

An Indexing Model for Stormwater Quality Assessment: Sustainable Stormwater Management in the Gold Coast

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Abstract: *In the age of climate change and rapid urbanisation, stormwater management and water sensitive urban design have become important issues for urban policy makers. This paper reports the initial findings of a research study that develops an indexing model for assessing stormwater quality in the Gold Coast.*

Keywords: *Sustainability, stormwater quality, stormwater infrastructure, stormwater management, climate change, water sensitive urban design, indexing model*

Introduction

Sustainable stormwater infrastructure should be able to provide the security of alleviating floods and removing stormwater from urban areas without harming the environment. This has not been the case, where the quality of urban stormwater has been shown to have steadily deteriorated due to urbanisation and population growth which has changed the composition of the water. The continual increase in impervious surfaces and anthropological inputs have resulted in stormwater to become highly polluted, and affecting the ecological integrity of the receiving water. Recent heightened awareness of these adverse impacts, along with the acknowledgement of climate change and the rising popularity of the concept of sustainability have prompted a change in planning schemes and policies in regulating stormwater quality and its associated infrastructure. One of the responses of achieving sustainable stormwater infrastructure is the rise in the popularity of sustainable indicator models. These have gained popularity as a tool for evaluation of sustainability levels for all sectors and levels of governance from global to local scales. This paper will focus on stormwater management and infrastructure affecting the City of Gold Coast, a highly urbanised coastal city, and the indexing model tailored to model the sustainability of its current and future stormwater infrastructure.

Climate change

The city of Gold Coast, initially established as a radial city to Brisbane's CBD, has experienced exponential growth and development to become a major regional centre by itself (Yigitcanlar, 2007a). With 55 kilometres of coastline to the east and lush hinterlands to the west, Gold Coast is a major tourist attraction and a vibrant economic hub, contributing significantly to Australia's GDP via its strong tourism and creative industries.

Along with the anticipated high growth rate, these features present many challenges in the wake of climate change. While the numbers of dry days in the Gold Coast are expected to stretch, precipitation events, when they occur, will be more intense. This extreme hydrological cycle will bring more extreme drought and flood events (CSIRO, 2007). With sea levels predicted to rise by a range of 18-79cm by the year 2100 (CSIRO, 2007), residential pressures on the coast will be even heavier as most of the population live on reclaimed dunes and coastal areas which are

only 5m above sea level, while much of its flood plains have been converted to canal estates which are surrounded by residential areas (Baum et al., 2009). Significant beach erosion and high waves from tropical cyclones is already an issue that impacts on the Gold Coast (Voice et al., 2006), where it threatens infrastructure, most which have considerable economic value. With the beach also playing an important aesthetic and cultural role in the Australian psyche, there is an intrinsic value in addition to the economic cost of protecting the coastlines.

Gold Coast City Council (GCCC) (2009) has acknowledged that many of its current infrastructure design is not equipped to adapt to or weather the impacts of climate change, and that historic records are no longer sufficient indicators for future plans. GCCC (2009), in their working copy of *Climate Change Strategy* document, has stated that there is a need for sound research specific to the Gold Coast that is required to be conducted as to provide new direction for policymaking and infrastructure planning that is both sustainable and is resilient to the anticipated impacts of climate change. This assessment model is one of the steps taken in collaboration with GCCC to assess current and future infrastructure, to direct policy and ensure that forthcoming infrastructure development will be sustainable and adaptable to climate change.

Stormwater management

As a dynamic process that has existed for millions of years, nature has managed Earth's water circulation through the hydrologic cycle. Through rapid urbanisation, human interaction with the hydrologic cycle has now changed significantly through activities such as land clearing, vegetation removal and land grading which have degraded aquatic and terrestrial habitats. When the land is developed, forests and agricultural areas are transformed into concrete surfaces; this conversion has created impervious surfaces such as buildings, rooftops, sidewalks, roads, and parking lots. These impervious surfaces prevent stormwater infiltration, increase the runoff volume and cause flooding problems with resulting loss of wildlife habitat and natural vegetation. Runoff can adversely affect the quality of receiving water due to high pollutant loadings (Livingston et al., 1992; Arnold et al., 1993):

In order to preserve the quality of water bodies and prevent pollution, stormwater need to be managed in an environmentally sustainable way. Stormwater management (SWM) is a method of control and utilisation of discharged waters through best management practices. A variety of techniques have been developed to manage stormwater runoff, including the use of large diameter pipes, porous pavements, detention and retention systems, vegetative practices and surface basins (Hogan et al., 2007). SWM is an effective way of maintaining the health of water resources and aquatic ecosystems as well as meeting the human needs of water by minimising the impacts of urban development. Flood and water quality protection, erosion control, improved landscape aesthetics and reuse of water resources are the basic objectives of SWM.

