Science–policy processes for transboundary water governance

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Abstract

In this policy perspective, we outline several conditions to support effective science-policy interaction, with a particular emphasis on improving water governance in transboundary basins. Key conditions include: 1) recognizing that science is a crucial but bounded input into water resource decision making processes; 2) establishing conditions for collaboration and shared commitment among actors; 3) understanding that social or group learning processes linked to science-policy interaction are enhanced through greater collaboration; 4) accepting that the collaborative production of knowledge about hydrological issues and associated socio-economic change and institutional responses is essential to build legitimate decision making processes; and 5) engaging boundary organizations and informal networks of scientists, policy makers and civil society. We elaborate on these conditions with a diverse set of international examples drawn from a synthesis of our collective experiences in assessing the opportunities and constraints (including the role of power relations) related to governance for water in transboundary settings.

Introduction

Climate change will exacerbate already severe pressure on freshwater resources from agriculture, industry and growing urban populations (Vörösmarty et al. 2000; Milly et al. 2008). Globally, significant changes in river flow have already been observed, while projected changes in river flow under different climate and water withdrawal scenarios point to significantly increased water stress in many jurisdictions (Palmer et al. 2008; MacDonald 2010; Grafton et al. 2013).

Many of these changes are occurring in transboundary basins, which adds to the complexity of problem analysis and identification of effective responses in these key systems (Pahl-Wostl et al. 2013). About 45 percent of the Earth's land surface is covered by 276 river basins shared by more than one country (De Stefano et al. 2012). Transboundary basins at sub-national levels number in the thousands. Hundreds of transboundary aquifers present even more challenging settings for governance (UNESCO 2009).

Barriers to effective water governance in transboundary settings are significant, and include power imbalances, inadequate attention to rapidly changing biophysical conditions and a growing array of social actors with a stake in decision making (Zeitoun et al. 2013). Integrating different forms of knowledge – e.g., scientific, local, indigenous, bureaucratic (Edelenbos et al. 2011) – has emerged as a key determinant of governance success (Karl et al. 2007). Scientific knowledge – which for our purpose refers to knowledge about social and natural phenomena that has been generated by people using scientific methods – has long been considered authoritative. However, this is changing. It is now widely accepted that scientific knowledge alone is not sufficient for dealing with complex environmental issues (Lejano and Ingram 2009). At the same time, the gulf that often exists between "decision makers" and scientists can be wide (Cash et al. 2003). Recognition of this fact accounts for the enormous amount that is being written about strategies to improve science-policy interaction (e.g., Roux et al. 2006; Karl et al. 2007; Pielke 2007; Ascher et al. 2010; Kasperson and Berberian 2011).

Without diminishing the importance of other forms of knowledge, scientific knowledge clearly remains central to addressing current and emerging water challenges. The barriers to effective science-policy interaction for transboundary water governance are many and can include military and security issues unrelated to water resources, pressures associated with exploitation of resources of economic value (including water), imbalances of power among and between decision makers and societies (see discussion below), and the self-interest of upstream stakeholders over those downstream (Zeitoun et al. 2013; Zeitoun and Warner 2006). Other political challenges to science-policy interactions for transboundary water governance include allocating the high costs of organizing and sharing data and information, disagreements about the accuracy and acceptability of existing baseline data, and the use of data or information as a 'weapon' in directing blame toward particular actors in a transboundary setting (Turton et al. 2003; Timmerman and Langaas 2004; Grossman 2006).

In this brief perspective we identify five important conditions that – on the basis of our combined expertise – can be identified as supportive of effective science-policy interactions. The key conditions we emphasize include 1) recognizing that science is a crucial but bounded aspect in water resource decision making processes; 2) establishing initial conditions and shared commitment among actors; 3) understanding that social or group learning processes linked to science-policy interaction are enhanced through greater collaboration; 4) accepting that the collaborative production of knowledge about hydrological and associated socio-economic change and institutional responses is essential to build legitimate decision making processes; and 5) engaging boundary organizations and supporting informal networks of scientists, policy makers and civil society.

Our arguments emerge from our collective international experience and extensive knowledge with science-policy processes in a wide range of transboundary basin settings. During the past decade, we have worked on a range of natural and social science studies in a variety of river basins, including most of the basins from which examples used in this paper are drawn (see Table 1). To catalyze this synthesis of conditions, we met as a group in 2012 for a symposium and workshop to refine our perspectives on the key conditions presented here. We do not claim this list of conditions to be the final word. However, they resonate with experiences in the literature in a host of environmental contexts. The value they add comes from the way they are grounded in transboundary basin settings where institutional conditions for governance and effective science-policy interactions are highly complex.

Challenges for effective science-policy interaction

How science-policy processes can be enhanced to improve decisions about water (and other resources) is a topic of much debate within the environmental science and policy communities, and broad agreement exists around some key principles. For instance, scientists are often encouraged to better communicate risk and uncertainty to non-scientific audiences, and policy makers are urged to use the best available scientific evidence (Guston 2004; Pielke 2007; Toderi et al. 2007). Overcoming disciplinary isolation is also recognized as a priority (Kasperson and Berberian 2011).

