Thinking in systems about integrated water management – a case study

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Key Points

- Application of systems thinking in UK and Australian contexts has been used to identify different types of outcomes and leverage points.
- Systems thinking can be tailored to different scales: Regional catchment, Urban catchments and Infrastructure scale. Each scale will reveal relevant and useful insights and benefits to organisations operating in those systems.
- Organisations can use leverage points to strategically develop partnerships or justify co-investment opportunities more effectively.
- The systems thinking approach holds significant potential for wider adoption in strategic water and catchment management. With wider engagement, policy and interventions are more robust, adaptive, and synergistically linked.

Abstract

Thinking in systems provides decision makers the ability to create a connected framework that communicates the complexity of integrated water management systems and enables better understanding of management objectives and benefits for the entire water system.

Mott MacDonald has pioneered the application of participatory system mapping (PSM) coupled with quantitative modelling. PSM brings stakeholders together from multiple water sectors to work toward agreement on common objectives, connect issues, identify potential unintended consequences, and highlight opportunities to cooperate via funding or policy. Completed system maps are used to inform quantitative modelling, which helps to validate policy decisions, interventions, and risks. Furthermore, experience from applying these projects at different scales, shows the approach can be useful and tailored to the scale and context it is being applied to.

Challenges arise when organisations within the same region plan across different time horizons and use several types of models for their individual system. This can make it challenging to compare results and assess co-benefits. Moreover, organisations often address issues such as water resources, flooding, and water quality in isolation, rather than in an integrated manner. The application of system mapping has enabled agencies to surpass jurisdictional boundaries, facilitating shared learning and investment opportunities. It has demonstrated how systems thinking identifies leverage points across different scales and sectors. This methodology promises broader application for informed water and catchment planning, leading to more resilient, adaptive, and interconnected outcomes.

Keywords

Systems thinking, integrated water management, catchment management, co-benefits, engagement, system connections

Introduction

“I have yet to see any problem, however complicated, which, when looked at in the right way, did not become still more complicated.” – Poul Anderson

A system is an interconnected set of elements that is coherently organised in a way that achieves something (Meadows, 2008). Systems thinking is a framework for seeing the inter connections in a system and a discipline for seeing and understanding the whole system; the ‘structures’ that underlie complex systems.

The approach can lead to paradigm shifts in water management by highlighting multiple complimentary and competing objectives at various scales and across agencies. For example, water can be managed not only to preserve a valued resource but also to ensure the continuity of our natural heritage, provide food security, meet environmental needs, or increase opportunities for connections with First Nations.

The systems approach brings to light components that would otherwise be overlooked by typical infrastructure planning and assessment, such as ecosystem services, community trust, and community acceptance. A key step in this approach is early and meaningful stakeholder engagement in the process through Participatory System Mapping (PSM). Engagement with stakeholders across the system provides a mechanism to recognise their discipline’s contribution to the overall system, potential benefits to be gained, and complex problems they face (and need to solve).

To shift stakeholders into the fold of a systems thinking mindset, it is essential to communicate the benefits, which can be achieved by:

- Sharing examples from previous projects that resonate.
- Providing co-learning opportunities to build collective understanding.
- Demonstrating the positive outcomes through case studies or pilot projects.
- Giving tools which can be shared internally with colleagues and executives about the prudency and suitability of this approach.

Application of Systems Thinking

“Beware of the assumption that the way you work is the best way simply because it’s the way you’ve done it before” –Rick Ruben, The Creative Act

In Australia, there is significant potential for taking a systems approach, which has yet to be unlocked. Mott MacDonald has successfully implemented the approach with water utilities but has yet to see implementation by all catchment players. Wide stakeholder inclusion in the process is necessary to identify and achieve wider catchment and system objectives.

While there are general approaches that can be used to delve into understanding a system, it is important to acknowledge that every system is unique. The application of systems thinking needs to be tailored for different scales, i.e., regional catchments, urban catchments, and localised infrastructure scales. This approach will yield different results depending on specifics of the system, dynamics, players involved, desired outcomes, constraints, and interventions. Every implementation which adopts a systems approach will have unique outcomes and leverage points that are specific for that system.

The systems approach can demonstrate more than just relationships. It can also be used to understand metrics within the system. Metrics are values within a system that can be measured, for example: changes in population / development, levels of pollution, environmental pressures, contaminants of emerging concern, soil health, etc.