Water Sensitive Urban Design (WSUD), as an integrated approach to stormwater management, aims to design sustainable urban water cycle management for creating better ecological and environmental outcomes. Different than the conventional point of view, WSUD focuses on evaluating stormwater as a resource rather than as a nuisance by providing opportunities to integrate water features in urban design as well as to enhance the social and environmental amenity of urban development (Victorian Stormwater Committee, 1999). Its multiple benefits include stormwater drainage, water quality improvements, aquatic habitat protection, stormwater harvesting and use, and recreational opportunities (Lloyd et al., 2002). Briefly, WSUD is an alternative planning and design framework for urban development that attempts to find more economical, and less environmentally damaging ways of providing urban water, wastewater and stormwater solutions (Wong, 2006b).

Gold Coast is one of the most rapidly growing areas in South East Queensland. As a result of the rapid development and population growth pace, urban water systems are not unable to meet

the demands of the population, which resulted in an increased pressure on natural water systems and the degradation of waterways and beaches (Yigitcanlar, 2008). In response to this, GCCC has released a WSUD Guideline in 2007 to assist local developers and the Council in addressing water-related urban design issues (Gold Coast City Council, 2007). This guideline introduces a number of engineering practices including the detailed planning, design and technical drawings of WSUD stormwater systems, and details steps involved in implementation. It opens a new era by bringing “sensitivity to water” as an urban design principle for building water sensitive cities in the wake of climate change (Wong, 2006b; 2002).

Climate change and sustainable stormwater infrastructure

An important feature for a sustainable infrastructure system is to ensure that it is able to deal with the variable impacts that are expected from the onset of climate change (Sundberg et al., 2004). The Gold Coast is especially vulnerable to expected sea level rises and increased rainfall intensity due to its exposure to the coast and numerous canals and waterways that snake through the city, which may result in decreased or even a failure of the stormwater infrastructure capacity (GCCC, 2009). The design and functionality of the infrastructure has been made even more complicated by rapid urbanisation, a phenomena which is able to drastically alter natural hydrological cycles.

The role of sustainable stormwater system, then, is to continue to provide reliable service to society whilst not compromising on their environmental, hydrological and social integrity (Rijsberman & van der Ven, 1999). They also need to be able to respond to change, which are forced upon infrastructure systems continuously, from the environment if not from internal forces (Sundberg et al., 2004). One of the major challenges of reacting to the external force of climate change impacts remains the development of a robust model in order to ensure the design and incorporation of resilient and adaptable infrastructure. Because the magnitude and timeframe of the impacts of climate change are still uncertain, a sustainable stormwater system needs to be able to accommodate the variability of rainfall and consequent peak runoff flows of precipitation in order to prevent local flooding, one of the most important roles of a stormwater system. One of the key drivers for design of stormwater infrastructure is the number and intensity of rainfall within a catchment area for a certain period (Shaw et al., 2005). Previously, this estimation was based on historical records of observed rainfall and its frequency (Arisz & Burrell, 2006). However, climate change is predicted to alter this by changing the amount and intensity of rainfall, as well as altering the antecedent moisture loading of soils and the amount of moisture held by the atmosphere (Shaw et al., 2005). Thus, design of future stormwater infrastructure based on this traditional, static model would lead to errors.

Climate change resilient stormwater infrastructure should be able to not only alleviate flooding, but also provide benefits such as conservation of water, improving the quality of runoff as well as act as an alternative source of water, if needed (Sundberg et al., 2004). New developments should therefore reflect this by incorporating appropriate features and drainage systems, such as WSUD, which attempts to mirror the natural hydrological cycle in the sustainable management of stormwater (Andoh, 2002).

However, measures for stormwater infrastructure should be holistic and take into account the multi-dimensional aspects of urban water infrastructure, not just in providing a service and as a resource, but also acknowledging the inputs of stakeholders and the role of education. However, for policy to be efficient and specific to local scenarios, current problems must be evaluated in order to assess the severity of the problem, and to identify areas in which improvements need to be conducted. The first step towards this would be constructing an indexing model to assist planning and decision making, as discussed in the next section.

An indexing model for stormwater quality

There has been a great effort in the academic and policy domains towards measurement and assessment of sustainability performance at different levels ranging from global to neighbourhood to single product. Naturally, these specific scales demand different measurement methods and strategies to produce concrete tools for sustainability assessment. In general, indicator-based assessment methodology is the most widely employed sustainability accounting procedure by international, national and local institutions. Reporting an individual indicator score in order to reveal the status of or the progress towards one of the sustainability domains is accepted as an informative and ethical way of sustainability accounting. This way the aggregation of indicators as a composite index reveals the overall picture of the sustainability performance, which is an innovative reporting method for sustainability assessment.

