of pathogens, toxicants, acid sulphate soils and other issues from the analysis.

Using the EMSS catchment modelling, levels of SS, P and N under a range of intervention strategies are predicted. Table 1 presents these modelled loads for the project area for the *Base Case*, *No Intervention* and *Intervention* scenarios.

***Table 1.*** *Summary of modelled reductions in sediment, nutrient and phosphorus loads under different intervention scenarios*

| | TSS (tonnes) | TN (tonnes) | TP (tonnes) |
|---|---|---|---|
| Base Case (2004) | 240,000 | 3800 | 1,360 |
| No Intervention (2026) | 280,000 | 5,200 | 2,000 |
| Intervention (2026) | 150,000 | 3,100 | 540 |
| Difference by 2026 | 130,000 | 2,100 | 1,460 |

In order to calculate the net social benefit of introducing load reducing best management strategies, annual net changes need to be compared for the *No Intervention* and *Intervention* scenarios. The basis for this comparison is the annual difference between SS, TN and TP loads for the two scenarios starting in 2004 and running through to 2026. In the *Intervention* scenario, TSS loads are predicted to fall below current levels by 90,000 t/yr to 150,000 t/yr. TN levels will have decreased by 700 t/yr below current levels to 3,100 t/yr and TP by 820 t/yr to 540 t/yr (Table 1). These are the key water quality outcomes of the intervention strategies. The next step is to identify costs of alternative strategies to achieve these load reduction outcomes.

### 4.2 Estimates of Costs

There are a number of intervention strategies identified to improve water quality levels in the case study area. The broad areas where these may occur include:

- *Point source facilities*: including improvements to sewerage treatment plants, industrial facilities and intensive agriculture sites;
- *Diffuse urban facilities*: including improvements to urban diffuse waste and greenfields development sites; and
- *Diffuse rural areas*: reducing sediment and nutrient movement off agricultural lands and down waterways.

In some cases the intervention strategies have already commenced and program costs committed by different public agencies and communities. In other cases a sample of representative programs has been approximately costed to provide a guide to potential intervention commitments. The broad types of programs that have been assessed are:

- waste water and sewerage treatment plant upgrades;
- retrofitting urban facilities to reduce urban diffuse emissions;
- establishing riparian grass buffers in partnership with landholders on rural lands; and
- rehabilitating riparian zones on selected major streams.

The cost estimates used in this analysis relate only to the additional costs of implementing the best practice management actions outlined under the *Intervention* scenario. They do not include expenses outlined in the *No Intervention* scenario or expenses associated with implementing best practice water quality management strategies for greenfield urban developments.

The cost estimates for these three types of program are summarised below:

***Agricultural Diffuse Expenses:*** The total length of 1$^{st}$ and 2$^{nd}$ order streams in the SEQ region is approximately 5,000 km. The cost of establishing grassed riparian filter/buffer strips along the stream is estimated at $5,600/km to cover capital expenses (e.g. fencing and off stream watering points) and annual maintenance costs.

Based on consideration of the SEQ Regional Water Quality Management Strategy's scientific results and characteristics of the region's various stream orders it was decided that in addition to grassed riparian strips, riparian rehabilitation strips in SEQ should be established in half of the region's 2$^{nd}$ order streams, all 3$^{rd}$ order streams and half the 4$^{th}$

order streams (EPA, 2004a). The total length of 2nd, 3rd and 4th order streams requiring riparian rehabilitation strips in the project area is 2,700 km (EPA, 2004a). Riparian rehabilitation strips are considerably more expensive to construct than grassed riparian filter strips. An estimate of $25,000/km to cover establishment and 12 months maintenance costs is used in this study. These cost estimates do not include any allowance for opportunity costs (production losses), and therefore may be an underestimate if high participation rates are required. Table 2 provides a summary of the kilometres of riparian and riparian rehabilitation strips included in the *intervention* case for the SEQ project area and the estimated cost of ($/km) each.

