Using a Catchment Water Quality Model to Quantify the Value of an Ecosystem Service

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EXTENDED ABSTRACT

The development of catchment modelling tools has gained considerable momentum through the Cooperative Research Centre for Catchment Hydrology's Catchment Modelling Toolkit. This repository of models (see www.toolkit.net.au) allows the modeller to select the most appropriate tools with which to best represent their catchment and associated constituent processes. While this has improved the ability to predict catchment runoff and pollutant loads, it has also presented an opportunity to use these tools in ways they may not have been initially designed for.

The application of these models and their further development has usually been driven by the need to support decision-making processes by land management agencies. The outcomes of the water quality models however, which typically represent constituent generation and transport processes, are usually only one of a range of factors considered in those processes and usually the one with the most science and predictive accuracy. Whilst this may be sufficient for some agencies, it is also considerable more appropriate to present economic and social implications of the implementation of management actions.

Ecosystem services and their valuation are seen as a potential solution to the economic descriptors required in decision-making processes. Ecosystem services have been defined as the transformation of natural assets into things that can be attributed with an economic value. The implementation of management actions can therefore be ascribed an economic value if they are seen introducing or enhancing an existing ecosystem service. In the case of the project described, the implementation of riparian revegetation could be associated with savings in water treatment costs where that revegetation was effective in reducing suspended sediment loads being delivered to downstream water treatment plants.

The Lockyer Creek catchment in South East Queensland is dominated by agricultural activities and is heavily extracted. The riparian zone has largely been cleared as part of those activities and large quantities of water are extracted from waterways within the catchment. As such, Lockyer Creek itself flows rarely, however when it does flow, it is responsible for delivering significant quantities of suspended sediment and associated turbidity to the raw water supply of the Mt Crosby potable water treatment plants.

Water treatment costing data was obtained for the treatment plants at Mt Crosby however the use of this data was constrained due to its commercial sensitivity. Analysis of this data however, showed that a statistical relationship was valid between raw water supply turbidity and monthly treatment cost. This relationship was then used to determine likely costs savings due to the suspended solids mitigation of effective riparian vegetation to demonstrate the likely value, as savings in water treatment cost, of the ecosystem service that may be provided by the vegetation within the Lockyer Creek Catchment.

The EMSS model was one tool available with which to undertake the analysis of riparian vegetation in reducing suspended sediment loads. Developed by the Cooperative Research Centre for Catchment Hydrology, the EMSS is a node-link style catchment model which can predict suspended solids, nitrogen and phosphorus at any point within a waterway or catchment.

To determine the value of the ecosystem service provided by riparian vegetation, results from EMSS were used to determine reduction in total suspended solids concentrations from the implementation of riparian revegetation in all streams within the catchment. This showed likely savings in water treatment cost up to $20,000 per month and could therefore be attributed as the ecosystem service value of having 100% of the riparian zones within the Lockyer Creek catchment being effective for reduction of suspended solids.

The use of catchment models such as EMSS have shown that having access to a toolkit of models provides the basis of predictive modelling to support more holistic decision-making rather than simply the water quality predictions that these models have been design for.

1. INTRODUCTION

Catchment modelling tools have undergone considerable development through the Cooperative Research Centre for Catchment Hydrology's "Catchment Modelling Toolkit". One of the forerunners to these tools was the Environmental Management Support System or EMSS. This was originally developed for South East Queensland (Chiew, 2002), and has subsequently been applied in several other catchments across the country, including the Yarra, Goulburn-Broken, Murrumbidgee, Fitzroy and Mt Lofty catchments.

EMSS and similar catchment models are designed to simulate constituent generation and movement processes. However, with the complex interactions of natural resource processes and their effect on management, it is often important that catchment stakeholders develop a greater understanding of catchment management impacts, rather than simply focusing on water quality or pollutant loads results from catchment modelling. The assessment of economic impacts is seen as one way of obtaining a better understanding of the effects of management actions.

