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Derivation of Economic and Social Indicators for a Spatial Decision Support System to Evaluate the Impacts of Urban Development on Water Bodies in New Zealand

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Abstract

There is mounting evidence that urban development in New Zealand has contributed to poor water quality and ecological degradation of coastal and fresh water receiving waters. As a consequence, local governments have identified the need for improved methods to guide decision making to achieve improved outcomes for those receiving waters. This paper reports progress on a research programme to develop a catchment-scale spatial decision-support system (SDSS) that will aid evaluation of the impacts of urban development on attributes such as water and sediment quality; ecosystem health; and economic, social and cultural values. The SDSS aims to express indicators of impacts on these values within a sustainability indexing system in order to allow local governments to consider them holistically over planning timeframes of several decades. The SDSS will use a combination of deterministic and probabilistic methods to, firstly, estimate changes to environmental stressors such as contaminant loads from different land use and stormwater management scenarios and, secondly, use these results and information from a range of other sources to generate indicator values. This paper describes the project's approach to the derivation of indicators of economic and social well being associated with the effects of urban storm water run-off on freshwater and estuarine receiving waters.

Introduction

Freshwater and coastal water bodies are an important feature of many New Zealand cities, providing opportunities for recreation, industry, transport, fishing, trade and tourism. However, there is substantial evidence that the expansion of the built environment and the modification and use of lakes, streams, rivers and estuaries for the disposal of urban runoff has contributed to poor water quality, ecological degradation and unsuitability of some water bodies for recreation. Examples of these impacts are evident in changes to the characteristics of water bodies associated with New Zealand's largest cities, Auckland and Christchurch.

More than half of sediment sampling sites in Auckland's Waitemata and Manukau Harbours contain heavy metals at concentrations considered moderate or high risk to the harbour ecosystems (Williamson and Kelly, 2003). Christchurch's Avon and Heathcote Rivers exceed guideline values for nutrient and microbiological contamination (PDP, 2007). Both cities are undergoing rapid population growth: over the past 50 years, Auckland's population has doubled to 1.3 million and Christchurch has grown by 70% to 390,000 (Statistics NZ, 2006), and this trend is continuing. Auckland's population is expected to reach 2.2 million by 2050 (ARGF, 1999) and Christchuch's to well over half a million by 2041 (GCUDF, 2007).

Population growth is likely to result in the continued outwards expansion of our cities. For example, Auckland's geographic footprint is projected to expand by 10% over the first half of this century (ARGF, 1999) despite a growing consensus that urban sprawl has a greater environmental impact than evolving alternatives such as the intensification of land use in established suburbs and inner city regeneration. Unless growth can be better managed, urban water bodies are likely to have their capacity to support ecosystem services compromised, reducing their ability to provide for the economic, social and cultural needs of urban communities.

Local government has identified a lack of methods and information to demonstrate and quantify the connectivity between alternative forms of development and improved outcomes for urban water bodies as being a critical barrier in the planning of sustainable cities. This paper reports progress in a NIWA – Cawthron Institute research collaboration called "Urban Planning that Sustains Waterbodies" (UPSW). Funded by the Ministry for Science and Innovation (MSI), the project aims to address this gap by developing a catchment-scale spatial decision-support system (SDSS).

The SDSS will aid evaluation of the impacts of urban development on attributes such as water and sediment quality; ecosystem health; and the associated changes to economic, social and cultural values. The impacts on these values will be reported using a sustainability indexing system. The SDSS will use a combination of deterministic and probabilistic methods to, firstly, estimate changes to environmental stressors such as

contaminant loads from different land use and stormwater management scenarios and, secondly, use these results and information from a range of other sources to generate indicator values that align with the four well-beings concept identified as reporting categories by the Local Government Act 2002.

This paper describes the development of a sustainability indexing system that provides a measure of integration of the four well-beings. While a complete assessment of the costs and benefits of alternate land use scenarios includes both terrestrial and marine effects, for reasons of tractability / feasibility this project focuses on the receiving water body ecosystems. The "boundary" of the analysis of receiving water body effects is the network of small streams and storm water management devices through which rainfall enters the fresh water, and in turn, estuarine ecosystems. While the research project's scope lies across the four wellbeing categories, this paper focuses on the development of indicators for the social and economic well-beings.

The balance of the paper is organised as follows. The next section, Spatial Decision Support Systems, discusses the conceptual design of the spatial decision support system, addressing the underlying methods that are proposed for the prediction of outputs (indicators) from inputs (urban development scenarios). Subsequent sections are devoted to the sustainability indexing system and the derivation of indicators of social and economic well-being.

