The Importance of Retrofitting WSUD in Restoring Urbanised Catchments

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ABSTRACT

The application of Water Sensitive Urban Design (WSUD) in Australia has achieved the highest implementation rates in new urban developments, especially in the "greenfield" context. The majority of guidelines and fact sheets written to support WSUD implementation also tend to have a focus on new development. Recent assessments in the Botany Bay catchment in South Eastern Australia have shown that this may not be the most effective pathway in which to deliver sustained water quality and ecosystem health improvement as these new urban areas are not a major proportion of the overall urban land use in the catchment.

Recent water quality assessment in the Botany Bay region has focussed on catchment management practices and their ultimate impacts on receiving environments. This has been facilitated by coupling catchment models (including both MUSIC and E2/WaterCast modelling frameworks) with receiving water quality and ecosystem health models (DYRESM-ELCOM). This has allowed detailed assessments of the efficacy of various urban catchment management scenarios to be tested for likely improvements in receiving environments.

Through the analysis of both the catchment and receiving environment responses to each of the management scenarios, it has been clearly demonstrated that in order to achieve significant change in existing water quality, the implementation of WSUD must occur both through implementation on new developments (in both greenfield and brownfield contexts), but most importantly, through retrofitting WSUD technologies in existing urban areas. This paper also examines the likely effectiveness of several WSUD options suitable for the retrofit context, such as street scale biofiltration systems, raingardens, rainwater and stormwater harvesting and infiltration systems and suggests that an approach that considers both the treatment and reuse of stormwater is an appropriate methodology for achieving maximum benefits in the retrofit context

KEYWORDS

Development, greenfield, modelling, retrofit, Water Sensitive Urban Design

INTRODUCTION

Water Sensitive Urban Design (WSUD) has been in the water quality lexicon for around twenty years. Within this time there has been some reasonable adoption of WSUD in new developments with considerable efforts being made in the development of guidance documents and planning schemes and the adoption rate is rapidly increasing in this area. The recognition of the value of WSUD has been brought about by better understanding of the technologies through dedicated research undertaken by range of agencies across the country.

Botany Bay is one of Australia's iconic waterways with significant historical, cultural, economic and ecological attributes that require active management to ensure that they are preserved and enhanced for the future. The Sydney Metropolitan Catchment Management Authority (SMCMA) has undertaken the development of a better predictive capability for the Botany Bay catchment and receiving waters to provide information and decision support to assist in achieving this.

The use of predictive tools to estimate the effects of land use change and management has increased over the last several years with the development of catchment modelling tools through the former CRC for Catchment Hydrology and its successor, the eWater CRC. These tools, once they are developed and calibrated, allow for reliable assessments of the impacts of land use change, best management practices (e.g. Water Sensitive Urban Design, riparian buffers etc), climate variability and climate change on catchment response in terms of constituent loads and runoff.

Within the Botany Bay catchments, the WaterCAST modelling framework, coupled to a receiving water quality model was applied to simulate a range of catchment land uses, including rural lands, urban residential areas, commercial, industrial and special use zones (e.g. airports) and significant parklands and areas of native vegetation. In addition, MUSIC modelling was conducted to simulate the performance of both greenfield and retrofit WSUD measures, at varying rates of implementation. The analysis of these results showed the importance of retrofitting WSUD in delivering substantial reductions in pollutant loads into the receiving waters of Botany Bay.

METHODS

The assessment of the contributions of pollutants from existing urban and greenfield development (when fully developed) areas was undertaken using a combination of local and broad scale assessments facilitated by two catchment modelling tools. The results of the local scale assessments were used to provide inputs into the broad scale catchment model, so as to assess the effectiveness of using WSUD in either or both areas on the whole of river basin. The methodology below summarises the approaches used in two recent applications to assess retrofit and greenfield WSUD applications in NSW. Ideally, the actual locations modelled would have been presented, however there are sensitivities regarding the results and their implications in a political context which have yet to be resolved, hence the localities are only given in general terms.

Precinct Scale WSUD modelling

Modelling of the performance of WSUD efficacy at the local (precinct) scale was undertaken using the Model for Urban Stormwater Improvement Conceptualisation, or MUSIC (Fletcher *et al*, 2001). This software tool was developed by the former Cooperative Research Centre for Catchment Hydrology and uses hydrologic and water quality algorithms to predict the performance of a range of user-configured sources and WSUD treatment nodes, joined through links which can also be configured to represent routing of flows through a drainage network. An example of a MUSIC model used in this assessment is shown below.