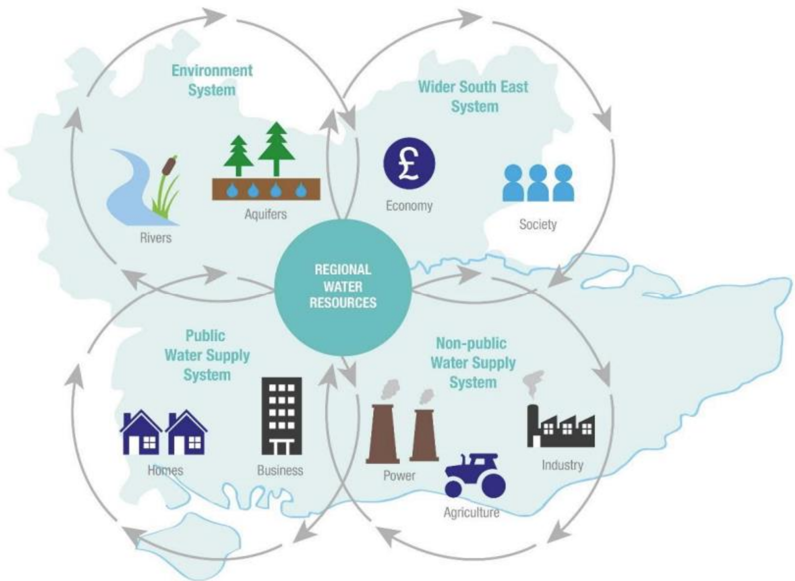
Application of systems thinking adds value to stakeholder engagement by creating the ability to trace inputs that are used to identify the co-benefits, unintended consequences, management objectives, and metrics. Agreement between stakeholders on the operation of the system ultimately leads to cooperation, mutual understanding of effective leverage points, and potential co-funding opportunities. Systems thinking can be applied to examine complex problems, identify issues that require ‘deep dives,’ and determine leverage points that can influence intervention decisions.

To demonstrate effectiveness, the following sections provide case studies at multiple scales: regional, catchment, and urban infrastructure level. Each case study demonstrates the types of outcomes and leverage points that can be uncovered as part of the process.

Regional scale – Multi sector resilience planning

Water Resources South East (WRSE) provides an excellent example of a regional scale systems approach to water management. WRSE is a sector-wide partnership in the UK with responsibility for developing a regional plan for water resources. The partnership is formed by Affinity Water, South East Water, Southern Water, SES Water, Portsmouth Water and Thames Water – working alongside other stakeholders to deliver the region's water needs. Mott MacDonald worked with the WRSE resilience and systems approaches project, which came from a national policy drive for a systems approach. This was driven by the policy statement: "National Infrastructure Commission frames its appeal for resilience in terms of infrastructure systems." In addition, Department for Environment, Food & Rural Affairs set out the 25 Year Environment Plan (25 YEP) with an appeal that the environment is "managed more as a system." Further, the Water Services Regulation Authority (Ofwat) strategy, 'Time to act, together' embraces 'systems thinking' building on earlier work in 'Resilience in the Round' which located the water sector within multiple interdependent systems.

WRSE required a set of metrics by which to assess the resilience of options for inclusion in the regional plan. Feedback from the regulator Ofwat on the original set of metrics was that the rationale from a systemic perspective needed to be indicated. In response to a commission to consult stakeholders and enhance the resilience framework, Mott MacDonald used a system mapping as an engagement tool to develop a shared understanding of resilience for what system and what aspects of that system needed to be measured to assess options for the regional plan. The system was characterised as having environment, social and economic, public water supply and non-public water supply (multi-sector water use) as shown below in Figure 1.



Source: WRSE Method Statement: Resilience – Consultation version – July 2020

Figure 1 Systems and subsystems mapped for the WRSE project

The WRSE project focused on the resilience of the water sector – using the systems approach to better understand its susceptibility to "shocks and stressors" in the face of climate change, biodiversity loss and pandemics. Key drivers that were considered included: improving the understanding of society's objectives for environmental stewardship, improving reliable water supplies, and lowering utility bills. The resilience metrics enabled a wider set of considerations to be included in the multi-criteria analysis. Alongside the infrastructure related metrics broader considerations such as customer relations were included in the assessment of a resilient water sector. Examples of the new metrics that were introduced to assess resilience included customer relations and soil health:

- Strong customer relations mean that water users are more likely to comply with water management actions during drought such as hosepipe bans. The system mapping demonstrated the rationale for using metrics such as customer relations in the overall assessment of resilience.
- Improved soil health reduces peak loads of nutrients and sediment that can disrupt water treatment works. It also allows more water to infiltrate and seep into aquifers rather than runoff and pass out to sea in storm flows. These benefits to the water system are in addition to resilience benefits to agriculture who have better soil water retention and soil drainage.