In different contexts, indicators are defined differently. The review undertaken by Gallopin (1997) notes that an indicator has been defined as a 'variable', 'parameter', 'measure', 'statistical measure', 'a proxy for a measure', and 'a subindex'. They are used to explain divergent and changing aspects of a respective system, and are employed for the descriptive analysis, either quantitative or qualitative, of the system; and also it is more convenient to define indicators as 'variables'. As Veleva et al. (2001) pointed this definition also reflects the dynamism and interrelated nature of the indicators.

In urban planning, sustainability of the urban settings is discussed under the heading of sustainable urban development (SUD). It encompasses interaction of a wide range of urban functions and consequent effects of this interaction, such as, energy used, pollution produced, accumulation and distribution of wealth, and so on. Specifically, stormwater quality issues are described such as the amount of gross and fine pollutants entering a stormwater system from urban areas and reaching sensitive water bodies without treatment. Amounts of fine pollutants in different water bodies originating from urban areas are critical because it jeopardises the health and balance of the ecosystems. The fine pollutants in urban stormwater runoff are related to the two main sources: land use and transportation activities. Different land uses generate air, soil, and water pollutants produced through household, commerce and industrial activities. The use of petroleum-based fuels in transportation activities produces emissions which are considered as the main causes of greenhouse and carcinogen gases into the atmosphere, and airborne fine particulates accumulating on the impervious surfaces in the urban areas and washed off by rainfall.

While unsustainable urban activities are the key factors which causes environmental degradation in and around urban environments, land use and transportation is primarily tied with the economic growth and wealth of the people (Yigitcanlar, 2009). Therefore, any policies affecting land use decisions and transportation activities have contingent results on overall urban economy. It is these contingent results that have been accentuated as the source of conflict between the proponents of environmental protection and economic development. Yet, at the community level, the just share of wealth/cost among inhabitants and sense of place considerations have immense importance for formulating and implementing economic and environmental policies. Because of that, the three pillars of sustainability should be reflected in the indicator set selected. By this way it is possible to depict a comprehensive framework of SUD in assessing urban development and infrastructure policies, specifically about those related to stormwater runoff pollution alleviation.

The specific aim of this study is to incorporate all related domains affecting urban stormwater quality and propose a practical method that helps the decision making process. More specifically:

- Measuring and assessing the current sustainability performance of the urban settings via urban sustainability indicators;
- Aggregating indicators as a composite index, and;
- Employing the composite index for benchmarking and policy making process, which are the objectives for framing alternative assessment technique proposed in this study.

Measurement and assessment of the urban settings in terms of sustainability performance are gauged by designated indicators. As pointed in the recent literature, in sustainability assessment studies the indicators are generally selected considering the main categories of demography, urban form and transportation. After investigation of interrelationships among these indicators and relative contribution of them to overall sustainability level, an indexing model is developed to assess performance of the urban settlements and their impacts on stormwater quality. In this model the main focus is on areas where there is a need for intervention due to low sustainability performance and where actions would help to ameliorate sustainability problems. According to the decision makers' preference for anticipated actions, it would be possible to generate urban development policies. At the last stage, policies affecting assessed parameters in the model will be tested to see if the designated actions/ policies would generate intended outcomes. The structure of the model illustrating the related procedures is given in Figure 1.