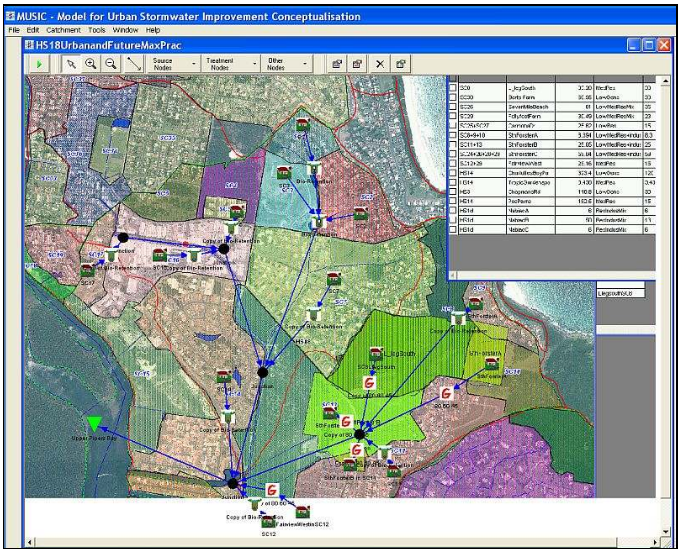

Figure 1 **MUSIC Model of an Urban Catchment in Coastal NSW**

MUSIC allows the determination of flows, total suspended solids (TSS), total nitrogen (TN), total phosphorus (TP) and gross pollutants. Other pollutants/constituents can be simulated using one of the above constituents as a surrogate and manipulating the pollutant export parameters accordingly, however care must be taken in the treatment performance of pollutants other than those used in the model as the removal of these can vary markedly.

Existing Urban Areas. The implementation of WSUD into existing areas usually occurs via two pathways, as part of a dedicated retrofit program, or through redevelopment. The latter is covered by planning regulations for all developments (in both greenfield and existing areas), and the rate of development can be quantified from the number of development applications processed in those existing areas. Recent analysis of a typical regional centre in coastal NSW using this method suggests this redevelopment rate was approximately 0.9% over the last 5 years, though other anecdotal evidence from discussions with planning officers has suggested rates as high as 2% in areas under development pressure. Given that these redevelopments are covered by planning regulations, the performance of these was quantified by assuming compliance with the planning regulations, and thus achievement of the water quality targets (usually pollutant load reduction objectives) required by the regulations. The redevelopment rate was assumed to be linear and predictions of the resultant pollutant load reductions from WSUD implementation in redevelopment was estimated after a given time period or planning horizon, typically 30 years. Results of this redevelopment reduction are then combined with an assessment of retrofitting WSUD technologies.

To quantify the performance of retrofit programs, areas available for retrofitting WSUD into existing urban areas were determined. Using Geographical Information System (GIS) analysis of aerial photography, digital terrain models, drainage networks and existing land uses, potential locations for treatment measures were identified, though it was been found that it was critical to follow this by ground-truthing in conjunction with those responsible to implement retrofit options, usually local government agency staff. The final locations and measures suitable for those locations were then identified and used as inputs into MUSIC modelling. The types of WSUD retrofit measures used for the assessments were based on successful applications in other areas of Australia.

The modelling of redevelopment areas was also undertaken using the MUSIC urban stormwater quality modelling tool. Several examples of current redevelopment configurations were examined and water quality management measures placed within each of them to achieve pollutant load reductions. The measures used were also reviewed by development industry representatives and local government agency staff to ensure that the proposed measures were feasible, cost-effective and practical to implement. From this, it was determined that the measures were able to achieve the best practice pollutant load reduction targets nominated within the region of 80% total suspended solids , 45% total phosphorus and 45% total nitrogen reductions from the developed case with no mitigation measures. As such, the extent of redevelopment became the determining factor in the magnitude of pollutant load reductions expected and was assessed as discussed above.

To determine the actual pollutant load reductions achieved, a span of analysis of 30 years was assumed, and a constant redevelopment rate applied over that 30 years. From this, a total area of redevelopment was expected to be approximately 27% of the existing urban area, and that the areas of redevelopment would achieve the required pollutant load reduction targets mentioned above.

Whole of Catchment Modelling

Broad scale modelling of the contributions of urban, rural and forested land uses was undertaken using the E2/WaterCAST catchment modelling framework (Argent et al 2005). The use of catchment decision support tools has been facilitated greatly through the availability of modelling tools provided by the former CRC for Catchment Hydrology and the current eWater CRC through the Catchment Modelling Toolkit (see www.toolkit.net.au). The tools available on the toolkit website allow a catchment modeller to define catchments, calibrate hydrology and develop simulations of catchment responses.

