Assessing urban water strategies for Total Water Cycle Management

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Summary

This paper reports on a study undertaken as part of the Urban Water Security Research Alliance to explore the applicability of a number of emerging integrated assessment methods to Total Water Cycle Management planning. The decision making context is elaborated on, and then the assessment methods are briefly described. The paper concludes with a discussion on how these integration assessment activities can help in Total Water Cycle Management planning in South East Queensland (SEQ). The discussion is undertaken with the target context of Moreton Bay, but with no explicit case study being described.

Key words

Integrated assessment; Total Water Cycle Management; Optimisation; Uncertainty analysis; Cost effectiveness

Introduction

Total Water Cycle Management (TWCM) is described as a management philosophy based on systems thinking that recognises that all elements of the water cycle are interdependent (Water by Design, 2010), and has been applied to decrease water demand, reduce stormwater run-off and improve pollutant wash-off from urban catchments by adopting sustainable water management practices (Chanan and Woods, 2006; van der Sterren et al., 2009). The approach has been incorporated into water planning and management practices in a number of Australian contexts (Arbon and Ireland, 2003; Chanan and Woods, 2006; Najia and Lustig, 2006; van der Sterren et al., 2009). It is a value-driven philosophy with holistic aspirations of managing the full total water cycle to achieve desirable environmental outcomes. As such, it is similar in aspirations and values to other concepts such as Water Sensitive Urban Design (Wong, 2006), Sustainable Urban Water Management (Larsen and Gujer, 1997), and Integrated Urban Water Management (Burn et al., 2012; Maheepala et al., 2010). Activities that are typically associated with TWCM are greywater recycling, sewer mining, rainwater harvesting or stormwater harvesting; or Water Sensitive Urban Design (Arbon and Ireland, 2003; Chanan and Woods, 2006; Najia and Lustig, 2006; van der Sterren et al., 2009).

In SEQ, a recent history of water scarcity has prompted major investments into infrastructure, with “the grid” being a key part of the strategy to link water supplies across SEQ that include new dams, desalination facilities and water recycling infrastructure (Brown et al., 2009). The response to water scarcity also included water restrictions and mandated water conservation efforts for new developments (Brown et al., 2009; Queensland Government, 2008). Brown and colleagues argue, perhaps unfairly, that SEQ missed the opportunity to adopt modern concepts of urban water management (such as TWCM) as a means to deal with this crisis because they did not develop contingency plans for alternative, future climatic scenarios and overlooked the existing suite of decentralised technological approaches available (Brown et al., 2009). However, Total Water Cycle Management plans are now required for all councils in the region aiming to achieve a larger SEQ Healthy Waterways Vision as part of the wider SEQ Water Strategy developed by the Queensland Water Commission (QWC) (Harman and Wallington, 2010). Key elements in the QWC’s commitment to TWCM are the consideration of all water sources (including wastewater and stormwater), sustainable use of water, equitable allocation of water, and the consideration of natural water processes (Harman and Wallington, 2010). TWCM is currently being implemented in SEQ at the regional, sub-regional and local scales, including a number of projects, programs and initiatives.

To support decision makers and managers in SEQ, Dutra and colleagues (2010) have developed a Management Strategy Evaluation (MSE) tool to support decision makers in SEQ to assess different strategic options. Decision makers in this case are managers from local councils and natural resource management bodies. It is important to note that the management strategies that are considered involve not only those related to urban water management, but also those that relate to farming practices, vegetation, channel erosion, rural stormwater, wastewater disposal, urban stormwater and urban design. The evaluation of strategies is done on the basis of indicators of water quality (total nitrogen, total phosphorous, turbidity, chlorophyll, light penetration and...
dissolved oxygen) which are used to assess health of waterways. Social perceptions of the value of the health of waterways are also considered as well as economic assessments of management options. The process of designing management strategies for evaluation is done through a MSE computer model and results are simply displayed to show outcomes for Water Quality Scorecards and cost approximations.