A host of factors makes effective science-policy integration challenging in most water decision making contexts, and especially in those involving more than one jurisdiction. Institutional fragmentation across jurisdictions, unequal power among basin actors in different jurisdictions, a potential for high levels of political conflict, and differences in a culture of decision making contribute to ‘wicked’ (or ‘super-wicked’) problem contexts (see Levin et al. 2012), and can undermine efforts to make the science-policy interface work better. Here, we refer to wicked problems as those types of problems that are very difficult (and perhaps impossible) to resolve because they are characterized by strong interconnections and high degrees of uncertainty, incomplete information or contradictory understandings, and value conflicts (see Rittel and Webber 1973).

Sutherland et al. (2013) recently synthesized twenty suggestions or ‘tips’ to improve the integration of science in political decision making, with a focus on policy makers’ understanding of the imperfect nature of science. The list is helpful but ultimately application of the ideas requires a social context in which scientists, policy makers and others attempting to and engaged in governing can actually interact and deliberate. This social context includes the diverse norms and values among the constellation of actors in a water decision making process (e.g., industry groups, aboriginal communities) as well as differences in power and authority among those individuals and organizations (see below). These constraints have material consequences, and, as a result, uptake of suggestions to improve integration of science in political decision making in real-world settings will continue to be slow unless the social and institutional context for science-policy interactions in transboundary water governance is accounted for and, where inadequate, improved. The conditions we highlight in this perspective are a key part of these improvements.

Doing and using science differently requires reflecting on what science is being used for; understanding how results will be mobilized and by whom; overcoming fragmentation among organizations and the knowledge used to inform decisions; recognizing the social and political aspects of science-policy practices; and accounting for multiple framings of problems and solutions (Roux et al. 2006; Lejano and Ingram 2009; Sutherland et al. 2013). Our experiences and the cases we draw upon for this paper demonstrate that *ad hoc* approaches to science-policy integration are unlikely to succeed in complex settings such as transboundary basins. The likelihood of success increases dramatically when science-policy integration processes are institutionalized, in particular, when they are incorporated into the culture, values and structures of transboundary water governance. Multi-level networks catalyzed by a shared commitment to resolving transboundary water problems have proven to be one effective way to help scientists, policy makers and members of the communities they serve interact effectively (Sabatier et al. 2005).

The need to take into account the role of power and its manifestations in constraining, facilitating and ultimately shaping science-policy interactions informs our perspective. We suggest that scientists and policy makers must reflect more explicitly on how the social relationships and institutional structures they co-create frame, constrain and enable the agency of individuals and groups, as well as the way in which these relationships and structure have material effects (e.g., influencing the uptake of ideas, how rules and regulations are exercised). Agrawal and Ribot (1999) offer a practical way to consider power, and draw attention to the power to create rules, make decisions, ensure compliance with rules and decisions, and adjudicate resulting disputes. Moreover, within these categories and among the various actors involved (e.g., state, NGOs, industry), power may be visible, invisible and/or hidden (see Cornwall 2000). These various dimensions of power and asymmetries of power they reflect strongly influence the five conditions addressed here (Zeitoun and Warner 2006). Power asymmetries can at times be extreme in transboundary settings (Zeitoun and Mirumachi 2008), as there is always an upstream and a downstream party. Upstream parties usually have their way (see for example Conca 2005) and natural dependencies can be exacerbated by differences in economic and political clout (e.g., China’s role in the Mekong region – see the discussion below). Understanding who benefits and who loses is essential in any natural resource management process (Raik et al. 2008), especially water governance (Ingram 1990).

Conditions that support effective science-policy interaction in transboundary settings

In this section we elaborate on the five conditions identified previously. The discussion is grounded in a diverse group of international transboundary settings where we have collective experience (Table 1). We recognize that there is an underlying normative assumption associated with the conditions we outline (e.g., that engaging with bridging organizations or fostering learning will yield beneficial outcomes). The five conditions we have identified here are not a panacea for what often seem to be intractable problems in transboundary settings, or for problems with roots in state sovereignty concerns or long-term historical conflicts among upstream and downstream water users. Rather, we view these conditions as a starting point to address ongoing challenges when integrating science and policy in a wide range of contexts, and as a basis to highlight the need to better understand how to create a social context for science-policy interactions. This need exists in numerous environmental contexts. Hence, the transboundary frame we use here provides a concrete setting to explore these issues.

Science as one input to policy making

Perceptions of science-policy processes as linear ignore the messy reality in which decisions are actually made (McNie 2007; Vogel et al. 2007). A wide range of actors is now involved in making decisions about water (Pahl-Wostl and Kranz 2010), and the position and role of scientists in decision processes has changed. This trend is part of a broader shift in society towards greater citizen skepticism about science combined with the democratization of knowledge (Pielke 2007; Lejano and Ingram 2009). For scientists, these trends demand a greater willingness to work in settings where other players are helping to shape the research agenda. Scientists who work in these settings need support from governments and universities (e.g., access to databases and literature behind paywalls, flexibility to take more time to do research that involves communities), and they must be open as well to communicating their science better to a diversity of audiences. Rewards, incentives and requirements for scientists to participate in more open, collaborative and learning-centered processes are also needed (Ison et al. 2007; Wolfe et al. 2007). In Canada's Mackenzie Basin, for example, the Aurora Research Institute (which assigns permits to conduct scientific research in the Northwest Territories portion of the basin) has developed templates for scientists (natural and social) to use when communicating their research to communities. Implicit in this shift to share and communicate knowledge more effectively is a concern that scientific knowledge is not 'elevated' above or valued to the detriment of traditional knowledge and traditional knowledge holders which has (and often continues to be) the case (Nadasdy 1999).