In order to provide the ability to simulate current catchment characteristics and responses, in addition to evaluating impacts of land use change and the implementation of best management practices, the WaterCAST modelling framework was chosen as the most appropriate tool for application in Botany Bay. The WaterCAST framework is not one model, but a framework in which groups of different models can be selected and linked such that the most suitable model to describe a particular aspect of the catchment can be used.

To construct a catchment model within WaterCAST therefore requires the user to define which model components are required and how they should be linked together. The underlying data within the model is some spatial description of the catchment, whether simply a subcatchment map, or a digital elevation model. These are then joined together via a node-link network, which is then parameterised and calibrated to complete the catchment model. A screenshot of the Botany Bay WaterCAST model is shown below.

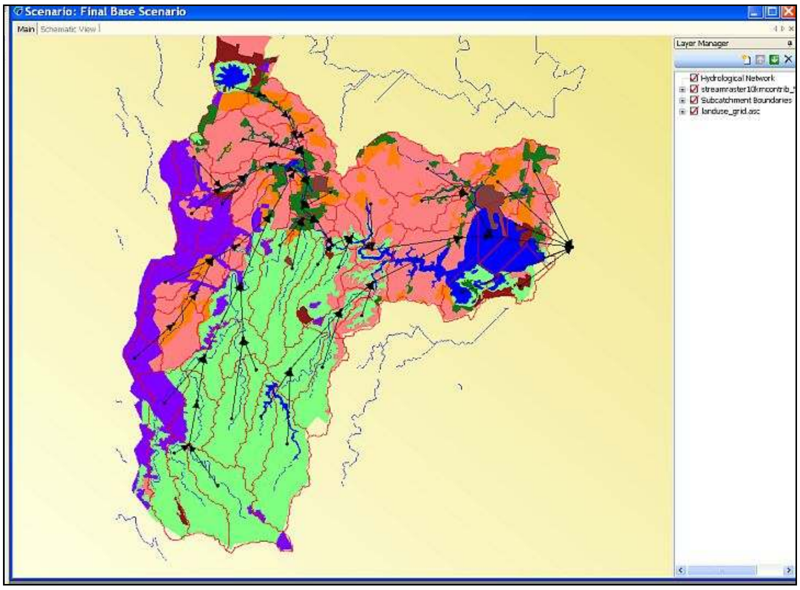

Figure 2 **WaterCAST Catchment Model of Botany**

Model Linkage

The linkage of both models occurs via extraction of a time series of daily flows and loads from MUSIC and importing those to represent specific urban land use areas in the WaterCAST catchment model. Alternatively, for larger subcatchments or those areas where there is a mix of land uses, predictions regarding pollutant load reductions through the implementation of urban retrofit measures are made using the MUSIC model in the first instance. Once this modeling is completed, the resultant load reductions are used as a “filter” of pollutant loads for urban land uses in particular subcatchments where retrofit measures are to be applied. This has the advantage of being readily modified if alternative retrofit schemes are trialed.

RESULTS

Within the Botany Bay catchment, an assessment of several different scenarios was conducted to evaluate the comparative efficacy of several different WSUD applications in greenfield, retrofit and redevelopment contexts. These results were also compared to existing land use loads, and those likely to be consistent with pre-European settlement. The latter scenario loads were predicted through consideration that the entire catchment was likely to have been heavily vegetated which is consistent with the woody vegetation dataset derived for pre-European settlement (Carnahan 1990). The final results are shown in Table 1.

The results were obtained from extracting the results of the local scale assessments completed through the MUSIC model, with the pollutant load reductions attributed to each WSUD application scenario then applied within the WaterCAST model. The annual loads for a 21 year climate time series (1986-2006) were extracted from the model and mean annual loads calculated after discarding the first year of results to allow for model warmup.

Table 1 Results of Scenario Analyses – This table outlines the results of assessing WSUD efficacy in several application contexts with comparison to existing land use pollutant loads and pre-European development loads.

Scenario	TSS (t/yr)	TN (t/yr)	TP (t/yr)	TSS % reduction	TN % reduction	TP % reduction
Predevelopment	7600	180	16			
Existing	22200	377	42			
Future with Greenfield	25900	423	48			
Future - Greenfield WSUD only	25600	420	47.2	1.0%	0.8%	1.7%
Future - Retrofit WSUD only	15400	349	33.2	40%	17%	31%
Future - Redevelopment WSUD only	21200	391	42.2	18%	8%	12%
Future - Retrofit and Redevelopment	10800	318	27.4	58%	25%	43%
Future - WSUD all areas	10600	314	26.6	59%	26%	45%

The above results are also presented visually below for TSS, TN and TP.