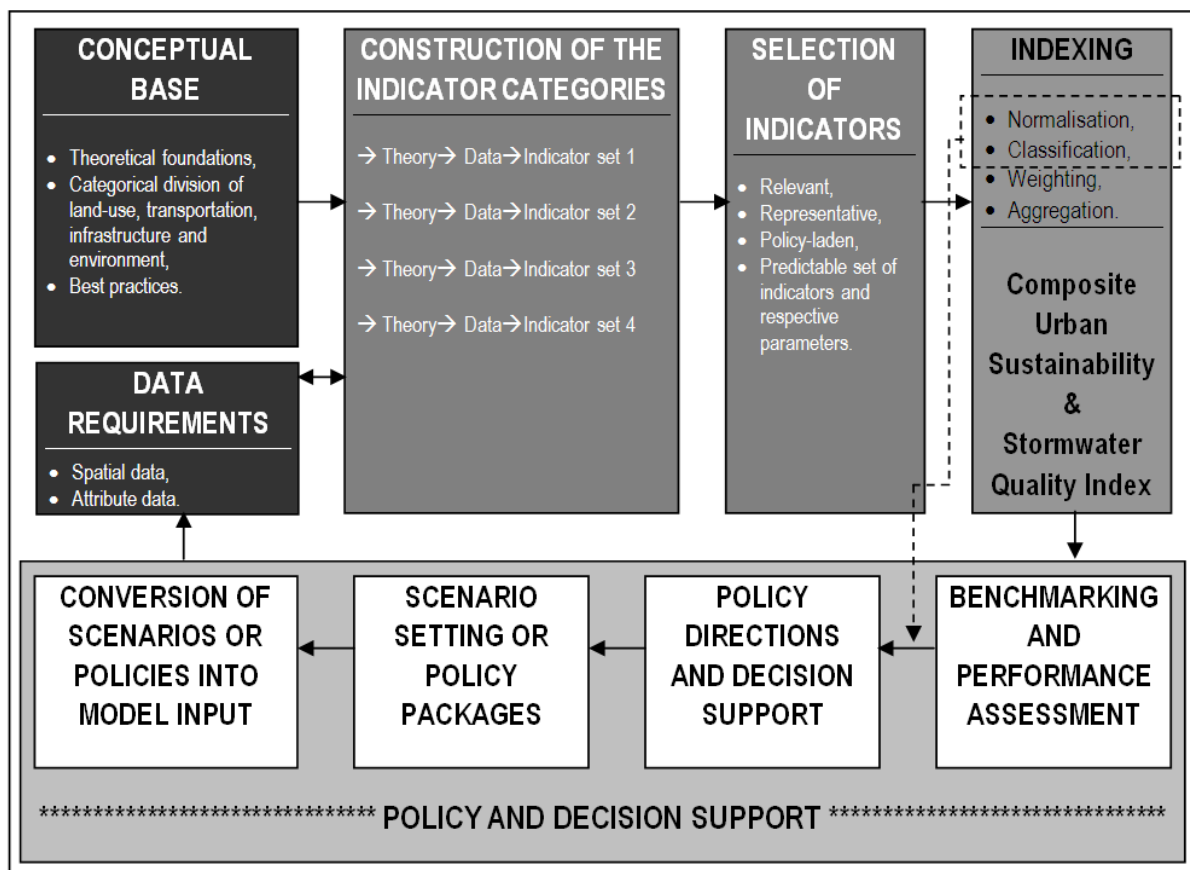


Figure 1. Structure of the indexing model

In Figure 1 above, there are four constituent parts of the model: (1) conceptual base and data requirements of the model; (2) construction of the indicator base of the model; (3) urban sustainability indexing system of the model, and; (4) policy and decision support system. Each part in the model produces specific outputs which are used at the consequent part and the

circular structure of the model reflects iterative processes which are employed for purposes of model feedback and assessment of alternative policies.

Conceptual base and data requirements

In order to clarify the key concepts and consolidate the model structure, theoretical debates on definition and measures of urban sustainability and, particularly, stormwater related urban sustainability problems should be identified. The concept of sustainability and its spatial or urban structure dimension constitute the theoretical foundation of this model. In terms of sustainable urban development and sustainable communities, the urban form, mobility pattern and infrastructure provision are the primary issues connected to the environmental domain of sustainability. Mainly focussing on stormwater runoff pollution, compels us to include not only characteristics and content of the pollutants or infrastructure planning and design issues but also to take the drivers of this phenomenon into consideration from an urban policy perspective. Naturally, all endeavours related to the urban development carry infrastructure and service considerations into the planning activities. Therefore, the question remains: how to define and measure the interrelated qualities of this construct to portray interventions towards more sustainable communities? Indicators and indices are frequently used means for generating sustainability policies and making comparison among different aspects of sustainability performance. Even if they are widely used tools, the theory behind the indicator-based description of urban sustainability with scientific reasoning frames the structure of the research and has immense importance for the robustness and reliability of the proposed methods. Even though there is no unified method in the indicator-based sustainability assessment, in the literature there are a considerable number of studies with different concerns, such as development, market and economy, innovation and knowledge and ecosystem (Singh et al., 2009), which employs indicators or index-based models to perform sustainability performance evaluation (Yigitcanlar, 2007b). These are invaluable sources that shed light on practicability and theoretical weaknesses of this approach.

