

1 **Science-policy processes for transboundary water governance**

2

3 **Abstract**

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

18

19 **Introduction**

20

21 Climate change will exacerbate already severe pressure on freshwater resources from
22 agriculture, industry and growing urban populations (Vörösmarty et al. 2000; Milly et al.
23 2008). Globally, significant changes in river flow have already been observed, while
24 projected changes in river flow under different climate and water withdrawal scenarios

25 point to significantly increased water stress in many jurisdictions (Palmer et al. 2008;
26 MacDonald 2010; Grafton et al. 2013).

27

28 Many of these changes are occurring in transboundary basins, which adds to the
29 complexity of problem analysis and identification of effective responses in these key
30 systems (Pahl-Wostl et al. 2013). About 45 percent of the Earth’s land surface is covered
31 by 276 river basins shared by more than one country (De Stefano et al. 2012).

32 Transboundary basins at sub-national levels number in the thousands. Hundreds of
33 transboundary aquifers present even more challenging settings for governance (UNESCO
34 2009).

35

36 Barriers to effective water governance in transboundary settings are significant, and
37 include power imbalances, inadequate attention to rapidly changing biophysical
38 conditions and a growing array of social actors with a stake in decision making (Zeitoun
39 et al. 2013). Integrating different forms of knowledge – e.g., scientific, local, indigenous,
40 bureaucratic (Edelenbos et al. 2011) – has emerged as a key determinant of governance
41 success (Karl et al. 2007). Scientific knowledge – which for our purpose refers to
42 knowledge about social and natural phenomena that has been generated by people using
43 scientific methods – has long been considered authoritative. However, this is changing. It
44 is now widely accepted that scientific knowledge alone is not sufficient for dealing with
45 complex environmental issues (Lejano and Ingram 2009). At the same time, the gulf that
46 often exists between “decision makers” and scientists can be wide (Cash et al. 2003).

47 Recognition of this fact accounts for the enormous amount that is being written about

48 strategies to improve science-policy interaction (e.g., Roux et al. 2006; Karl et al. 2007;
49 Pielke 2007; Ascher et al. 2010; Kasperson and Berberian 2011).

50

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

64

65 In this brief perspective we identify five important conditions that – on the basis of our
66 combined expertise – can be identified as supportive of effective science-policy
67 interactions. The key conditions we emphasize include 1) recognizing that science is a
68 crucial but bounded aspect in water resource decision making processes; 2) establishing
69 initial conditions and shared commitment among actors; 3) understanding that social or
70 group learning processes linked to science-policy interaction are enhanced through

71 greater collaboration; 4) accepting that the collaborative production of knowledge about
72 hydrological and associated socio-economic change and institutional responses is
73 essential to build legitimate decision making processes; and 5) engaging boundary
74 organizations and supporting informal networks of scientists, policy makers and civil
75 society.

76

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

88

89 **Challenges for effective science-policy interaction**

90

91 How science-policy processes can be enhanced to improve decisions about water (and
92 other resources) is a topic of much debate within the environmental science and policy
93 communities, and broad agreement exists around some key principles. For instance,

94 scientists are often encouraged to better communicate risk and uncertainty to non-
95 scientific audiences, and policy makers are urged to use the best available scientific
96 evidence (Guston 2004; Pielke 2007; Toderi et al. 2007). Overcoming disciplinary
97 isolation is also recognized as a priority (Kasperson and Berberian 2011).

98

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

109

110 Sutherland et al. (2013) recently synthesized twenty suggestions or ‘tips’ to improve the
111 integration of science in political decision making, with a focus on policy makers’
112 understanding of the imperfect nature of science. The list is helpful but ultimately
113 application of the ideas requires a social context in which scientists, policy makers and
114 others attempting to and engaged in governing can actually interact and deliberate. This
115 social context includes the diverse norms and values among the constellation of actors in
116 a water decision making process (e.g., industry groups, aboriginal communities) as well

117 as differences in power and authority among those individuals and organizations (see
118 below). These constraints have material consequences, and, as a result, uptake of
119 suggestions to improve integration of science in political decision making in real-world
120 settings will continue to be slow unless the social and institutional context for science-
121 policy interactions in transboundary water governance is accounted for and, where
122 inadequate, improved. The conditions we highlight in this perspective are a key part of
123 these improvements.