2. ECOSYSTEM SERVICES

Research in the emerging area of ecosystem goods and services (ecosystem services) focuses on identifying, quantifying and valuing the goods and services provided by nature to our economy and our lifestyle. Ecosystem services have been defined as the transformation of a set of natural assets (soil, biota, air, water) into things that human's value (Cork et al, 2001). The services derived from these natural assets are diverse, multifunctional and interrelated. Some examples of these services include:

- Provision of clean and pure water
- Maintenance of livable climates and atmospheres
- Pollination of crops and native vegetation
- Control of pests, weeds and diseases
- Buffering from climatic extremes
- Fulfillment of cultural, spiritual and intellectual needs
- Providing for the future.

The valuation of ecosystem services is a newly emerging research area focused on the economics of ecosystem goods and services. The intent is not to minimise the importance of other ways of valuing the environment. For example, the intrinsic value of wildlife or its potential value for food or pharmaceuticals from native flora and fauna. Investigations into Ecosystem services focus firstly on the links between the goods and services in the economy and the support they gain directly from ecological processes and products. The technical challenges of establishing these links are at the centre of current research efforts. The technical challenges of also focusing on the support, which ecosystem services provide more indirectly to our economy and society, for example their contribution of our lifestyles, are also under investigation.

Research work on quantifying and valuing ecosystem services adds to the list of techniques developed over the last 20 years in response to the pressing need to calculate impacts, losses and gains for human society resulting from extensive environmental modification.

It should be realised that many benefits, both tangible and intangible, may be derived from on-ground actions that improve water quality. For example, the revegetation of a length of stream may result in reductions in total suspended solids, nutrients and turbidity. This may save expenditure at a water treatment plant, but it may also result in improved property values due to increased scenic amenity and improvements in recreational activities (e.g. fishing) from improved ecosystem health. Offsetting these benefits may be losses experienced by the landowner due to reductions in the area of available productive land. In addition, other risks, such as increased risk of flooding from increased roughness of the channel due to revegetation, may be impacted by the management actions. Other measures such as the perceived and actual changes to public health from a "do nothing" scenario may be very important.

3. APPLICATION OF CATCHMENT MODELS TO ECOSYSTEM SERVICE VALUATION

3.1. Background

In the application of catchment models, it is necessary to identify an ecosystem service that is associated with a constituent being modeled. A recent project focused on the water quality improvement service provided by a major catchment in South East Queensland. The Lockyer Creek catchment is heavily extracted due to the large extent of horticultural activities. This catchment contributes to the supply of water to Brisbane's major potable water treatment plants at Mt Crosby, most of which is derived from the

Upper Brisbane and Stanley River. Lockyer Ck, because of its over-utilisation, tends to flow only during larger rainfall events and at this time delivers considerable quantities of sediment to the raw water supply of the treatment plant.

3.2. Identification of an Ecosystem Service

The rehabilitation of riparian vegetation has been commonly used as a method of rural diffuse pollutant load mitigation. In the Lockyer catchment, significant areas adjacent to waterways have been cleared as part of preparing the land for cultivation. As such, little existing riparian vegetation remains and what is left tends to be fragmented or isolated to short lengths of first and second order streams. This riparian zone, if properly configured, can be an effective measure in reducing suspended sediment transport to streams, with removal rates of up to 98% quoted (WBM 2005). The implementation of riparian rehabilitation, through reducing suspended sediment transport, may therefore lead to lower costs to treat so called “dirty water” events associated with suspended sediment at the Mt Crosby Water Treatment Plants. This riparian vegetation could then be considered as providing an ecosystem service with a value (purely in water treatment terms) equivalent to the savings in treatment cost.

3.3. Analysis of Treatment Costs

Brisbane Water, the corporation responsible for supplying potable water to Brisbane City and some surrounding shires, provided a considerable quantity of costing data. With recent emphasis on commercialization and cost competitiveness, the use of this data was only allowed if it remained “in-confidence” due to its commercial sensitivity. Due to this constraint, only a summary of the analysis can be provided and no raw data, or functions which may allow calculation of treatment cost, can be provided.