Data requirements part of the model points out the dual relationship between theoretical robustness and data accessibility and quality considerations. While the theories related to the variables of urban sustainability considerations convey a very wide and interrelated picture, finding respective data from available sources is not always an easy task. In some cases available data may not have the desired scope (e.g. the statistics produced by census offices of different countries with dissimilar methods) or have statistical flaws that may cause bias in measurement and forecasting (e.g. the surveys with limited number of sample or a population strata because of the budget constraints). Additionally, existence of highly correlated indicators in the assessment mode is another problem that could jeopardise model reliability. In some respect, the selection of data will be based on partly intuition and partly subjective judgement, an occurrence not uncommon when building a decision support model (see Hanafizadeh et al. 2009; Singh et al. 2009). Properly designed indicator selection and election procedure may help make the model parsimonious and avoiding unnecessary data collection costs. The criterion for data availability and selection of proper indicators is explained by Hák et al. (2007) as indicators being merely assessment tools, therefore, the cost of improvements should not limit the capacity to implement policy and must be matched in cost-effective ways.

Indicator base of the model

As a rule of thumb, each indicator included in the model should have a theoretical background which shows related variables, the direction of relationship among variables and parameters to be used in measurement. Parameters are thresholds that represent critical values where changes in the values of respective indicators can be differentiated from other intervals. For example, till reaching a specific value, volume capacity ratio of a road could be defined as

underutilised, but after some value it could be classified as congested or low level of service. In essence, it works as the practice-oriented interpretation of a variable. Parameters could be based on literature or local regulations but in some cases it is inevitably hard to define both indicators and parameters related theory, especially for social and value-dependent measures. For these, searching for an innovative approach, localising measures via public involvement and reconciliation or using proxy variables could be considered as a solution. If data verified by theory is available, they can be used to form indicator sets which contain an easily understood rationale behind the indicator system. Following this deductive reasoning, it is possible to convert indicator sets into indicators and then making them more definitive according to the parameters.

On the theoretical level, indicators should be relevant to the respective aspect of sustainability and represent different domains of sustainability. On the practical front, they should refer to correct parameters that would be used for policy development and should have enough data background to be used for forecasting. Lautso et al. (2002) define these qualities as relevance, representativeness, policy sensitiveness and predictability. In relation to data availability and quality, they should be parsimonious as possible, but they should not suffer from omission of any key indicators. The main difficulty faced whilst using indicators is to find a common unit of measurement to compare performance of the setting or policy package. Gasparatos et al. (2007) state that there are three widely used sustainability assessment methods: (a) monetary tools; (b) biophysical models, and; (c) sustainability indicators and composite indices. Externalities converted into monetary terms (money or value of time) is the most preferred approach as undertaken for cost-benefit analysis in environmental assessment, while another popular method is to convert variables into units of global hectares as conducted by the carbon footprint concept. Biophysical models refer to entropy and/or carrying capacity concepts. For example, global hectares concept posed by carbon foot-printing method is a biophysical measure which is easily understandable, comparable and frequently used for policy formulation. However, it is not an easy task to convert social and some environmental qualities such as traffic fatalities, endangered species, protected habitats, human health into common units.

In this study, four basic indicator categories are employed to the structure indicator system. These four categories are separated into 10 theme and 14 indicators. Under these indicators, 47 parameters are selected. Table 1 below shows the indicator sets that will be used in the Gold Coast case study. These indicators are collected from various studies and public documents, including GCCC's 2007 Planning Scheme. At this initial stage of the study, the indicator sets are kept comprehensive so as not to risk of omission of key indicators and theoretical backing.

Table 1. Selected indicators for urban sustainability, derived from Hasse et al. (2003); Jeon et al. (2005); Allen (2008)

Categories	Indicator Set	Indicators
Demographics	Residents' characteristics	Employment rate
		Population density
		Car ownership
	Employees' characteristic	Jobs to housing balance
		Employment density
Land Use	Housing Compactness	Use mix ratio
		Dwelling density
		Single-family parcel size
		Single-family dwelling density
		Multifamily dwelling density
	Resource consumption	Wastewater generation
		Solid waste generation

		Energy use
		Residential water consumption
	Local characteristics	Park/social/cultural facility supply
	Transit orientation	Transit adjacency to residents, services and recreation
Transportation	Non-auto travel pattern	Transit adjacency to employment
		Transit proximity to employment
		Pedestrian network coverage
		Bicycle network coverage
	Auto travel pattern	Home-based vehicle kms travelled
		Non home-based vehicle kms travelled
		Home-based vehicle trips
		Non home-based vehicle trips
		Parking supply
	Pollution generated	Emissions of CO ₂ , SO ₂ , heavy metals and poly-aromatic hydrocarbons

Urban sustainability indexing system

In the literature, the terms of composite indicators and indices are considered as synonymous (Munda, 2005; Singh et al., 2009). While the final product of some studies is a composite indicator, the others produce a series of comparable indices; particularly in measuring sustainability which are grouped under the usual environmental, economic and social indices (Lautso et al., 2002). The main characteristic of the indices is that they do not have a unit, so that they are considered neutral and comparison between them is viable. The procedure followed in generation of the indices also highlights the main weakness of the composite indicators. Components are assigned weights with the proportion of variances in the original set of indicators, and can then be aggregated using an addition or a functional nature. Weights are used to correct the information overlap of correlated indicators, as to ensure that the results do not display a bias (Hanafizadeh et al., 2009). The weighting methodology carries value-dependent bias and, in some cases, weighting with linear aggregation causes substitution among indicators giving rise to acquire overly-normalised index values (Munda et al., 2005).

