A TOOL FOR EVALUATING STORMWATER MANAGEMENT OUTCOMES ACROSS THE FOUR WELLBEINGS

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ABSTRACT

A sustainable development approach to stormwater management involves taking into account the social, economic, and cultural wellbeing of people and communities as well as maintaining and enhancing the quality of the environment. In order to support this approach, a pilot decision support system (DSS) has been developed which evaluates stormwater management outcomes for receiving water bodies by predicting indicators for the four wellbeings. Inputs representing alternative catchment-scale stormwater management scenarios drive models which predict changes in water and sediment quality and indicators of ecosystem health in rivers and estuaries, providing a measure of environmental wellbeing. These environmental indicators are in turn used to evaluate effects on the ways in which people and communities interact with the water bodies, expressed as indicators of social wellbeing and the economic benefits arising from a given stormwater management scenario. These benefits are combined with the results of a costing model to give an assessment of changes in economic wellbeing. The development of a pilot DSS has involved assembling, linking and testing these various methods. Further research aims to extend the pilot DSS to include indicators of cultural well-being.

KEYWORDS

Stormwater management; urban development; decision support system; environmental, economic, social and cultural wellbeing; indicators.

PRESENTER PROFILE

Jonathan Moores is Group Manager of NIWA's Urban Aquatic Environments Group. He leads research on stormwater quality and its effects on receiving waterbodies, including predictive modeling studies and field-based investigations characterising stormwater quality and treatment device performance. He has previous regulatory, policy development and public liaison experience working in local government.

1 INTRODUCTION

The Urban Planning that Sustains Waterbodies (UPSW) research project aims to help local government in New Zealand plan the sustainable development of the country's cities and settlements in a way which protects and enhances the values and services associated with urban waterbodies. The project is part of a wider multi-institutional and multi-disciplinary collaboration, the ‘Resilient Urban Futures’ research programme, funded by the Ministry of Business, Innovation and Employment (MBIE) over the four-year period October 2012 to September 2016.

The UPSW project involves the development of a pilot decision support system (DSS) that allows urban planners and stormwater managers to consider holistically the impacts of urban development on indicators of environmental, social, economic and cultural wellbeing. In this paper we provide an overview of the background to the development of the pilot DSS, describe how the effects of urban development are felt across the four wellbeings and summarise the design and use of the pilot DSS.

2 BACKGROUND

New Zealand’s cities were established next to streams, rivers and harbours. As a consequence, urban New Zealanders have a strong economic, social and cultural connection with natural water bodies, making extensive use of them for recreation, industry, transport, fishing, trade and tourism. Auckland’s Waitemata Harbour, for instance, is an iconic waterbody that contributes strongly to the identity of the country’s largest city.

However, there is substantial evidence that urban development is harming the very water bodies beside which New Zealand’s cities were founded. Urbanisation has resulted in the expansion of the built environment along riparian and coastal margins and the use of streams and estuaries for the disposal of urban stormwater. Parts of Auckland’s harbours, for instance, have suffered from increased rates of sedimentation, toxic metal accumulation, reduced ecological health and a growing unsuitability for recreation and the harvesting of shellfish (ARC, 2010).

Unless alternative, sustainable forms of urban development and stormwater management can be found, the impacts of historic urbanisation are likely to be exacerbated by continued urban growth. Auckland’s population is projected to increase from its current 1.5 million to between 1.8 and 2.5 million by 2041, requiring the construction of up to 400,000 new dwellings (Auckland Council, 2012). The pressure of population growth co-exists with a demand from communities for improvements in water quality, an aspiration which has been recognised through the legislation of the National Policy Statement for Freshwater Management (NZ Government, 2011).

In recent years, local government in Auckland has facilitated consultative processes aimed at informing the planning of urban development into the middle of the 21st century. The results of these processes, the Auckland Regional Growth Strategy (ARGF, 1999) and the Auckland Plan (Auckland Council, 2012), propose a strategy for urban development over the next 30-40 years. In general, the strategy favours a compact city form rather than the continued expansion of the urban footprint. This reflects, among other things, a view that a compact form will help to minimise environmental impacts, including those associated with the discharge of urban stormwater to receiving waterbodies (Auckland Council, 2012).