The system map for WRSE is shown Figure 2. The system map has been annotated with the resilience metrics used in the multi-criterial analysis (the small blue discs). The system map shows environmental factors in green, engineering and management factors in white, social and economic factors in yellow and a golden node close to the centre of the map which represents a resilient supply-demand balance. Shocks and stresses are in red and orange. The distribution of metrics shows that both sides of the supply demand balance are measured and that environmental factors are considered as well as engineering factors.

The mapping enabled a broader set of criteria to be considered alongside the cost-benefit analysis. The system mapping exercise provided the audit trail linking the collective expert judgement on resilience within the metrics used for option evaluation.

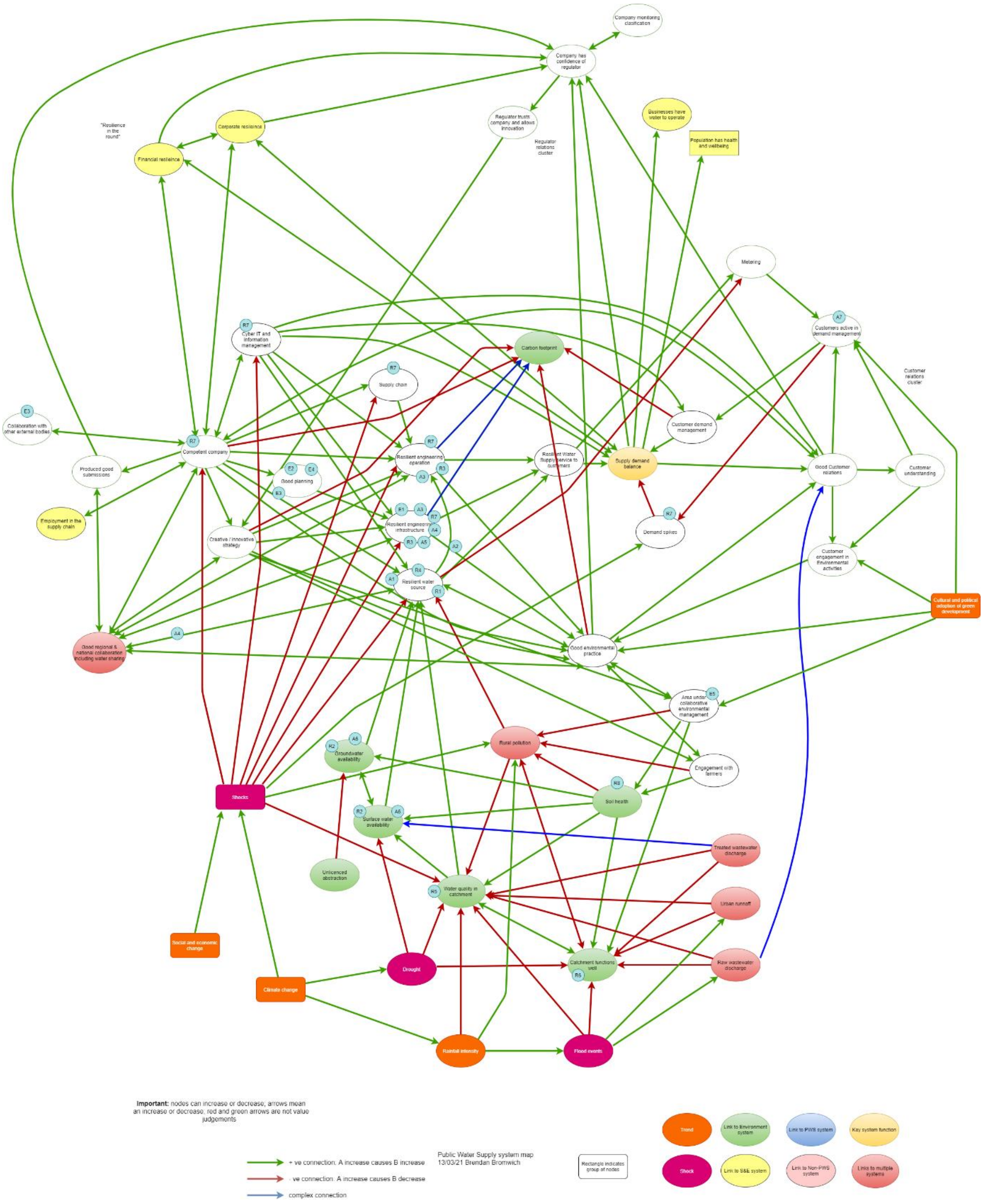


Figure 2 Public water supply system (May 2021)

Catchment scale – Changes in objectives and the rules of a system

Mott MacDonald worked with Urban Utilities to undertake Participatory Systems Mapping at a catchment level, within Moreton Bay, Queensland. The engagement was completed with various teams within the organisation. This case study demonstrates how the waterways in the upper catchments affect the downstream uses and receiving waters of Moreton Bay, which are mainly dependent on the water quality and ecology of the estuary and marine environments. The process of identifying this leverage point is explained below.

As illustrated in Figure 3, receiving waters are primarily affected by two pathways, including the nutrient and sediment load:

1. **Point source pollution.** Point source pollution can lead to increased nutrients which can cause eutrophication and lead to poor water quality in the bay.