The importance of accepting that science is only one input into policy making is particularly evident in transboundary basins. Governments are – and likely always will remain – critical actors in transboundary settings because of their political authority and jurisdiction. However, increasingly it is recognized that governance in transboundary basins involves diverse government and non-government actors, and that a global shift in views about roles and responsibilities of the state is underway (Bruch et al. 2005; Cosens 2010; Akamani and Wilson 2011). Governments are being expected to transition from being primarily holders of expertise and the main decision making power to also be facilitators and knowledge brokers (Pielke 2007; Kasperspon and Berberian 2011).

However, there can be significant differences between participatory transboundary water governance and actually crafting inclusive and effective science-policy interactions that value a range of knowledge sources and types (see below).

While not without its challenges, increased participation by a greater array of non-government actors in transboundary settings can lead to greater legitimacy, more effective and equitable allocation of resources, a better ratio of costs to benefits, and improved access to a diversity of knowledge and expertise (Raadgever et al. 2008), as well as broader acceptance and implementation success. For example, several ecological monitoring programs linking scientific and traditional knowledge have been developed for the Mackenzie River Basin, an enormous internal basin shared by five sub-national jurisdictions within Canada. These programs create space for local and traditional knowledge holders, along with scientists, to identify monitoring priorities and to conduct monitoring that provides information about local ecosystem conditions considered important to local communities. A recent example from this setting is the multi-actor Slave River and Delta Partnership. This partnership was created to facilitate community-based monitoring in response to the concerns of aboriginal people and local residents regarding ecosystem health and to provide a mechanisms to increase the ‘voice’ of communities in decision making (see Box 1).

Greater participation does certainly not always lead to acceptance and improved implementation if other conditions for success are not in place. For example, Mirumachi and Van Wyk (2010) have pointed to the risks associated with an emphasis on cooperation for inclusive, participatory water governance in South Africa and the Orange-Senqu River Basin. They suggest that processes of devolving decision-making authority and including non-state actors may simply reproduce power asymmetries, preventing meaningful empowerment and inclusion and ultimately, more equitable water governance. In such cases, participatory processes may not adequately address the underlying conflicts that constrain implementation, despite institutional frameworks set up to promote better water governance. Experiences in managing the transboundary waters of the Orange-Senqu River in particular highlight the complex political and economic contexts in which water supply and demand become contested. For example, the Orange-Senqu Water Information System has been established to collate, share and disseminate reports and data for public use. However, the inter-state political negotiations over water allocation are bound by considerations of existing water use, highlighting that data sharing in and of itself does not address perceived inequity (Keller 2012).   Consequently, science needs to be understood as just one input in decisions about transboundary water governance and the ways in which unequal power can shape and constrain access to decision-making.

Establish conditions for collaboration and shared commitment early on

Governance of complex environmental problems (such as those experienced in many transboundary basins) requires joint activity, including joint-fact-finding, from which trust-building emerges at the onset of science-policy collaborations. Building relationships to overcome perceptions about the different logics of science (e.g., primarily facts, neutrality) and policy (e.g., primarily values, interests) takes time (Huitema and Turnhout 2009), with few tangible outcomes in the initial stages (Collins and Ison 2010). However, investing time up front in joint problem-framing, and engaging policy makers and other actors (civil society groups, industry, etc.) in the knowledge production process rather than treating them as passive end users helps to ensure that high initial transaction costs will yield dividends over the longer term. Early investments of time and resources are needed to create common understanding of key questions and the broader political and socio-cultural contexts that frame decisions about water. Also important are regular cycles of carefully designed workshops and stakeholder meetings, getting key people engaged for the duration of the process, and ensuring that any collective achievements are institutionalized through practices, agreements or legislation (Karl et al. 2007).

Recent experiences in Australia's Murray-Darling Basin (MDB) starkly reveal the importance of both initial conditions and shared commitment. The basin jurisdictions, including the Commonwealth government, demonstrated a strong commitment to jointly address the basin's water allocation problems including a significant financial investment of $A10 billion. Since 2007 a new MDB plan has emerged from an often fractious process. New institutions have been conceived and implemented such as 'environmental flows', 'environmental water' and the 'office of environmental water holder'. However, Wallis and Ison (2011) have argued that the structural constrains imposed on the Murray-Darling Basin Authority by the federal *Water Act 2007*, along with the deeply rooted competing interests among and within states, effectively guarantees that ongoing governance of the basin will be contested, and during implementation may be prone to systemic failure.