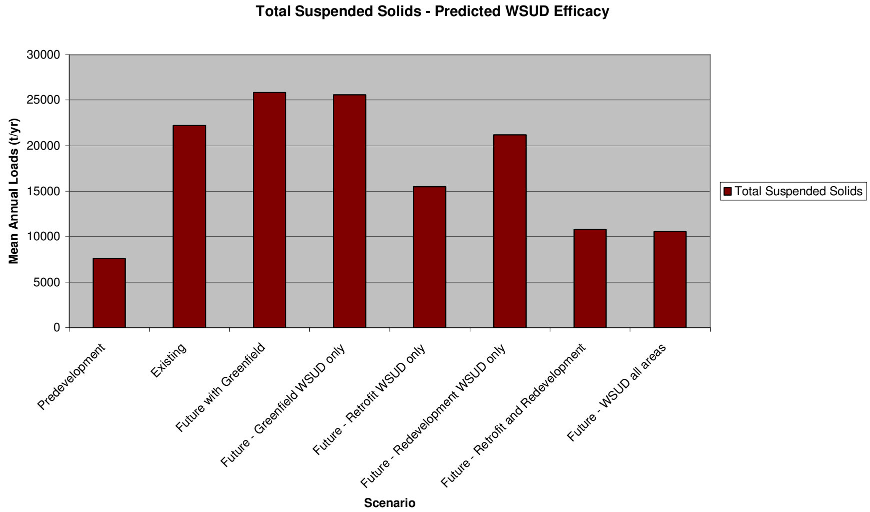

Figure 3 **Total Suspended Solids WSUD Efficacy**

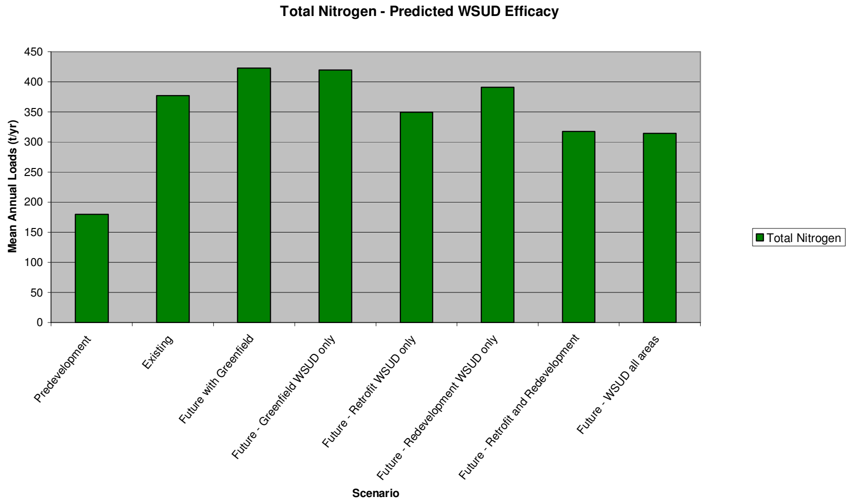

Figure 4 **Total Nitrogen WSUD Efficacy**

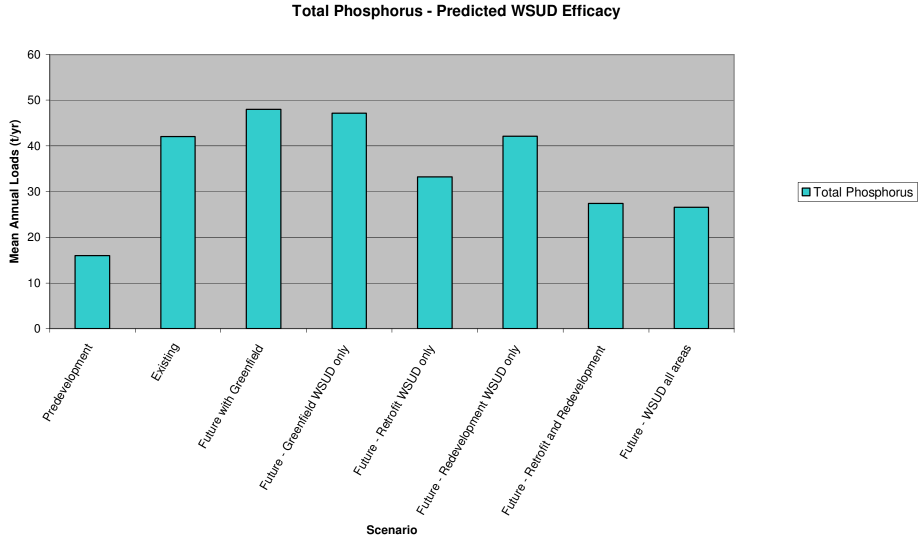

Figure 5 **Total Phosphorus WSUD Efficacy**

It can be seen from the above that WSUD is most effective at TSS removal and to a lesser extent TP, while TN removal is considered to be moderate. This is consistent both with the quality of stormwater inflows as predicted by the MUSIC model as based on stormwater quality monitoring data across Australia (Fletcher et al 2004), where TP is strongly correlated with particulate matter, hence treatment measures effective at TSS removal will also show high TP removals. The removal of TN is a function both of the TN associated with particulate matter (e.g. leaf litter etc), but also soluble uptake by biological components of the treatment system. Recent studies by the Facility for Advancing Water Biofiltration (FAWB, 2007) have shown the effectiveness of biological filtration systems, commonly referred to as biofiltration, bioretention or rain garden systems, in nutrient removal, confirming theoretical and monitored predictions from early research into these measures in Australia.

It is obvious from the above results that WSUD application in both the retrofit and redevelopment contexts is likely to result in the largest pollutant load reductions and this is simply a reflection of the spatial coverage of implementation. In current major capital cities across Australia, greenfield developments usually account for a minor increase in urban land use within a catchment, while the overall urban land use is substantial. Within the catchments of South East Queensland, this greenfield increase accounted for a 3% increase in urban land use within the catchments of Moreton Bay, whereas the total urban land use for the catchment was 11% (Weber and Chandler, 2003). In heavily urbanised catchments such as those around the major capital cities, the area for greenfield development is reducing or is moving outside of existing catchment boundaries. As such, the majority of development is redeveloping existing areas leading to densification of existing urban lands. In the context of the Botany Bay catchment, the estimate of greenfield development within the catchment was likely to lead to a 1% increase in urban land use within the catchment, however redevelopment was predicted as affecting at least 27% of the overall urban land use, both within a 30 year planning horizon. In addition to the redevelopment, it was estimated that the retrofit of WSUD measures was likely to treat between 40-50% of the existing urban lands. For this reason, the spatial extent of WSUD application in the retrofit and redevelopment context far outweighs that achievable in greenfield lands in the scenarios modeled, and hence retrofit and redevelopment WSUD application has a much higher efficacy. It must be realised that the efficacy of individual WSUD measures was considered identical in any of the application scenarios, hence the spatial extent becomes the determining factor for overall efficacy.