This paper reports on a study undertaken as part of the Urban Water Security Research Alliance to explore the applicability of a number of emerging integrated assessment methods to TWCM planning. Secondly we will discuss how the emerging integrated assessment methods can be applied to develop evidence based TWCM plans in SEQ. The study backdrop is the Moreton Bay Regional Council local government area where a TWCM plan is currently being developed by the Moreton Bay Regional Council. Methods are being developed to support TWCM in this location.

The decision problem
To support decision makers in assessment activities, it is imperative to first understand the decision making context. On the surface, the task seems relatively simple, i.e. a) define a number of possible strategies, b) evaluate which strategy that will best achieve goals according to defined criteria, and c) choose and implement the strategy that appears to be the most appropriate. Obviously, reality does not quite oblige to allow this simple process, for a number of reasons. These seven points, inspired by Rittel and Webber (1973), are difficulties that decision making tools/frameworks should ideally consider and/or address, including difficulties relating to:

1. **Goal formulation**: this is not well-defined and there are many possible goals that one may want to achieve, and the choice of assessment metrics is a value-driven process.

2. **Limited scope**: strategies are not always within the control of decision makers: they will only be able to influence a sub-set of those factors that have an impact on the desired outcomes.

3. **Unlimited option space**: it is virtually impossible to define an exhaustive list of conceivable strategy options, and the formulation of such a list is a process that requires creativity and analysis, in combination with some kind of filtering out of solutions that are not, for various reasons, appropriate.

4. **Assessment difficulties**: the nature of the TWCM problem is difficult to describe in a way that easily helps us to evaluate the effectiveness of strategies (in achieving goals). Systems are usually not very well understood, and there are serious limitations in terms of data, limiting the scope of assessments.

5. **Limited planning capacity**: the amount of effort spent on the task of finding and choosing strategies is more constrained by issues like the availability of money, time or understanding, rather than the sense of “being sure of having found a good solution”.

6. **One-off operations**: every time this exercise is undertaken there are unique factors, such as local weather patterns, land use patterns and geography, that can’t be ignored, and there are therefore limited opportunities to learn by trial-and-error. Incorporating judgments on the importance of such factors would be important.

7. **High stakes**: every TWCM decision will have (sometimes serious) impacts on the community, and the planner is in some ways to be found responsible for the outcomes of his recommendations.

Considering these issues, it is perhaps not surprising that there is a complex set of classes of interacting factors that contribute to good decision making in the TWCM context (Dutra et al., 2010): leadership (presence of transactional leaders or not, etc), information (availability and quality), regulatory framework (existence or not, conflicting or not), conditions (favourable or not), assumptions (robust or not), communication (effective or not; good or bad quality), and logistics (implementation and timing of strategies, etc). The relative importance of each of these factors for a perceived successful strategy choice and implementation depends on the application. Modelling primarily concerns information and assumptions, but could also support communication, realisation, logistics and even leadership. The function of modelling activities in a decision making contexts like this needs to be viewed in a holistic sense and not just in terms of the validity of models. The paper describes four activities in TWCM planning (as per Figure 1 but excluding the evaluation), and subsequently presents how integration assessment activities in the study context of Moreton Bay can contribute to this process in a way that hopefully deals with some of the properties of the decision problem described above.
Activities in TWCM Planning

The process of TWCM planning involves a number of steps, as per Figure 1, and the outcome of the planning process is a recommendation. This is a similar process to that of decision making in general, and in fact similar to the (structured) process of deciding which car to purchase. When purchasing a car, one may consider what the assessment metrics are (fuel efficiency, reliability, price, safety, aesthetics, etc), and would identify some viable options (Honda Jazz, Toyota Yaris, etc), then collect information about each of the options against each of the assessment metrics and finally synthesise all this and come to a recommendation. TWCM planning is similar, where a large set of assessment metrics are broadly grouped in three major groups (economic, environmental and social). However, other categories like health and system reliability are now being added as main assessment metrics. In the case of TWCM planning, problem definition is not as clear.