In the Danube and Orange-Senqu river basins, organizations such as the International Commission for the Protection of the Danube River and Orange-Senqu River Commission, respectively, encourage data sharing and coordination among multiple parties (but not without its problems, as explained below on the latter basin). In the Mackenzie River Basin, the Mackenzie River Basin Board's Traditional Knowledge and Strengthening Partnership Steering Committee is identifying best practices to incorporate local, indigenous knowledge in water management practices based on reflection and ongoing initiatives. Although capacity challenges persist, efforts to share data, develop common objectives and institutionalize processes of knowledge exchange can contribute to improved water governance in these contexts.

High political stakes, including a potential for conflict and often unequal power relations, are common in transboundary settings such as the ones considered in Table 1. This makes the challenge to establish inclusive initial conditions for science-policy interactions all the more crucial (Paisley and Henshaw 2013). Actors on different sides of political boundaries may have competing interests, and strong reasons to avoid scientific input; they may only seek scientific input to support particular bargaining positions. In the absence of a supportive institutional framework, legitimate decision making processes and shared framing of science can be particularly hard to achieve in transboundary basins (Pahl-Wostl and Kranz 2010).

Political commitment to cooperation, demonstrated tangibly through, for example, transfers of decision authority and resources and non-state actors involved in knowledge production processes, is also vital. This level of commitment is difficult to achieve in transboundary basins because national economic development objectives can trump the precaution required to address scientifically and socially complex issues (Lebel et al. 2005). For example, in the case of rapid hydropower development in the Mekong River basin, national interests of basin states have undermined the ability of the Mekong River Commission (convened by Laos, Thailand, Cambodia and Vietnam) to facilitate joint problem framing (Hirsch et al. 2006). China is not part of the Commission, but rather an observer, raising questions about the extent to which the river basin organisation can address the issue of hydropower development, some of which is going on in upstream Chinese territory. Moreover, hydropower development is operationalized by both the private sector and government in the form of public–private partnerships and build-operate-transfer schemes (Middleton et al. 2014). Understanding how national economic development objectives are forged by certain stakeholders is important. Power asymmetries and obstacles to commitment to cooperation exist not just at the international transboundary level but also within the individual basin states themselves.

Space for alternative development scenarios is reduced when national governments prioritize large hydro-electric projects to the exclusion of other possible avenues of economic development. This process is supported by macro-economic studies and cost-benefit analysis that suggest significant economic benefits from hydropower (see Flyvberg 2005). Alternative considerations of non-market values and the lived experiences of hydropower development do not inform such studies and approaches (Mirumachi and Torriti 2012). As a result, reports by civil society groups pointing to less desirable impacts of dams based on alternative metrics commonly count less in the decision making process.

Learning to learn through collaboration

Shared understanding of problems and solutions is essential for dealing with complex environmental problems. Social learning is one way this can be achieved, and refers to changes in understanding that go “beyond the individual to become situated within wider social units or communities of practice through social interactions between actors within social networks” (Reed et al. 2010). Social learning processes may seem outside the remit of scientists, especially when science-policy linkages are viewed as linear. However, social learning processes can help to link policy makers, scientists and other key actors (members of the public, non-governmental organizations, aboriginal groups) through their emphasis on communication, deliberation and group interaction (e.g., meetings, workshops, study tours and visits) (Scott et al. 2012). This can help stakeholders to deal with significant uncertainty and complexity, and if social learning processes are well designed (see Bos et al. 2013), they can help surface the relationships of power that must be accounted for if meaningful actions are to be taken (Armitage et al. 2009). In the Murray-Darling Basin, salinity management programs at the regional level in New South Wales incorporated context-specific learning, community participation and multiple types of knowledge. These programs resulted in community and government acceptance of salinity-control measures and greater awareness of salinity hazards. Unfortunately, however, governance has shifted from a community-based to state-dominated model predicated on centralization that has made institutionalizing social learning and transformative change difficult (Wallis et al. 2013) and introduced social inequities due to top-down innovation approaches for irrigation renewal (Wallis et al. 2015).

Learning to learn together ultimately requires that scientists, policy makers and a wide range of non-state actors are open to hybrid roles and a new ‘social contract’ (Lubchenco 1998; Palmer 2012). In transboundary water governance settings, barriers to social learning can exist that go beyond simply the presence of political boundaries. A desire on the part of actors in different jurisdictions to learn together may be insufficient in the face of institutional rigidity often created by less flexible treaties and compacts. The Colorado River offers an instructive case in the long-term challenge of moving towards a more learning-oriented and collaborative approach.

The history of river management in the Colorado basin is one of fragmentation with competition among a broad array of water interests (agriculture, ranching, municipal), including conflict between the United States federal government and various states (Getches 1997). However, an incremental approach to more inclusive governance of the Colorado River basin has emerged over several decades with greater attention to bi-national cooperation between the United States and Mexico (Getches 2003; Gerlak et al. 2013). Most recently, the Colorado Basin Study – a multi-agency and multi-government effort – offers an example of how a broad array of non-state and state actors, along with diverse scientific expertise, can be brought together to redefine management problems, and to incorporate science into decision making about current and projected challenges (United States Department of the Interior 2012). Issues in the Colorado River Basin have not been resolved and climatic changes in the region will exacerbate challenges requiring ongoing attention to building knowledge collaboratively. Still, in comparison to the prior history of science-policy interactions and governance in the basin, significant steps forward are evident especially in the Colorado River Delta, and in the lower part of the Basin. For example, in recent years, a diverse set of government officials, scientists and NGOs have been engaged in experimental management practices, as exemplified by the 2014 pulse flow event which brought water to the parched Colorado River Delta, to collaboratively learn about river restoration (Howard 2014; Gerlak 2015).

