Knowledge – Action Systems for Integrated Water Management: National and International Experiences, and Implications for South East Queensland

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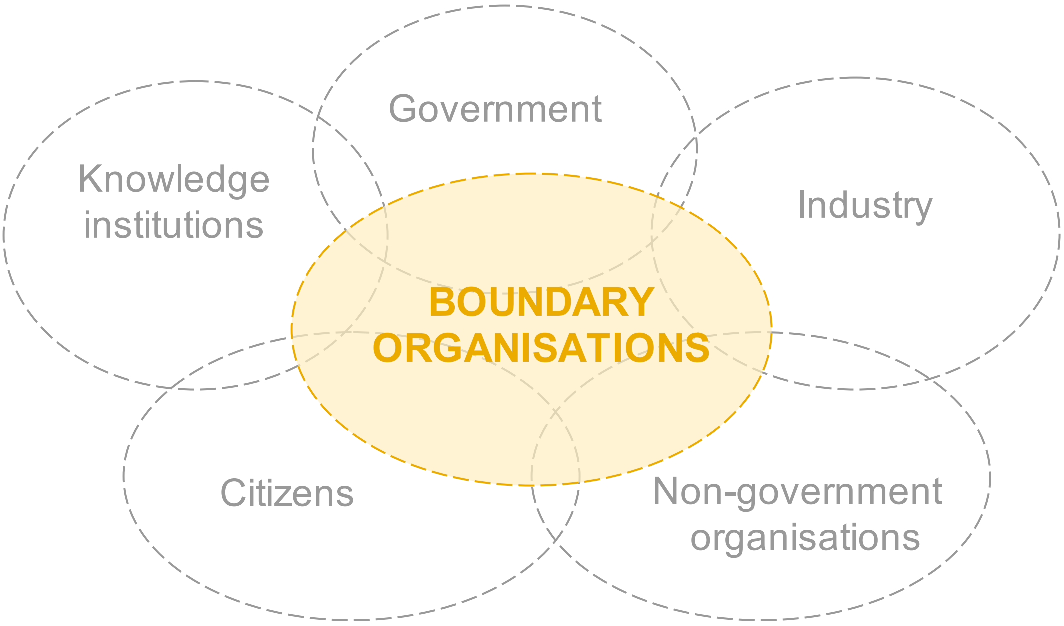

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The Urban Water Security Research Alliance (UWSRA) is a $50 million partnership over five years between the Queensland Government, CSIRO's Water for a Healthy Country Flagship, Griffith University and The University of Queensland. The Alliance has been formed to address South East Queensland's emerging urban water issues with a focus on water security and recycling. The program will bring new research capacity to South East Queensland tailored to tackling existing and anticipated future issues to inform the implementation of the Water Strategy.

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FOREWORD

Water is fundamental to our quality of life, to economic growth and to the environment. With its booming economy and growing population, Australia's South East Queensland (SEQ) region faces increasing pressure on its water resources. These pressures are compounded by the impact of climate variability and accelerating climate change.

The Urban Water Security Research Alliance, through targeted, multidisciplinary research initiatives, has been formed to address the region's emerging urban water issues.

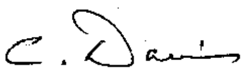
As the largest regionally focused urban water research program in Australia, the Alliance is focused on water security and recycling, but will align research where appropriate with other water research programs such as those of other SEQ water agencies, CSIRO's Water for a Healthy Country National Research Flagship, Water Quality Research Australia, eWater CRC and the Water Services Association of Australia (WSAA).

The Alliance is a partnership between the Queensland Government, CSIRO's Water for a Healthy Country National Research Flagship, The University of Queensland and Griffith University. It brings new research capacity to SEQ, tailored to tackling existing and anticipated future risks, assumptions and uncertainties facing water supply strategy. It is a $50 million partnership over five years.

Alliance research is examining fundamental issues necessary to deliver the region's water needs, including:

- ensuring the reliability and safety of recycled water systems.
- advising on infrastructure and technology for the recycling of wastewater and stormwater.
- building scientific knowledge into the management of health and safety risks in the water supply system.
- increasing community confidence in the future of water supply.

This report is part of a series summarising the output from the Urban Water Security Research Alliance. All reports and additional information about the Alliance can be found at http://www.urbanwateralliance.org.au/about.html.



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PREFACE

The onset of the worst recorded drought in South East Queensland (SEQ) raised the need to identify and implement a number of key water policy, planning and institutional innovations to meet future water needs. The dynamic context of water reform in SEQ is matched by the call for institutional change to tackle complex natural resource issues internationally, where the key role of knowledge and learning to bring about specific actions for sustainable development is highlighted (Dietz et al 2003, Folke et al 2005). This report is part of a larger project, which aims to improve understanding of the institutional capacities for sustainable and integrated urban water management in SEQ in the context of social and environmental change.

An earlier phase of this research reported in Wallington et al (2009) identified the capacity of government, industry and community organisations to transfer, translate and integrate different types of knowledge to inform water policy and management responses as a key challenge for progress towards integrated water management in SEQ. Institutional conditions to ensure that planners have adequate knowledge to make and evaluate decisions is emerging as a critical subset of integrated water management (IWM) theory and practice. Research under the banner of 'sustainability science' has been dedicated to understanding the characteristics of knowledge systems to support sustainable development for over a decade (Kates et al 2001). The link between knowledge and action for sustainable development is at the heart of this new inquiry domain (Clarke 2007).

Several factors contribute to this need for knowledge–action systems to underpin integrated water planning and management:

- the increasing need for evidence-based planning to ensure decisions are credible and accountable (e.g. Head 2008);
- the recognition that uncertainty underpins many IWM contexts and decisions; and
- the recognition that 'adequate knowledge' does not equate with scientific knowledge, but rather needs mechanisms to facilitate the joint production (or 'co-production') of knowledge, and to continually integrate new knowledge sources.

A focus on the formal and informal social relationships that catalyse the link between knowledge and action, in turn, brings institutional structures and capacities to the fore as a focus of research and practice.

Institutional and organisational arrangements designed to effectively link knowledge to water resource decision-making and action are required to promote technical and organisational learning, thereby contributing to the problem-solving and innovation that underpin effective and flexible integrated urban water systems (Pahl-Wostl 2008). Internationally and in Australia, the value of brokers to translate knowledge across the interface between science, management and policy, and the value of 'boundary organisations' to integrate multiple water policy goals across organisational boundaries, have been explored (e.g. Cash et al 2002, Ingram and Bradley 2006, Warner et al 2010).

The current phase of this research aims to review these and other strategic experiments in IWM to identify the institutional conditions required to build knowledge capacities in the SEQ water system. This paper will present a review of national and international experiences, distilling the implications for the design of adaptive knowledge institutions for IWM in SEQ. Key questions include: What institutional structures and practices might provide effective vehicles for knowledge communication, translation and integration? How do these knowledge-based interactions help to link knowledge with decision-making and implementation? What institutional conditions enable technical and organisational learning? This work contributes to the broader understanding of how institutions actually affect water management options and outcomes.

EXECUTIVE SUMMARY

This report is a review of knowledge–action systems in integrated water management (IWM) research and practice in Australia and overseas, addressing in particular the current state of knowledge and role of comprehensive knowledge integration and boundary institutions as a central element of sustainable urban water planning. This is part of a broader research project that has been pursued for the Urban Water Security Research Alliance which aims to improve understanding of the institutional capacities for sustainable and integrated water management in South East Queensland (SEQ). IWM efforts in this region have emerged in response to the need to ensure that the use of available water policy delivery instruments is governed through principles that comply with the National Water Initiative and consider the range of water-related values held by SEQ stakeholders. This review shows that planning reforms in SEQ echo water policy development occurring across a range of watersheds and regions. Critical insights from research conducted to date highlight the significant limits to IWM approaches. Parties involved in efforts to build capacity and consensus between relevant stakeholders can face high transaction costs and uncertain political dynamics. Decisions based on negotiation and coordination often challenge policy makers in their efforts to tackle highly contentious issues, such as a strategic response to water scarcity. Yet the success of some IWM efforts shows the value of facilitating the authentic participation of all stakeholders to ensure that water management objectives fit the social-political context in which they are to be implemented, and to ensure that management responses do not compromise the sustainability of this vital resource.

Research findings from Wallington et al (2009) indicate that the institutional capacity to translate available science to make strategic decisions is a critical requirement of IWM systems. Efforts to build and resource 'boundary organisations' (e.g. the CALFED Bay-Delta Program) reflect a 'hard-wired' or structural approach to translating knowledge into water policy decision-making. Institutional support requirements to manage the role of scientists and the information requirements of policy makers provide useful insights to inform the efforts of boundary organisations, such as the SEQ Healthy Waterways Partnership.

Insights from IWM experiences and analyses also show that a strategic response to the co-ordinated development of water, land and related resources cannot be resolved through structural responses alone. 'Soft-wired' responses (communication, information sharing, institutional learning, etc.) are also required to link knowledge with action for sustainable development through participatory and adaptive processes. This becomes critical when IWM systems are required to work across scales, or tackle complex issues that often contain high levels of uncertainty. Such conditions exist in SEQ, where water policy makers and stakeholders continue to engage in a fluid and often challenging dialogue to align effort and priorities in response to the evidence of impacts caused by recent droughts, as well as the predictions of climate forecasting.

Understanding how integration has been analysed and practised in other water planning domains can help inform the design and review of knowledge–action systems for IWM in SEQ. Careful design of such knowledge institutions can enable science to be shared and critiqued by multiple stakeholders and support particular problem types and policy settings needed for sustainable water management solutions in Queensland.