Definition of key indicators

There are many potential goals that could be considered in TWCM, and an important step in planning processes is to identify which assessment metrics should be the basis for analysis. For example, the assessment metrics used in the MSE (Dutra et al., 2010) are different to those explored by Sharma and colleagues (2009), which in turn are different to those that are explored in our context of Moreton Bay. Choosing the “right” set of assessment metrics is a strategic decision that is value-driven and where stakeholder input is essential; and this is a step that is outside of the scope of traditional modelling activities. The choice of assessment metrics should not however be dictated fully by what is “easy to evaluate”. To only assess that which is easy would be like deciding which car to purchase on the basis of what it looks like alone. Further relatively straight-forward research may reveal critical aspects, such as its fuel efficiency, safety, reliability and its general condition. Further assessments of the car, such as inspection of the detailed condition of the car may be considered crucial, but will come at a significant cost. Such more detailed assessment would only be undertaken once you are “almost certain” that you’d like to make the purchase. This example illustrates how assessments typically need to be undertaken at different levels of detail at different stages of the assessment process.

Definition of strategies

TWCM strategies include, but are not limited to, a range of water supply options, farming practices, riparian re-vegetation, channel erosion and bank stabilisation, rural stormwater, wastewater disposal, urban stormwater and urban design. Different approaches to urban water management that include rainwater harvesting are also considered. Strategies are also both spatial (i.e. different actions at different locations) and temporal (i.e. different actions at different times). As such, even when the individual actions are within a limited set, the total number of possible strategies is very large. Also, not all strategic actions are available for decision makers, and this shows that there is a need to coordinate actions across a range of stakeholders. Furthermore, the reality of the TWCM process is that the definition of strategies is an on-going and adaptive process, with feedback from assessment of strategies and synthesis into the definition of strategies as in Figure 1.

Assessing strategies against indicators

When evaluating different strategies in TWCM, there are a range of aspects to consider. These are often categorised as social, economic and environmental aspects, in a triple bottom line framework as Baldwin and Uhlmann (2010) claim is needed for water planning in SEQ. This prompts the following questions, relating to each strategy’s range of impacts (i.e. its assessment metrics):
• What are the environmental impacts, locally and globally? In the target context of Moreton Bay, such questions are answered by means of Life Cycle Assessments (LCA) with the evaluation of a number of assessment metrics: freshwater extraction, eutrophication potential, global warming potential, ozone depletion potential, etc.
• What are the social impacts, locally and globally? In the target context of Moreton Bay, Externalities assessments help answer such questions.
• What are the economic implications? In the target context of Moreton Bay, this would be assessed in terms of costs and cost-effectiveness of strategies.

It is very common that some assessment metrics, such as community acceptance or logistic feasibility, cannot be assessed (or are too costly to assess) by means of analytic approaches and in such cases it is possible to rely on expert knowledge, or other judgments that are considered to be reliable.

Synthesising assessment results into a coherent recommendation
To reach recommendations for TWCM, assessments of a range of strategies must be synthesised into one single analysis. This is problematic from the point of view that one typically has to balance the achievement of one goal against the achievement of another. It is a rare situation when the maximum achievement of all assessment metrics occurs for a single solution; and this raises the need for considering the priorities of stakeholders such as the public, business interests and government. Furthermore, one may at this point have to consider uncertainty in outcomes, for example the cost for one solution may vary considerably depending on what the future brings (as for example would be the case if the cost relied on the price of petrol), whilst another strategy carries a completely certain cost. The synthesis would also have to consider the adequacy of the information that is available, and perhaps whether better information is required before a recommendation can be made.

Integration assessment activities
There are three integration assessment-related methods that could support decision making in the TWCM context either by themselves individually, or in a combined framework. These are briefly described below.