Spatial Decision Support Systems

An SDSS is an interactive, spatially-distributed model designed to support decision-making for problems which are spatially variable. A key requirement of an SDSS is the ability to geo-visualise problems and possible solutions. This ability can improve communication between decision makers and other stakeholders. The components of an SDSS (e.g., Densham, 1991) are; a user interface; a geo-spatial database; the ability to represent complex spatial relationships; a set of models that can query the database to forecast the outcomes of alternative solutions; and the ability to display outcomes in a variety of forms (e.g., maps, tables, reports and graphs). They are well suited to deal with problems characterised by:

- Multiple and disparate data types (e.g., images, metrics, indices, maps, texts) and sources (e.g. private, commercial or public) with data held in large datasets;
- Multiple contexts and objectives (e.g., environmental, cultural, legal, social, financial);
- Multiple decision alternatives leading to multiple (spatially variable) outcomes;
- Multiple stakeholders / decision makers with often conflicting interests; and
- Multiple evaluation criteria which can be quantitative, qualitative or both.

Existing Decision Support For Stormwater Management

In order to inform the design process a review of existing decision support systems, including several SDSSs, specific to urban water management was undertaken. Tools

identified included the drainage and water quality model SUSTAIN (US EPA, Shoemaker et al., 2009) and planning applications developed for the DayWater (e.g., Ellis et al., 2006), SWITCH (Viavattene et al., 2008) and WaND (e.g., Makropolous et al., 2008) projects. Applications of these tools can be broken into four broad tasks: (a) sizing and costing of water management options, (b) selection of water management options based on site characteristics and comparative indices of possible outcomes; (c) selection of locations suitable for specific water management options; and (d) evaluation of the performance or cost effectiveness of water management infrastructure with respect to contaminant removal or flow reduction. While different aspects of these tools are informative for our SDSS design, none enable the impacts of urban development scenarios on receiving environments to be evaluated through the response of indicators of economic, social, culture and environmental values. This is the gap that our research aims to fill.

Stakeholder Engagement In SDSS Design

Stakeholder engagement is essential not only for successful sustainable urban water management (Taylor and Fletcher, 2005), but also to ensure that tools developed for stakeholders are fit for purpose (Voinov and Brown Gaddis, 2008). The two needs are related in that one of the key roles of an SDSS is to facilitate communication and stakeholder participation in decision making. To do this, an SDSS should be designed with consideration to all possible eventual uses and in consultation with the range of eventual users. Engaging stakeholders at all levels of the design process should lead to greater usability and wider acceptance of the SDSS as well as providing disparate knowledge essential to integrated decision making. The way an SDSS looks and feels will depend on its planned usage. Other aspects of SDSS design include the choice of software environment, spatial and temporal resolution, data types and availability, representation of physical processes and testability of outcomes.

In this project, we are engaging with planners, environmental scientists and stormwater managers from local government in Auckland and Christchurch in order to ensure that the SDSS meets their needs. Original project planning saw two end-user locations in Auckland and Christchurch. However the series of earthquakes experienced by Christchurch has left this project as an understandably low priority for managers and planners. Accordingly the focus of the project is now on locations in the jurisdiction of the newly formed Auckland Council.

This engagement has aimed to establish the purposes for which the SDSS will be used; who will use it; the outcomes required and the eventual audience for those outcomes. Local government staff favour an SDSS which aids catchment-scale urban planning over time frames of up to 50 years. They support a tool which allows the outcomes of different urban development scenarios to be assessed holistically across the ‘four well-beings’ (i.e., social, cultural, economic and ecological values). As well as supporting policy and planning decisions, they envisage the tool being used to communicate with the public and to engage communities in planning processes. Finally, there is a preference for a tool that is compatible with their existing software and geo-spatial data.

While the needs of different users and audiences is likely to be accommodated iteratively as the development of the SDSS progresses, early guidance on its potential future uses is invaluable, not only in terms of scoping the required functionality of the SDSS but also in defining the appearance of the interface and the outcome display.