1. INTRODUCTION

There is a widespread crisis of urban water governance…. Fragmented institutions (geographically and across different aspects of the water cycle), weak regulatory and institutional frameworks, excessive centralization, an unclear division of responsibilities between the central and local governments, inefficient and outdated management practices, and misguided decision-making due to short-term political or commercial interests lead to inadequate capacity to address urban water challenges (UNESCO Paris-2007 Statement).

Water planning initiatives currently under way in South East Queensland (SEQ) reflect experiments with water governance arrangements occurring in many democratic countries around the world. Institutional challenges[1] are now widely recognised as integral to the 'crisis' of urban water governance, as captured in the statement agreed by 200 participants from 50 countries cited above. A critical area of concern is the need to resolve complex, fragmented and competing policy initiatives that affect equitable access to water resources, efficiency in water use, and effective management of water ecosystems. This has resulted in a growing interest in the theory and practice of integrated water management (IWM).

The imperative of integration stems from the recognition that human and natural systems are interdependent, as expressed in the policy agenda of sustainable development. The central role of water in the achievement of industrial, agricultural, economic, social and cultural forms of development was a core impetus in the drive to progress strategic and integrated approaches to water management (Jeffrey and Gearey 2006). As the understanding of critical human–environment interconnections has increased, so the inadequacies of existing institutional frameworks and management arrangements have become increasingly apparent (Kidd and Shaw 2007).

In the international arena, this institutional need has been expressed in the aim of IWM, which advocates 'the coordinated development and management of water, land, and related resources by maximising economic and social welfare without compromising the sustainability of vital environmental systems' (Global Water Partnership 2010). Integration in the natural system - of land and water; of surface and groundwater management; and of quantity and quality (including water and wastewater) in water resource management - is therefore dependent on integration in the system of governance. Stakeholder participation is considered central to the integration challenge, in a process that seeks to bring together fragmented water uses and users into an integrated planning, allocation and management framework (Saravanan et al 2009).

The social and institutional challenge of IWM is identified as pivotal to achieving water sustainability in Australia (Senate Committee 2002). Integrated approaches to water governance are widely promoted to address several core challenges associated with the fragmentation of previous efforts:

… the significant intellectual, operational and financial investments made in environmental policy and management over the past decade have been frustrated by lack of integration of substantive matters in policy design and by the lack of vertical and horizontal coordination in systems of natural resource governance (Lane and Robinson 2009).

To address this integration deficit, the Australian Government is committed to innovation and diversified water sources in the urban environment as part of a wider transition to water sensitive cities and total water cycle management (National Water Commission (NWC) 2007, Prime Minister's Science, Engineering and Innovation Council (PMSEIC) 2007). The implementation of technical and regulatory innovations, in turn, requires institutional and policy changes to foster their adoption and diffusion.

[1] Institutions are defined here as relatively stable systems of established social rules that assign roles to participants involved in water planning and management practices, and structure the interactions between these participants (Hodgson 2006). Organisations are the physical manifestation of institutions.

In general, however, innovation within the water industry is frustrated by the traditionally risk-averse nature of the water industry (Environment Business Australia 2002, Wallington et al 2009). In practice, this means that innovation is fragmented and focused on short-term needs, with sub-optimal sharing of information. The timely availability of high quality 'fit-for-purpose' data and information for decision making remains a key challenge (Claydon 2007). In many water planning contexts, such as SEQ, this 'fit' requires information about how to ensure proposed strategies are technically robust and politically palatable. Information generation and transfer, coordination across government and private organisations, and attention to the appropriate scale of implementation are key priorities for urban water governance in Australia (NWC 2007). In turn, the Queensland Government (DNRW 2009) has recognised the need to develop networks and partnerships to provide access to information and facilitate the exchange of ideas to meet the information needs of water planning and management.

The role of social institutions in the response to water governance challenges has received dedicated effort by the international research community over the past decade (O'Riordan and Jordan 1999, Young et al 2008). By facilitating and ordering the interactions between multiple actors in complex situations, institutions are especially significant when a task requires coordination (Blomquist et al 2004). At the same time, constantly changing social, environmental and technological circumstances create pressure on society to adapt by means of institutional innovation (Livingston 1993). The ability of water institutions to transfer and translate knowledge across organisational boundaries is fundamental to their adaptive capacity and improved performance (Wallington et al 2009, Robinson et al. 2009, Senate Committee 2002).

For any system of water governance to be effective, knowledge systems must be managed appropriately. A central claim of IWM is that institutional integration and coordination constitute the best strategies to organise knowledge production for sustainability (Medema et al 2008). This includes the value of management frameworks that link research- and experience-based knowledge to collective decision-making and management action by a range of actors in order to adequately reflect the complex relationships between water and land processes and their governance systems.

This report will survey the national and international literature to identify the institutional ingredients for effective knowledge systems to support sustainable water management. In the next section, we set the context by providing an overview of the policy developments that underpin IWM internationally, in Australia, and in SEQ. We then review experiences with IWM to identify the institutional barriers and pathways to integrated and adaptive approaches to water planning and management. The institutional structures and processes that appear most conducive to knowledge integration for adaptive IWM are subsequently elaborated by means of case studies from Australia, Europe and the United States. The paper concludes with a discussion of the benefits and limits to institutional innovations that aim to link knowledge and action for IWM, which may help to inform the design and review of institutional arrangements for IWM in SEQ.

2. THE POLICY CONTEXT OF INTEGRATED WATER MANAGEMENT

International discussion about the multiple and competing uses of water begun at the first UNESCO International Conference on Water held at Mar del Plata, Argentina, in 1977 (Jeffrey and Gearey 2006). Since then, international interest and action regarding the principles of integrated water management has escalated. A number of countries - including Australia, the United Kingdom, western United States, South Africa and Chile - have taken up elements of the Integrated Water Resource Management approach (Watson 2007). Notably, IWM was adopted as a prerequisite for compliance with the European Union's Water Framework Directive of 2000, and has guided many of the subsequent EU water development programs, such as the EU Water Initiative. It is therefore not surprising that there is widespread endorsement of IWM. Examples of international conferences that have sought to address urban water management issues are listed in Table 1.

In Australia, the adoption and implementation of an integrated water reform framework is a core element of a broader sustainability strategy, complemented by a regional approach to deliver on-ground action (Claydon and Milligan 2003). Australia's commitment to IWM is embodied in the National Water Initiative (NWI), where governments express 'a shared commitment … to increase the efficiency of Australia's water use, leading to greater certainty for investment and productivity, for rural and urban communities, and for the environment' (NWC 2008).

Table 1: International Endorsement of Integrated Water Management

1977	United National International Conference on Water, Mar del Plata, Argentina
1992	Dublin Statement on Water and Development, International Conference on Water and the Environment
1992	Agenda 21: Programme of Action for Sustainable Development, United Nations Conference on Environment and Development
1996	Global Water Partnership (founded by the World Bank, the United Nations Development Program, and the Swedish International Development Aid Agency)
1997	Paris Statement 1997, Symposium on Water, City and Urban Planning
2000	Second World Water Forum and Ministerial Conference, the Hague
2001	International Conference on Freshwater, Bonn
2001	Marseille Statement, UNESCO Symposium on Frontiers in Urban Water Management: Deadlock or Hope?
2002	Johannesburg Plan of Implementation, World Summit on Sustainable Development
2003	Third World Water Forum

A majority of NWI actions require cooperation and collaboration between governments for their implementation toward equitable and effective water resource management (Hussey and Dovers 2007). Key elements of the NWI include (NWC 2008):

- integrated management of water for environmental and other public benefit outcomes, and the development and implementation of management practices and institutional arrangements to achieve these outcomes;
- a water access and planning framework to establish water entitlements, including water for the environment, providing for an adaptive management approach; and
- community participation to engage water users and other stakeholders in achieving the objectives of the NWI by building confidence in the reform process, ensuring transparency in decision-making, and ensuring that sound information is available to all sectors at key decision points.

Sustainability concerns in urban Australia, heightened by extended drought conditions and recognition of the legitimate contribution of stakeholder knowledge in policy-making, have influenced the shifting emphasis on IWM over the past decade. In Queensland, as in other Australian States, NWI actions have been translated into state-based legislative and planning commitments (Harman and Wallington 2009). The rapidly growing population of SEQ made the need for greater coordination of water planning and service delivery all the more pressing in this region. Arrangements for service delivery were notably fragmented across numerous local councils, with a proliferation of differing policy positions on service levels and standards (DNRW 2006, QWC 2008). The overarching policy goal of water governance, in response, is to ensure 'that water in the region is to be managed on a sustainable and integrated basis to provide secure and reliable supplies of water of acceptable quality for all uses' (Queensland Government 2009). This integration strategy is captured in the SEQ Regional Plan 2009–2031 through a commitment to Total Water Cycle Management (Queensland Government).

The NWI (COAG 2004) remains the primary and enduring national blueprint for Australian urban and rural water reform. Despite considerable change in Australia's urban and rural water circumstances in the five years since the NWI was ratified, the policy prescriptions and objectives continue to be widely accepted as salient and appropriate for Australia. In accord with the NWI paragraph 92(iv), The Australian, State and Territory Governments committed to a review of institutional and regulatory models for achieving integrated urban water cycle management. In principle, there are three fundamental objectives of Integrated Water Cycle Management and Water Sensitive Urban Design (NWC 2007): first, to minimise the impact of urban development on regional water balances inclusive of the claims of dependent ecosystems and the natural environment; second, to address water scarcity in cities by diversifying supply options to include all components of the urban water cycle; and third, to improve urban water 'metabolism' by retaining, reusing and recycling water entering the urban water management cycle for as long as possible.

