Towards a socio-technical framework for mapping and diagnosing transformational dynamics in urban water systems

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ABSTRACT
As the stress on urban water systems from climate change impacts, population growth and resource limitations continues to grow, the need to transition to sustainable urban water management is being increasingly acknowledged. However, understanding of how strategic planning should be made operational to enable this transition is limited, as the links between strategic action and the processes of transitional change are poorly understood. This paper reports on a social research investigation that aims to develop a diagnostic tool that can be used to inform the design of strategic action in urban water systems from the perspective of dynamic transformative change. A meta-analysis of literature that proposes frameworks for understanding the sustainability of complex socio-technical systems was undertaken in relation to an empirical case of recent transformational change in the stormwater management system of Melbourne, Australia. Each framework revealed useful insights but none were sufficient to fully map, explain and predict the transformational change in the case study. Comparison of the frameworks identified their distinct aims and key strengths and each was located within a schema that highlights how they could most usefully be used within an overall diagnostic process.

KEYWORDS
Urban water; transition; transformative change; strategic planning; diagnostic framework; sustainability

INTRODUCTION
Urban water systems are coming under increasing pressure due to climate change, population growth, ongoing urbanisation, environmental pollution, resource limitations and ageing infrastructure. These stresses have caused threats to water supply security, heightened flooding risk and the deterioration of urban waterway health in cities around the world (Pahl-Wostl *et al.*, 2010). The ensuing water management challenges will be exacerbated into the future, particularly as global impacts of climate change become more severe (Bates *et al.*, 2008), and there is now a growing awareness and acceptance of the need for urban water servicing to transition to sustainable approaches (Pahl-Wostl, 2009; Pahl-Wostl *et al.*, 2010).

For this transition in urban water systems to occur there will need to radical changes to its social and biophysical structures and processes. However, transformative change is impeded by a range of socio-institutional barriers, including institutional inertia and fragmentation, lock-in due to path-dependencies, and inadequate institutional, professional and community capacity to engage in new management practices (Brown, 2008; Pahl-Wostl, 2009).

There is limited research on how strategic planning should be made operational in order to overcome such socio-institutional barriers and enable a transition (Brown, 2008), although academic discourse is now starting to explore the topic. Recent literature argues the need to avoid panaceas or blueprints, which have been widely critiqued as being too simplistic to cope with complex, uncertain, nonlinear and changing contexts within which interdisciplinary systems are managed. Instead scholars (eg. Ostrom, 2009; Pahl-Wostl *et al.*, 2010) argue that diagnostic approaches need to be developed, which typically aim to determine the nature, cause or source of some problem, undesirable outcome or system state by considering complexity in a systemic fashion (Ostrom and Cox, 2010; Pahl-Wostl, 2009).

Despite these recent calls for new approaches, diagnostic tools have not yet been applied to gain operational insights for urban water servicing. Such insights would be particularly valuable for situations where radical changes to the way in which water servicing is designed, operated, managed, governed or valued are required to achieve more sustainable, or water sensitive, outcomes. Fundamental system-wide change in the structure of a system and the way in which it functions, as described above for water servicing, is more generally referred to as transformative or transitional change.

There is currently limited understanding of the links between strategic action and complex dynamics of transformative change (Chapin III *et al.*, 2010), so more research is required in order for tools to be developed to support strategic planning from this perspective. This paper reports on the first phase of a qualitative social research investigation that aims to develop a diagnostic tool that planners, policy analysts and decision-makers can use to inform the design of strategic action in urban water systems from the perspective of dynamic transformative change.

APPROACH

The methodological approach for this research involved theory testing and comparison as part of a meta-analysis of literature that examines the sustainability of complex interdisciplinary systems. Four analytic frameworks were applied to a common empirical case study in order to compare their features and test their potential value as platforms from which to build a diagnostic tool for transformative change in urban water servicing.

The frameworks were selected for review and application to the empirical case based on their interdisciplinary and systemic nature, their focus on sustainability and their applicability to the context of urban water servicing. The key attributes of each framework are outlined in Table 1.