However, aggregation of these indicators as an index can cause, in some cases, critical information losses which make it difficult to identify negative or positive changes in the indicator due to the offsetting effects of positive indicators on negative ones. One example is in Oregon, where a framework measuring the levels of environmental, social and economic sustainability showed the rise in social and economic indices and a falling environmental index, but with a rise in the overall sustainability index (Schlossberg et al., 2003; Frame et al., 2006). The inability to identify negative movement of indicators may lead to remedial efforts that are applied too late, which would then render the whole exercise fruitless. Composite indices have also been criticized for its inability to show the negative movements of particular indicators, making it difficult to implement strategies that target specific problem areas (Neuman, 2006). Therefore, while working with composite indices, there is a need to control indicators in a disaggregated form, or at least, to select critical indicators that can be used for early warnings about criticality of the status.

In this study, as the first step, the relationship between indicators and stormwater runoff pollution will be clarified. For this, linear regression and factor analysis method will be used. By linear regression, the elasticity of each parameter will be gauged as to their contribution to stormwater runoff pollution. By using this information it would be possible to convey the policy options, namely, corresponding indicator set by which the stormwater runoff quality would be enhanced by its operationalisation. In the case of high co-linearity among variables,

alternatively, an initial search with which the interrelationship between the themes and indicators of the model is explored becomes inevitable. Instead of inputting all parameters into the regression model, the representative variables in accordance to their individual and partially composite contribution to overall stormwater quality will be selected via factor analysis. Regarding the respective factors in the model, it would be possible to calculate the effects of main drivers of the construct. It helps us to control the overall effects of highly correlated variables by incorporating them under the factors according to their communalities. After designation of the number of factors, it would be possible to make the necessary variable distribution among factor via factor rotation.

The second step in the model is to normalise the values of each indicator before weighting and aggregation procedures. There are three widely used methods for normalisations (Singh et al., 2009). The first method is to use standardised distributions, such as, normal or t-distribution. Secondly, it is possible to convert all values into standard ordinal scale, e.g. LIKERT scale, or thirdly, linear arithmetic normalisation procedures could be employed using minimum and maximum values of the indicators. The main differences between these approaches are that they give different weights to the values as to their difference from the mean value. Or, as in LIKERT scale, the values are placed into distribution-free scale bringing researchers' or public perceptions into the normalisation procedure.

The third step involves the weighting of each indicator or factors. Various techniques such as, multivariate analysis, factor analysis, public and expert opinion techniques, and so on, are employed for this procedure (Hass et al., 2002; Hák et al., 2007; Singh et al., 2009). The main consideration at this stage is to select a robust method that evaluates weights as to their relative importance in the model or alternatively, in the decision making procedure. The latter consideration is the reason for usage of public polls or Delphi method.

The last step in the model is aggregation of the respective indicators to produce a composite index or set of indices. While simple additive rules are generally employed in the literature, it is possible to define a functional form for aggregation. As stated by Singh (2009), ideally, composite indices should remain relatively simple in terms of their construction and interpretation, and the choice of method employed in weighting and aggregation is ultimately dependent on the nature and scope of the particular study.

Policy and decision support system

The index developed by the model will be used for benchmarking and performance assessment of stormwater infrastructure, its related policies and strategies, both current and future. This will allow for the review of the capacity and sustainability levels of current stormwater infrastructure, and enable the forecasting of future scenarios. Critical indicators will be able to be used for policy direction, strategic formation and used as a decision support system. As the fastest growing region in Australia, the model outcomes are expected to offer GCCC decision makers guides to the planning of future developments and for the long term sustainability of the City and significant ecological regions in the area, including national parks and RAMSAR wetlands. An index model has the communicative advantage of being easy to convey levels of sustainability, making it a relatively simple exercise for the general public as well as decision makers. The model will also be used for forecasting with future infrastructure scenarios being evaluated using predicted data, for example, the assessment on infrastructure plans in the South East Queensland Plan and Program 2009-2031. This is a never ending process, for a new scenario, new scientific evidence and new knowledge will always emerge.