Recent reviews by the National Water Commission (NWC) (2009), the Productivity Commission (2008) and the Council of Australian Governments (COAG) (2008), conclude that whilst the NWI reform process has made substantial progress in addressing the constraints and tensions associated with over-allocated rural water economies, the reforms have had limited influence on the management of urban water systems. In the five years since the formulation and ratification of the NWI, contextual factors stimulating urban water reform have altered substantially (NWC 2009, Radcliffe 2007). The influence of mature urban water economies and climate uncertainty are key contemporary challenges in this regard.

Most Australian cities are subject to increasingly variable rainfall patterns, acute water stress and increasing populations. As a corollary, they are experiencing mature urban water economies, originally described by Randall (1981) and characterised by limited opportunities for future water impoundments, rising incremental supply and impoundment costs, intensified competition between diverse users including the environment and increased interdependencies amongst water uses. In response, urban water utilities and governments, including SEQ, have extended existing water supplies through demand management and sought new water supply options (e.g. desalination) that both buffer against climate uncertainties and are independent of traditional, rainfed storages.

In addition to increases in urban populations and densities, increasing concern about climate uncertainties, increasingly stringent effluent disposal options and extractive opportunities, supply shortages leading to prolonged and more severe water restrictions, and opportunities to access Commonwealth water funds are identified as primary motivators in the recent emphasis on urban water reform (Radcliffe 2007).

Guided by the changed context motivating urban water reform and the recent biennial assessment, the NWC (2009) contends that the NWI provisions, commitments and evaluation metrics for urban water reform are necessary but insufficient to meet the challenges of contemporary urban water reform. Recently articulated key principles by the Productivity Commission (2008) and COAG (2008) argue for similar modification to the NWI to achieve a more ambitious urban water reform agenda that is coordinated across managing agencies and community interests.

In deliberating the status of urban water reform, the NWC and Productivity Commission relied on metrics generally defined in terms of optimality and concordance: that is, economic efficiency, revenue adequacy, flexibility of supply deployment, administrative simplicity and concordance or 'fit' with existing governance. Additional performance metrics that correspond with and help coordinate these more ambitious reform agendas include:

- the effectiveness of knowledge integration;
- transparency of decision processes and distributional equity;
- levels of agency trust, and prospects of ongoing innovation;
- meeting environmental targets; and
- the capacity to balance the costs of supply security with assignment of risk.

Summary analysis of research requirements articulated by water agencies, industry and statutory bodies concerned with monitoring the progress of the NWI reveal consistent social, economic and institutional research themes for urban water reform (NWC 2009, COAG 2008). The themes are summarised as:

- improved whole-of-system urban water supply planning, focussing on diversification towards less climate-dependent sources of supply, inclusive of recycling and manufactured water;
- clearer community transparency regarding the risks to water supplies, rationalisation of water restrictions and levels of supply security;
- a partnership approach so that the community is able to make an informed contribution to urban water planning, including consideration of the appropriate supply/demand balance;
- design alternatives to governments (operating as water planners, suppliers, distributors and retailers) making supply investments and managing available water with only limited knowledge about the value that users place on water;
- a review of institutional, market and charging/pricing arrangements such that full cost pricing is consistent regardless of source: pricing should be timely, transparent, accurately reflect scarcity and account for externalities. Specific to water recycling, pricing needs to reflect fit-for-purpose water supply: i.e. variable water qualities suitable for a range of alternate water demands;
- efficient water supply decision-making needs based on cost-benefit frameworks that result in cost-effective water service provision at agreed levels of security and reliability; and
- institutional reform to address the monopoly provision of urban water that impedes opportunities to develop alternative supply sources. Reform has been confined to governance arrangements rather than attending to the structural changes necessary to achieve more efficient outcomes.

The NWI states that science- and community-based water plans, specifying levels of water appropriation, need to be agreed prior to the choice of policy instruments that distribute individually vested water entitlements and facilitate market exchange. The NWC (2009) and COAG (2008) appraisals of the state of urban water reform also stress the research deficits in institutional factors influencing water planning outcomes and contend that improved understanding is central to advancing the urban water reform agenda and promoting community acceptance.

This review addresses issues raised by the first three of these themes, describing the current state of knowledge and emphasising the role of comprehensive knowledge integration and boundary institutions as a central element of sustainable urban water planning.

3. IMPLEMENTING INTEGRATED WATER MANAGEMENT: LESSONS FROM EXPERIENCE

Although there is a concerted effort by nations around the world to manage water in a more integrated way, the provision of adequate and integrated governance systems to do so effectively remains elusive. Many of the countries that were party to the Johannesburg World Summit on Sustainable Development (WSSD) in 2002 have formulated IWM plans and have embodied the tenets of the IWM paradigm in their legal instruments. However, the actual implementation of IWM through sympathetic governance arrangements for day-to-day water management is yet to be achieved in many of these countries (McDonnell 2008). This deficit relates to the challenges of establishing political structures that enact the principles of IWM, as well as the operational barriers to enacting the more innovative management instruments required.

Despite the fact that the IWM concept has achieved significant academic and policy interest, it has been argued that the concept remains normative and prescriptive (Jeffrey and Gearey 2006, Saravanan et al 2009). That is, IWM is a prescriptive framework about how things should be done: 'IWRM has neither been unambiguously defined, nor has the question of how it is to be implemented been fully addressed. What has to be integrated and how is it best done? Can the broad principles of IWRM be operationalised in practice – and, if so, how?' (Global Water Partnership/Technical Advisory Committee 2000). These practical shortfalls are recognised by other prominent advocates of the framework, including the United Nations Environment Programme, which has been prompted to declare that the conversion of the concepts of integrated water resources management into practice remains ‘unfinished business’ (IWA/UNEP 2002).

Limited implementation of IWM is attributed by many to the fact that the framework is based on a management paradigm that conceives of uncertainties as quantifiable by experts, and thus amenable to management and control with technology (Colebatch 2006; Jeffrey and Gearey 2006). Engineering knowledge typically results in the creation of large-scale infrastructure and technology for the supply of potable water and the removal of wastewater (dams and pipes). This quantify-manage-control management style tends to be culturally reinforced by water planners and managers, typically trained as hydrologists and engineers, and thus professionally socialised to regard socio-economic issues as irrelevant to water management goals (Ioris 2008).

The public invisibility of water management has meant that the technocratic approach has prevailed unchallenged, until recently. The operations of water utilities in Australia have traditionally been relatively insulated from the scrutiny of Parliament and Cabinet due to their statutory authority and regulatory powers (Colebatch 2006). The public invisibility of these authorities coincides with the invisibility of the infrastructure enabling the reliable provision of safe drinking water and removal of wastewater, ensuring the insulation of their operations from public scrutiny (Lach et al 2005). The shift to IWM and participatory governance has opened the way for public scrutiny of the water sector in contemporary times.

A significant implication of the public visibility of water is the increasing number and variety of actors and interest groups involved in water governance debates and processes (Medd and Marvin 2008). The social and institutional complexity of water management has increased, in turn, so that:

> *… the hitherto well-defined boundaries of the sector have begun to erode. Participation within the sector is now more complex and less predictable and water policy characterised by numerous cross-sectoral linkages. The number of policy actors who might participate in some aspect of water policy is now potentially in the hundreds rather than the tens (Maloney and Richardson 1995:112).*

The expansion of interests and organisational mandates has been accompanied by an expectation that increased stakeholder engagement in planning and implementation activities will lead to greater public acceptance of decisions, and more sustainable water use. The need to build public confidence in decisions and decision-makers is a core motivation for institutional and governance innovations in the transition to more sustainable urban water regimes. Conflicts around proposals for recycled water and for new dams provide indications of diminished confidence and broader questioning of the way water use is governed (Colebatch 2006). In line with global trends to gain public acceptance for large infrastructure projects and policy changes before they are implemented (Dore et al 2004), stakeholder and citizen engagement strategies are increasingly being introduced to complement centralised state-based systems (van Kerkhoff and Szlezak 2010, Jacobs et al 2010).

At the same time, institutional innovation is hampered by the ‘institutional inertia’ that is widely identified to characterise water governance regimes internationally and in Australia (Brown 2008, Livingston et al 2004, Stenekes 2008). Despite the technical potential for novel management solutions since the 1980s, management structures to facilitate the technical cooperation of different components of the urban water system have been slow to develop. Water institutions have co-evolved alongside large-scale technological infrastructure and entrenched stakeholder expectations in a manner that is highly resistant to change. Inertia in both the ‘hardware’ (longevity of infrastructure and the resource commitments necessary to build it) and the ‘software’ (shared knowledge, rules and habits) are interdependent and reinforcing (Rayner et al 2005).

Such path-dependence can also generate lock-in situations, where established policies and technologies continue to dominate despite their inferior performance (Ingram and Bradley 2006, Arthur 1994). The result of these mutually reinforcing and path dependent institutional configurations has been that traditional systems of water management exhibit limited capacity for change generally, and for integrating different types and sources of knowledge specifically. New sources and types of knowledge may be needed to both fully understand resource governance problems and to be able to identify innovative solutions to address them (Berkes and Folke 2002, Ingram and Bradley 2006).

The lack of attention to changing social and environmental circumstances, and associated capacity requirements, remains a significant criticism of new IWM approaches (Jeffrey and Gearey 2006). There is a need to acknowledge that the quality and availability of managed resources will always change as a result of human intervention, that surprises are inevitable, and that new uncertainties will emerge. Tackling water stress therefore requires 'an intellectual shift to recognise that the agenda has moved from issues of supply reliability or demand reduction to more complex issues of variable water quality, excess and deficit water quantity; a shift which necessitates social, cultural and economic adaptation' (Jeffrey and Gearey 2006:1-2).