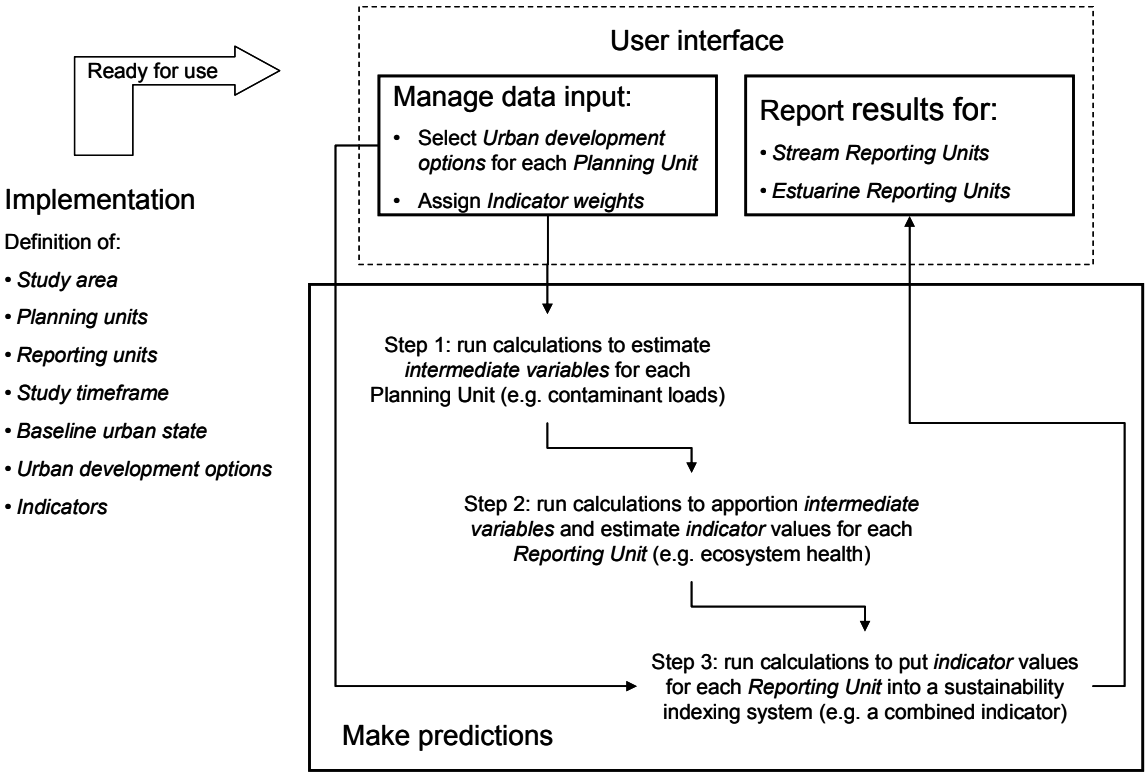
Conceptual Design

Four key questions have been addressed as part of conceptualising the design of the SDSS:

- what steps need to be taken to prepare the system so that it is ready for use?
- what will the user enter as inputs?
- what sort of outputs will the system provide?
- how will the system generate the outputs from the inputs?

The steps taken to prepare the SDSS for a given study area will constitute the 'implementation' of the system (see Figure 1).

Figure 1: Implementation and conceptual design of the SDSS



Implementation will involve specifying:

- the spatial and temporal domain over which the system operates, including the boundaries between planning units, PLUs, (the spatial units for which inputs to

the system are entered) and reporting units (the spatial units for which outputs are generated). PLUs are roughly equivalent to stormwater catchments whereas reporting units represent one of two types of receiving waters: streams and estuaries;

- The baseline urban state, representing the current form of urban development;
- Urban development options (UDOs), representing alternative forms of future urban development selected by users of the SDSS for each PLU. The attributes of UDOs will vary to reflect differences in land use, methods of land development, stormwater management and transport characteristics – the attributes which characterise these variations are the independent variables from which the SDSS will make its predictions;
- The set of indicators for which the SDSS will make its predictions.

Once implemented for a given study area, the SDSS will be ready for use. This involves,

- managing the input of data required by the system;
- manipulating that data to make predictions; and,
- reporting those predictions.

The management of input data and reporting of predictions will be delivered via a user interface. The generation of those predictions has been conceptualized in a three step process for each PLU:

Step 1: the estimation of 'intermediate variables,' such as contaminant loads, from the attributes of urban development options;

Step 2: the estimation of indicator values, such as measures of ecosystem health, from the intermediate variables; and,

Step 3: the expression of indicators within a sustainability indexing system, for instance the calculation of a combined indicator score for each wellbeing based on weights assigned to individual indicators by the user of the SDSS, and scores from step 2 above..

Step 1 – From Inputs To Intermediate Variables

Step 1 involves estimating a range of environmental stressors associated with urban development. One of these, stormwater contaminants is discussed here. The contaminant loads generated in a PLU vary with land use, urban activities such as transport, and stormwater management. For the SDSS, the principal contaminants of concern are sediment and dissolved and particulate zinc, copper and lead. Loads of these contaminants are deterministically estimated using a modification of the Catchment Contaminants Annual Loads Model (C-CALM, see Semadeni-Davies et al., 2010). The method estimates annual loads as the product of source areas and contaminant yields less contaminant removal by stormwater management devices. Sources include roofing materials, roads, paving and permeable surfaces. The source classes and their yields are the same as those used by the Auckland Council (Timperley, 2008).

The UDO for each PLU is defined by land use, method of land development, transport characteristics and level of stormwater management. The first three elements determine contaminant yields whereas the fourth determines the extent of contaminant load reduction resulting from treatment in stormwater management devices. Users will make selections to define the UDO, which represents the final form of the urban development in a given PLU. The initial form (the baseline urban state) is set as part of implementation of the SDSS.