2. **Non-point source pollution.** Sediments lost from the upper catchment end up in the bay and act as a blocker to the benthic phytoplankton which provide ecosystem services by maintaining normal levels of nutrients in the bay (Grinham, 2024).

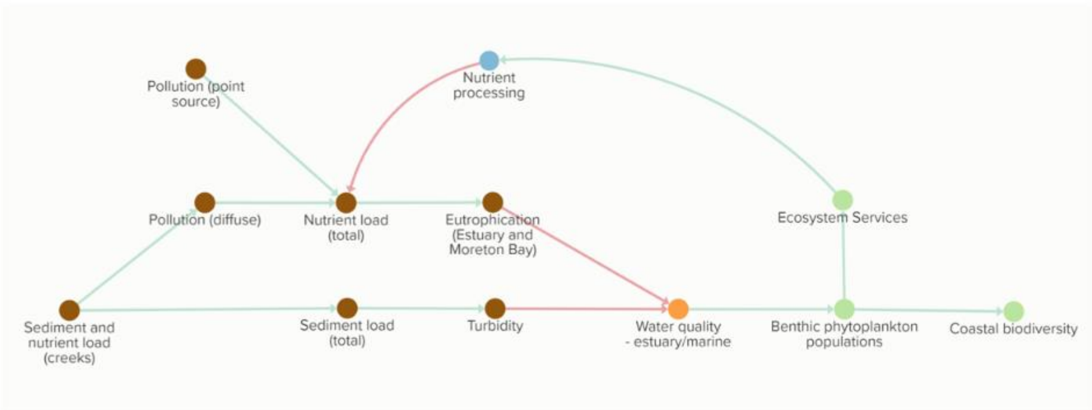


Figure 3 Downstream users and Moreton bay system case study

Current environmental authority policy focuses on the first pathway through discharge licences, which the utility has already invested $600 million in addressing. The second pathway shows how the impact of turbidity on Ecosystem Services is affecting the bay. To improve the Bay water quality, sediments from channel erosion upstream must be addressed in addition to point source pollution.

Using system mapping the source of the sediment was tracked back to the upper reaches of the tributary catchment during flood events. Nutrients and sediment in the bay could be significantly reduced, by addressing the root cause of poor water quality in the Bay. The root cause is channel erosion, which is directly connected to the upstream catchment conditions. This interaction was analysed and reported on in the study by Grinham and others in the paper *"Nitrogen loading resulting from major floods and sediment resuspension to a large coastal embayment".*

In this case, streambank restoration and intervention upstream could achieve the desired water quality outcomes in the Bay. As seen in Figure 4, clearly mapping this relationship and impacts enabled support by the relevant policy and finance drivers to support highly impactful interventions, i.e. streambank restoration in the upstream catchment. Investing in streambank restoration has a far broader reach than investing in a single point source intervention at the downstream end of the catchment.