124

125 Doing and using science differently requires reflecting on what science is being used for;
126 understanding how results will be mobilized and by whom; overcoming fragmentation
127 among organizations and the knowledge used to inform decisions; recognizing the social
128 and political aspects of science-policy practices; and accounting for multiple framings of
129 problems and solutions (Roux et al. 2006; Lejano and Ingram 2009; Sutherland et al.
130 2013). Our experiences and the cases we draw upon for this paper demonstrate that *ad*
131 *hoc* approaches to science-policy integration are unlikely to succeed in complex settings
132 such as transboundary basins. The likelihood of success increases dramatically when
133 science-policy integration processes are institutionalized, in particular, when they are
134 incorporated into the culture, values and structures of transboundary water governance.
135 Multi-level networks catalyzed by a shared commitment to resolving transboundary water
136 problems have proven to be one effective way to help scientists, policy makers and
137 members of the communities they serve interact effectively (Sabatier et al. 2005).

138

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

158

159 **Conditions that support effective science-policy interaction in transboundary**

160 **settings**

161

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

175

176 *Science as one input to policy making*

177

178 Perceptions of science-policy processes as linear ignore the messy reality in which
179 decisions are actually made (McNie 2007; Vogel et al. 2007). A wide range of actors is
180 now involved in making decisions about water (Pahl-Wostl and Kranz 2010), and the
181 position and role of scientists in decision processes has changed. This trend is part of a
182 broader shift in society towards greater citizen skepticism about science combined with
183 the democratization of knowledge (Pielke 2007; Lejano and Ingram 2009). For scientists,
184 these trends demand a greater willingness to work in settings where other players are

185 helping to shape the research agenda. Scientists who work in these settings need support
186 from governments and universities (e.g., access to databases and literature behind
187 paywalls, flexibility to take more time to do research that involves communities), and
188 they must be open as well to communicating their science better to a diversity of
189 audiences. Rewards, incentives and requirements for scientists to participate in more open,
190 collaborative and learning-centered processes are also needed (Ison et al. 2007; Wolfe et
191 al. 2007). In Canada's Mackenzie Basin, for example, the Aurora Research Institute
192 (which assigns permits to conduct scientific research in the Northwest Territories portion
193 of the basin) has developed templates for scientists (natural and social) to use when
194 communicating their research to communities. Implicit in this shift to share and
195 communicate knowledge more effectively is a concern that scientific knowledge is not
196 'elevated' above or valued to the detriment of traditional knowledge and traditional
197 knowledge holders which has (and often continues to be) the case (Nadasdy 1999).

198

199 The importance of accepting that science is only one input into policy making is
200 particularly evident in transboundary basins. Governments are – and likely always will
201 remain – critical actors in transboundary settings because of their political authority and
202 jurisdiction. However, increasingly it is recognized that governance in transboundary
203 basins involves diverse government and non-government actors, and that a global shift in
204 views about roles and responsibilities of the state is underway (Bruch et al. 2005; Cosens
205 2010; Akamani and Wilson 2011). Governments are being expected to transition from
206 being primarily holders of expertise and the main decision making power to also be
207 facilitators and knowledge brokers (Pielke 2007; Kasperspon and Berberian 2011).

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

211

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

227

228 Greater participation does certainly not always lead to acceptance and improved
229 implementation if other conditions for success are not in place. For example, Mirumachi
230 and Van Wyk (2010) have pointed to the risks associated with an emphasis on

231 cooperation for inclusive, participatory water governance in South Africa and the
232 Orange-Senqu River Basin. They suggest that processes of devolving decision-making
233 authority and including non-state actors may simply reproduce power asymmetries,
234 preventing meaningful empowerment and inclusion and ultimately, more equitable water
235 governance. In such cases, participatory processes may not adequately address the
236 underlying conflicts that constrain implementation, despite institutional frameworks set
237 up to promote better water governance. Experiences in managing the transboundary
238 waters of the Orange-Senqu River in particular highlight the complex political and
239 economic contexts in which water supply and demand become contested. For example,
240 the Orange-Senqu Water Information System has been established to collate, share and
241 disseminate reports and data for public use. However, the inter-state political
242 negotiations over water allocation are bound by considerations of existing water use,
243 highlighting that data sharing in and of itself does not address perceived inequity (Keller
244 2012). Consequently, science needs to be understood as just one input in decisions
245 about transboundary water governance and the ways in which unequal power can shape
246 and constrain access to decision-making.