However, while there is a wealth of evidence of the historical impact of urban development (ARC, 2010), there has been little quantitative analysis of the extent to which alternative forms of urban development may contribute to improved outcomes for urban water bodies. Trends in harbour sediment quality in Auckland’s Waitemata and Manukau Harbours over the 21st century have been projected for alternative stormwater management approaches but not for variations in the footprint of urban development (Green et al., 2010). Nor have there been the tools available to demonstrate and quantify the linkages between alternative forms of urban development and potential benefits for receiving waterbodies. While there are a range of existing DSSs available for urban water quality management, these generally provide guidance on the selection, design and performance of stormwater management infrastructure (Shoemaker et al., 2009; Ellis et al., 2006; Viavattene et al., 2008; and Makropolous et al., 2008) rather than allowing the evaluation of the impacts of alternative urban development scenarios on receiving waterbodies. It is this gap and its significance for the planning of sustainable forms of urban development that provided the motivation for the development of the pilot DSS.

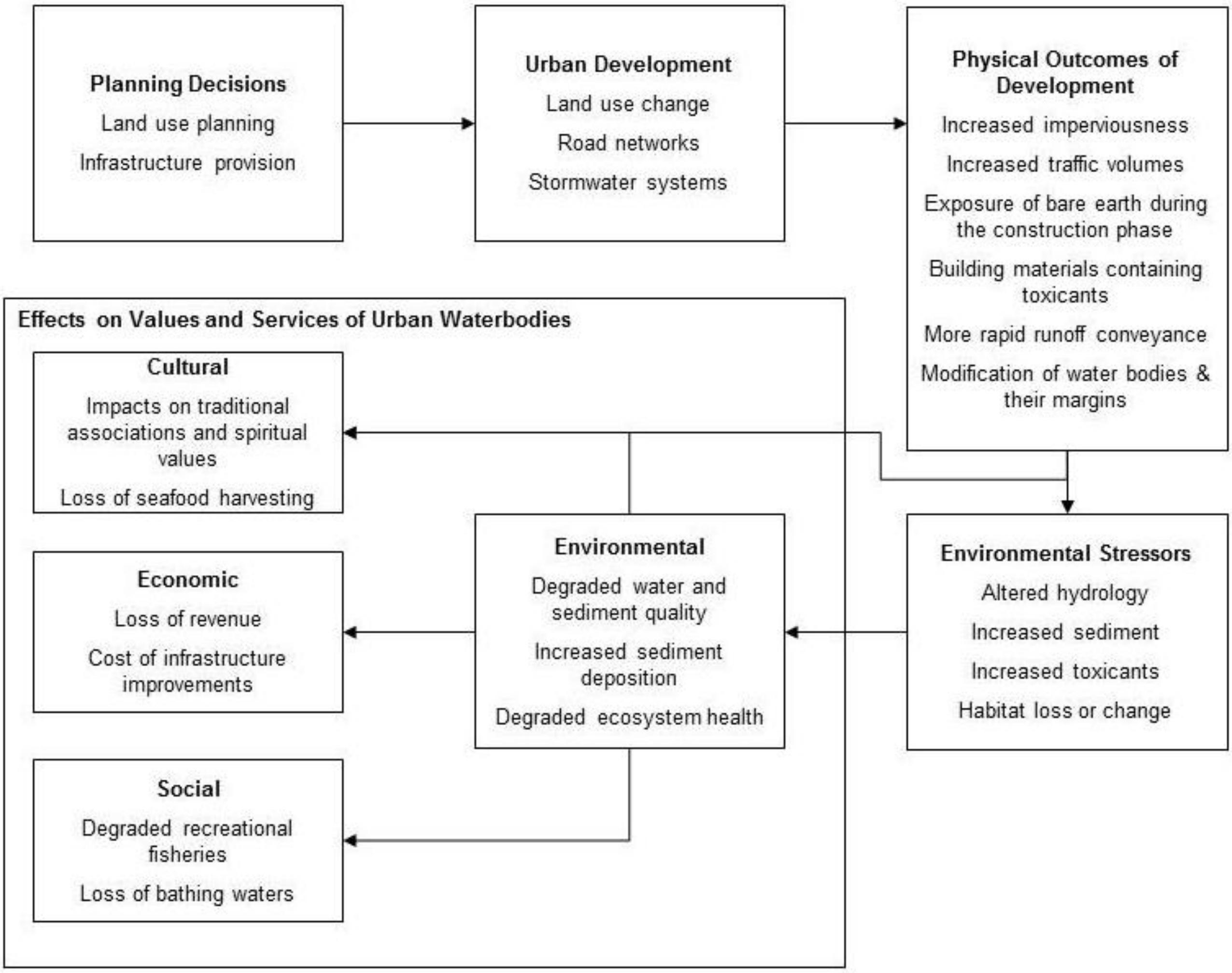
3 FOUR WELLBEINGS APPROACH

Figure 1 represents a four wellbeings approach to understanding the ways in which the values and services of waterbodies can be affected by urban development. Guided by planning decisions, urban development involves changes in land use, road networks and infrastructure for managing urban stormwater runoff. Many of the physical outcomes resulting from these changes have the potential to generate environmental stressors. Increased imperviousness alters the hydrological characteristics of stream and rivers by increasing stream peak flows and reducing stream baseflows (Butler and Davis, 2009). The exposure of areas of bare earth during construction can result in increased generation of sediment (Wolman and Schick, 1967). Increased traffic volumes and the use of certain building materials result in the generation of increased quantities of toxicants such as heavy metals (Göbel et al., 2007). The collection and conveyance of runoff via reticulated stormwater pipe networks exacerbates the effects of increased imperviousness on hydrology and provides a pathway for the discharge of sediments and contaminants to receiving waterbodies (Butler and Davis, 2009). Modification of waterbodies and their margins, such as the piping and channelizing of streams, can result in a change or loss of aquatic habitat (Riley, 1998).