***Table 2:*** *Rural diffuse intervention expenses*

| Rural diffuse strategy | Kilometres of riparian strip | Total cost of establishing riparian strips ($M) | $M/yr for the next 20 years |
|---|---|---|---|
| Grassed riparian strip | 5,000 | $28.00 | $1.40 |
| Riparian rehabilitation strip | 2,700 | $67.50 | $3.38 |
| Total | 7,700 | $95.50 | $4.78 |

***Urban Retrofit Expenses:*** Urban retrofit expenses relate to investments in a number of structural and non-structural urban diffuse management actions in existing urban areas. These actions include increased compliance monitoring, education and awareness programs, construction of stormwater management devices (e.g. gross pollutant traps, sediment traps and mini-wetlands), and increased incidence of street sweeping and riparian vegetation protection in urban areas. The EPA (2004a) estimated that in the SEQ region approximately $8M/annum was spent on urban retrofit actions.

In the *intervention* scenario, a $580M expenditure program over 20 years was necessary to effectively retrofit a combination of best practice water quality measures to existing urban and rural residential land in the SEQ region (WBM, 2004). However, according to WBM (2004), approximately 40% of this expense will occur via natural attrition as old plants are replaced with new and more efficient plants and future redevelopment projects incorporate best practice water objectives as a requirement of their development approval. With this in mind, the anticipated additional urban retrofit costs associated with the introduction of best practice water quality management objectives in the SEQ region is estimated to be $350M over 20 years or $17.5M per year.

***Point Source Expenses:*** Point source polluter expenses fall into two categories – intervention expenses associated with upgrades to existing sewerage treatment plants, and intervention strategies to reduce the quantity of point source pollution entering waterways via major industrial and aquaculture discharges in the SEQ project area. Information from the 5-year forward estimates on submissions from Local Government, under the *Local Governing Bodies Capital Works Subsidy Scheme* for water and waste sewage infrastructure (40% State Government subsidy for eligible works) and sewage effluent re-use infrastructure (50% State Government subsidy for eligible works), have been used as the cost estimates for modelling cases. It should be noted that this costs do not differentiate between sewage plant upgrades to service population increases, or to achieve best practice environmental management. The current 5-year forward estimate for planned works under the above Scheme is $544M for SEQ (Rolfe *et al.,* 2005). However a portion of these funds will be required to service population increases independent of the environmental assets and water quality objectives assessed here. Whilst it is not possible to differentiate between planned expenditure on sewage treatment upgrades to service population increases from expenditure on BMP's to reduce sewage nutrient emissions to waterways and water reuse strategies, a 50:50 split was assumed. That means, $272M was assumed to be allocated to STP upgrades to deal with anticipated population growth and $272M was assumed to be allocated to BMP's to reduce sewage nutrient emissions to SEQ waterways.

In estimating both the pollutant load reductions and cost, other point source emissions regulated under the *Environmental Protection Act 1997* are excluded as their proportional contribution to nutrient emissions is small on a regional scale and relatively few activities are involved. Whilst *other point source emitters* have been excluded from this analysis, there are several thousand licensed industrial emitters in South-east Queensland. Higher water quality standards may impact on some of these emitters, although existing licence conditions are expected to be maintained in the short term. The majority of costs of reducing industrial emissions are expected to be private costs, which will vary widely between sites and industry types. In this study estimates of those costs have not been assessed because:

- modelled reductions in industrial emissions are a relatively low proportion of overall emissions,
- it is difficult to gain estimates of private costs, and
- costs are expected to vary according to which mechanism might be modelled for reducing industrial emissions.

The total costs for intervention strategies in 2004 dollars are summarised in Table 3.

***Table 3:*** *Present value of intervention case costs*

| Items | Costs ($M) |
|---|---|
| Waste water treatment plants | 242.90 |
| Riparian grassed | 28.00 |
| Riparian rehabilitation | 67.50 |
| Retrofit urban facilities | 212.77 |
| Total present value of annual expenses | 551.17 |

The *Intervention* scenario can be achieved through a number of actions targeting rural diffuse sources, urban diffuse sources and urban point sources. The total cost of these various actions in the period to 2026 is assessed at $551.17M (in 2004 dollars). This translates to an annual cost of $23.96M per year over the period. These amounts do not include potential private costs of industry and agriculture of reducing emissions further, or the private costs for greenfield urban developers. Furthermore, these estimates need to be treated with some caution, because:

(a) data on waste water treatment plants have been estimated from planned expenditure by local government, with a 50% apportionment for improving water quality. These cost estimates may be subject to change by local authorities;

(b) estimates of riparian protection and rehabilitation costs may underestimate some opportunity costs to landholders, and hence may understate the costs if voluntary, wide-spread adoption is to be achieved; and
(c) estimates of private costs arising from impacts on point source emitters or urban greenfields development have not been included.