Produce and use knowledge of all types

As noted in the introduction, contemporary water governance must draw on knowledge in its many different forms (scientific, local, indigenous, bureaucratic). This knowledge is held, formulated and communicated by a variety of actors inside and outside government, at all scales (Lejano and Ingram 2009). Integrating different kinds of knowledge in water decision making can be extremely challenging because of differing, potentially contradictory and sometimes incompatible ways of knowing (e.g., between scientific and traditional knowledge systems). Openness to the use of multiple types of knowledge is important for legitimate decision making processes (Taylor and de Loë 2012), as is a commitment to processes of 'knowledge co-production' in which a plurality of knowledge sources and types is brought together to define and resolve problems (Armitage et al. 2011). Processes of knowledge co-production are not intended to resolve situations where knowledge and understanding about water conditions are incommensurate. For example, there may be instances where fundamental disagreements remain on sources of water contamination, as is happening in Mackenzie Basin with regard to oil sands contamination in downstream deltas (Timoney and Lee 2009; Hall et al. 2012). However, knowledge co-production processes do help participants to view knowledge not simply as a product, but instead as an outcome of relationships in which different information, knowledge and values are recognized as being tightly connected (Edelenbos et al. 2011). In transboundary water governance settings, these forms of interaction have important implications for how science and scientists are engaged with a broader range of actors and in ways that challenge notions of certainty about system conditions.

In the Mackenzie Basin, for example, scientists and traditional knowledge holders (those individuals with a long-term engagement on the land as harvesters and trappers) are working together in new ways through the Peace-Athabasca Delta Ecological Monitoring Program, and specifically, by collaborating on wildlife and environmental surveys. Initially, there was some apprehension among scientists and traditional knowledge holders about working together but over time they have come to value collaborating to share knowledge, as has been our experience in similar contexts (Wolfe et al. 2007). It is often difficult for people more comfortable with technical information and ‘hard facts’ to engage someone whose knowledge emerges from ongoing interactions with the land, and who might communicate that knowledge through stories, perceptions of change and a tendency to situate their knowledge in a broader discourse about values (Wolfe et al., 2007; Armitage et al. 2011; Taylor and de Loë 2012). Ultimately, these changes in relationships and focus on knowledge require a tacit recognition of differences in power, willingness on the part of the individuals involved to relinquish in some cases the positions of power they do hold, and a commitment to trust building (Armitage et al. 2009).

The co-production of knowledge can be especially important in transboundary water governance settings where objectives, targets and goals often must be negotiated among actors who lack the power to enforce their views on each other. Monitoring in a transboundary water governance context is one vehicle for knowledge co-production because it also situates assessment, reflection, and learning in specific empirical contexts. Along the Danube River, information sharing, exchange, and harmonization have been primary objectives of the International Commission for the Protection of the Danube River (ICPDR) from its inception in the early-1990s (ICPDR 2007). Such efforts feed into the Danube River Basin Management Plan, which outlines concrete measures to be implemented by the year 2015 to improve environmental conditions (Weller and Popovici 2011). Demonstrating improvements in ecological conditions and coordinating among the diverse institutions involved in managing the Danube prove challenging (Gerlak 2004). However, the information collected provides: (i) a solid foundation of agreed-upon data which simplifies the process of developing management plans, and (ii) consistent reporting on achievements and remaining challenges in restoring water quality throughout the basin to better guide decision makers on policy measures (Schmeier 2014).

Engage boundary organizations and informal networks

Boundary organizations work at the interface of governmental and non-governmental spheres, and typically are the formal bodies that mediate interactions (e.g., about values, purposes, strategies) among social actors (Guston 2004; Crona and Parker 2012). Evidence from different environmental policy and governance settings indicates that these organizations can serve as clearing houses for information, foster conflict resolution, and, where supported by legislation, build the legitimacy and credibility needed to encourage behavioral change (Cash et al. 2003; Huitema and Turnhout 2009; Crona and Parker 2012). To achieve these potential benefits, however, boundary organizations require cultivation, experience and involvement from stakeholders at higher and lower levels of governance. Where boundary organizations do not exist, or where they are ineffective, informal networks of scientists, policy makers, and community members can sometimes fill gaps (Huitema and Meijerink 2009). In these settings informal networks may emerge that can institutionalize science-policy processes longer-term. Informal networks can utilize scientific information and local knowledge to help work around political resistance, entrenched approaches, or attachments to the old ways of doing things. In turn, such networks can catalyze demonstration projects at smaller scales (e.g., demonstration projects or sites within a transboundary context), and subsequently communicate lessons learned to a broader policy context (Roux et al. 2006).