Regression analysis of monthly treatment plant costing data was carried out with various water treatment plant parameters being tested against total treatment cost to evaluate correlation and significance of the functions derived.

From this, it became obvious that the only water quality parameter that demonstrated any significant correlation with water treatment costs was turbidity. This is understandable, as the coagulation process at water treatment plants is facilitated by the use of liquid alum (aluminium sulfate). The amount of alum required is dependent upon the amount of particulate and organic matter contained in the raw water and given that turbidity is a useful measure of particulate matter, alum dose is usually correlated with turbidity. As this is the most variable volumetric cost ($ per megalitre of treated water), i.e. for the same treated volume the most variable cost is the value of the liquid alum used, it follows that the parameter that would correlate best with treatment cost would be turbidity.

While other parameters (e.g. colour, manganese, taste and odour, pathogens) may have some bearing on overall costs, they are not strongly correlated with total treatment cost.

Further analysis of the data showed that a statistical relationship was only valid between raw water supply turbidity and monthly treatment cost when turbidity values exceeded 10NTU on any day during a month. As such, they could be correlated with “dirty water” events from the Lockyer catchment.

The difficulty with this approach was that the EMSS model predicts suspended solids concentrations rather than turbidity, hence using a catchment model to predict treatment cost savings due to best management practices required a relationship between turbidity and suspended solids to be developed.

3.4. Relationship of Turbidity and Total Suspended Solids

The relationship between turbidity and suspended solids concentration is influenced by a range of factors including particle size, particle composition and water colour (Gippel 1995). However, a high correlation exists between turbidity and mass of suspended matter for individual sediment types such as those derived from a particular soil type (Duchrow 1971). Turbidity and total suspended solids are both measures of particulate matter suspended in the water column, however turbidity is dependent on the particle size and their ability to scatter light, whereas suspended solids is related to the mass of the particles. As size and mass of particles is highly spatially variable, it follows that a relationship between turbidity and total suspended solids may only be valid for a specific location. Between 1948 and 1962, considerable data was collected at the Mt Crosby water treatment plants for both these parameters. This allowed a function to be developed to describe the relationship between turbidity and total suspended solids at his location (Figure 1).

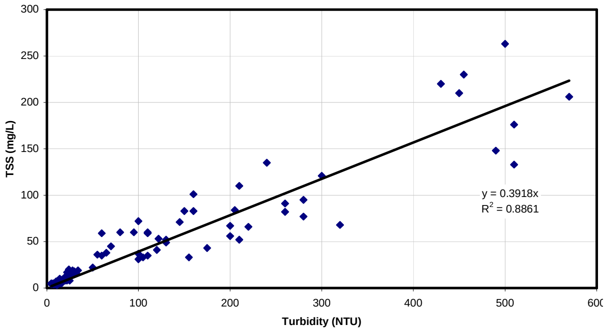


Figure 1 Turbidity vs Suspended Solids

Given that the relationship appeared to be satisfactory, the EMSS model was then used to derive daily turbidity values that could then be used with the costing function.

3.5. The Environmental Management Support System

The Environmental Management Support System (*EMSS*) is a PC based application designed to assist with the planning of catchment management actions to improve water quality (*Vertessy et. al. 2001*). Until the development of catchment models such as EMSS, there was no easy way to gain a synoptic view of where pollutant loads originated from within catchments, how they might be reduced (*or exacerbated*) by different kinds of catchment management actions and land use change, and how they are conveyed, and potentially transformed, by the river and stream networks to their ultimate 'receiving' waters, be these coastal, estuarine or freshwater.

The EMSS is built in Tarsier, a model-building framework developed by CSIRO and implemented in several applications in Australia and the USA. Tarsier provides the ability to use GIS raster and polygon layers as input data in developing model networks and inputs.