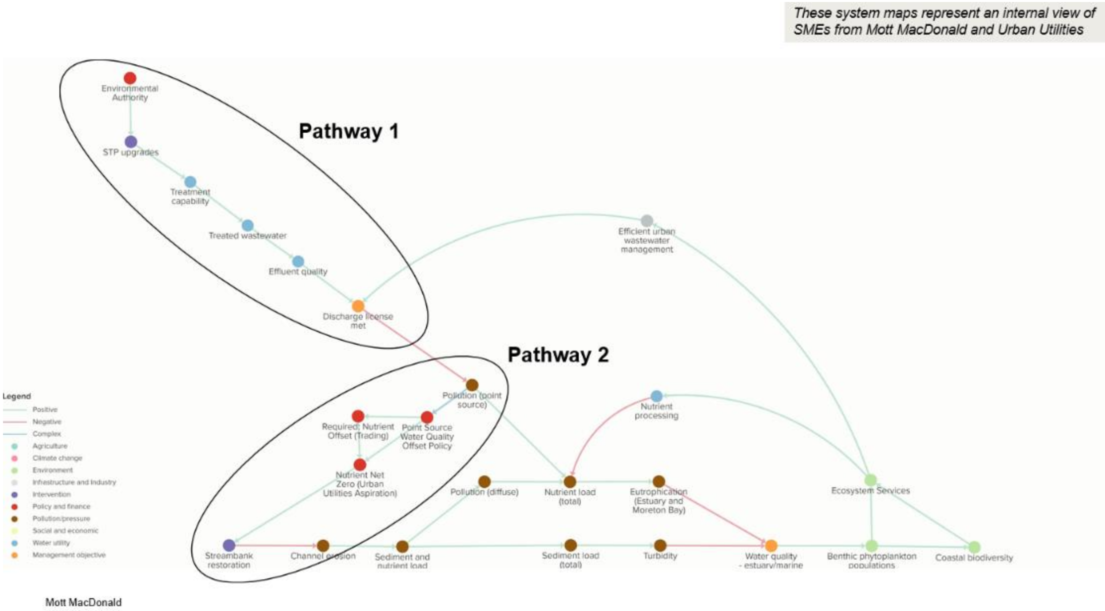


Figure 4 Downstream users and the bay potential intervention pathways

Figure 5 shows the next layer which highlights the related co-benefits and unintended consequences of the streambank restoration across the other subsystems including waterway health and ecology, environment, upstream communities, First Nations, agriculture, and water resources.

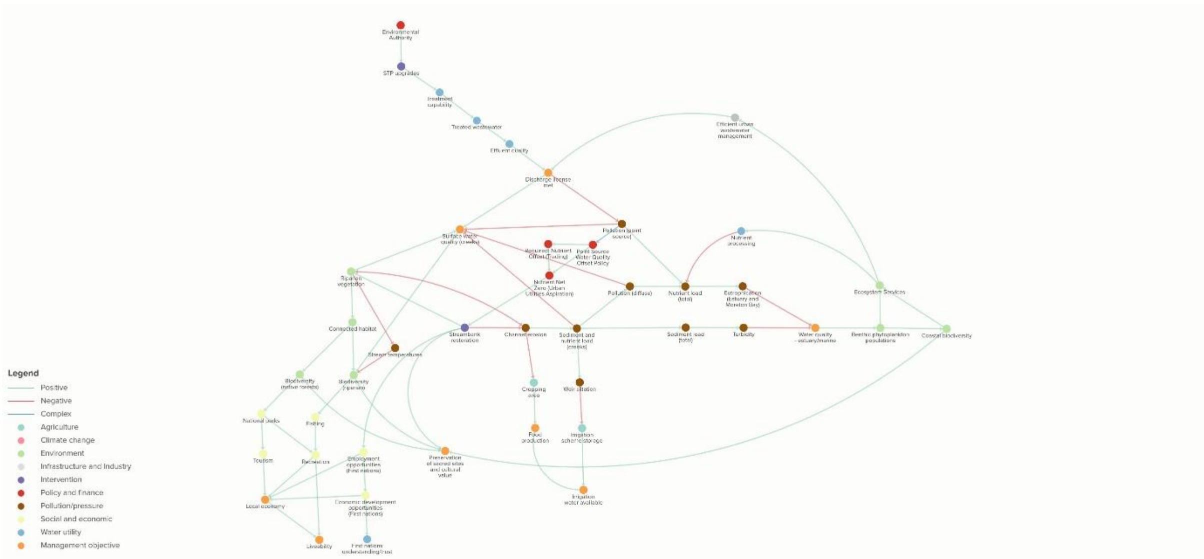


Figure 5 Downstream users and the bay integrated systems map

System mapping allows the simple communication of this complex narrative to other people within their organisation and other organisations. The leverage point for this case study was to rethink the system objectives. Management objectives were shifted away from a single point of discharge license, to a “bubble licence” approach, which enables the implementation of holistic catchment management interventions that realise multiple benefits.