To address problems of institutional inertia, coordination and integration are considered central to the organisation of knowledge production for IWM (Medema et al 2008). These strategies parallel two governance mechanisms that may be employed to implement change: coercion/regulation, and collaborative/deliberative approaches. These approaches are elaborated below, with examples of their practice, to illustrate the partial nature of any one institutional solution to the integration challenge. This review will not canvas the third governance strategy for institutional reform, namely market-based instruments. As noted in Section 2 of this report, science-based planning that engages community-based strategies to specify water appropriation levels are antecedent to the use of policy instruments for market exchange.

The first, top-down approach to improving coordination has been common across environmental planning domains internationally. Organisational restructuring is a prominent example of this kind of response, where the aim is to 'internalise' the multiple sectoral and jurisdictional dimensions of a problem through the creation of a new organisation (Lane and Robinson 2009). For example, in Australia, it was precisely the need for cross-jurisdictional cooperation in moments of significant political complexity and conflict that prompted the creation of the Murray-Darling Basin Commission (e.g. Kellow 1992) and the Wet Tropics Management Authority (e.g. McDonald and Lane 2000).

A narrow emphasis on governmental coordination is problematic, however, because it fails to engage important non-state actors in the solution to water management problems. A disadvantage of this approach is that it has the effect of 'internalising' or 'bureaucratising' matters that had previously been the subject of public contestation and debate (Lane 2003). To be effective, IWM depends on coordinating mechanisms that are also capable of bridging the gap between relevant government and non-government institutions that impact on water resources. The focus on institutional integration therefore reflects the widespread view that institutional complexity, fragmentation and duplication impede efforts to effectively manage natural resources (Margerum and Born 2000). Water authorities will be required to cooperate across political and administrative boundaries, and to interact closely with other policy fields that impact on the quality and availability of water resources.

> *[T]here is never a perfect 'fit' among legitimisation instruments, functions and structures. As a result, use is made of various processes and mechanisms to overcome the problems which occur because of imperfect matches. It is often these processes and mechanisms, informal and formal, which facilitate co-ordination and integration (Mitchell 1990:214).*

The second, 'bottom up' strategy of greater horizontal collaboration amongst organisations and interests is often induced via earlier top-down reform. The European Water Framework Directive (WFD) is an instructive example of induced institutional change 'from above', with the EU attempting to resolve problems of unsustainable and inefficient use of water by encouraging more participatory and collaborative forms of water governance at the regional level of river basins and catchments. It is an approach that echoes regional NRM in Australia, which has been described as the effort to develop an architecture in which the cooperation and agency of multiple actors across government and civil society can be better facilitated, coordinated and integrated (Lane et al 2010).

The capacity for communication and knowledge transfer introduced via these cooperative strategies is considered vital to such collaborative efforts if advances in scientific and other forms of knowledge (technical, bureaucratic, etc.) are to be translated and integrated into organisational decision-making (Owens et al 2006). Institutional capacity for communication and knowledge sharing between organisations has been identified as a critical ingredient for implementing integrated urban water management in Australia (van de Meene et al 2009). Interaction thus centres on deliberation between diverse actors so as to translate knowledge across organisational or stakeholder boundaries and, more ambitiously, to co-produce new knowledge.

The experience with IWM canvassed here shows that in a given watershed there is often a 'cocktail' of policy initiatives that have been tried to achieve more integrated and sustainable water systems. In a critical review of integrated water resource management, Saravanan et al (2009) chart the multiple theories and approaches that now exist to ensure diverse (state, corporate and community) institutions and actors integrate their planning and management activities. Achieving the integrated management of water resources requires decision-making structures and processes that collaboratively and adaptively engage local communities, government organisations and private sectors that are active in the management and utilisation of natural resources (Lane and Robinson 2009).

Participatory and adaptive approaches to IWM provide ways to cope with the increasing uncertainties that arise from rapidly changing socio-economic conditions and climate change (Pahl-Wostl 2007). The main premise of the adaptive approach is that 'intelligent' integration can lead to a governance capacity to learn, experiment and adapt creatively to threats and opportunities inherent in the complexities of environmental management (Munro and Jeffrey 2008). Collaboration across disciplinary and professional boundaries (for example: between researchers, scientists who acquire knowledge and decision makers; managers who seek to apply knowledge) provides a means to facilitate the creation of linkages between science, management and policy (Bosch et al 2003).

4. LINKING KNOWLEDGE WITH IWM PRACTICE

The extent of formal commitments to IWM in Australia and internationally reflects widespread agreement that flexible, adaptive and innovative institutional arrangements are needed to tackle complex water problems (Pahl-Wostl 2009). Research under the banner of 'sustainability science' has been dedicated to understanding the characteristics of knowledge systems to support sustainable development since the official launch of this research program in Science a decade ago (Kates et al 2001). The link between knowledge and action is at the heart of this new inquiry domain, which is 'defined by the problems it addresses rather than by the disciplines it employs; it serves the need for advancing both knowledge and action by creating a dynamic bridge between the two' (Clarke 2007:1737).

The identified need to bridge the gap between knowledge and action, with a focus on the formal and informal social relationships that catalyse this vital connection, brings institutional structures and capacities to the fore as a focus of research and practice. Harnessing relevant knowledge and information forms an important component of the enabling environment to bring about actions for the sustainable development and use of water resources (McDonnell 2008). As a result, there is a call for institutions that can deal with rapidly changing knowledge and have effective learning capabilities (van Kerkhoff and Szlezak 2010). Understanding institutional conditions to ensure that planners have adequate knowledge to make and evaluate decisions is therefore emerging as a critical subset of IWM theory and practice. Several factors underpin this approach:

- the increasing need for evidence-based planning to ensure decisions are credible and accountable (e.g. Head 2008);
- the recognition that uncertainty underpins many IWM contexts and decisions; and
- the recognition that 'adequate knowledge' does not equate with scientific knowledge, but rather needs mechanisms to facilitate and maintain 'knowledge co-production'.

As Lane and Robinson (2009) point out, improved water management requires that the knowledge, activities and perspectives of diverse government, corporate and civil society actors are integrated so that substantive matters are captured in policy design. As such, scientific knowledge needs to be integrated with managerial and experience-based knowledge in the context of policy action and implementation. The emphasis on knowledge integration aims to complement the prevailing focus on strategies to facilitate vertical and horizontal harmony in systems of resource governance (see also McDonald 1996). A knowledge systems perspective assists in understanding how institutional innovations can affect the generation, sharing, and application of scientific and technical knowledge for policy and management action (van Kerkhoff and Lebel 2006).

The capacity of new structures and processes to link knowledge with action, including public-private partnerships and cross-sectoral cooperation, is being investigated across a range of challenges (Jacobs et al 2010). For example, meeting and moderating demands for water in the context of highly variable water supplies has been at the forefront of political and practical concern in Australia in the wake of extended droughts (see Wallington et al 2009). Management goals centred on improving waterway health and economic efficiency add to the mix of knowledge bases that must be jointly considered in any water governance regime.

Following Healey (2008), we recognise that a strategic response to the problem of institutional fragmentation involves both 'hard' or structural responses, alongside 'soft' or process-based responses (see also Morrison et al 2004). The 'hard' or structural elements include formal organisations such as government agencies, committees, legislation, taxes and subsidies. The 'soft' or process-based elements include social relations, informal networks, administrative routines and professional cultures. Institutional innovation in the structures and processes of integrated and adaptive water governance regimes are discussed, in turn, below.

4.1. Institutional Structures to Link Knowledge with Action

4.1.1. The Role of Boundary Organisations

Whilst the importance of adaptive, flexible institutions and organisations to support actions for sustainable development is widely recognised, much remains to be learnt about their design. Katharine Jacobs and her colleagues have expressed the challenge as: 'Institutional and organisational arrangements designed to build connections between knowledge and action for water resources management are extremely diverse, and their performance is not yet well understood' (Jacobs et al 2010: 1).

Institutional collaboration has been promoted as one means of managing conflicts associated with water, and of enhancing the coordination of effort across organisational boundaries (Margerum 2008, Robinson et al in press). Benefits include:

- the co-ordination of effort between formal and informal institutions to promote more efficient and responsive management approaches needed to achieve environmental sustainability (Morrison et al 2004);
- the inclusion of a diverse range of perspectives to inform and support environmental management programs and options (Innes 1995);
- the management of conflict and enhancement of social and institutional responsibility (Ferreyra and Beard 2007); and
- the sharing, translation and integration of knowledge (Cash et al 2002).

A recent assessment of institutional requirements for integrated urban water management in Australia identified institutional capacity for communication and knowledge sharing between organisations as a critical ingredient (van de Meene et al 2009). In natural resource regimes characterised by multiple authorities and overlapping jurisdictions, knowledge and learning are key (Andersson and Ostrom 2008). Collaboration and coordination between institutions at multiple jurisdictional levels, and with multiple perspectives and knowledge-bases, can facilitate 'knowledge partnerships' which have been identified as critical to more integrated natural resource governance regimes (Berkes 2009).

An emerging focus of research and practice to underpin knowledge systems for integrated resource management is the potential of 'boundary organisations' (Figure 1). Managing organisational and knowledge boundaries through the work of boundary organisations provides a means of addressing both institutional fragmentation and knowledge integration, thus contributing to the coordination of effort for IWM.

A growing body of literature discusses how the disjuncture between the producers of knowledge and the makers of decisions is due to the boundaries that exist between science and policy, research disciplines, political jurisdictions, organisational scales, and differently organised knowledge systems (e.g. western knowledge and indigenous knowledge) (Guston 2001, Cash et al 2002). While boundaries can serve useful functions - for example, in the benefits that stem from the disciplinary specialisation of hydrologists and the policy focus of water planners - boundaries can also act as barriers to communication, collaboration, action and integration. As such, management of these boundaries is considered paramount to knowledge integration for policy-making and management action. Boundary organisations specialise in the management of these boundaries.