Multi-objective optimisation
Multi-objective optimisation (MOO) is a process that can be undertaken on mathematically formulated problems where the goals are clearly defined using one or a number of functions. It is a process that searches through a multitude of possible decisions and evaluates them based on how they perform against a set of assessment metrics. For the Moreton Bay case study (Grant et al., 2010), the decisions include which infrastructure to develop, and which policies to implement, for example whether to supply recycled water to urban users, or retrofit rainwater tanks to existing dwellings, etcetera, there being 35 solutions in all. With many such proposed strategies, the possible number of combinations grows exponentially, so an automated approach to searching through them may be warranted. After the optimisation is completed, a Pareto front of the optimal solutions is produced. Such a graph shows the trade-off between the objectives. This can be useful information to allow planners to remove those alternatives from consideration that are sub-optimal regardless of value judgments. This leaves the planner with a much smaller subset of possible strategies to deal with. The planner may subsequently select the most expensive, most effective solution, or compromise on price to achieve less benefit, while keeping in mind any objectives unable to be represented easily by software (such as public acceptability).

By creating a hypothetical model of Moreton Bay incorporating the many different proposed solutions, the aim is to determine the circumstances under which multi-objective optimisation approach is useful to TWCM. The main limiting factor for its usefulness will be the accuracy of the Moreton Bay model itself – optimising a model to a fine degree can be counter-productive if the model itself is a course representation of the real world system (Cunge, 2003). In such cases, analysing a few different scenarios by hand after a panel of experts has performed a Multi-criteria Analysis (MCA), the approach taken in Moreton Bay (Grant et al., 2010), may well be superior.

Cost-benefit analysis
Cost-benefit analysis calculates improvement in assessment metrics on a per invested dollar basis. This is a critical tool to allow for comparison of actions to improve assessment metrics (such as pollution of phosphorous into Moreton Bay) within the scope of the study context (for example urban stormwater harvesting) with those that are outside the scope of the Moreton Bay case study (for example changed agricultural practices in the catchment). This provides a way for policy makers to identify target areas in order to reach policy targets at minimum cost. The approach adopted in this study in Moreton Bay was to calculate an extended cost effectiveness (Hall, 2012). Pollution abatement costs within the catchment, when applied to the Moreton Bay study context, were calculated to reach a range of water quality objectives. The cost of abating pollution from the Moreton Bay study area was then added to the capital and operating costs of the strategy option. This
Uncertainty analysis
Bayesian Networks and Subjective Logic can be used in a framework to combine a number of assessments into one single assessment; either within a sustainability assessment framework (Moglia et al., 2011; Moglia et al., 2012b) that can be extended into a Multi-Criteria Decision Assessment framework that incorporates subjective value judgments by stakeholders (Hajkowicz and Collins, 2007), or in a Bayesian Network framework that calculates the combined likelihood of achieving all the separate goals defined in terms of thresholds (Moglia et al., 2012a). Furthermore, incorporating Subjective Logic into the framework adds the ability to assign a “reliability” judgment on all the probabilistic statements (i.e. sub-assessments), and hence allows for assessing the overall “reliability” of the integrated assessment, as well as the uncertainty in the overall outcomes. If monetary value judgments are assigned to different outcomes, it is also possible to estimate the aggregated value of a strategy outcome, both in terms of the statistical expectation (monetary) value as well as the standard deviation, describing the amount of expected uncertainty around this expected value outcome. This method is also particularly useful for incorporating different types of assessments and judgments into a coherent whole, and hence this allows for combine qualitative judgments made by experts with the more robust quantitative assessments made by analysts. It is thought that this type of analysis is particularly useful in the process of synthesising a range of assessments into a single recommendation.

Discussion
In this paper, the process of TWCM has been described both in terms of its process as well as some of its dilemmas. Furthermore, three types of integration assessment activities have been described, and now we intend to discuss how those activities can support the TWCM process, and where particular methods can bring value throughout the process of narrowing down options, see Table 1 describing their sequence.