Boundary organizations and informal networks can play especially important roles in linking scientists, policy makers, communities and other actors across jurisdictions or in transboundary basins (Huitema and Meijerink 2009). This is the case in the Canadian portion of the St. John River, a transboundary river shared by Canada and the United States. Here, an informal network of watershed organizations emerged, despite the failure by the provincial government to implement water protection recommendations from its own watershed classification strategy (Baird et al. 2014). This network advocated for the implementation of key provisions of the strategy, and had a scope and influence that ultimately had the government re-engage with the issue and with a range of water actors. One of the watershed organizations in the network requested the Provincial Ombudsman to investigate the process around the strategy. The investigation highlighted a long term and ongoing lack of communication both within government agencies and with watershed stakeholders regarding the status of the strategy and opportunities or alternatives to move forward (Office of the Ombudsman, 2014). Significant pressure is thus being directed on the new government to take corrective actions, while watershed organizations and other actors continue to forge important linkages about freshwater concerns in the basin.

More formal, government-led river basin organizations such as the Mekong River Commission or the Orange-Senqu River Commission also can serve as a type of boundary organization. These organizations can have specific responsibilities to link scientists, donor agencies, policy makers and communities vertically and horizontally, and as a result, they can function as key nodes in the development of more tightly-coupled networks of scientists, policy makers and civil society actors (e.g., industry, community organizations) seeking to be engaged in decision making. In the Orange-Senqu River Basin, the Orange-Senqu River Commission facilitates information gathering and sharing within the four basin nation states. However, it cannot fully resolve the differences in scientific and technical capacity between basin states which result in challenges providing timely and accurate data. The Mekong River Commission encourages data and information exchange regarding hydrology, biodiversity and fisheries in the form of State of the Basin Reports. It builds technical capacity (as well as institutional and social capacity), through its Flood Management and Mitigation Program and Initiative on Sustainable Hydropower, which supports adaptation to future stressors (Heikkila et al. 2013). However, like the Orange-Senqu, limited capacity in some states is a challenge for data acquisition. Furthermore, boundary organizations must contend with issues of data sharing with non-member states, as in the case of the Mekong River Commission and its interaction with upstream China. The Mekong River Commission has its strengths and weaknesses depending on different programmatic areas (Heikkila et al. 2013), and identifying areas with strong or weak organizational capacity will be important.

Conclusion

Blueprints for effective science-policy processes in transboundary water governance settings do not exist because, as in water governance generally, problems and solutions are complex and context specific (Ingram 2013). Nonetheless, it is possible to identify conditions that are likely to increase the chances of success based on international experiences. We have done so here using transboundary water governance examples but recognize the value of engaging with a wide range of practitioners and scholars in diverse settings to further reflect upon and build an evidence base of the conditions for effective science-policy processes.

The five conditions considered in this perspective reflect the importance of networks of science and policy actors, as well as a range of non-state actors engaging in new forms of collaboration. Engaging the right people as actors in these processes through experience and interdisciplinary training is necessary. Identifying and publicizing successful cases (in developed and developing countries) of science-policy interactions will help, as will recalibration of traditional measures of scientific success to emphasize processes that are credible, legitimate and salient.

Recent experiences in the vast transboundary Mackenzie Basin in Canada reflect many of the conditions and lessons outlined in this policy perspective (see Box 1), with the cases in Table 1 offering supporting examples. As previously noted, science-policy interactions often reflect unequal relations of power between nation states (or sub-national jurisdictions, such as is the case in the Mackenzie Basin). In some contexts, deliberative approaches in political arenas can create new spaces for actors to engage on difficult issues and build trust (Dore 2014). However, efforts to further science-policy interactions in the Mackenzie Basin are complicated by more than jurisdictional differences in power. There are vested industry interests associated with oil sands production and pressure to engage with new technologies (e.g., fracking) that can subvert local deliberative processes, transboundary governance and multi-scale efforts to institutionalize science-policy interactions. These circumstances do not imply that efforts to foster science-policy interactions will fail, and there are in fact many innovative efforts taking place in the Mackenzie Basin (See Box 1). However, they do make the task all that more challenging.

Given the expanding envelope of variability within which multi-jurisdictional decisions about water must be made, failure to 'invent' new, conducive, institutions and to institutionalize conditions for better decision making presents significant risks to society and ecosystems. Moving forward, therefore, systematic and comparative assessment is required to identify the full range of conditions for science-policy success (and those conditions that create barriers) across a large sample of transboundary river basins in a diversity of jurisdictional settings (e.g., international, sub-national). Even with the application of the five conditions we have identified, some failures in bridging science and policy are inevitable. An ongoing commitment to foster collaborative knowledge networks is required to deal with change in transboundary settings. However, as the examples in this perspective have shown, focusing on strategies and conditions to facilitate science-policy interactions is a pragmatic entrée to resolve water decision challenges in spite of the broader political forces (i.e., imbalances or asymmetries of power, upstream-downstream conflicts) that too often undermine the cooperation and integration crucial for sustainability.