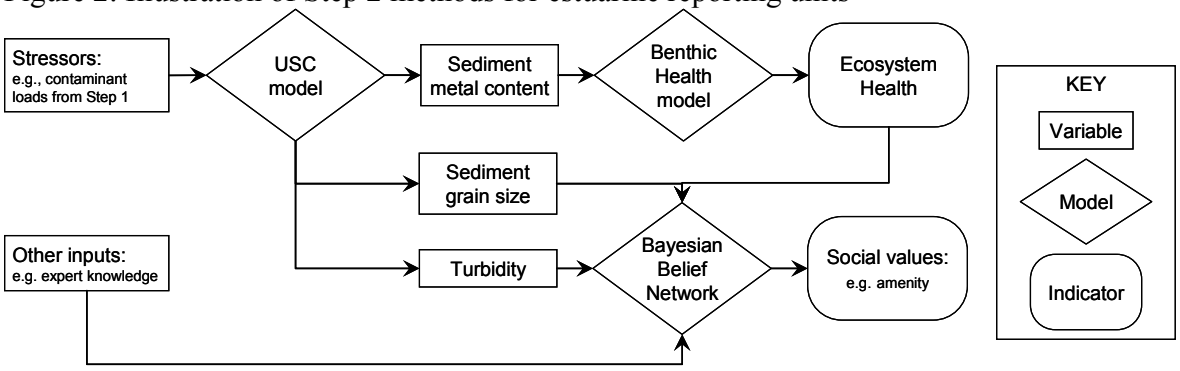
Each UDO may contain a number of land use types, each of which has its own mix of contaminant source areas. For instance, existing residential land use in New Zealand includes both traditional inner city / colonial style suburbs and lower density post-war outer suburbs which in their original form have lower yields of heavy metals than the former. However, infilling over recent years has increased both the level of traffic and the area of roofing, as a consequence, metal loads have also increased. Other differences reflect changes in building materials over time, for instance a gradual reduction in unpainted galvanised steel (a major source of zinc in New Zealand cities) in favour of covered steel or tiles.

A challenge for the characterisation of future urban development is the identification of land use types which adequately reflect likely future trends in urban design and building materials. Options relating to transport characteristics reflect the relative importance of public and private transport. Different options determine the types and extent of roads and change in traffic volumes over time. Options relating to the method of land development reflect the types of earthwork activities associated with urban development: these can be bulk (e.g., clearance of rural land for green-field development) and small sites (i.e., secondary clearance for infilling and brown-field development) earthworks. The source area for land development is approximated as the area of land undergoing land use change in a given year. Finally, stormwater management options determine the level of contaminant removal that can be expected for each land use type, ranging from no treatment through to 90% removal. Different land use types can be subject to different stormwater management options (levels of contaminant removal).

Step 2 – From Intermediate Variables To Indicators

The second step uses the contaminant loads estimated in Step 1, along with information on their impacts and other inputs, to generate indicator values which reflect the effects of urban development. Several of approaches are being investigated and these are likely to differ for estuarine reporting units compared to stream reporting units. For brevity, here we focus on the approach for estuarine reporting units, illustrated in Figure 2.

Figure 2: Illustration of Step 2 methods for estuarine reporting units



The approach for estuarine reporting units builds on three existing areas of research. Firstly, a modified version of an existing physically-based model (USC, Urban Stormwater Contaminants Model) takes the contaminant loads estimated in Step 1 and makes predictions of the accumulation of the metals copper, zinc and lead in estuarine bed sediments (Green, 2008). These predictions then act as inputs to a benthic health model which is an empirically-based relationship linking sediment quality and the health of benthic communities (Anderson et al., 2006). The outcome of this model is used here as an indicator of overall estuarine ecosystem health for each reporting unit. Other outputs from the USC model allow estimation of the grain size characteristics of estuarine sediments and water turbidity. Along with ecosystem health, these characteristics are important influences on indicators of economic and social values associated with uses (and non-uses) such as fishing, swimming, canoeing and walking.

A probabilistic Bayesian Belief Network (BBN) approach has been adopted in order to allow information from different sources, with different levels of associated uncertainty, to contribute to the estimation of these social indicators. This method allows information such as empirical observations, the results of modelling and expert knowledge to inform conditional probabilities assigned to each of a number of possible outcome states, given the state(s) of a set of input variables (Ticehurst et al., 2007). In this case, the inputs to the BBN include the predictions of bio-physical variables provided by the USC and benthic health model.

Step 3 – From Indicators To A Sustainability Indexing System

The third and final step is the expression of individual indicators within the framework of a sustainability indexing system. This will involve the combination of individual indicator values to generate single indicators of each of environmental, social, economic and cultural well-being. While greater aggregation of indicator scores leads to loss of information, local government stakeholders have indicated that high-level combined scores are likely to suit non-technical audiences interested in the 'big picture'. Other users, who want more detailed information, can evaluate results at the level of individual indicator values.

Examples of the types of environmental and social indicators that will be generated by the system are described above (see Step 2). A cultural health index (CHI) developed for

rural catchments (Tipa and Tierney, 2003) is currently being evaluated for its potential application to urban streams. An aspirational research goal is to incorporate this index, or an adaptation of it, within the sustainability indexing system of the SDSS. The next section of the paper, Sustainability Index System describes in more detail the methods for combining indicators to generate well-being indicators.

Sustainability Index System

Background

The goal of the UPSW sustainability index system is to discriminate effectively between contrasting urban development options. Those contrasts are expressed in terms of their likely effects on the fresh water and estuarine receiving water bodies for urban storm water run-off from a catchment or series of linked catchments. The New Zealand administrative and legal context requires those effects to be considered in terms of four categories of information, the four well-beings.