While the above results are of interest in showing pollutant load reductions, the results of the WaterCAST and MUSIC model outputs have been used as boundary conditions for receiving water quality and ecosystem health models. The linkage of the catchment and receiving water quality models allows the estimate of ecosystem health change in the receiving environment as a result of the application of any of the above scenarios and has been very beneficial in developing strategic actions for the protection of those receiving waters.

DISCUSSION

From the results shown in the previous section, it is quite obvious that far greater pollutant load reductions are achievable when WSUD is retrofitted into existing urban areas and/or made mandatory in any redevelopment of those areas. Current guidelines for WSUD design and application in Australia (Melbourne Water, 2005, SEQ Healthy Waterways Partnership, 2006) focuses on its application in greenfield contexts and few guidance documents are available that specifically show application in the retrofit context. While the guidance documents tend to have a greenfield development focus, the techniques and design requirements are readily adaptable to the retrofit context, if further consideration of the implementation issues is considered.

The application of WSUD in the greenfield context also will not lead to significant change in receiving water quality and is of no benefit to those areas where water quality is already an issue. In some areas, the focus of water quality objectives around a “no worsening” target which aims to prevent increase of pollutant loads is certainly one that may be achievable through greenfield WSUD retrofit, however those receiving environments already under stress require the management of existing water quality and pollutants associated with stormwater runoff. Given the benefits shown above for WSUD retrofit, it therefore implies that this WSUD implementation pathway is the one that may be most beneficial for already stressed waterways.

CONCLUSIONS

This paper has showed that retrofit and redevelopment WSUD applications can lead to the largest reductions in pollutant loads to receiving waters in the scenarios evaluated. It shows that while greenfield WSUD application can have benefits, they are usually minor, and are a reflection of the spatial extent of WSUD implementation in existing and future urban areas. The paper highlights the benefits of using predictive catchment modeling tools such as MUSIC and E2/WaterCAST in determining the overall efficacy of several water quality management scenarios and also has discussed the linkage of these catchment tools to receiving environment modeling tools, finally bridging the gap between predicting catchment management efficacy on ecosystem health response.

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