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<tr>
<th>Process</th>
<th>Issues and implications relating to integration assessment</th>
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<tr>
<td>1. Define key indicators</td>
<td>The definition of assessment metrics remains outside of the scope of integration assessment, but provides critical input into the process. The critical issue is that the subsequent feasibility of assessment should not limit the choice of metrics. Choose an integration framework that supports the incorporation of both quantitative assessments and expert judgments.</td>
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<td>2. Definition of strategies</td>
<td>Multi-criteria optimisation, if the problem can be translated into mathematical formulation, can help narrow down the number of interesting strategies into a smaller set that is manageable from the subsequent analysis point of view. Interestingly however, the optimisation approaches requires automated assessments, although the process of undertaking assessments is a subsequent step. Hence, the automated assessments are usually limited to only a sub-set of assessment metrics and to approximations, and therefore, this approach has to be seen as a first attempt at reducing the complexity of the decision problem rather than a tool that provides recommendations.</td>
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<td>3. Assessments of strategies against indicators</td>
<td>Assessments need to be carried out for all assessment metrics, even though some of these are based on rigorous and quantitative analysis; whilst other assessments are most likely based on expert judgments. To be incorporated into subsequent uncertainty analysis, assessments need to evaluate uncertainty as well judgments on the reliability of each sub-assessment.</td>
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<td>4. Synthesis of assessments into recommendations</td>
<td>This can be done using Multi-Criteria Assessment, Cost-benefit analysis, or Uncertainty Analysis. Uncertainty analysis using Bayesian Networks and/or Subjective Logic provides a way to incorporate all the assessments into a single recommendation in a way that makes transparent the uncertainty in outcomes as well as the reliability of assessment (i.e. whether you can trust it). This allows the planner to formally describe his reasons for why further analysis and/or data collection is needed. It also provides a way to formally undertake risk management. Given the high stakes of the problem, it is prudent that the planner makes sure that he/she does not put the community at risk of severe unwarranted consequences. Sometimes a certain (i.e. low risk) but not optimal solution is better than an optimal but risky solution (on average good but small chance of very poor performance). This is likely to reduce the cognitive load for the planner and is hoped to reduce any cognitive biases.</td>
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<td>5. Recommendations for TWCM</td>
<td>Cost-benefit analysis provides a way to compare different assessment outcomes, both within the decision makers range of influence, as well as outside of this range; and hence provides an excellent approach for communicating results. It is thought that recommendations have to be provided to government as well as to stakeholders, and that estimated cost-effectiveness provides a way to justify expenditure on strategies.</td>
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Other considerations in the process of synthesising a number of assessments into a single recommendation relate to the nature of the decision making problem (see the 7 dilemmas previously described). Some of these dilemmas have already been addressed in Table 1 (i.e. relating to goal formulation, definition of strategies, limitations on data and the need to incorporate expert judgments). Perhaps the most important dilemma relates to decision makers limited availability of time and funds in order to come to a recommendation; and the fact that data and analysis is not necessarily the only pathway towards good decision making. This critical factor, and the complex nature of the problem, means that a straightforward approach (in terms of the decision makers’ process, not in terms of underlying algorithm) such as the MSE (Dutra et al., 2010) would seem appropriate. This approach allows for easy formulation and assessment of strategies against a range of criteria, which means that the decision maker can quickly learn about the nature of the TWCM problem. The MSE would appear to be, at the very least, an appropriate tool in the initial stages of TWCM planning. The question is whether more in depth and detailed analysis is warranted? The answer to this question depends on the level of risk taking that is appropriate. If there is a need for more detailed analysis of TWCM strategies (as would be indicated by dilemma 6 and 7 above) then uncertainty analysis may provide a good framework for the incorporating detailed analysis, based on initial Life Cycle Analysis and incorporating externalities.

Finally in terms of strengths of different approaches, it is thought that the cost-benefit analysis provides an excellent means for communicating results both within and outside of the planners’ organisation. It provides a way to benchmark the actions (for example in relation to reducing pollution loads into Moreton Bay) against other plausible actions by others or oneself. This addressed the concern that any action that is recommended by the planner depends on what is considered to be within the scope of the planner; whilst ignoring potential other strategies that may be much more cost-effective means of achieving the same goals. To conclude, we believe that the integration assessment activities within the context of Moreton Bay can definitely support the TWCM planning process, but that the practical testing of these activities to real cases would need to be undertaken to ensure that this is indeed the case.

References