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Table 1: Overview of selected transboundary water basin science-policy successes and challenges

Transboundary basin	Key issues, successes and challenges
Colorado Drainage area: 640,000 km^2 River length: 2,334 km Average annual natural* flow: 641 m^3/s Average annual actual flow, measured at the southern international border: 75.3 m^3/s Population: 40 million Jurisdictions: 10 (international)	Issues • Over-allocation, anticipated increased duration and severity of drought, growing population and demand for water Successes • Emerging *network* of science, government and non-government actors that has facilitated research coordination for the lower Colorado River • Increased deliberation and collaboration focused on critical needs relating to environmental flow and allocation reflecting key concerns and illustrating new opportunities for use different types of *knowledge* and opportunities for *learning* among different actors Challenges • Establishing formal, long-term processes for stakeholder engagement that sustain collaboration and knowledge sharing through time • Balancing competing values about water use among upstream and downstream users with different levels of *power*
Mackenzie Drainage area: 1.8 million km^2 River length: 4,241 km Average annual flow: 9910 m^3/s Population: 397,000 Jurisdictions: 7 (sub-national)	Issues • Anticipated flow reductions, existing and proposed hydroelectric development and increased human demand for water from industry; anticipated increases of pollution from oil sands mining and processing; Aboriginal populations and competing values about water use Successes • Development of multi-stakeholder monitoring partnerships that proactively link communities, researchers and governments and that have built upon existing informal networks • Strong emphasis in basin on incorporating science and traditional *knowledge* in decision making • Innovative measures to create *positive conditions early on* for decision making processes by embedding credible scientists on land and water boards Challenges • Developing and implementing effective, long-term inter-jurisdictional and trans-jurisdictional water management agreements given significant power asymmetries and competing interests among jurisdictions • Developing science-policy processes that reflect local considerations in the broader water stewardship context • Capacity building among traditional knowledge-based actors and in circumstances where there are historical and continued distrust among government agencies, industries, southern-based scientists and local and Aboriginal organizations
Mekong Drainage area: 760,000 km^2 Average annual flow: 14,500 m^3/s	Issues • Existing and proposed hydroelectric facilities, asymmetric cooperation among basin states and the role of the Mekong River Commission (convened by Laos, Thailand, Cambodia and Vietnam), poverty and economic development pressures

River length: 4,909 km Population: 70 million Jurisdictions: 6 (international)	<u>Successes</u> • Emergence of civil society-based *network* using action-based research to inform and open-up decision making vertically and horizontally • Potential for alternative track to the official inter-state negotiations given role of Mekong River Commission as *boundary organization* – i.e., connecting actors through *shadow* networks <u>Challenges</u> • Capacity building for the development of different kinds of *knowledge* held by various stakeholders and ways to include them in the decision-making process – *science as one input* to decision making processes can preclude the views and inputs of more marginalized communities in Mekong context • Addressing hydropower projects that are not necessarily state-led projects but in the form of public-private partnerships and build-own (-operate)-transfer schemes – these initiatives may emerge in absence of legitimate and transparent processes and undermine *initial conditions* needed for collaboration among science, policy and community actors
Murray-Darling Drainage area: 1,064,469 km^2 Average annual natural* flow: 409 m^3/s Average annual actual flow: 161 m^3/s River length: Darling 2,740km Murray 2,530 km Population: 2.1 million Jurisdictions: 5 (sub-national)	<u>Issues</u> • Water quantity and water quality, flow fragmentation, historical over allocation, ecological rehabilitation; effective implementation and adaptation of a new whole-of-basin plan in conditions where 'co-operative Federalism' is breaking down once more <u>Successes</u> • Institutionalization of environmental flows and Federal and State offices of an Office of Environmental Water Holder help create *initial conditions for better decisions* over the longer term • Scientific input into the Water Basin Plan and evaluative reviews conducted by the former National Water Commission illustrates effective *learning* given past gaps in linking scientific inputs into formal decision making • Market mechanisms employed for buy-back of over-allocated water reflect awareness of need for diverse solutions and perspective (i.e., industry) and also reflect increased awareness that *science is ultimately one input* • Trading of water rights and/or allocations has expanded economic opportunity for irrigators and increase options for environmental buyback <u>Challenges</u> • Sustaining effective river governance across all sub-catchments in the face of state and regional institutional diversity and lack of security of funding to local organisations reflecting an inability to forge a coherent *network* to support science and policy • Future national policy setting is uncertain with the demise of the National Water Commission which was charged with oversight of delivery of the National Water Initiative suggesting some important *initial conditions* for collaboration and science-policy interaction are not in place. • Uncertain implementation and adaption of the National Plan in the face of climate change and potential institutional failure indicating science inputs will need enhanced institutional networks and institutionalization of *learning* through change