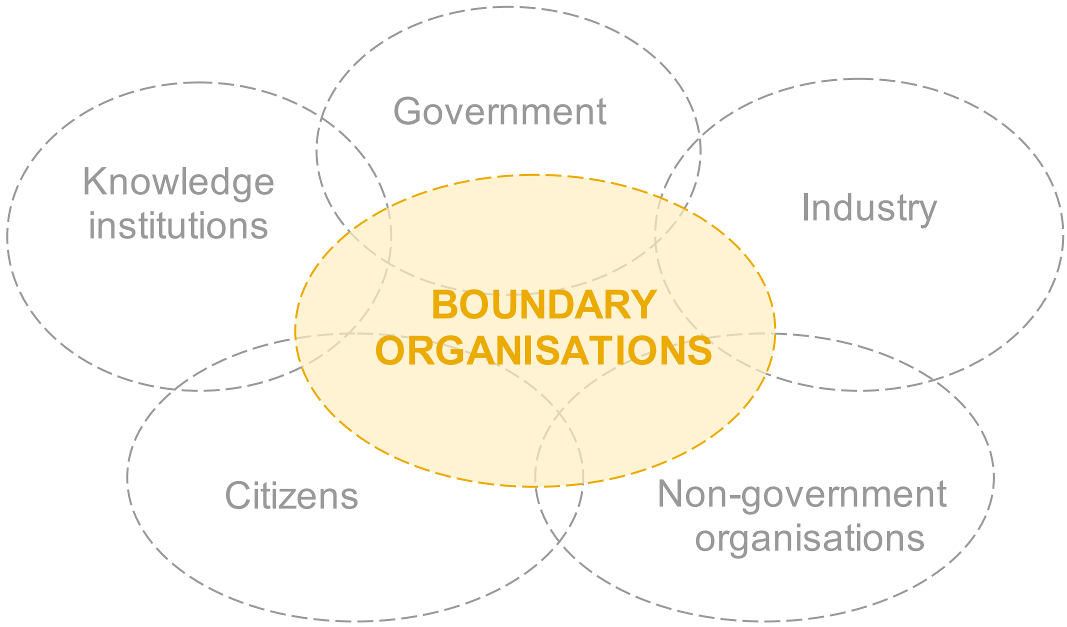

Figure 1: Boundary Organisations

(Source: adapted from Regeer and Bunders 2009:29)

Boundary organisations are situated between different social and organisational worlds, such as between science and policy (Ingham and Bradley 2006). Analysis of knowledge management regimes across regions (including water management in the USA, agricultural research systems in Mexico, El Nino forecasting systems in the Pacific and southern Africa, and fisheries management in the North Atlantic) has distilled several characteristics of successful boundary organisations (Guston 1999, Cash et al 2002, Ingram and Bradley 2006):

- they provide incentives to produce boundary objects (e.g. plans and products such as decision support software, maps), which provide a focal point for common understanding and encourage discussion and dialogue between stakeholders;
- they involve the participation of actors across boundaries; and
- they are accountable to organisations on both sides of the boundary.

Boundary organisations provide institutional capacity for communication and knowledge sharing between organisations, which is vital if advances in scientific, technical and local knowledge are to be translated and integrated into organisational decision-making (Owens et al 2006, Robinson et al 2009). This has been demonstrated by a growing base of evidence from Australia, the western United States, and Europe.

In Australia, water governance regimes in Great Barrier Reef and SEQ regions have been the subject of research effort. A key role of boundary organisations in Great Barrier Reef water planning has been to facilitate the transfer of relevant and useable knowledge between scientific and policy domains (Robinson et al 2009). In SEQ, the Healthy Waterways Partnership has facilitated the translation of scientific and technical knowledge for water quality management (Wallington et al 2009). Boundary work between different levels of action, and between diverse values and knowledge bases, has also been identified as critical to communication and knowledge transfer in the California water sector (Ingram and Bradley 2006). In Europe, boundary organisations have played several roles in water management (Moss et al 2009): in bridging the boundaries between water utilities, consumers and regulators (e.g. by building up a knowledge network for sustainable water management); in working across scales (e.g. by translating national agendas into everyday management practice); and in translating technology into particular social contexts (e.g. by matching innovative technological solutions to the business of water management).

Boundary organisations have also been identified as critical to the innovation process (Guston 2001). The implementation of technical innovations requires institutional and policy changes to foster their adoption and diffusion (Ingram and Bradley 2006). Understanding the conditions for information transfer and institutional coordination at the appropriate scale of implementation is thus required to build institutional capacity for innovation in the water industry.

The emergence, workings, functions and impacts of boundary organisations have been the subject of empirical research in natural resource domains ranging across agriculture, health, conservation, energy and manufacturing (Clarke and Holliday 2006). Here we illustrate the role and potential of boundary organisations in the water sector by expanding on the experience of CALFED, a state-federal collaboration to address water allocation and ecosystem restoration efforts in the California Bay-Delta region. The novelty and scale of this regional effort to integrate scientific knowledge into management and policy decisions, combined with the level of sustained critical analysis its implementation has attracted, make the CALFED case unique for the insights it conveys for other such efforts, including in SEQ. As Norgaard et al (2009:644) point out, 'what started as an experiment developed into one of the most important water and ecosystem management institutions in the world', not least for the insights it provides for the improved governance approaches to the management of complex socio-ecological systems.

4.1.2. Institutional Lessons from the CALFED Bay-Delta Program

The policy-level collaborative of the CALFED Bay-Delta Program emerged as a unique boundary organisation between 25 state and federal agencies that came together with the aim of improving the quality of California's water supply and the ecological health of the San Francisco Bay/Sacramento-San Joaquin River Delta (see Calwater 2010, Taylor and Short 2009). Further aims included advancement of scientific understanding of the Bay-Delta system, improved incorporation of scientific information into management decisions, and overcoming the problem of regulatory fragmentation (Doremus 2009).

The California Delta is the largest estuarine system on the west coast of the USA. The waterways and wetlands provide habitat for fish and migratory birds, and approximately 40% of California's 'plumbed' water (Norgaard et al 2009). CALFED emerged in 1994 as a multi-stakeholder process to balance water use with environmental objectives and to mange water conveyance through the Delta (Norgaard et al 2009). Prior to 1993 a 'science war' had resulted from interest group competition and conflict whereby no one outside a given organisation accepted the legitimacy of data or analysis originating from a competitor organisation (Ingram and Bradley 2006). In 2002, the California Bay-

Delta Authority (CBDA) was established to implement the CALFED program, which used a series of grants as the primary tool to implement conservation. The aim was to facilitate water management decision-making between multiple government agencies, farmers, urban water utilities and users as well as environmental groups.

The accounts and criticisms of CALFED are many (see Kallis et al 2009). For our purposes, a key issue raised by many commentators relates to the complexities associated with taking an adaptive, multi-stakeholder approach to meeting environmental and water supply goals. As Norgaard et al (2009) point out, this approach resulted in an overwhelming complexity of knowledge and information whereby environmental goals were not met and the quality of water supplied became less dependable. Although there was an advance in the scientific understanding of the Bay-Delta System as a natural and a managed system (Doremus 2009), the complex knowledge that resulted was identified as reducing the potential for scientific knowledge integration into management decisions. This is because policy makers felt there was a lack of clarity with no specific answers provided to satisfy their management challenges (Norgaard et al 2009). Further, Ingram and Bradley (2006) argue that despite the collaborative nature of the CBDA, not all policy was informed by adaptive and inclusive management theory. Rather, much of the policy carried forward previous practices – for example, rules that meant only professionals and applied scientists would be able to complete a successful grant proposal; the explicit exclusion of other public agencies (e.g. land use, environmental health) from applying for grants; and the dominance of the organisation representing the urban *water supply* agenda, which protected the water agency hierarchy and set limitations on the definition of issues. These constraints limited CBDA's ability to act as a forum for multiple voices about *water efficiency*, resulting in path-dependant water decisions that reinforced, rather than transformed, past practice: "By privileging urban water providers through BMPs, and then setting up a grant system that favored sending state money to these same agencies, the program overlooked ideas and perspectives challenging the status quo" (Ingram and Bradley 2006:76).

In this context, Norgaard et al (2009) argue that CALFED should not be judged a partial failure, but should rather be seen as an interesting and incomplete experiment in the integration of science and management:

> *These critical interpretations hide the important successes of the CALFED SP [Science Program] in reframing key questions, enhancing understandings about the complexity of Delta dynamics and exposing individual scientists, policy-makers and stakeholders to each others' knowledge and the limitations of any single framing or simple explanation (Norgaard 2009:651).*

Examples of such accomplishments are evident in the CBDA (Environmental Water Account) and CALFED (Agricultural Water Use Efficiency Program) policy initiatives described in Boxes 1 and 2 respectively below. Despite the fact that neither program continues to be implemented, they provide insights into the institutional structures and conditions that enabled successful collaboration, knowledge-sharing and learning between stakeholder groups that were previously in conflict. These insights relate to institutional support for boundary organisations and science integration for IWM, the role of the state, and adaptive management.

- CALFED'S success shows that institutional conditions that foster boundary organisations, support boundary managers and encourage the creation of boundary objects are critical for knowledge integration, co-creation and mutual learning for IWM (Ingram and Bradley 2006, Doremus 2009, Fuller 2009).
- Institutional support for such boundary organisations requires extensive investment of skills, time and finances to deliver positive processes and results, especially in association with regional and policy-scale initiatives (Robinson et al in press).
- Linking science and policy making creates an even greater awareness of uncertainty (and a lack of clarity for policy makers). The disjuncture appears with the blurring of the role of scientists as providers of objective answers, to their role as providers of insights into complex social-ecological systems. In the CALFED case, the complex systems view opened more questions that heightened the uncertainty of decision-making for policy makers (Norgaard et al 2009).