The aim of system development is to build an index system that effectively allows differentiation between potential UDOs while,

- minimizing information loads,
- presenting the four well-beings and their constitutent indicators in a manner that easily accessible to non-numerate audiences, and,
- having the capability to drill down into the data for more technically inclined decision makers.

Methods for generating indicators include composite index approaches (Nardo et al., 2005) and multi-criteria analysis (UK Government, 2009; Proctor and Qureshi, 2005). Drawing on these methods, there are three key aspects involved in the generation of combined indicators which are being addressed.

The first is the need to allow weights to be assigned to individual indicator values (either pre-defined or assigned by end-users). An analytical hierarchy process (AHP) has been adopted as the preferred option for developing a weighting method. This method involves establishing weights based on surveys of either experts (e.g. an expert panel) or a stakeholder group(s). AHP was developed as a general theory of measurement. It is has found wide application in multi-criteria decision making and planning. In its general form it is a process for carrying out both inductive and deductive thinking by taking several factors into consideration at the same time, making trade-offs in a numerical format (Saaty, 1987).

This approach to creating a weighting system has advantages for the UPSW project in the pilot phase in that it,

- provides a weighting technique that is consistent with data generated by knowledge network models,
- considers pair-wise trade-offs between indicators / variables,

- has a sound theoretical basis in the mathematics of linear algebra, is widely used in multi-criteria analysis, providing adequate precedent for its adoption, and,
- has the capacity to integrate a number of alternate techniques by providing a transparent framework that elicits preferences from experts, decision makers, and stakeholders, making trade-offs explicit.

The second key aspect of the functionality required to generate combined indicators reflects the fact that different indicators are likely to have different mathematical properties. For example, one indicator may be measured quantitatively and another qualitatively. Such differences present a significant challenge for their combination. A necessary step for resolving differences of this nature is to express indicators in a consistent format, for instance by assigning them a value within a fixed range. Nardo et al. (2005) refer to this process as normalization.

The third aspect is the reporting of indicator levels relative to a standard, such as a water quality standard, or a target, such as a goal set in relation to the rehabilitation of a degraded stream. Indicator levels relative to these goals can be expressed via traffic light system reflecting distance from a standard or proximity to a target.

The Four Well-beings

The UPSW sustainability index system will report four categories of composite indicators that correspond to "well-beings". In New Zealand when local government bodies take decisions about sustainability they must consider their effects on four "categories" of well being: environmental, social, cultural and economic (Local Government Act 2002).

The issue of aggregation is challenging. While a statistic that summarizes all contributing information into one measure is attractive for decision makers (witness the growth of multi-criteria schemes), there are real technical challenges in achieving a reliable aggregate measure. Those challenges lie in issues such as high levels of correlation between social domain indicators and environmental health scores such as Benthic Health Index for estuarine systems, and double counting amongst the social domain well-beings. For example when is a cultural effect not a social effect that may be capable of expression as an economic measure?

Economists have long proposed that the appropriate avenue to resolve these kinds of problems is to adopt the Total Economic Value approach. While this is an effective theoretical solution (in the economics discipline) to the problem of integration across the well-beings reporting a single TEV score does not satisfy the requirement of the Local Government Act to inform sustainability decisions in terms of four well-beings. These constraints determine the indicators and level of mathematical aggregation reported.

Social Well-Being Indicator

Humans relate to freshwater bodies such as streams, rivers, and lakes in a variety of ways ranging from full immersion (swimming) to food gathering and walking and picnicking on adjacent margins. Based in World Health Organisation guidelines (WHO, 1998), the guiding New Zealand document that creates standards for fresh water bodies, the ANZECC water quality guidelines (Ministry for the Environment, 2000) specifies acceptable levels of pollutants in terms of those classes of activity. ANZECC guidelines recognize them in three categories identified by the level of contact with the freshwater body the activity requires. Full immersion activities such as swimming, surfing, or water skiing are classified as contact activities. Partial contact activities include boating, and activities in which the connection with the fresh water body is limited to visual or aural effects due to proximity on the riparian margins is referred to as non-contact.

The UPSW social well-being is calculated by integrating five indicators that express the suitability of a specific water body in terms of four use and one non-use categories. The five indicators are:

- Non-contact (e.g. picnicking, walking the margins of the water body)
- Partial contact (some measure of contact e.g. boating)
- Full contact (e.g. swimming, surfing)
- Extraction: food gathering
- Non-use: e.g. sense of place, bequest value, existence value etc.

A number of studies (for example Kerr and Sharp, 2006; Batstone and Sinner, 2009)) have undertaken choice experiments to understand community preferences for urban estuarine and freshwater water body management in the Auckland region. These and other sources in regional / city authority archives provide assessments of the intermediate variable precursors to each of the social indicators. For example with respect to streams, Kerr and Sharp (2006) found the following attributes important determinants of utility:

- Water clarity
- Native fish species
- Fish habitat
- Native streamside vegetation, and,
- Channel form

Batstone and Sinner (2009) found these attributes to be important determinants of the utility Aucklanders derive from estuarine environments:

- Underfoot conditions (muddiness)
- Water clarity, and,
- Ecological health.