The end-point of this process is the interaction of the various stressors with the values and services of receiving waterbodies. These interactions can be direct or indirect and can be of significance for environmental, economic, social and/or cultural wellbeing. Direct environmental effects include: increased rates of stream erosion; elevated metal concentrations in stream water; increased rates of sediment accumulation and increased sediment metal concentrations in estuaries and harbours; and reduced freshwater and marine ecosystem health, for instance the loss of sensitive macroinvertebrate and fish species in urban streams (Abrahim and Parker, 2002; Hammer, 1972; Paul and Meyer, 2001; Suren and Elliott, 2004).

Social and economic effects are indirect, resulting from changes in environmental quality. Impacts on social wellbeing can include the deterioration of recreational fisheries or reduced opportunities for contact recreation as a result of water quality degradation (Brown and Clarke, 2007; Van Houten et al., 2007). Deterioration in environmental quality can also have an economic impact, for example through the loss of related commercial or tourism-related revenue or, alternatively, in terms of the costs of infrastructure improvements required for the avoidance of mitigation of these effects (Visitacion et al., 2009). Effects on the cultural values and services of waterbodies can be both direct and indirect. For Māori, a significant example of a direct effect is the denigration or loss of the spiritual value or *mauri* of water resulting from any inappropriate use or modification (Ministry for the Environment, 2005). On the other hand, the reduction or loss of opportunities to collect seafood (*kaimoana*) is an indirect effect, which can result from increased sedimentation and contamination in areas of traditional shellfish harvesting.

Figure 1: Four wellbeings approach to understanding the effects of urban development on the values and services of water bodies. Examples to illustrate these relationships are shown.