Orange-Senqu Drainage area: 896,368 km^2 Average annual flow: 364 m^3/s River length: 2,200 km Population: 19 million Jurisdictions: 5 (international)	<u>Issues</u> • Flow fragmentation, declining water quality and variability of quantity, ecological health, human and financial capacity constraints; major challenges related to collection of data needed to make decisions <u>Successes</u> • Institutionalized body (Orange-Senqu River Commission: ORASECOM) established in 2000 which has the potential to serve as *boundary organization* and encourage opportunities for learning • Joint Water Quality Baseline Survey conducted by a joint research team of scientists from each of the member states as well as members from the ORASECOM enhanced efforts to bridge perspective and *knowledge* needed to measure key ecological components and function as a baseline against future 5-year surveys <u>Challenges</u> • Despite presence of an important boundary organization (i.e., the Commission), limited success establishing public participation processes that are sustainable and feed into decision-making has limited opportunities for meaningful *learning* and efforts to build vertical and horizontal *networks*
Danube Drainage area: 801,463 km^2 Average annual flow: 6,550 m^3/s River length: 2,857 km Population: 82 million Jurisdictions: 19 (international)	<u>Issues</u> • Pollution, flood protection / prevention and ecological rehabilitation (e.g., delta) <u>Successes</u> • Long-standing and institutionalized *boundary organization* (International Commission for the Protection of the Danube River) established in 1994 to build capacity to link science and policy across 19 jurisdictions • Major reductions in pollution, increased basin-wide monitoring and regular Joint Danube Surveys to guide management actions reflect on-going process of *knowledge co-production* and *learning* <u>Challenges</u> • Demonstrating improvements in ecological conditions remains a challenge reflecting need communicate story of success *beyond the science* • Coordination among diverse institutions in region because of various capacity and organizational issues undermines network of actors and constrains establishment of *conditions* needed for long-term success

Sources: US Department of the Interior 2012; Gerlak et al. 2013; Earle et al. 2005; Huisman et al. 2000; MRBB 2003; MRC 2010; MDBC, 2003; ORASECOM 2010; Wolfe et al. 2012; Government of Canada 2010; N.B.: Over the past decade, the authors have worked on a range of natural and social science studies in all of these basins

Box 1: Science, policy and transboundary water governance in the Mackenzie Basin, Canada

The Mackenzie River Basin (MRB) drains approximately 20% of Canada's landmass within the provinces of British Columbia, Alberta, Saskatchewan, as well as Yukon Territory, the Northwest Territories (NWT) and Nunavut. Despite being located within one country, this enormous basin is truly transboundary because of the control these political jurisdictions have over water in Canada's federation. The MRB's headwaters begin in the Peace and Athabasca sub-basins in British Columbia and Alberta, respectively, which converge at the Peace-Athabasca Delta in Alberta. The system flows north as the Slave River into the Northwest Territories, which eventually becomes the Mackenzie River and drains into the Arctic Ocean. Upstream jurisdictions (notably Alberta) are conventionally thought of as having significantly more power than downstream jurisdictions (notably the Northwest Territories). The MRB hosts internationally- and culturally-significant deltas and wetlands that are staging and breeding grounds for a variety of migratory birds and are important to local aboriginal communities. Freshwater discharge from the Mackenzie River has a globally significant role in regulating ocean and climate systems (MRBB 2003).

Climate variability is emerging as a key driver of uncertainty in water levels and flood frequency in the deltas, and the weight of evidence points to long-term water availability decline in the upper MRB (Wolfe et al. 2012) with long-term consequences for aquatic ecosystems of global significance. The basin also figures prominently in plans for resource development in Canada, which include hydroelectric and mining projects in the Peace and Athabasca sub-basins and the potential expansion of mining and oil and gas development (including fracking) in downstream Northwest Territories. In the face of climate and development drivers, better science-policy processes to preserve environmental flows is a vital component of transboundary water governance in this basin.

Foundations for better science-policy processes have emerged in several crucial ways. For example, a number of ecological monitoring programs that seek to link scientific and traditional knowledge have been developed for important parts of the MRB. The Peace-Athabasca Delta Ecological Monitoring Program (PADEMP) is an effort in knowledge co-production between federal, provincial, territorial, indigenous governments and environmental non-governmental organizations. Participants are jointly identifying vulnerabilities and key ecological monitoring priorities in the Peace-Athabasca Delta that will be cooperatively evaluated. More recently, the Slave River and Delta Partnership (SRDP) was created to facilitate community-based monitoring in response to local concerns regarding ecosystem health. Actors involved include the federal, territorial and aboriginal governments, academic institutions and local residents. Key outputs thus far have included improved partnerships and understanding, state of knowledge and vulnerability assessment reports, and a greater voice for communities in water-related decisions.

The SRDP is an outcome of efforts to establish conditions for future success, including the development (and associated implementation plan) of the Northwest Territories Water Stewardship Strategy (2010), and initiatives to build science capacity into land and water management boards. For example, the Mackenzie Valley Land and Water Board has developed science-based policies and procedures that have directly resulted in wiser decisions that most observers conclude have protected ecological integrity while preserving the profitability of industrial operations. Credible decisions have also strengthened the Board's relations with government agencies and industry, and have fostered trust-building with aboriginal governments and peoples, thus contributing to its role as a bridging organization.

Monitoring partnerships and other science-policy initiatives are relatively recent ventures, and their long-term success is uncertain. However, they do display some of the key characteristics of successful science-policy integration including building greater integration among scientists, policy makers and non-state actors (aboriginal interests in particular); emphasizing social or group learning processes; fostering the collaborative production of knowledge about hydrological change and the range of possible governance responses; and recognizing how science is a crucial but bounded part of the sustainability dilemma in transboundary water governance settings. The challenge remains to institutionalize gains made in an adaptive manner and to scale up science-policy processes for the longer term.