Linear additive or geometric aggregation techniques (Nardo et al 2005) may be employed to generate the combined social wellbeing. These techniques require weights to be assigned to each indicator. A variety of techniques are available to elicit weights

from Delphi processes to community data collection using the approach described by Saaty (1987). Alternatives to this approach lie in a variety of statistical treatments including choice modeling (Nardo et al 2005). The key difference between the two aggregation schemes is that the additive scheme implies full compensability, while the geometric option limits compensability.

Compensability is the capacity for poor performance of one or more of the sub-indicators to that contribute to a composite to be offset by strong performance in others. Linear aggregation schemes imply full compensability, while geometric aggregation limits compensability. The weights in additive schemes have the meaning of substitution rates, i.e. the trade offs between sub-indicators, and therefore should not be interpreted as the importance associated with a sub-indicator in respect of other sub-indicators. When full non-compensability is required a Non-compensatory multiple criteria approach (Nardo et al 2005:76) may be adopted. This not the case in the UPSW project, since the governance recommendations promote trade-offs as a desirable feature of the overall process.

The type of aggregation scheme employed is strongly related with the normalization method enacted on raw scores that emerge form the knowledge network process. Linear additive aggregation yields meaningful composite indicators only when in partially and fully comparable scales. Where this property is not present geometric aggregation should be used.

Arrow's impossibility theorem (Arrow, 1963) demonstrates that no perfect aggregation scheme can exist. It is important that the key properties of the sub-indicators in respect of the issue the composite is assessing are not lost in the aggregation process. Sensitivity analysis should be undertaken to investigate the degree to which the final composite indicators respond to the differing aggregation options.

Economic Well-Being Indicator

Changes in land use, storm water management and stream management impact freshwater and estuarine ecosystems so that the flows of goods and services they produce in turn changes. Those changes to receiving ecosystems have implications for the community that are amenable to expression in terms of costs and benefits associated with each urban development option.

In order to make the research tractable it has been necessary to limit the scope of the analysis. In this phase of the research assessment of the costs and benefits associated with each urban development option are limited to those that arise in the receiving water bodies. The boundary of the scope of the analysis in this phase is therefore set at the points where precipitation enters the receiving water bodies. It is envisaged that this scope will be expanded as the research progresses to include costs and benefits that arise in terrestrial locations – benefits of changed land use in terms of contribution to enhanced productivity for example. It is envisaged that further "aspirational" research

will extend the boundaries of the system under consideration to include terrestrial costs and benefits.

A key feature of index system design in the context of sustainability assessment is the capacity of an index system to capture the trade-offs that are involved in land use change and the associated storm water and stream regimes (Gibson, 2006). Development of sub-indicators for economic wellbeing that incorporate assessment of costs and benefits addresses that requirement. Derivation of cost benefit ratios make the trade-offs explicit and enable cost effectiveness analysis.

Costs

Each of the urban development options is specified in terms of the attributes of the terrestrial catchments (percent impervious surface, for example) and storm water and stream management programmes. Storm water management programmes incur costs (SWMC) through expenditure on devices that collect and hold volumes of storm water to reduce sediment and contaminant loads entering receiving water bodies. Stream management costs (SMC) are incurred through riparian planting to stabilize stream banks, to slow nutrient and contaminant bearing storm run off, and to absorb contaminants. Additional stream management costs are incurred through in-stream works designed to stabilize banks and to mitigate the effects of high flow periods.

For each UDO in a planning unit (PLU) a set of engineering projects has effects on two kinds of receiving water bodies characterized as estuary reporting units (ERU) and stream reporting units (SRU). Mitigation expenditure such as SWMC and SMC may have effects in both the ERUs and SRUs associated with the PLU in which they are carried out as well as in the ERU(s) associated with an adjacent PLU.

Since the mitigation expenditure promotes a flow of benefits over time, for analytical purposes it is reasonable to allocate costs proportionally to the location(s) experiencing the effects that result from the expenditure. Allocation of these costs between these receiving areas is complex and non-trivial. The research is exploring the use of an expert panel approach to identify reasonable cost allocations.

Consider a situation in which there are:

- 2 x PLU: PLU1 and PLU2
- 2x SRU (one in each PLU), and,
- 2x ERU (one corresponding to each PLU, but receiving non-point discharges from both PLUs).

Storm water management in each PLU may consist of a number of projects. These might be installation of ponds for example. The costs of the projects are allocated between receiving bodies – both ERU and SRU - associated with both PLU on the basis of expert assessment of the distribution of the effects of the works undertaken.