The Lockyer catchment covers an area of 2,983 km^2 and encompasses a diversity of soil types, land-uses and climates. The Lockyer EMSS model segments the region into 176 Subcatchments, each with an average area of about 10 km^2. For each sub-catchment, the EMSS model predicts a daily runoff volume and a daily load of suspended sediment, total phosphorus and total nitrogen. The flows and pollutant loads from each sub-catchment are routed through a stream network, down to the outlet node at the confluence with the Brisbane River. The EMSS contains a simple representation of water supply storages and their effect on sediment and nutrient trapping and water losses.

Within the EMSS, the user can simulate point source inputs and extractions, providing data is available. In the Lockyer EMSS, no point source data was available. The runoff and pollutant predictions for sub-catchments are responsive to changes in land-use, diffuse management treatments and riparian management. Each of these 'actions' is ascribed a particular pollutant stripping potential that will reduce the original pollutant load prediction. In the EMSS, their efficacy is assumed to vary spatially and temporally.

The EMSS is composed of three linked models, as follows:

A runoff and pollutant export model (*referred to as 'Colobus'*), which operates on each subcatchment providing estimates of daily runoff (*Q*) and daily loads of total suspended sediment (*TSS*), total phosphorus (*TP*) and total nitrogen (*TN*). The sub-catchments are linked to one another using a 'node-link' system to represent the river network.

Flow and pollutant loads from subcatchments are conveyed down through the river network using a routing model (*referred to as 'Marmoset'*).

As many rivers are regulated by storages, a storage model (*referred to as 'Mandrill'*) has been included in the EMSS. This model regulates river flows, traps pollutants, and accounts for evaporative losses. The Lockyer EMSS has a representation of Atkinsons Dam as the only major storage within the catchment.

A schematic representation of the EMSS models and objects and how they are interlinked is shown in Figure 2.

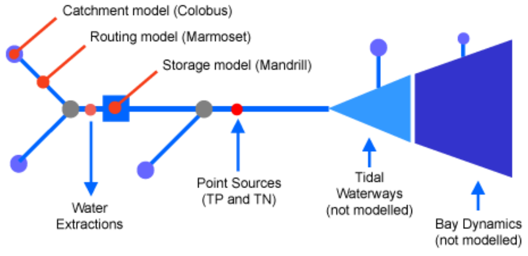


Figure 2 EMSS Schematic Representation

Major inputs to the EMSS are as follows:

Elevation - a digital elevation model is used to compute subcatchment boundaries and the river network. This is done automatically by the EMSS according to a user-specified drainage area (*set at 10 km^2 for this EMSS*) and flow gauging station positions. A 25 m DEM provided by the Queensland Department of Natural Resources and Mines was used in this regard.

Rainfall - a 100-year series of gridded (*5 km*) daily rainfall values, obtained from the SILO database. The EMSS interrogates this grid and produces a continuous time series of data for each subcatchment.

Potential evapotranspiration - a grid (*5 km*) of average monthly values for each subcatchment, derived from Bureau of Meteorology national evaporation maps. The EMSS interrogates this grid and produces a continuous time series of data for each subcatchment.

Land use - eleven different land use classes, derived from the 2001 State Land and Tree Survey (*SLATS*) coverage and updated to reflect 2002 planning schemes in the region. The EMSS automatically determines the proportion of subcatchment area devoted to each land use.

Pollutant concentrations - Event Mean Concentration (*EMC*) and Dry Weather Concentration (*DWC*) values for total suspended sediment, total phosphorus and total nitrogen, with discrete values for each of the eleven land use classes as derived from Chiew and Scanlon (2001) and modified through Task BSES for the South East Queensland Regional Water Quality Management Strategy, Brisbane City Council's Urban Water Strategy Task 1.1 project and recent studies on sustainable loads into Wivenhoe Dam.

Point source inputs - major point source inputs of pollutants into the river network. In the Lockyer EMSS, no point sources are included.