**4.3 Cost-Effectiveness Analysis of Mitigation Strategies**
A basic CEA has been performed to identify where strategies may best be targeted for water quality improvement in the study area. The results of the CEA presented in Table 4 are expressed in terms of cost per ton pollution load reduction, that means, the focus is on the effectiveness of load-reducing strategies. These measures should be comparable across various scenarios, and capable of capturing the impact of different interventions with different effects.

***Table 4:*** *Cost-effectiveness of point and diffuse source load intervention strategies*

| Pollution load | Average annual point source load reduction (t/yr) | Average annual cost of point source load reduction ($/t/yr) | Average annual diffuse load reduction (t/yr) | Average annual cost of diffuse source load reduction ($/t/yr) |
|---|---|---|---|---|
| TSS | NA | NA | 86,948 | $54 |
| TN | 820 | $6,729 | 546 | $8,553 |
| TP | 1,022 | $5,400 | 118 | $39,735 |

Table 4 presents the results of the comparison of cost-effectiveness of pollutant control measures from point and diffuse sources respectively. Reducing sediment loads through diffuse management actions (i.e. riparian grassed filter strips) may be cost effective at $54/t, in addition to reducing the associated nitrogen and phosphorus loads. However, previous work indicates that point source SS loads are negligible compared to diffuse source SS loads and were not included in the modeling (Rolfe *et al.*, 2005). Therefore, a comparison between point and diffuse sources were not possible. A significant amount of TN can be removed through both point source and diffuse strategies. However, the point source strategies to reduce TN are cheaper ($1,824/t/yr) to implement than diffuse improvements. Similarly a significant amount of TP can be removed as a result of both the diffuse and point source strategies. In this case however, per unit reductions in TP are significantly cheaper ($34,335/yr) to achieve through investment in point source reduction strategies than diffuse mitigation strategies.

The analysis indicates that the cost for reducing the load of N from point source is slightly lower than the cost for corresponding decreases from non-point source. In contrast, the costs of reducing P are much higher from non-point sources than point sources, with the cost of P reductions from diffuse source more than seven times the cost from point sources. As a whole, the CEA shows which mitigation strategies have the lowest average cost of reduction.

**5. Conclusion**
The purpose of the study is to assess the cost-effectiveness of different water quality mitigation strategies in South-east Queensland. To perform the study, scenarios had to be

developed about the types of catchment interventions that could be considered, and the resulting changes in water quality indicators that may result. Once these catchment scenarios were modelled, the range of expected outcomes are assessed and costs of mitigation interventions were estimated.

The cost effectiveness analysis (CEA) conducted for this study demonstrates the value of the technique in informing policy makers about the choice of alternative mitigation actions for water quality improvement. To achieve water quality objectives, costs can be reduced by implementing less costly (i.e. more cost-effective) strategies. The analysis reported in this paper suggests there is substantial potential for cost savings by targeting intervention strategies in south-east Queensland. The analyses provide some indication of the most cost-effective reduction strategies for TSS, TN and TP in the region. It appears to be more cost-effective to reduce TSS from diffuse sources, and to reduce TN and TP within point source loads.

These are general findings, and there will need to be some sensitivity to individual sites/catchments where variations in loads and appropriate intervention strategies can be expected. At the more localised case study level, it is likely that different mixes of intervention strategies for both diffuse and point sources will be optimal to meet desired targets.

It should be noted that the CEA results do not allow a clear conclusion to be drawn about the overall desirability of water quality improvement programs. From the policy decision-making perspective, the CEA of competing alternatives can be used to determine which specific mitigation strategies should be funded over others. A more detailed cost benefit analysis would be needed to assess the net benefits of various *Intervention* strategies at individual catchments. As well, impact assessment studies might be needed to identify the groups in society that bear any economic or social impacts of different mitigation strategies. This means that the overall desirability of cost-effective solutions should be evaluated on a case by case basis.

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