Conclusions

In order to maintain the natural hydrologic cycle and protect receiving water quality, several planning strategies have been developed to manage human activities. Among them, SWM consists of a series of practices that ensures preventative approaches including site design to reduce runoff and protection of aquatic environments in urban areas. WSUD is an effective decision making process for SWM that offers a sustainable solution for integrating land development and water cycle in urban areas. As Wong (2006b) stated, the words 'water sensitive' define a new paradigm in integrated urban water cycle management that combines the various disciplines of engineering and environmental sciences associated with the provision of water services, including the protection of aquatic environments in urban areas.

Rapid population growth, combined with development pressure, in the City of Gold Coast has significant impacts on quality and quantity of natural water systems and the degradation of waterways and beaches. In response to this, GCCC have developed several technical resources including Land Development Guidelines, WSUD Guidelines, and Amended 'Works for Infrastructure Code'. In this context, the proposed indexing model for stormwater quality can be used as a decision-making tool for identifying the environmental impacts of urban stormwater by measuring the current sustainability performance of urban areas and proposing future infrastructure scenarios for the Gold Coast.

The stormwater quality indexing model is currently developed by the authors as part of an Australian Research Council Linkage Project: ARC-LP0882637 – Adaptation of Water Sensitive Urban Design to Climate Change, Changing Transport Patterns and Urban Form. The indexing model is currently being pilot tested in several pilot studies. Following the completion of this pilot testing the model will be amended, if necessary, and will be re-tested in a number of suburbs in the Gold Coast. The findings of this study are expected to provide insights and shed light on SWM development and assist municipalities, planners and other stakeholders to undertake planning projects. In brief, the model will support the future SWM projects of Gold Coast from a sustainability perspective and propose policies and strategies for both current and future needs.

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References

- Allen, E. (2008). Clicking Toward Better Outcomes: Experience With INDEX 1994-2006. In R. Brail (Ed.), *Planning Support Systems for Cities and Regions*. Cambridge, MA: Lincoln Institute of Land Policy.
- Andoh, R.Y.G. (2002). Urban drainage and wastewater treatment for the 21st century. In: 9th International Conference on Urban Drainage, 9-13th September 2002, Portland, Oregon.
- Arisz, H. & Burrell, B. (2006). Urban drainage infrastructure planning and design considering climate change. In: EIC Climate Change Technology Conference, 10-12th May 2006, Ottawa, Canada.
- Arnold, J.A., Line, D.E., Coffey, S.W., Spooner, J. (1993). *Stormwater Management Guidance Manual*, North Carolina Cooperative Extension Service and Division of Environmental Management, Raleigh, NC
- Commonwealth Scientific and Industrial Research Organisation (CSIRO), (2007). *Climate change in Australia—Technical Report 2007*. CSIRO, Australia.