- Institutional responses to knowledge integration for IWM only provide partial solutions. The agreements made via boundary organisations that incorporate all the 'right' stakeholders and views, are not always the final step in a policy process. Much can change in implementation, and success ultimately depends upon funding support which, in the case of CALFED, was withdrawn with a change of administration (Bobker 2009, Fuller 2009, Taylor and Short 2009).
- Knowledge integration for IWM takes time. Luoma (2009) suggests that the CALFED experience elucidates how a decade is not enough time to create a solution to a wicked, long-standing water management problem. CALFED should be regarded as a first step in a long process of water management reform.
- Given the above, institutional structures must support adaptive management approaches. Ingram and Bradley (2006:29) express how the CALFED and CBDA offer 'the very best laboratory available for assessing the possibilities of innovation in water institutions and policy'.

Box 1 The Environmental Water Account

The Environmental Water Account (EWA) facilitated by the California Bay Delta Authority (CBDA) is portrayed by Ingram and Bradley (2006) as a successful program of CALFED as it facilitated water management decision-making and action between multiple government agencies. These include state and federal agencies responsible for fish management (the California Department of Natural Resources, the US Department of the Interior and the National Marine Fisheries Service) and agencies responsible for water operation management (the California State Department of Water Resources, the US Bureau of Reclamation and the US Army Corps of Engineers).

Although the EWA did not prevent further declines in listed fish species populations, and has been superseded by court-ordered water export reductions, the close coordination between government agencies continues (Bobker 2009). The access that fish management agencies gained to environmental water rights through markets facilitated working relationships across boundaries of perception, knowledge and organisation. The fish management agencies had to collaborate with the water operation managers to determine times to release water from storage facilities that helped fish and accommodated water users (Ingram and Bradley 2006). This was in contrast to past practice where fish managers mandated water releases and let water contractors bear the costs of reduced water supplies.

Ingram and Bradley (2006) explain how the environmental water account acted as a boundary object that enabled managers to bridge the various boundaries. For example, fisheries managers now operate as water brokers, deciding whether to expend assets to address present fisheries challenges or to save water for future challenges. Previously, these managers 'looked at water resources from a fish's point of view' (p64) and saw human influences as the greatest threats to fish (as opposed to the view by contractors that water is a commodity and fish form one of many claimants on water resources).

Following the inclusive management process inaugurated by the CBDA, fisheries managers held regular meetings with water contractors to determine the best management of the boundary object. Cultural exchange and understanding in relation to the other's management pressures and constraints was one result of this work (Fullerton 2009). Water operation managers, for example, began to better understand the multiple aspects of water favourable to fish survival. Networks, relationships and a shared language provided ways to transcend organisational and knowledge boundaries. Ingram and Bradley (2006) report that the EWA has resulted in a paradigm shift for some managers, and certainly attitudinal change, as well as new levels of trust.

This case substantiates the contention that institutional structures that support the development of boundary organisations are essential for knowledge integration, co-production and mutual learning for IWM. The CALFED institutional conditions supported collaborative network development between previously fragmented institutions. Although these collaborations did not reduce further decline in listed fish species populations, they represent ongoing adaptive management of knowledge integration for IWM in the region. They also highlight the complex nature of fish management as part of the socio-ecological system.

Box 2 The Agricultural Water Use Efficiency Program

The CALFED Agricultural Water Use Efficiency (AWUE) program was designed to foster efficient water use to support a sustainable economy and ecosystem. The first CALFED subcommittee, the AWUE Working Group, failed to reach agreement between the agricultural and environmental groups in California who had fought for three decades over how much water would represent the goal of water efficiency (Fuller 2009). Although a subsequent change of government has rendered the AWUE program unsuccessful in implementation (due to lack of funding), much can be gleaned from CALFED's second consensus building process, the AWUE Steering Committee, that was able to reach consensus between the very same stakeholders (Bobker 2009).

All stakeholders contested CALFED's estimates for the potential of agriculture for water conservation as well as the methodology used to determine this estimate. The lack of consensus between different stakeholder groups related to how much water could be saved, the most appropriate management practices to use, and how they should be applied. This was based upon the underlying disjuncture of values, deep-seated mistrust of the other's motivations and a belief that the other side did not understand the basic science of the problem (Fuller 2009).

The Steering Committee used a variety of adaptive management approaches to generate consensus between the stakeholders. These included: an Independent Review Panel of Agricultural Water Conservation Potential (the Panel of technical experts) selected by all stakeholders; and the proposition of a new framework to move forward. This framework included the setting of downstream goals (e.g. the restoration of a specific habitat), specific quantifiable objectives to achieve the goals (e.g. maximum amount of salt entering that habitat), and case-by-case basis interventions to meet those objectives. This framework resonated with stakeholders as it acknowledged how actions link with downstream outcomes, and advocated water conservation methods suitable to local contexts. Via this process, trust was built between stakeholders and the Panel, a forum was created where members could openly express their ideas, and a set of norms was developed to govern group behaviour that included listening, no ownership of ideas and an 'inter-language'. Further, material artefacts such as spreadsheets, PowerPoint visual presentations and diagrams were developed by the group. These 'boundary objects' enabled problem solving, new learning and transparency in process (Fuller 2009).

This case highlights that institutional support for boundary organisations requires extensive investment. For the AWUE program, extensive investment was required to develop trust between stakeholders, involvement of skilled facilitators, creation of boundary objects and knowledge, and creation of new panels and the steering committee. This case study elucidates how these structural responses only provide a partial solution, however, a situation that may have provided justification for its discontinuation with a change in government administration.

4.2. Institutional Processes to Link Knowledge with Action

4.2.1. Strategies for Building Capacity for Knowledge Sharing and Integration

The generation of information and its integration into decision making is recognised as key to integrated urban water planning in Australia (NWC 2007, Marsden Jacob 2008). Whilst the prevailing view amongst biophysical scientists is that 'good science' will automatically be translated into 'good policy', social research has determined that good information does not automatically influence policy and management decisions (Cash et al 2006, Roux et al 2006).

The political and technical nature of this challenge has been met with efforts to engage stakeholders and others to assist in the process of integrating multiple sources of knowledge and the diversity of perspectives associated with these interests. The past two decades have seen traditional state-based water regimes complemented and challenged by new forms of collaboration (van Kerkhoff and Szlezak 2010). In particular, there has been a marked interest in the international research community on policy-level collaboration for water, most notably in Europe (Water Framework Directive) and the United States (e.g. Northwest Power and Water, California Bay-Delta, Rogue River Basin, and Chesapeake Bay). These studies have identified a number of advantages to collaborative approaches, including increased levels of stakeholder commitment, the achievement of more comprehensive and effective solutions, and resource efficiencies. At the same time, the transaction costs in terms of time and resources associated with these processes are remarkably high.

A comparative study of four knowledge systems for water management by Jacobs et al (2010) to investigate the role of participatory governance and scientific information in water management decision-making is insightful. The results of this study across river basins in Brazil, Mexico, Thailand and the United States confirm the benefits of expanded citizen engagement for enlarging the culture of integrated learning that underpins adaptive management styles and solutions. An important caveat that was found to hold across each of these disparate watersheds is that the benefits of participatory processes are more often harnessed in the context of short-term decisions, such as water-allocation decisions, which can be easily adjusted. Such processes, it was found, do not work as well for longer-term, high-stakes decisions regarding large infrastructure projects. The authors of this study describe the implications for adaptive management in this way: 'The reality is that some kinds of decisions, for example major infrastructure decisions, do not leave much scope for fine-tuning or reversing once the facilities are completed. This consideration, along with the major financial investments required, may be part of the explanation for not involving stakeholders in such high-stakes decisions' (Jacobs et al 2010:5).

Sustainable water governance regimes need to be flexible enough to integrate new sources of knowledge. Research by Jacobs and others suggests that the joint learning induced by expanded stakeholder participation in short-term, water-related decision-making 'has not been matched by comparable institutional capacities to learn through and about issues involving longer time frames' (Jacobs et al 2010:5, see also Pahl-Wostl 2009). In the following, we explore a range of institutional attributes and processes, illustrated through a range of related cases, to identify discernable strategies for building institutional capacity to induce knowledge sharing and integration for adaptive IWM.

One such area of research in the domain of sustainability science has focused on the attributes of knowledge that underpin its uptake in decision-making. In this work, Cash et al (2002, 2003) have found that information that is regarded by all stakeholders as salient, credible and legitimate is more likely to be taken up by decision-makers. These knowledge attributes might be thought of as a set of 'performance metrics' for knowledge integration (Table 2).

Table 2: Metrics for Knowledge Integration in Decision-Making

Salience	Relevance to the decision at hand	*Does the assessment address questions relevant to decision-makers' needs?*
Credibility	Scientific authority	*Does the assessment meet scientific and technical standards?*
Legitimacy	Procedural fairness	*Were the various stakeholder interests taken into account fairly during the assessment process?*

Source: Cash et al (2002)

Salient information considers ecological, administrative, spatial and temporal scales, and takes into account existing policy and decision-making processes. Salient information is useful because it recognises how issues have been defined and framed and why various options have been considered (rather than just listing the actions taken to address problems).

Information must also be credible, or regarded as accurate and dependable by policy and other decision-makers with the levels of uncertainty attached to the information made transparent.

Finally, information must be legitimate, or produced through a process that is considered fair and free of bias. As such, legitimacy requires that the knowledge generation and transmission process is transparent, the production of information is respectful towards stakeholders' divergent values and beliefs, and the relationship between information producer and information user is characterised by mutual trust and respect (McNie 2007, Cash et al 2003).