The frameworks in Table 1 were each applied to an established empirical case of recent transformational change. The case study was a grounded historical analysis of how urban stormwater management in Melbourne has changed from mid 1960s to 2006 (for full details of the case study see Brown and Clarke, 2007). The empirical data in this case provided a reference case study with which to compare and benchmark the different analytic frameworks.

The context for the reference case study is the management of diffuse sources of pollution in the stormwater drainage system in Melbourne, Australia. During the period of study, growing awareness and community concern about the poor health of Melbourne's waterways led to a scientific focus on understanding the causes of urban waterway degradation and developing ways in which stormwater pollution could be reduced. New innovative technologies for

improving the quality of stormwater before it enters urban waterways were developed and, over time, practices that prioritised urban stormwater quality management (USQM) were institutionalised, fundamentally changing the direction of mainstream stormwater management policy (Brown and Clarke, 2007). The reference case study provides an analysis of how and why these transformative processes occurred. It is significant as an international exemplar of a city in which stormwater quality management practices have been mainstreamed.

Table 1. Attributes of the analytic frameworks.

Attribute	Panarchy Framework	SES Sustainability Framework	Management and Transitions Framework	Multi-Pattern Transitions Framework
Purpose	Analyse adaptive capacity and resilience in social-ecological systems.	Analyse sustainability in social-ecological systems.	Analyse water governance processes.	Analyse societal transitions.
Analytic Goal	Describe and explain dynamics of system-wide change and their implications for governance.	Describe, explain and organise the key variables that are significant for system sustainability.	Organise the structures and processes in a transitional system and their implications for governance.	Describe and explain the conditions, patterns and pathways of system-wide change.
Theoretical roots	Ecology; social-ecological systems; resilience.	Institutional Analysis and Development; ecology; socio-economic systems; social-ecological systems; resilience.	Institutional Analysis and Development; social-ecological systems; multi-loop social learning; adaptive management; transitions.	Complexity theory; integrated assessment; technology diffusion; innovation; societal transitions.
Theoretical concepts	Adaptive cycle; panarchy; rigidity trap; poverty trap.	Nested tiers of variables; networked action situations.	Action arenas and action situations; single, double and triple-loop learning.	Conditions – tension, stress, pressure; patterns – empowerment, reconstellation, adaptation.
Key references	Berkes *et al.*, 2003; Folke, 2006; Gunderson and Holling, 2002.	McGinnis, 2010; Ostrom, 2009; Ostrom and Cox, 2010.	Knieper *et al.*, 2010; Pahl-Wostl, 2009; Pahl-Wostl *et al.*, 2010.	de Haan, 2010; de Haan and Rotmans, 2011; Rotmans and Loorbach, 2009.

This paper reinterprets the reference case study through the application of the four frameworks to compare and contrast their features in relation to the development of a tool for mapping and diagnosing transformative change. Key understandings about the reference case study that were revealed through each framework were explored and any clear analytic gaps were identified.

While the frameworks have distinct backgrounds and purposes, the results provided insights on the ability of the existing concepts in these analytic frameworks to explain the variables, mechanisms and dynamics in the empirical case study. These insights were then used to outline the necessary features of a diagnostic tool that can map, explain and predict transformational change in urban water servicing.

APPLICATION OF FRAMEWORKS

The four frameworks were applied to the reference case study. Key understandings about the case study that were revealed through each analysis are described in the following sections.

Panarchy Framework

The framework revealed a long period of policy development around large-scale centralised drainage infrastructure. This regime was stuck in a "rigidity trap" for around 20 years, which limited the system's ability to adapt to new conditions. Growing community awareness and expectations around environmental issues led to significant contextual changes, forcing the regime to break from its rigidity trap as its traditional stormwater management policy began to fail; it was no longer adequate to the meet society's need for healthy waterways and bays.

This failure offered a window of opportunity for the innovative developments to transform mainstream policy. While the regime was in its rigidity trap, the lower scale innovation around decentralised USQM infrastructure had been developing new technologies. When the policy failure intensified, the innovation could provide the regime with a range of infrastructure options to support the policy alternatives.

The policy options stimulated by the USQM innovation were underpinned by a new paradigm, based on small-scale decentralised flexible infrastructure. As the regime began to adopt these policy alternatives, it entered a new and different adaptive cycle, exiting from the old centralised drainage cycle; in other words a transition took place. The transition, however, is only partially complete as policy plans in the new adaptive cycle are still in development and there is much growth needed before the new policy regime is implemented and stabilised.