Similarly, stream management in each PLU may be seen as consisting of a number of projects. It is assumed that the effects of stream management in any PLU impacts only the receiving bodies directly associated with that PLU. The costs of the projects that constitute stream management are allocated between the receiving ERU and SRU on the basis of expert assessment of the distribution of the effects of the works undertaken. For example, riparian planting may be seen to consist of a number of projects defined in terms of species with specific roles in mitigation, and the effects of the roles are differentially distributed between receiving water bodies.

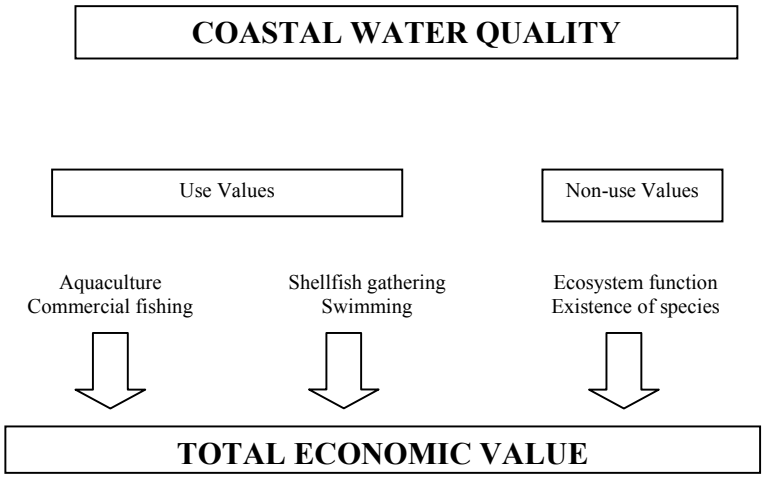
Costs are assessed as life cycle costs, estimated over the (say) 50 year time horizon of the analysis, and discounted to a present value figure. Costs are distributed over the study area to find expression as cost per household per year. This specification aligns the cost estimate with the units in which storm water mitigation benefits have been estimated (dollars per household per year) (Batstone et al 2010). Consideration of a wide range of mitigation devices and costs allows determination of the range of possible costs. This in turn permits normalization of the costs associated with each PLU to a value in the range {0 100}.

Benefits

Changes in land use, in conjunction with the stream management and storm water management works, results in changes to the biophysical condition of the receiving water bodies. Key measures such as water clarity and underfoot conditions are likely to be impacted. Individuals derive benefits determined in extent by the nature of their relationship expressed in terms of use and non-use.

The total economic value concept provides a useful framework used to assess benefits of improvements to coastal water quality. Figure 3 describes the Total Economic Value concept.

Figure 3: Total Economic Value



In the first stages of development of the SDSS it is assumed there are no commercial activities based in the flow of goods and services associated with the estuaries and streams. Assessment of the non-commercial benefits will be carried out using non-market valuation – e.g. discrete choice modeling – approaches.

Initially a benefit transfer approach will be considered. However recent research that considered benefit transfer of values associated with Auckland region streams (Kerr and Sharp 2002) shows benefit transfer should be used with caution even between locations as close as northern and southern Auckland metropolitan areas. This may be a feature of the diverse socio-economic mix that has settled across the Auckland region.

It is envisaged that choice modeling will be used to derive an assessment of the benefits of storm water mitigation. Those benefits will be captured as consumer surplus reflected in willingness to pay (WTP) estimates for changes in relevant water body attributes. Choice modeling produces estimates of consumer surplus that take account of income effects in the specification of the demand curves, and through its design approach overcomes many of the methodological criticisms made of contingent valuation.

Benefit estimates are expressed in dollars per household per year and discounted to a present value over the 50 year horizon of the analysis. The range of possible benefits is determined by examining the potential benefits from all land use scenarios and mitigation works options for streams and storm water. This in turn permits normalization of the costs associated with each PLU to a value in the range {0 100}.

Benefit Cost Ratio

Costs and benefits associated with each alternate land use scenario have been calculated to the same units (present value $ per household per year) and normalised over their respective possible ranges. Combining these to a cost benefit ratio and setting the index level to 100 in the first year of the analysis permits discrimination between land use scenarios on the basis of their differing cost benefit ratios assessed at the point of departure and potentially modeled as a time series with starting value = 1.