McNie (2007) makes the important point that salient, credible, and legitimate scientific information is dependent upon supportive social processes that focus upon building social capital. Knowledge and information creation processes that build social capital, for example by improving the links between scientists and managers, are more likely to result in information that meets the needs of decision-makers (McNie 2007, Bosch et al 2003). In particular, these processes are explicit about power sharing between scientists and stakeholders to ensure that the problem is defined and knowledge is shared through an inclusive, collaborative process.

The policy-level institutional collaboration that has occurred around the Great Barrier Reef Plan in northern Australia illustrates the value of these knowledge attributes as performance indicators toward a more coordinated approach to the integration of knowledge into decision-making for water quality improvement (Box 3). A key premise of the study was that 'Communication and knowledge-sharing are vital to collaborative efforts if advances in scientific and other forms of knowledge (technical, bureaucratic etc.) are to be integrated and translated to bridge the knowledge–policy "gap"' (Robinson et al 2010:2).

Box 3 Knowledge Integration for Strategic Decision-Making in the Great Barrier Reef

Robinson et al (2010) examine the interactions between formal and informal policy-level collaborations through a case study concerning environmental governance of the internationally significant ecological system known as the Great Barrier Reef in the wet tropics of northern Australia. A Reef Plan to coordinate activity with the aim of halting deteriorating water quality in Reef lagoons was initially formulated via a bilateral agreement between the Queensland and Australian Governments in 2003. This agreement entailed very little stakeholder involvement. In order to implement the plan, more than 7 formal collaborative partnerships between government and non-government organisations were formed from 2005 onwards. Beyond state and national government participation, the partnerships were inclusive, drawing in natural resource management, peak agricultural industry, conservation, and science stakeholders. These policy-level collaborative fora generally lasted 6–12 months, employed formal processes (e.g. Terms of Reference and record keeping) and enjoyed administrative support. As the formal partnerships involved government and non-government agency representatives, they tended to be slow-moving and cumbersome. Interviewed participants complained that a 'deadening' strategy of passive participation was taken by some agencies and that representatives lacked power to affect change in their home organisations as a result of collaborative effort (p13).

This inflexibility was overcome by the formation of an informal and ephemeral collaboration, the 'Reef Alliance' to take advantage of a 'policy window' that opened up with the opportunity provided by a national election. Comprised of a network of individuals from non-government organisations, the Reef Alliance 'presented a common position across the traditionally polarised agricultural and conservation sectors' (p13). These efforts culminated in the Reef Rescue Plan of 2008, a $200 million program focused on improving agricultural land management practices with the aim of reducing diffuse water pollution. The program 'built on the formal collaborative agreements negotiated over the previous two years, and utilised informal collaborative networks to access the political decision-making processes during an election phase' (p14).

Three types of knowledge proved pivotal to the decision-making tasks of prioritising, investing and evaluating Reef Plan actions: technical and industry knowledge, scientific and place-based knowledge, and bureaucratic and operational knowledge. The interplay between the formal collaborative partnerships and the informal collaborative networks in the effort to integrate these three types of knowledge illustrates the tensions and trade-offs between salience, credibility and legitimacy (see also Cash et al 2002). The informal Reef Alliance was made up of politically savvy individuals with access to high-level bureaucrats and Ministerial Offices. Thus, it effectively provided highly salient knowledge during a policy window. However, the strength of the formal collaborations was grounded in their capacity to co-produce credible and legitimate knowledge. Formally co-produced knowledge was more credible because a broad range of expertise and evidence (e.g. socio-economic data, water quality data, star fish damage data) was integrated. It was more legitimate knowledge in that it was produced by inclusive representation of relevant interests. Thus '... the ability of informal networks to influence changes stems from their capacity to quickly provide salient political and scientific information when a "policy window" opens up, utilising knowledge for which credibility and legitimacy is already sufficiently established' (p20).

Communication approaches that recognise the role of social learning are considered to be essential for sustainable and adaptive water management in the context of social and environmental change (e.g. Pahl-Wostl 2007, Collins et al 2009). Active, iterative and inclusive communication between experts and decision makers is more likely to mobilise knowledge for sustainability than communication that is largely one-way, infrequent and perceived to exclude some actors. The results of comparative analyses internationally has identified integrated cooperation structures (including non-governmental stakeholders, governments from different sectors and different hierarchical levels), and advanced information management (including joint/participative information production, consideration of uncertainties, and broad communication) as the key factors leading towards higher levels of learning (Pahl-Wostl 2009). Box 4 provides the example of the HarmoniCOP (Harmonising Collaborative Planning) research program to investigate the relationship between participatory approaches and the integration of knowledge for water-related decision-making.

Box 4 Social Learning for Adaptive Management – the Case of HarmoniCOP

Issued in 2000, The European Water Framework Directive (WFD) requires the restoration and maintenance of river basins to improve the ecological status of aquatic ecosystems. The Directive has stimulated a shift in Europe towards managing rivers and floodplains adaptively for multiple purposes. This new emphasis on floodplain management interrupts a historically centralised (state to national) emphasis on flood control. Given the social and ecological complexity of river basins, adaptive management of floodplains is plagued by many factual uncertainties. In addition to the uncertainties associated with climate change drivers, basic hydrological data is often unavailable, or needs to be integrated with spatial urban planning data to get a picture of land and water interdependencies (Pahl-Wostl et al 2005). Factual uncertainty is compounded by the ambiguity posed by the way relevant stakeholders frame IWM issues differently (Pahl-Wostl 2006). Frames originate in different scientific disciplines, levels of government as well as industries and NGOs (Dewulf et al 2005). The knowledge translation issue here concerns the negotiation of a common framing of the water management issues at stake in river basins and development of a river basin knowledge base (Weible et al 2010:1).

The HarmoniCOP (Harmonising Collaborative Planning) was established 'to increase the understanding of participatory river basin management planning in Europe' (www.harmonicop.uos.de/ov_objective.html). Learnings were harnessed from ten national cases studies of river basin management which ran from 2002 to 2005. The project concerned social learning to build trust between stakeholders, to develop a common view of the issues at stake and to arrive at 'joint solutions that are technically sound and actually implemented in practise' (HarmonicCOP 2005:II, Tippett et al 2005). Social learning is here regarded as 'a prerequisite to understanding why there are different perspectives and dealing with them constructively' (Pahl-Wostl 2006:8). Stakeholder interaction to share data and information, to co-produce new monitoring systems, and to involve stakeholders in data collection and monitoring formed a pivotal focus (Pahl-Wostl et al 2005). Such interaction is expected to lead, in the medium- to long-term, to the design of more adaptive river governance structures by these stakeholders as they learn about the shortcomings of existing institutional arrangements and identify and test alternatives.

HarmoniCOP's consensus-building approach to knowledge integration for IWM is resource intensive. Work was preceded by stakeholder analyses, and the use of specialised facilitators, as well as the time investment of participants, made transaction costs high. Critics also note that this emphasis on developing a common understanding may also disallow radical options because they tend to be politically charged. Turning key policy knobs for the return of agricultural land to 'nature', for example, may be spurned in favour of incremental adjustments such as increasing water use efficiency (Jacobs et al 2010:4). Consensus-based means of integrating knowledge also appear inappropriate for expensive and long-term decisions such as investment in large physical infrastructure (Jacobs et al 2010:5), and unable to deal with distributive dilemmas. Some consider the quest for consensus as constituting an abrogation of political responsibility by central administrations (Kallis et al 2009). Notwithstanding these concerns, emphasis on social learning through mutual recognition of other points of view in an interactive process to facilitate the sharing and joint production of knowledge can encourage awareness by stakeholders of their interdependence, and yield a much richer view of the 'facts' (Jacobs et al 2010:5).

Whilst the translation of knowledge into action requires mutual understanding between experts and decision-makers, this is often hindered by jargon, experiences, and varying understandings of what constitutes credible information. Blaike et al (1997) have identified mechanisms for knowledge sharing and co-creation between different stakeholders, including:

- a negotiated set of rules for appropriate participation between actors that defines how power is exercised and development knowledge is created;
- improved personal information sharing, the establishment of trust and functional working arrangements;
- negotiation regarding local and external agendas; and
- inclusion of local voices at the project/program scoping stage.

Information flow that results from mechanisms for improved knowledge translation does not always reduce conflict between interest groups, however. Mediation can assist further by 'enhancing the legitimacy of the process through increasing transparency, bringing all perspectives to the table, providing rules of conduct, and establishing criteria for decision making' (Cash et al 2003:8088).

4.2.2. Lessons from Attempts at Integrating Climate Data for Water Planning

The contemporary context of climate uncertainty for urban water planning, elevated to the national policy agenda in Australia by extended drought conditions in most capital cities, is a pertinent example of the need for knowledge institutions to assist in the transition to IWM. A range of studies in the Pacific Northwest context have confirmed that many water resource managers do not readily incorporate new information and forecasts about global-level processes in their decision-making. While weather forecasts and analyses of climate conditions should be helpful to decision-making, they are often resisted for institutional reasons, because they are not provided in a useful or timely way, or because there is little interest in using new sources of knowledge more generally (Rayner et al 2005). This work has provided several insights into the relationship between scientific and technical knowledge, and its role in decision-making:

- scientific and technical information is not privileged in organisational decision-making. It competes with local knowledge, political mandates and pressures, stakeholder pressures, and internal organisational needs;
- decision processes are often severely limited by political circumstances or existing regulatory requirements that overwhelm improvements in scientific information;
- organisational decision routines often undervalue externally generated information, or find it difficult to integrate; and
- successful integration of scientific information often depends on the presence of an internal translator, who can convert general information into organisationally relevant specifics.

Differences between two countries in their policy uptake of climate knowledge for water management highlighted here point to possible design insights for effective knowledge–action systems. The institutional conditions water managers operate in have a clear impact on their willingness and ability to embrace innovations such as climate forecasting (Lach et al 2005). This point is made by Engle and Lemos (2010) in their examination of Brazil's overhaul of its water management arrangements in the 1990s, and by Lemos (2008) in a comparison of the use of seasonal climate forecasting (based on the El Nino Southern Oscillation) in water management in the USA and Brazil.