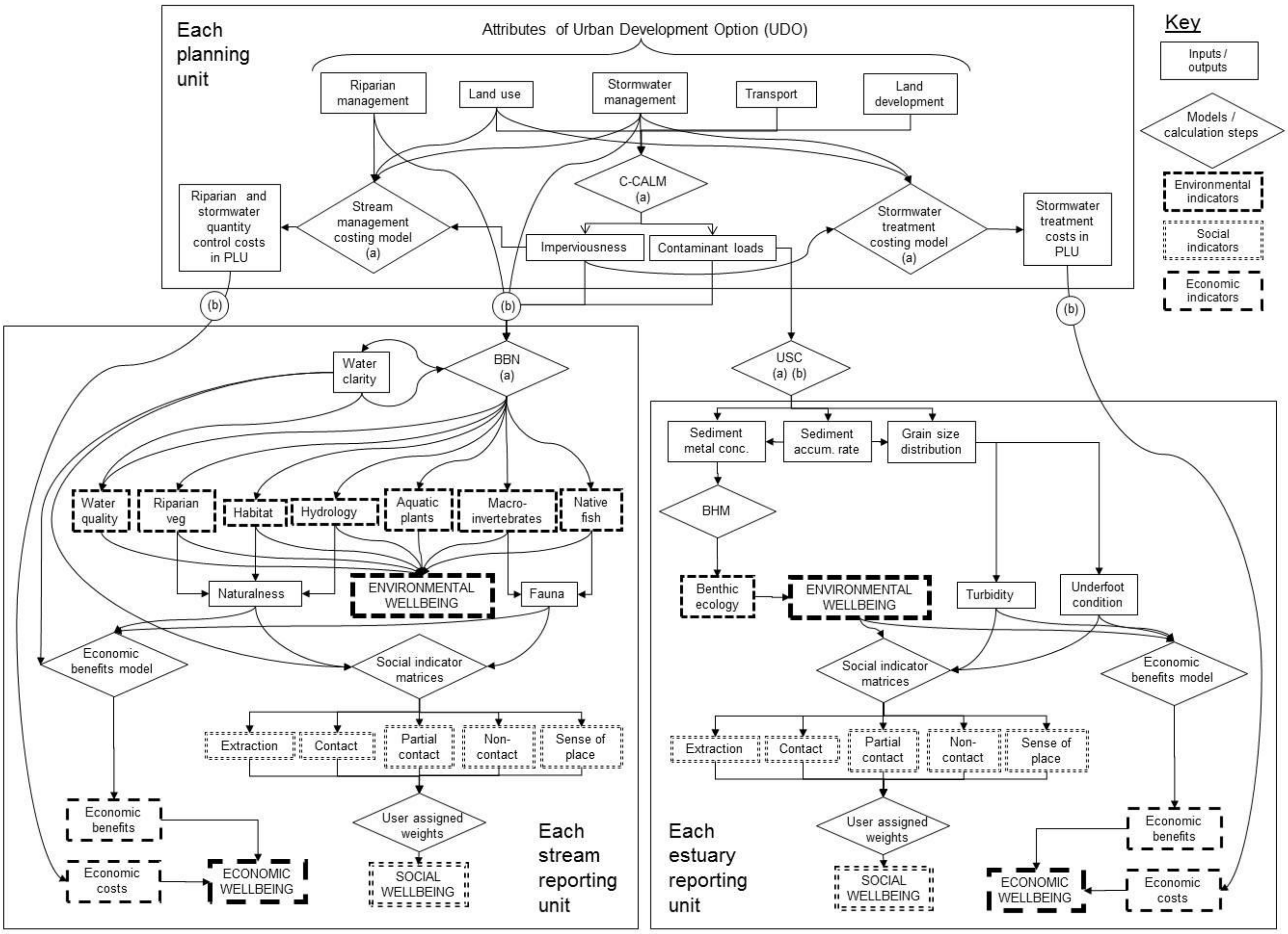
4 THE PILOT DSS

4.1 DESIGN

There are three novel aspects to the design of the pilot DSS. Firstly, it incorporates indicators of environmental, economic and social wellbeing, reflecting the approach outlined above. An aim of its further development is to also incorporate indicators of cultural wellbeing. Secondly, it links a number of distinct models and other methods in order to make predictions of outcomes under alternative urban development and stormwater management scenarios. These methods include: deterministic models; a probabilistic model; non-market valuation methods; look-up tables populated through expert elicitation techniques; and index construction. Thirdly, while a number of the methods have been appropriated from existing stand-alone applications, others have been developed specifically for incorporation in the pilot DSS. These include a model for estimating the costs of catchment-scale stormwater management, a stream ecosystem health model and a method for predicting social wellbeing indicators from environmental precursor attributes.

The pilot DSS operates as a single entity executed in MS Excel, which calls on each of the several constituent methods in a logical sequence (Figure 2). The inputs to the system are the characteristics of 'urban development options', specified for each of several 'planning units' within a study area. The outputs from the system are indicators of environmental, economic and social wellbeing, provided for each 'reporting unit' within the study area. Typically, each planning unit corresponds to a stream catchment and contains a single stream reporting unit. The estuarine environment to which these streams discharge is divided up into a number of estuary reporting units, each of which is representative of relatively homogeneous bed-sediment characteristics and sediment dynamics.