247

248 *Establish conditions for collaboration and shared commitment early on*

249

250 Governance of complex environmental problems (such as those experienced in many
251 transboundary basins) requires joint activity, including joint-fact-finding, from which
252 trust-building emerges at the onset of science-policy collaborations. Building
253 relationships to overcome perceptions about the different logics of science (e.g., primarily

254 facts, neutrality) and policy (e.g., primarily values, interests) takes time (Huitema and
255 Turnhout 2009), with few tangible outcomes in the initial stages (Collins and Ison 2010).
256 However, investing time up front in joint problem-framing, and engaging policy makers
257 and other actors (civil society groups, industry, etc.) in the knowledge production process
258 rather than treating them as passive end users helps to ensure that high initial transaction
259 costs will yield dividends over the longer term. Early investments of time and resources
260 are needed to create common understanding of key questions and the broader political
261 and socio-cultural contexts that frame decisions about water. Also important are regular
262 cycles of carefully designed workshops and stakeholder meetings, getting key people
263 engaged for the duration of the process, and ensuring that any collective achievements are
264 institutionalized through practices, agreements or legislation (Karl et al. 2007).

265

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

277 systemic failure.

278

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

289

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

299

300 Political commitment to cooperation, demonstrated tangibly through, for example,
301 transfers of decision authority and resources and non-state actors involved in knowledge
302 production processes, is also vital. This level of commitment is difficult to achieve in
303 transboundary basins because national economic development objectives can trump the
304 precaution required to address scientifically and socially complex issues (Lebel et al.
305 2005). For example, in the case of rapid hydropower development in the Mekong River
306 basin, national interests of basin states have undermined the ability of the Mekong River
307 Commission (convened by Laos, Thailand, Cambodia and Vietnam) to facilitate joint
308 problem framing (Hirsch et al. 2006). China is not part of the Commission, but rather an
309 observer, raising questions about the extent to which the river basin organisation can
310 address the issue of hydropower development, some of which is going on in upstream
311 Chinese territory. Moreover, hydropower development is operationalized by both the
312 private sector and government in the form of public-private partnerships and build-
313 operate-transfer schemes (Middleton et al. 2014). Understanding how national economic
314 development objectives are forged by certain stakeholders is important. Power
315 asymmetries and obstacles to commitment to cooperation exist not just at the
316 international transboundary level but also within the individual basin states themselves.

317

318 Space for alternative development scenarios is reduced when national governments
319 prioritize large hydro-electric projects to the exclusion of other possible avenues of
320 economic development. This process is supported by macro-economic studies and cost-
321 benefit analysis that suggest significant economic benefits from hydropower (see
322 Flyvberg 2005). Alternative considerations of non-market values and the lived

323 experiences of hydropower development do not inform such studies and approaches
324 (Mirumachi and Torriti 2012). As a result, reports by civil society groups pointing to less
325 desirable impacts of dams based on alternative metrics commonly count less in the
326 decision making process.

327

328 *Learning to learn through collaboration*

329

330 Shared understanding of problems and solutions is essential for dealing with complex
331 environmental problems. Social learning is one way this can be achieved, and refers to
332 changes in understanding that go “beyond the individual to become situated within wider
333 social units or communities of practice through social interactions between actors within
334 social networks” (Reed et al. 2010). Social learning processes may seem outside the remit
335 of scientists, especially when science-policy linkages are viewed as linear. However,
336 social learning processes can help to link policy makers, scientists and other key actors
337 (members of the public, non-governmental organizations, aboriginal groups) through
338 their emphasis on communication, deliberation and group interaction (e.g., meetings,
339 workshops, study tours and visits) (Scott et al. 2012). This can help stakeholders to deal
340 with significant uncertainty and complexity, and if social learning processes are well
341 designed (see Bos et al. 2013), they can help surface the relationships of power that must
342 be accounted for if meaningful actions are to be taken (Armitage et al. 2009). In the
343 Murray-Darling Basin, salinity management programs at the regional level in New South
344 Wales incorporated context-specific learning, community participation and multiple types
345 of knowledge. These programs resulted in community and government acceptance of

346 salinity-control measures and greater awareness of salinity hazards. Unfortunately,
347 however, governance has shifted from a community-based to state-dominated model
348 predicated on centralization that has made institutionalizing social learning and
349 transformative change difficult (Wallis et al. 2013) and introduced social inequities due to
350 top-down innovation approaches for irrigation renewal (Wallis et al. 2015).