Water extractions - major off-takes of water from the river network for irrigation and consumptive use, rather than extractions from the storages. As no data was available on major extractions from the river network, none have been modelled in this EMSS.

Storages - data on the major storage in the region (Atkinsons Dam). This includes storage geometry data (*stage versus surface area versus volume relationships*), spillway levels, extractions and flow release data.

Flow gaugings – Daily runoff data from the Queensland Department of Natural Resources and Mines was available at the time of developing the model and was used in validating the hydrological parameters previously derived for the this region in the SEQ EMSS.

Erosion Hazard – derived from national coverage provided as part of the National Land and Water Audit (Land and Water Australia 2002).

Land-use Data

The EMSS considers 11 different land uses, broadly grouped into woody, agricultural and urban classes. **Benefits**

The EMSS has a user-friendly interface that allows easy manipulation of scenarios to investigate land-use changes, the effects of best management practices and the modifications to pollutant loads from point and diffuse sources. A typical view of the EMSS interface is shown in Figure 3below.

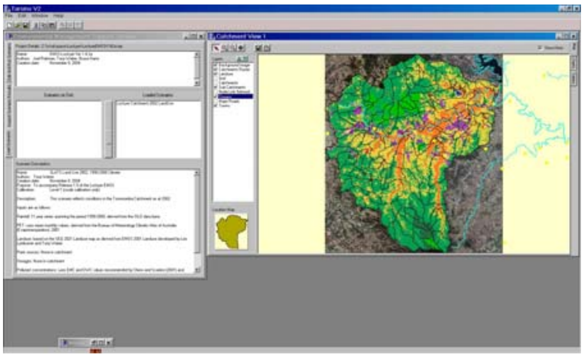


Figure 3EMSS Interface

Given this flexibility, the EMSS has been applied in 11 catchments within SEQ in addition to a regional SEQ model. This wide application has led to considerable development and refinement of pollutant load concentrations (EMC's and DWC's) based on local monitoring data. As such, EMSS models in SEQ benefit from the best available data for the entire region. As it uses a daily time step, the EMSS can be used to investigate particular flood events (e.g. May 1996) to evaluate likely pollutant load generation and export through a catchment.

Constraints

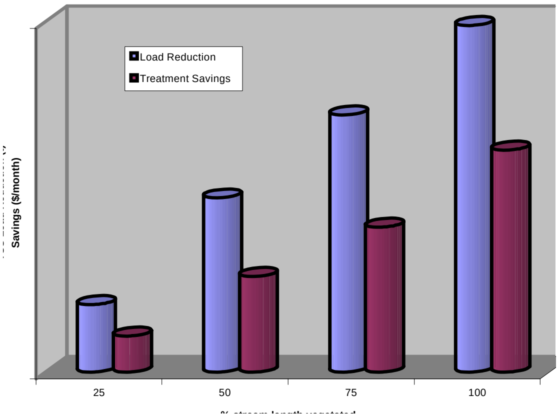
As the EMSS is a "lumped-conceptual" model, particular processes contributing to pollutant export are not explicitly modelled and therefore cannot be evaluated. The routing and storage models used in the EMSS are simplistic also, so are dependent on local data for calibration. This data is not always available, so further information regarding storage performance (e.g. Atkinsons Dam in the case of the Lockyer EMSS) is warranted to improve the predictive ability of the model. In addition, there is a paucity of data regarding the likely pollutant export from various rural and forested land uses across SEQ and Australia in general. The calibration results from local water quality data available at present really represents a "best guess" of the likely split between individual rural and forested land uses based on achieving the best fit to available data. This paucity of data extends to the efficacy of management practices such as riparian rehabilitation, which is commonly quoted as a rural best management practice (BMP), though little data is available to support its water quality improvement efficacy.