Figure 2: Structure of the pilot DSS



Alternative urban development options are represented in terms of their land use, land development controls, transport characteristics, stormwater management and riparian (stream bank) management characteristics. These attributes drive a suite of environmental models which predict changes in water and sediment quality and indicators of ecosystem health in rivers and estuaries, and are also used to estimate the costs of stormwater and stream management. The environmental models are:

- A modified version of the Catchment Contaminant Annual Loads Model (C-CALM), which makes predictions of the level of imperviousness and annual loads of sediments, copper, lead and zinc for each year of the study timeframe (Moores and Semadeni-Davies, 2011);

- A Bayesian Belief Network (BBN), which makes predictions of seven indicators of stream ecosystem health based on inputs relating to: riparian and stormwater management characteristics, level of imperviousness and contaminant loads predicted by C-CALM, and various stream characteristics established as part of implementing the system (Gadd and Storey, 2012);

- A modified version of the Urban Stormwater Contaminants (USC) model (Green, et al., 2010) , which makes annual predictions over the study timeframe of estuary bed sediment concentrations of copper, lead and zinc, sediment accumulation rates and sediment grain size distribution based on inputs of the contaminant loads predicted by C-CALM and various estuary characteristics established as part of implementing the system; and

- The Benthic Health Model (BHM; Anderson et al., 2006), which predicts a benthic health indicator score from inputs of the estuary bed sediment concentrations of copper, lead and zinc predicted by the USC model.

The economic costing models are:

- A catchment-scale stormwater treatment costing model, which makes predictions of the life-cycle costs of stormwater treatment over the study timeframe based on inputs relating to the extent and desired level of performance of treatment, land use and the level of imperviousness (Ira et al., 2012); and

- A catchment-scale stream management costing model, which makes predictions of the life-cycle costs of riparian management and stormwater quantity control over the study timeframe based on inputs relating to the extent and quality of riparian planting and maintenance, land use and level of imperviousness.

Outputs from the environmental models are used to derive the scores for the economic benefit indicators. The economic benefits models were developed through a technique referred to as benefit transfer in which the results of previous research described in Kerr and Sharp (2003) and Batstone et al. (2008) are applied to the pilot DSS. There are two economic benefits models, one each for streams and estuaries:

- The stream model makes predictions of the monetised environmental benefits of an urban development option based on the change over the study timeframe in water clarity (as predicted by the BBN) and ‘naturalness’ and ‘fauna’ (based on combinations of indicators predicted by the BBN); and

- The estuary model makes predictions of the monetised environmental benefits of an urban development option based on the change over the study timeframe in environmental wellbeing, turbidity and underfoot condition (the latter two being derived from sediment grain size distribution predicted by the USC model).

In addition to informing the economic benefits models, outputs from the environmental models are also used to derive scores of the social indicators, which are also predicted separately for streams and estuaries. These scores are generated by a set of social indicator matrices, which act as look-up tables for the prediction of four classes of recreation (extraction, contact, partial contact and non-contact) one non-use value (‘sense of place’). The look-up tables are populated with scores ascribed by focus group participants to combinations of the same inputs used by the economic benefits models.

4.2 USING THE PILOT DSS

The first step in using the pilot DSS is to implement it, or set it up, for a given study area. This involves defining:

- the number and size of planning units (or stormwater management catchments) and reporting units (i.e. streams and estuaries) that make up the study area;
- the baseline year and the year for which indicators are to be reported;
- baseline land use, stormwater management and other characteristics of the planning units;
- baseline characteristics of streams in the study area, such as slope, length and substrate;
- baseline characteristics of estuaries in the study area, such as their size, bed sediment particle size distribution and bed sediment metal concentrations; and
- relationships between planning units and reporting units, for instance specifying how the contaminant load generated in a particular subcatchment is distributed among several receiving estuaries.

Once implemented, the system is ready for use. Before entering an urban development scenario, the user can choose to set indicator targets to provide a benchmark against which the results of any scenario can be compared. The user also has the option of assigning weights to social indicators. These weights are used in the calculation of social wellbeing from the scores of the five individual social indicators and provide an opportunity for more importance to be placed on some social indicators than others. For example, it might be the case that a particular stream is seldom used for swimming but walking tracks along its banks are in frequent use. In that case, a higher weight could be assigned to ‘non-contact recreation’ than to ‘contact recreation’ in calculating the social wellbeing score. The weights for each indicator are assigned by the user of the pilot DSS using a method known as an analytical hierarchy process (Saaty, 1987). The method involves comparing pairs of indicators at a time and making a judgement as to their relative importance. An overall weight for each indicator is calculated once all pairs have been compared.