- Frame, B., & Vale, R. (2006). Increasing uptake of low impact urban design and development: The role of sustainability assessment systems. *Local Environment*, 11(3), 287-306.
- Gallopín, G. (1997). Indicators and their use: information for decisionmaking. In B. Moldan & S. Billharz (Eds.), *Sustainability Indicators: Report of the Project on Indicators of Sustainable Development*. Chichester, GB: John Wiley and Sons Ltd.
- Gasparatos, A., El-Haram, M., & Horner, M. (2007). *The argument against a reductionist approach for assessing sustainability*. Paper presented at the International Conference on Whole Life Urban Sustainability and its Assessment, Glasgow.
- Gold Coast City Council (2007) *Water Sensitive Urban Design Guidelines, Section 13 of Planning Scheme Policy 11*, GCCC, Gold Coast.
- Gold Coast City Council (GCCC). (2009). *Climate Change Strategy*. Gold Coast City Council, Gold Coast, Australia.
- Hák, T., Moldan, B., & Dahl, A. L. (2007). *Sustainability indicators: a scientific assessment*. Washington, D.C.: Island Press.
- Hanafizadeh, M. R., Saghaei, A., & Hanafizadeh, P. (2009). An index for cross-country analysis of ICT infrastructure and access. *Telecommunications Policy*, 33, 385–405.
- Hass, J. L., Brunvoll, F., & Høie, H. (2002). Overview of sustainable development indicators used by national and international agencies, *OECD Statistics Working Paper 2002/2*. Paris: OECD Publishing.
- Hasse, J. E., & Lathrop, R. G. (2003). Land resource impact indicators of urban sprawl. *Applied Geography*, 23(2-3), 159-175.
- Hogan, D.M., Walbridge, M.R. (2007). Best Management Practices for Nutrient and Sediment Retention in Urban Stormwater Runoff, *Journal of Environmental Quality*, 36, 386-395.
- Jeon, C. M., & Amekudzi, A. (2005). Addressing sustainability in transportation systems: Definitions, indicators, and metrics. *Journal of Infrastructure Systems*, 11(1), 31-50.
- Lautso, K., Spiekermann, K., & Wegener, M. (2002). *Modelling policies for urban sustainability*. Paper presented at the 42nd Congress of the European Regional Science Association (ERSA), Dortmund.
- Livingston, E.H., McCarron, E. (1992). *Stormwater Management: A Guide for Floridians, Stormwater/Nonpoint Source Management*, Florida Department of Environmental Regulation, Tallahassee, FL.
- Lloyd, S. D. (2001) *Water sensitive urban design in the Australian context; synthesis of a conference held 30-31 August 2000, Melbourne, Australia (CRC for Catchment Hydrology Technical Report 01/7)*. Melbourne: Cooperative Research Centre for Catchment Hydrology.
- Lloyd, S.D., Wong, T.H.F., Porter, B. (2002). The planning and construction of an urban stormwater management scheme, *Water Science and Technology*, 45(7), 1-10.
- Munda, G. (2005). Multiple Criteria Decision Analysis and Sustainable Development. In J. Figueira, S. Greco & M. Ehrogott (Eds.), *Multiple Criteria Decision Analysis: State of the Art Surveys* (pp. 953-986).
- Munda, G., & Nardo, M. (2005). *Constructing consistent composite indicators: the issue of weights*. Italy: European Commissions, Luxemburg: EU Institute for the Protection and Security of the Citizen.
- Neuman, M. (2006). Infiltrating infrastructures: On the nature of networked infrastructure. *Journal of Urban Technology*, 13(1), 3-31.
- Rijsberman, M.A. & van der Ven, F.H.M. (2000). Different approaches to assessment of design and management of sustainable urban water systems. *Environmental Impact Assessment Review*, 20, 333-345.
- Schlossberg, M., & Zimmerman, A. (2003). Developing statewide indices of environmental, economic, and social sustainability: a look at Oregon and the Oregon Benchmarks. *Local Environment*, 8(6), 641-660.
- Shaw, H., Reisinger, A., Larsen, H. & Stumbles, C. (2005). Incorporating climate change into stormwater design—why and how? In: 4th South Pacific Conference on Stormwater and Aquatic Resource Protection, 4-5th May 2005, Auckland, New Zealand.

- Singh, R. K., Murty, H. R., Gupta, S. K., & Dikshit, A. K. (2009). An overview of sustainability assessment methodologies. *Ecological Indicators*, 9, 189-212.
- Sundberg, C., Söderberg, H. & Svensson, G. (2004). Re-framing the assessment of sustainable stormwater systems. *Clean Technology Environmental Policy*, 6, 120-127.
- The Australian Government National Water Commission. Available from: <<http://www.nwc.gov.au/www/html/214-integrated-urban-planning.asp>>.
- Veleva, V., & Ellenbecker, M. (2001). Indicators of sustainable production: framework and methodology. *Journal of Cleaner Production*, 9(6), 519-549.
- Victorian Stormwater Committee (1999). Urban stormwater: best practice environmental management guidelines, Melbourne: CSIRO Publishing.
- Voice, M., Harvey, N. and Walsh, K. (2006). (Editors) Vulnerability to Climate Change of Australia's Coastal Zone: Analysis of gaps in methods, data and system thresholds. Report to the Australian Greenhouse Office, Canberra, Australia. June 2006.
- Wong, T.H.F. (2002). *Urban Stormwater Management and Water Sensitive Urban Design in Australia*, paper presented at the 9th International Conference on Urban Drainage, Portland, Oregon, USA.
- Wong, T.H.F. (2006b). Water Sensitive Urban Design – the Journey Thus Far, *Australian Journal of Water Resources*, 10(3), 213-222.
- Yigitcanlar, T., Fabian, L. and Coiacetto, E., (2007a). Urban transport sustainability in the Gold Coast, Australia. *ABACUS Journal*, 2(1), 50–66.
- Yigitcanlar, T., Sipe, N., Evans, R. and Pitot, M., (2007b). A GIS-based land use and public transport accessibility indexing model. *Australian Planner*, 44(3), 30-37.
- Yigitcanlar, T., Fabian, L. and Coiacetto, E., (2008). Challenges to urban transport sustainability and smart transport in a tourist city: The Gold Coast, Australia. *The Open Transportation Journal*, 1(2), 19-36.
- Yigitcanlar, T., (2009). Planning for smart urban ecosystems: information technology applications for capacity building in environmental decision making. *Theoretical and Empirical Researches in Urban Management*, 3(12), 5-21.