While the user interface in EMSS is relatively simple to use, the model build process is complex and the Tarsier modelling framework has been superseded through the development of TIME. Completed as part of a contract to the Moreton Bay Waterways and Catchments Partnership, the EMSS is considered the ‘prototype’ for a more advanced catchment modelling tool being developed by the CRCCH, known as “E2”. This “E2” model is not one particular model, but an easily customisable tool that will allow users to build an application that is tailored to the project at hand.

4. RESULTS & DISCUSSION

EMSS was used to estimate total suspended solids (TSS) loads if 25, 50, 75 and 100% of stream length were revegetated in the catchment simply as a test to evaluate the performance of the treatment cost function derived rather than being a simulation of true management intervention within the catchment. Using the EMSS model, daily simulated suspended solids concentrations were then converted to turbidity reductions likely to be achieved at the water treatment plant. From this, a range of treatment costs were calculated for each of the riparian revegetation scenarios and potential treatment plant savings derived. These results are shown in Figure 4 below.

Figure 4 Treatment Savings for Progressive



Revegetation

From the results presented above it could be shown that cost savings of up to $20,000 per month were possible with 100% riparian revegetation scenario. This 100% scenario was undertaken to show the upper limit of cost savings possible if all riparian vegetation was operating at maximum efficiency and therefore the likely value of the ecosystem service provided by effective riparian vegetation zones within the Lockyer Catchment.

This analysis showed that it is possible to value an ecosystem service, however this was only possible due to considerable costing data for a related function, in this case water treatment costs, that is, it has been possible where a strong dependence between a water quality parameter (i.e. turbidity), and a unit cost were available.

5. FURTHER RESEARCH

The project has identified that further work will be needed where this is not the case, especially for parameters associated with dry weather flows. It is likely that cost functions derived will be dependent on the values of likely capital expenditure to meet water quality targets as a result of increased challenge to the water treatment plants from deteriorations in water quality. To exemplify this, the following figure shows a likely cost function that could be derived.

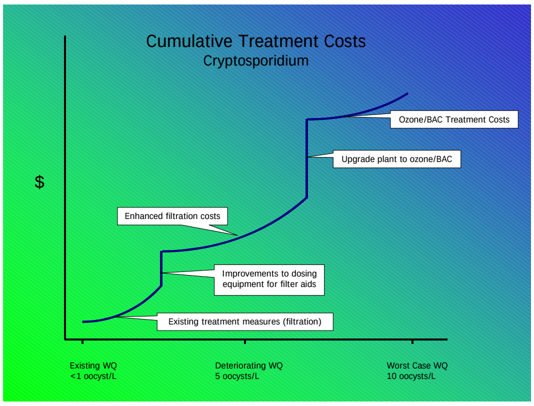


Figure 5Treatment Cost Function for a Dry Weather Water Quality Parameter (example)

Figure 5 shows that significant “steps” are likely due to capital infrastructure requirements and these would need to be valued by further investigations into the exact infrastructure required and the resultant expenditure necessary to construct and commission it.

5 CONCLUSIONS

The application of catchment modelling tools to gain better understanding of issues other than pollutant loads and water quality is possible; especially give the wealth of existing tools now available.

Using these tools, it has been possible to influence decision-making processes and gaining a better appreciation for the likely economic and environmental impacts of the implementation of management actions. Current emphasis on catchment management is to provide a more holistic analysis than the water quality benefits of management intervention. The modelling tools currently available could therefore be further developed to allow this type of analysis to be undertaken on a more regular basis and this is exemplified by the recent development of a life-cycle costing module for the MUSIC software.

The sensitivity of costing data, and therefore its availability and the ability to use it

6. ACKNOWLEDGMENTS

The assistance of Dr John Tisdell of Griffith University is greatly appreciated, especially in the analysis of treatment costs and their relationship to water quality parameters.

The supply of water quality and treatment cost data by Brisbane Water staff is also greatly appreciated, without which this project would not have been able to proceed.

Finally, the foresight of South East Queensland Water Corporation to examine this topic provided the necessary impetus and resources to allow the project to be undertaken.

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