Urban infrastructure scale – Shift in mindset

Water infrastructure artificially connects natural catchments with urbanised waterways using pipes, pumps and treatment plants, which can lead to rigid and static infrastructure within cities. This rigidity is challenged by increasing demands of growing populations, adaption to climate change impact, and agricultural shifts, which often leads to situations where the demand for water outstrips traditional supply sources.

A typical 'blue water cycle' focused approach would suggest desalination as a viable option. However, a systems view highlights its limitations, particularly in the face of climate change and associated impacts such as sea-level rise. Systems thinking also helps to consider energy requirement, and the embodied carbon in infrastructure associated with desalination.

The shift towards recycled water is a promising avenue, as it represents a sustainable and resilient approach to water management (Tortajada, 2020). However, recycled water requires a paradigm shift in industry practices and public perception. If this shift is successful, it could successfully provide a step towards addressing the medium- and long-term imbalance between water demand and availability.

Adaptive water management strategies in industry are crucial for decision makers in this context. They provide a framework for responding to changing conditions and uncertainties, particularly in the face of climate variability. Adaptive planning tipping points often include a balance of risk and necessity, where the urgency of water scarcity may compel a shift away from the traditional 'blue water cycle' methods to more innovative and sustainable solutions.

Ultimately, the success of adaptive strategies may hinge on a point where scientific understanding and engineering solutions can effectively inform and influence policy decisions, transcending political barriers to safeguard water security for the future. A systems approach can provide a wider understanding, which can be used to holistically bridge the gap between science/engineering and policy/decision-making.

A systems approach can uncover links to leverage paradigm shifts at an urban infrastructure scale, for example:

- **Shifts in stakeholder perspectives.** PSM emphasises neutrality in personal/agency perspectives and biases, engages with empathy, and creates a mechanism for listening to those with different perspectives. Visuals of a system provides transparent, open, and honest communication.
- **Identification of Desire pathways.** Desire pathways are unplanned route that are used in preference to or in the absence of a designated alternative pathway. In terms of systems thinking, decision makers or planners may be unaware of desire pathways within a system until they engage more broadly with stakeholders to understand various perspectives.
- **Points of compromise**. Potential solutions to address system issues can be visualised. Competing objectives can be prioritised and interventions can be tested, which enables compromise.
- **Removal of barriers.** Often complex problems are lumped into the 'too hard' basket and left unresolved. Systems thinking provides a tool to break down complex systems, dive into micro-systems, test solutions, and communicate outcomes or results. Recycled water has often been lumped into the 'too complex' category, which makes it subject to a lack of 'political will' driven by public fear (or misunderstanding and lack of trust).
- **Fear of unknowns.** Within every system, there are portions that are poorly understood. A systems approach can help to identify knowledge gaps (like microplastics or forever chemicals). Once the gaps are identified, this section of the system can be examined further to highlight potential implications or consequences associated with the unknown – and actions required to reduce potential risks.
- **Small shifts can produce big changes.** Leverage points in a system are seen as 'magic bullets' to address issues. Systems thinking can highlight that sometimes policy or decision makers may already be pushing on these leverage points, but perhaps in the wrong direction. Small interventions or policy shifts can lead to big changes in outcomes.

These paradigm shifts may seem too ambitious; however, a systems approach makes them achievable. The outcomes of a systems approach allow these shifts to be easily applied in a realistic manner.

Broader applications

The systems approach of working beyond the standard silos of jurisdiction does not only apply to integrated water management. Mott MacDonald teams have used systems thinking across the transport, cities and precincts, climate, and sustainability practices to improve stakeholder engagement, system resilience and efficacy of policy interventions.