Aggregation Potential

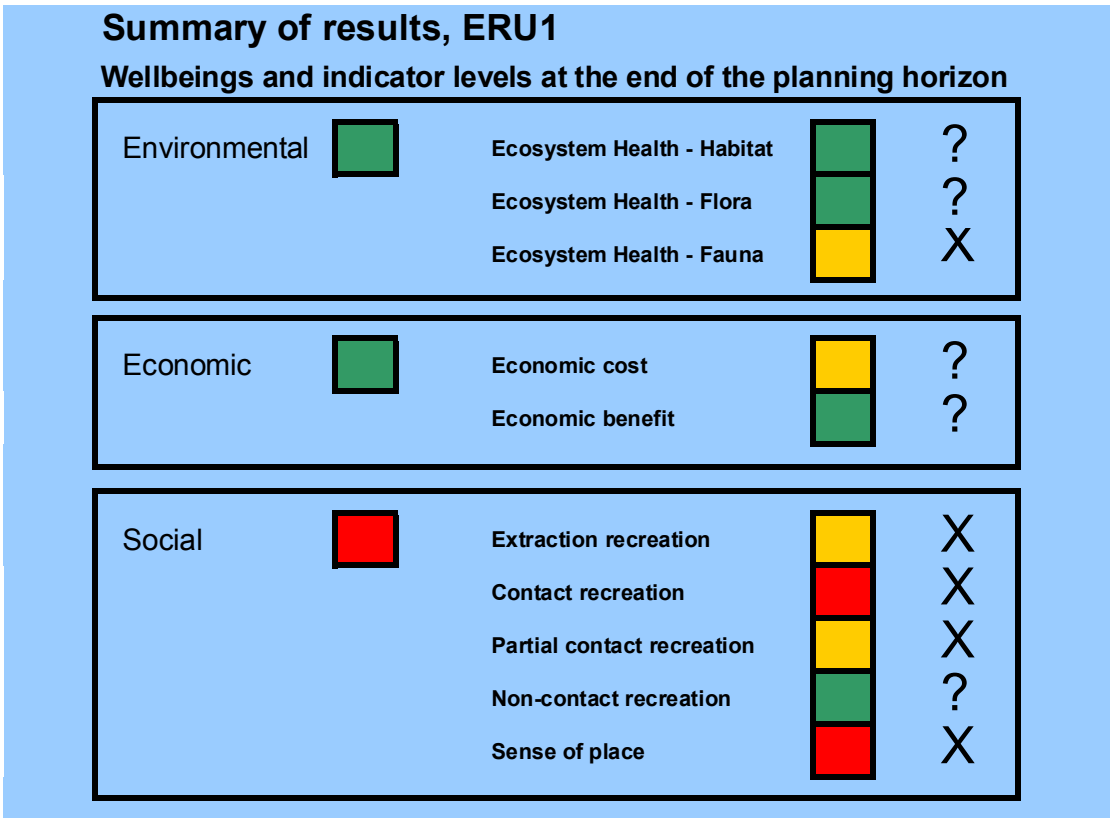
Both composite indicator and multi-criteria approaches result in aggregation of sub-indicators to a single overall statistic that describes the state of the system. While it may be attractive to some stakeholders to be able to track quality changes in a water body across time or to be able to discriminate between land use scenarios with a single overall indicator, this is not feasible in the UPSW project because of the double counting problem that arises when seeking to combine the four well-beings to one overall sustainability score.

Economists have suggested that there is a single statistic that summarises the socio-economic portion. This is the derivation of willingness to pay (WTP) or willingness to accept compensation (WTA) through non-market valuation processes such as discrete

choice modeling (Hensher et al 2005). There is great potential in generating summary statistics that communicate changes in storm water receiving water bodies based on the value to people of changes to state variables such as water clarity. However, describing the state of the environment in monetary terms is an anathema to many natural scientists who question the legitimacy of economic considerations in decisions about the persistence or other wise of nature.

The approach taken in this project to the issue of aggregation is to recognize the limitations of the overall score approach, and to allow users of the tool to undertake the aggregation exercise. To achieve this traffic light approach has been taken that incorporates symbols and colors to communicate outcomes.

Figure 4: Final presentation of UPSW indicators



The simple traffic light indicator system employed in the proof of concept phase of the research (Figure 4) uses three categories represented by three colours. Green is positive, yellow neutral, and red the negative outcome. Establishment of the bounds of the categories is achieved through expert assessment. As the research progresses this reporting structure may become more sophisticated, for example displaying outcomes as 5 categories. The column of symbols to the right of the traffic light array describe progress toward targets or standards in terms of three symbols: X; ?; ☺.

In each of the social and environmental wellbeings the overall wellbeing score is depicted in terms of a score that results from linear aggregation of the weighted contributing indicator scores. The aggregation method used in the economic wellbeing is through creation of a cost – benefit ratio. Accordingly, these two kinds of indicators do not share a common units basis and are therefore not amenable to consolidation to a single metric.

This method of aggregating to where double counting takes place and presenting the outcomes in a traffic light format allows individual users to perform the overall aggregation in their own minds, according to their own preferences and priorities.

Conclusions

This paper describes the conceptual design of a SDSS being developed to aid urban development planning in New Zealand in the face of increasing pressure on the values of the country's urban waterbodies. The SDSS differs from existing tools in that it aims to allow holistic evaluation of the effects of urban development based on indicators of the environmental, social, economic and cultural values associated with receiving waterbodies. The SDSS will use both deterministic and probabilistic methods in a three step process: the estimation of stressors such as contaminant loads from the attributes of urban development options; the derivation of indicator values from these stressors; and the expression of individual indicators within a sustainability indexing system.

It may be that this project makes a unique contribution to the development of non-market valuation techniques by investigating their suitability for incorporation into environmental sustainability software design. The authors are unaware of other similar instances of non-market valuation being used "industrially" in this way.

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