The user runs the system by entering an urban development option for each planning unit in the study area. This involves specifying (see Table 1):

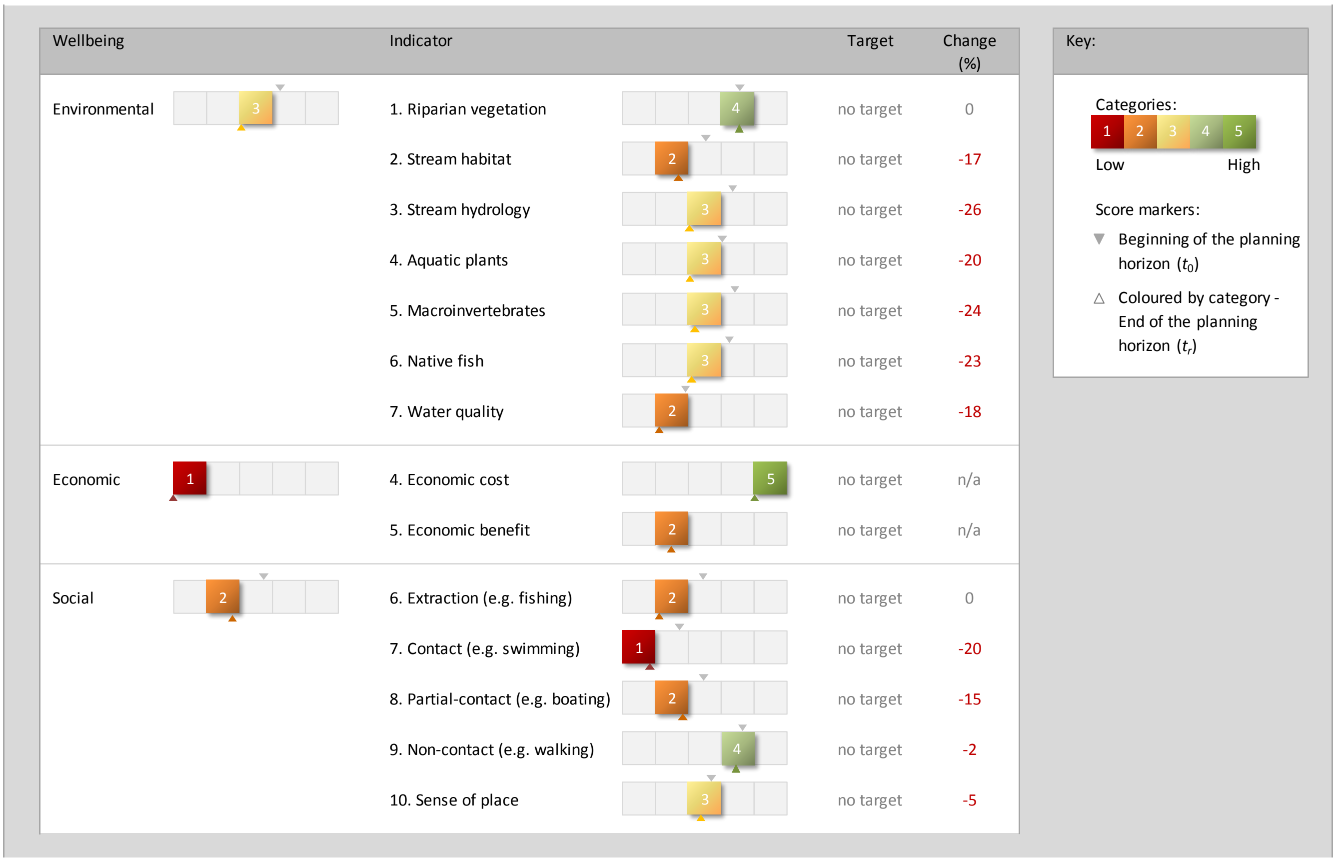
- the time to the start and end of the development phase;
- the development phasing;
- the proportion of the planning unit in each land-use category;
- stormwater treatment characteristics;
- characteristics of earthworks controls associated with land development;
- the rate of change in vehicle numbers; and
- the characteristics of riparian management.