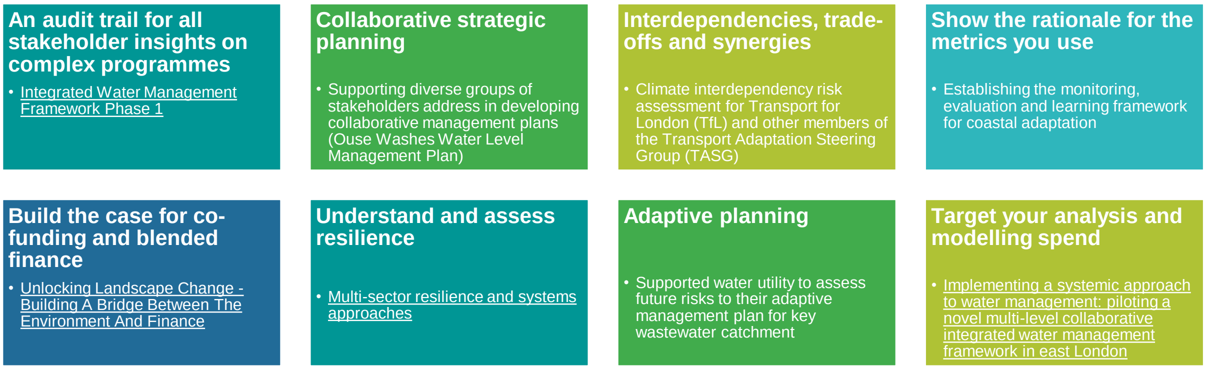


Figure 6 Potential benefits of undertaking a systems approach.

The primary objective of the system approach is bringing people together to develop a shared understanding of systems, develop a plan to monitor and measure against objectives and identify leverage points to enable multi-sector benefits. Systems approach has been used to benefit client organisations in Australia and internationally across the Mott MacDonald sectors, as shown in Figure 6. Some of these projects have been published as papers and publicly available reports, for example the Mott MacDonald and North Star Transition review of two reservoir investments. North Star Transition is a collaboration network designed to increase the impact response to humankind's climate, biodiversity loss, and social crises. The joint project with Mott MacDonald used the systems approach to analyse reservoir and landscape systems to understand how reservoir investments can create opportunities for additional interventions that would increase overall holistic landscape value (Mott MacDonald and North Star Transition, 2022).

In 2023, Greater London Authority with Mott MacDonald and Imperial College London utilised a multi-level collaborative integrated water management framework for regional water planning, demonstrated through London's Sub-Regional Integrated Water Management Strategy (SIWMS). The framework combines stakeholder engagement, integrated modelling, and collaborative decision-making to address urban growth, resource competition, and environmental degradation. Results show its effectiveness in systems-level analysis, prioritizing multi-benefit schemes, and enhancing stakeholder collaboration for robust regional water planning. This approach with integrated and holistic system modelling enables more targeted detailed modelling for more beneficial schemes. This project also demonstrated how a systems approach can utilise scenario modelling and horizon planning activities.

This 'systems thinking' framework and methodology could be used along with futures/foresight methods that empower robust policy decisions under uncertainty or Physical Climate Risk Adaptation Modelling (PCRAM). The respective teams at Mott MacDonald have been developing strategies to collaborate across these two concepts. Other ways the systems approach can benefit the water resources sector, include value asset management, governance, and co-creating theories of change.

Conclusions

Experience so far from the application of systems thinking in the UK and Australian contexts has identified different types of outcomes and leverage points. This paper explored several case studies and alluded to different leverage points that can be identified through system mapping and used to unlock multi-sector benefits and enhance community outcomes.

1. **Regional scale system** mapping identified system leverage points within system elements. These leverage points can be used to identify and justify system interventions such as increasing farm storage and improving soil health to achieve public water supply objectives whilst managing community expectations and balancing ecological impacts.
2. **Catchment scale system** mapping identified relevant management objectives that could be leveraged to manage water quality and mitigate impacts to downstream users and receiving waters.
3. **Urban scale system** mapping identified challenges with the implementation of innovative and sustainable approaches to water management that could resolve future water security issues but requires a paradigm shift in the way the industry, community and governance currently operates. Hence it is challenging to leverage a system in this way but can be the most impactful and effective.

The use of the system approach in the examples given above, empowered the participating agencies to transcend jurisdictional limits, foster collective learning, and identify potential for co-investment partnerships. The examples show that systems thinking is an effective tool for pinpointing influential factors across water systems and beyond. This approach holds significant potential for wider adoption in strategic water and catchment management, promising to yield policy and interventions that are more robust, adaptive, and synergistically linked.

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