A key institutional difference between the two national water management systems is Brazil's devolution of management to the catchment level, replacing state and federal water jurisdictions. User participation organised via 150 river basin councils (Lemos 1998:1391), and a water resources management company created with 'an interesting blend of engineers, hydrologists, and social scientists' (Lemos 2008:1392), also distinguish the situation in Brazil. Local water managers in one Brazilian river basin built reservoir scenarios using climate forecasts to communicate likely water availability to water users. The Brazilian water reforms made preparing and responding to climate change more feasible by bringing forecasting information to bear on difficult public decisions regarding allocation of scarce water by proactive river basin councils (Engle and Lemos 2010:4). In contrast, the American water management system largely rejects climate forecasts as too uncertain to use. Lemos (2008) attributes this aversion to the system being more heavily constrained legally, highly fragmented organisationally, and suffering the inertia that expensive, large infrastructure entails.

This view is supported by the work of Rayner et al (2005) in Southern California to understand why water resource managers do not use climate forecasts. Climate forecasting has high salience in California as the El Nino-based forecasts are widely perceived as reliable, the water infrastructure is vulnerable to extreme weather, and there is high-level political support for emergency preparedness (Rayner et al 2005:214). A deep reluctance to move into aggressive demand-side management persists, with higher level managers the most reluctant to use forecasting to promote analytical and operational innovation in the water sector (2005:212-213). The authors attribute this to a common outlook amongst managers that reliable water supplied at the right quality (for households, agriculture and salmon) and at a low cost has achieved a level of political invisibility that would be threatened by experimentation and innovation (Rayner et al 2005:209-210). Institutional innovation to assist in the knowledge integration task persists in the United States with a program of Regional Integrated Scientific Assessments to construct regionally specific knowledge systems regarding climatic conditions and water management (see Box 5).

Box 5 Collaboration for Climate Data Integration – the Case of CLIMAS

Climate science is highly significant for IWM, in particular, scientific understanding of the El Nino Southern Oscillation (ENSO) arising from the interplay between the tropical Pacific Ocean and the atmosphere. Although local fishermen have woven knowledge of ENSO into their livelihood strategies for many decades, the first successful ENSO forecast was produced in 1986 by Columbia University researchers (Buizer et al 2010). Subsequently, the National Oceanographic and Atmospheric Administration (NOAA) established the Pacific ENSO Applications Climate (PEAC) Centre in 1994 to service the USA with seasonal to annual ENSO forecasting relevant to climatically sensitive sectors such as the water resource dependent sectors of agriculture, hydro-electricity, fisheries, and forestry as well as coastal disaster preparedness. As part of this initiative, NOAA's Office of Global Projects also funded a program of eight Regional Integrated Scientific Assessments (RISAs) to construct regionally specific knowledge systems regarding climatic conditions and water management (Liverman 2009). CLIMAS, the RISA for the America's Southwest (comprised of Arizona and New Mexico), sought to translate climate science for use by the region's water managers (Lemos and Morehouse 2005:58).

The knowledge translation challenge for CLIMAS was two sided. Firstly, a picture of local to regional climatic impacts was built by integrating hydrological, anthropological, climatic, geographic and resource economic knowledge. This regional science was furthermore integrated with the knowledge of multiple public and private decision-makers positioned in sectors affected by droughts, floods and cyclones. In addition to targeting the water management sector, CLIMAS targets the agricultural and ranching, climate service, ecosystem management energy, emergency management, fire management, public health, tourism and recreation and urban sectors. Stakeholders from these sectors were included in all research phases to bridge the knowledge forecast producer-user divide and to co-produce knowledge that tailors climate science to particular decision making contexts. For example, snowpack was modelled to support river forecasters and regional forecasts used to support drought planning for the state of Arizona.

CLIMAS employed 'iterative research' that: "produces sustained, regular interaction among participants and creates relationships between science and decision-making that can shape the ways knowledge is produced as well as how the usefulness and value of knowledge is perceived" (Lemos and Morehouse 2005:61). One product arising out of these interactions, the monthly Southwest Climate Outlook newsletter, has been published for a decade. Each newsletter includes reservoir levels, a status report and forecast for El Nino, temperature, rainfall, drought and stream flow forecasts, verification of the previous month's forecasts to communicate their degree of reliability, as well as a topical feature article (http://www.climas.arizona.edu/outlooks/swco).

CLIMAS was resource intensive, taking five years and considerable resource expenditure (Lemos and Morehouse 2005). Engaging with the multiple decision-making contexts for using climate science generated high transaction costs which made attracting ongoing investment difficult. Dependence upon key individuals (champions and innovators, mediators and translators) was also high. However, employing highly collaborative processes that built sufficient trust and mutual understanding between scientific disciplines and stakeholders anchored in climatically vulnerable sectors brought climate science to bear on multiple on-ground decisions in America's southwest. The case supports the contention that knowledge systems necessary to support IWM cannot be built with agency or scientific knowledge alone (Lane and McDonald 2005, Lane and Robinson 2009, Weible et al in press).

5. IMPLICATIONS OF THE KNOWLEDGE – ACTION SYSTEMS REVIEW FOR SEQ

The shift toward IWM approaches in SEQ has emerged in response to the need to ensure that available water policy delivery instruments are governed through principles that comply with the NWI and consider the range of water-related values held by SEQ stakeholders. This review highlights that planning reforms in SEQ echo water policy development occurring across a range of watersheds and regions. Institutional mechanisms that translate available knowledge into strategic water decisions are a critical feature of IWM. The imperative for linking knowledge with action stems from the realisation that planning decisions need to tackle complexities and uncertainties inherent in water management decisions. Mechanisms to facilitate joint knowledge production between knowledge providers and knowledge users are critical to this task.

The insights of institutional responses to the challenge of IWM reviewed in this report suggest that strategic responses to the 'boundary work' features of linking knowledge with action in the pursuit of sustainable water management requires both 'hard' structural responses and 'soft' process-based approaches. Adaptive and participatory structures and processes have much to offer. Governance institutions that support collaboration across disciplinary and professional boundaries facilitate the necessary creation of linkages between science, policy and management. National and international case study examples (Boxes 1-5) illustrate how boundary organisations can facilitate and create linkages across these boundaries. These case studies also highlight the constraints of, and external challenges facing, such organisations.

Boxes 1 and 2 describe case studies of IWM in the San Francisco Bay/Sacramento-San Joaquin River Delta of North America. These experiences provide insight into the 'hard' institutional structures, conditions and mechanisms necessary for knowledge integration for IWM in SEQ. Institutional conditions that foster boundary organisations, support boundary managers and encourage the creation of boundary objects are critical for the knowledge integration, co-creation and learning necessary for IWM. Institutional support for these organisations requires extensive investment. Also, structures should provide for the management of relationships, as well as knowledge co-creation mechanisms to reduce 'explosions of complexity' (see Norgaard et al 2009). For example, in the CALFED case, this resulted from a blurring of roles between scientists as providers of answers to policy makers, and as providers of insights into complex systems. One such mechanism would be to take a long timeframe perspective of IWM as an ongoing experiment in knowledge co-creation and co-learning, as opposed to something that can be solved via short-lived projects and programs. Related institutional conditions need to foster and support adaptive management approaches to IWM. Finally, it is important to recognise that institutional responses to knowledge integration for IWM only provide partial solutions. For example, institutional support in the form of funding is often contingent upon the existing government. However, formal commitments to IWM in the SEQ Regional Plan 2009-2031 and in the NWI may potentially serve to motivate and maintain commitment despite a change of government, such as that observed in relation to CALFED in California.

Boxes 3-5 describe case studies of 'soft' process-based approaches used to undertake boundary work. The major lessons relate to 'soft' knowledge translation processes. These processes facilitate interaction between the organisations, stakeholders and scientific providers relevant to IWM. The formal and informal collaborative partnerships regarding diffuse water pollution in the Great Barrier Reef provide an example of the form such approaches can take (Box 4). The case of seasonal to annual climate forecasting featured in Section 4.3 of this review provides specific guidance on the purpose of interaction. Interactive processes are here used to marshal an end-to-end relationship between forecasting communities and user communities.

The review supports research findings from Wallington et al (2009) based on interviews with senior water managers in SEQ, which found that the institutional capacity to translate available science to make strategic decisions is a critical requirement of IWM systems. Efforts to build and resource boundary organisations reflect 'hard-wired' or structural approaches to translate knowledge into water policy decision-making that have been tried through organisations such as CALFED and the Reef

Water Quality Partnership. Institutional support requirements to manage the role of scientists and the information requirements of policy makers provide useful insights to inform the efforts of boundary organisations, such as the Healthy Waterways Partnership in SEQ.

Insights from IWM experiences and analyses also show that a strategic response to co-ordinated development of water, land and related resources cannot be resolved through structural responses alone. 'Soft-wired' responses (communication, information sharing, institutional learning etc.) are also required to link knowledge with action through participatory and adaptive processes. This becomes critical when IWM systems are required to work across scales, or tackle complex issues that often contain high levels of uncertainty (Andersson and Ostrom 2008). Such conditions exist in SEQ where water policy makers and stakeholders continue to engage in a fluid, often challenging dialogue to align effort and priorities in response to the evidence of impacts caused by recent droughts as well as the predictions of climate forecasting. Understanding how integration has been analysed and practised in other water planning domains can help inform the design and review of knowledge institutions created for integrated water management in SEQ. Careful design of such knowledge institutions can enable science to be shared and critiqued by multiple stakeholders and support particular problem types and policy settings needed for sustainable water management solutions in Queensland.

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