SES Sustainability Framework

The framework identified six distinct action situations that were important for creating change to the way in which stormwater is managed were identified: society and politics; rule-making; provision; implementation; use; monitoring and sanctioning. These action situations form a network, with outcomes of one action situation providing inputs to an adjacent action situation (McGinnis, 2010), emphasising the need for entities to be interacting in each of the different adjacent functional action situations in order for the system to function properly.

There was significant overlap in the types of actors that were involved in the rule-making, provision and implementation action situations, indicating the strong potential for self-organisation amongst the actors and potentially explains the success of the transition towards more sustainable stormwater management. In particular, the state-owned water utility and the

municipalities were shown to be key actors in almost all the action situations, highlighting the need for positive interactions between these key actors and their relative importance for successful functioning of the system.

Management and Transitions Framework
Informal processes (double- and triple-loop learning) played a key role in transforming the way in which stormwater was managed. Informal action situations covered all the phases in a learning cycle and all three institutional rule levels (constitutional, collective-choice, operational), potentially explaining the success of the innovation's growth to date. Formal action situations typically stemmed from previous informal action situations, further highlighting their importance in the overall transition.

There was a lack of locally driven action situations; most local situations were driven by state actors. This explains the case study's conclusions that there needs to be a strong emphasis on increasing the capacity of local councils in the area of stormwater quality management. Finally, the analysis highlighted that most of the action situations have been focused on developing policy, operational goals and measures, with much less emphasis on formal strategic goal setting as part of the policy cycle, as well as the other end of the cycle, implementation and monitoring. Perhaps these gaps indicate where future efforts should be focused to finalise the transition and make stormwater quality management mainstream.

Multi-Pattern Transitions Framework
Over a period of 20-30 years, growing community engagement with the urban landscape and awareness of environmental issues led to a significant change in how society values the health of urban creeks, rivers and bays. This new prioritisation of urban waterway health was a key top-down driver for change to the way in which stormwater is managed and led to the empowerment of a niche centred on the development of decentralised technologies for improving stormwater quality before it enters receiving waterways.

As society's need for healthy waterways grew, the empowered stormwater quality technology niche offered an increasingly viable alternative to the established regime, which was focused on the efficient conveyance of stormwater through large-scale centralised drainage infrastructure. The power dynamics between the regime and the niche were critical factors in determining how the system transformed in terms of the functioning of its stormwater management.

RESULTS AND DISCUSSION

Analysis of the four interdisciplinary sustainability-focused frameworks showed that each revealed useful understanding about the reference case study but, in isolation, none were sufficient to fully map, explain and predict the transformational change that has occurred in Melbourne's stormwater quality management system. The strengths and weaknesses of each framework in relation to explaining the data in the reference case study are summarised in Table 2.

Comparing and contrasting the four frameworks highlights that each has distinct aims and strengths, all of which are useful for understanding different aspects of the sustainability of interdisciplinary systems. However none of the frameworks are explicit about what specific diagnostic questions each intends to address and therefore how they should be used within an overall diagnostic process.

Table 2. Analytic strengths and weaknesses of each framework in relation to explaining the data in the reference case study.

	Strengths	Weaknesses
Panarchy Framework	Reveals the relative adaptive capacity of different scales and how this influences system change. Highlights critical interactions between scales that shape system change.	Limited in providing insight for designing policy action. Relatively abstract framework, which can be difficult to operationalise for application to empirical cases.
SES Sustainability Framework	Organises nested levels of variables so those that are critical can be identified. Determines functional adjacent action situations and key actors involved. Provides a framework for organising the collection of data (to enable meta-analyses of different case studies).	Narrowly defines a social-ecological system to common-pool natural resources. Provides a static analysis only. Assumes that transformational change in a system is negative, focusing instead on avoiding disturbance to maintain resilience.
Management and Transitions Framework	Highlights key sequences of processes and links between formal policy processes and informal social learning processes. Determines the role of actors in different action situations.	Provides limited insight into the impact of context. Does not reveal power dynamics between established formal processes and innovative informal processes.
Multi-Pattern Transitions Framework	Provides analysis of narratives of system-wide change. Reveals contextual and internal influences on system changes. Explores power dynamics between an institutionalised regime and new niche-innovations. Considers societal needs and how they may be met in the future.	Does not reveal insight into the internal dynamics of subsystems. Limited ability to reveal the smaller-scale processes and lower level variables that drive the patterns of system-wide change. No reference to actors and their role in influencing system change.