Table 1: Characteristics of Urban Development Options

	Characteristic	Specified as:
Development period characteristics	Time to start of development (T_s)	Time in years in the range 0 to (T_r - 1) where T_r is the reporting time set at implementation
	Time to end of development (T_d)	Time in years in the range (T_s + 1) to T_r
	Development phasing option	Continuous, phased or stepwise (rate of change in land use over the development period)
Land use	Land use sub-category	0-100% of planning unit in each of the following sub-categories: • Rural: pasture, exotic forest, native forest, horticulture • Residential: low density, medium density, high density, CBD, residential LID • Commercial: suburban, commercial CBD, commercial LID • Industrial: traditional industrial, industrial LID • Major roads: three categories based on traffic numbers
	Roof runoff source control	Yes or no - where “yes” results in the replacement of high zinc-yielding roofing types (i.e., unpainted or poorly painted galvanised steel) in a particular land use type by low zinc-yielding roof types (equivalent to painting roofs)
Methods of land development	Bulk earthworks target TSS removal	0, 25, 75 or 90% (removal of earthworks-generated sediment associated with greenfield land development)
	Other earthworks target TSS removal	0, 25, 75 or 90% (removal of earthworks-generated sediment associated with infill land development)
Transport characteristics	Target change in vehicles per day	% change over period of development
	Direction of change	Increase or decrease
Stormwater management	Target TSS removal	0, 25, 50, 75 or 90% (removal of sediment)
	Effectiveness on other contaminants	Low, medium or high (removal of copper, lead and zinc)
Stream management	Extent of managed riparian vegetation	0-100% of stream length
	Width	Wide or narrow
	Extent of unmanaged riparian vegetation	0-100% of stream length

Once the urban development options for all planning units in the study area have been entered, the pilot DSS runs by calling on the constituent models in sequence. While the pilot DSS reports numeric values (scores) of all indicators, it also assigns an indicator ‘level,’ in order to allow communication of predictions to technical and non-technical audiences, respectively (Figure 3). There are five levels, each of which corresponds to a quintile (20%) of the range of indicator scores. The system adopts a traffic light approach to representing the indicator levels, with the highest level coloured green and the lowest level coloured red. The reporting of results also includes comparison of pre- and post-development indicator scores.

Figure 3: Example of predicted indicator levels for a stream reporting unit



Wellbeing		Indicator		Target	Change (%)
Environmental	3	1. Riparian vegetation	4	no target	0
		2. Stream habitat	2	no target	-17
		3. Stream hydrology	3	no target	-26
		4. Aquatic plants	3	no target	-20
		5. Macroinvertebrates	3	no target	-24
		6. Native fish	3	no target	-23
		7. Water quality	2	no target	-18
Economic	1	4. Economic cost	5	no target	n/a
		5. Economic benefit	2	no target	n/a
Social	2	6. Extraction (e.g. fishing)	2	no target	0
		7. Contact (e.g. swimming)	1	no target	-20
		8. Partial-contact (e.g. boating)	2	no target	-15
		9. Non-contact (e.g. walking)	4	no target	-2
		10. Sense of place	3	no target	-5

Key:

Categories:
1 2 3 4 5
Low High

Score markers:
▼ Beginning of the planning horizon (t_0)
△ Coloured by category - End of the planning horizon (t_r)

4.3 TESTING AND FURTHER DEVELOPMENT

The pilot DSS has been tested by implementing it for the Lucas Creek catchment on Auckland's North Shore. This case study involved, firstly, evaluating the performance of the pilot DSS at hindcasting the effects of historic urban development over the period 1960 to 2010 and, secondly, evaluating the performance of the pilot DSS for discriminating between outcomes under alternative future urban development scenarios over the period 2010 to 2060. A second case study is currently in progress with Auckland Council as part of assessments of future urban development scenarios being considered under the development of the Council's Unitary Plan.

As a result of these case studies, and in response to learnings gained as part of the broader development process, a number of tasks have been identified for the development of the DSS as an operational tool. These include further testing by conducting additional case studies, refinement of the existing methods, developing additional methods and enhancing the functionality and appearance of the system.

5 CONCLUSIONS

The continuing growth of New Zealand's urban population creates a tension between the need for further development and community aspirations to achieve better environmental outcomes in relation to the management of urban waterbodies. Within this context, this research has been motivated by the need for tools which support a four wellbeings approach to urban planning and stormwater management.

This paper has highlighted three novel aspects of this research: the prediction and combination of indicators of the environmental, economic, social and cultural wellbeing; the development of new methods for predicting certain of the indicators; and the linking of these and other appropriated models and methods to develop a pilot DSS. Further research aims to extend the pilot DSS to include indicators of cultural wellbeing and to develop the tool for operational use throughout New Zealand.

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