Comparison of the frameworks reveals two critical dimensions for mapping and diagnosis. The first is the scale of analysis. Analysis needs to be undertaken at both the system-wide scale and the scale of the individual system elements. The second is the dynamism of the analysis. Both static and dynamic perspectives are required in order to gain full understanding of the system. Figure 1 plots the frameworks considered in this research against these two dimensions, demonstrating where each currently provides focus (it is acknowledged that the frameworks are generally in early phases of development so their location may change with further research).

Figure 1 emphasises a key conclusion of this paper; there are different elements to diagnosis that require different analytic lenses to reveal useful information. So for an analyst with a particular problem that could be usefully addressed through a diagnostic approach, the framework that is selected for use depends on what specific diagnostic questions are being considered. For example, if understanding of the static individual variables that a system comprises were required for one point in time, then the SES Sustainability Framework would be the most suitable. If understanding of the system-wide dynamic changes were required, then the Multi-Pattern Transitions Framework would be the most suitable.

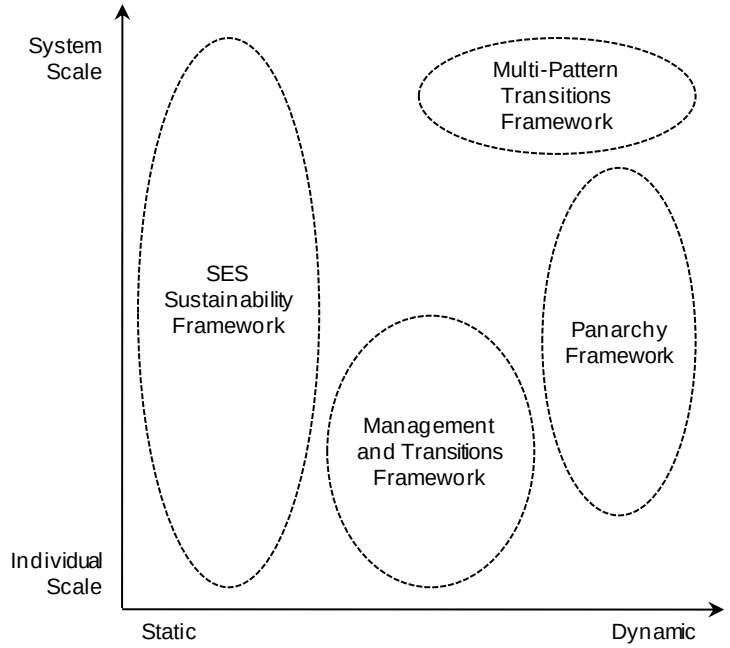

Figure 1. Key dimensions of diagnostic frameworks

If the diagnosis aims to fully map, explain and predict changes in the system, then multiple frameworks may need to be used. Application of multiple frameworks to provide a comprehensive diagnosis for transformative change in a system should provide understanding of the key institutional and biophysical dimensions of a system; the variables that describe the system's biophysical and social features; the processes or mechanisms that shape significant change within the system; the macro-level, meso-level and micro-level dynamics that explain how the system changes; and the dynamics of both incremental and transformative change in the system.

CONCLUSIONS

The analysis in this paper has shown that existing analytic sustainability frameworks revealed useful understanding but, in isolation, none were sufficient to fully map, explain and predict the transformational change that has occurred in Melbourne's stormwater management system since the 1960s.

Comparison of the different frameworks revealed that there are different elements to diagnosis that require different analytic lenses to reveal useful information. Understanding what specific diagnostic questions need to be considered is an important step to selecting the most suitable framework(s) for analysing a particular problem.

A combination of the frameworks reviewed in this research would provide a strong basis from which to build a diagnostic tool that can provide operational insights into strategic planning for transformative change in an urban systems such as Melbourne's water servicing.

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