351

352 Learning to learn together ultimately requires that scientists, policy makers and a wide
353 range of non-state actors are open to hybrid roles and a new ‘social contract’ (Lubchenco
354 1998; Palmer 2012). In transboundary water governance settings, barriers to social
355 learning can exist that go beyond simply the presence of political boundaries. A desire on
356 the part of actors in different jurisdictions to learn together may be insufficient in the face
357 of institutional rigidity often created by less flexible treaties and compacts. The Colorado
358 River offers an instructive case in the long-term challenge of moving towards a more
359 learning-oriented and collaborative approach.

360

361 The history of river management in the Colorado basin is one of fragmentation with
362 competition among a broad array of water interests (agriculture, ranching, municipal),
363 including conflict between the United States federal government and various states
364 (Getches 1997). However, an incremental approach to more inclusive governance of the
365 Colorado River basin has emerged over several decades with greater attention to bi-
366 national cooperation between the United States and Mexico (Getches 2003; Gerlak et al.
367 2013). Most recently, the Colorado Basin Study – a multi-agency and multi-government
368 effort – offers an example of how a broad array of non-state and state actors, along with

369 diverse scientific expertise, can be brought together to redefine management problems,
370 and to incorporate science into decision making about current and projected challenges
371 (United States Department of the Interior 2012). Issues in the Colorado River Basin have
372 not been resolved and climatic changes in the region will exacerbate challenges requiring
373 ongoing attention to building knowledge collaboratively. Still, in comparison to the prior
374 history of science-policy interactions and governance in the basin, significant steps
375 forward are evident especially in the Colorado River Delta, and in the lower part of the
376 Basin. For example, in recent years, a diverse set of government officials, scientists and
377 NGOs have been engaged in experimental management practices, as exemplified by the
378 2014 pulse flow event which brought water to the parched Colorado River Delta, to
379 collaboratively learn about river restoration (Howard 2014; Gerlak 2015).

380

381 *Produce and use knowledge of all types*

382

383 As noted in the introduction, contemporary water governance must draw on knowledge in
384 its many different forms (scientific, local, indigenous, bureaucratic). This knowledge is
385 held, formulated and communicated by a variety of actors inside and outside government,
386 at all scales (Lejano and Ingram 2009). Integrating different kinds of knowledge in water
387 decision making can be extremely challenging because of differing, potentially
388 contradictory and sometimes incompatible ways of knowing (e.g., between scientific and
389 traditional knowledge systems). Openness to the use of multiple types of knowledge is
390 important for legitimate decision making processes (Taylor and de Loë 2012), as is a
391 commitment to processes of ‘knowledge co-production’ in which a plurality of

392 knowledge sources and types is brought together to define and resolve problems
393 (Armitage et al. 2011). Processes of knowledge co-production are not intended to resolve
394 situations where knowledge and understanding about water conditions are
395 incommensurate. For example, there may be instances where fundamental disagreements
396 remain on sources of water contamination, as is happening in Mackenzie Basin with
397 regard to oil sands contamination in downstream deltas (Timoney and Lee 2009; Hall et
398 al. 2012). However, knowledge co-production processes do help participants to view
399 knowledge not simply as a product, but instead as an outcome of relationships in which
400 different information, knowledge and values are recognized as being tightly connected
401 (Edelenbos et al. 2011). In transboundary water governance settings, these forms of
402 interaction have important implications for how science and scientists are engaged with a
403 broader range of actors and in ways that challenge notions of certainty about system
404 conditions.

405

406 In the Mackenzie Basin, for example, scientists and traditional knowledge holders (those
407 individuals with a long-term engagement on the land as harvesters and trappers) are
408 working together in new ways through the Peace-Athabasca Delta Ecological Monitoring
409 Program, and specifically, by collaborating on wildlife and environmental surveys.
410 Initially, there was some apprehension among scientists and traditional knowledge
411 holders about working together but over time they have come to value collaborating to
412 share knowledge, as has been our experience in similar contexts (Wolfe et al. 2007). It is
413 often difficult for people more comfortable with technical information and ‘hard facts’ to
414 engage someone whose knowledge emerges from ongoing interactions with the land, and

415 who might communicate that knowledge through stories, perceptions of change and a
416 tendency to situate their knowledge in a broader discourse about values (Wolfe et al.,
417 2007; Armitage et al. 2011; Taylor and de Loë 2012). Ultimately, these changes in
418 relationships and focus on knowledge require a tacit recognition of differences in power,
419 willingness on the part of the individuals involved to relinquish in some cases the
420 positions of power they do hold, and a commitment to trust building (Armitage et al.
421 2009).

422

423 The co-production of knowledge can be especially important in transboundary water
424 governance settings where objectives, targets and goals often must be negotiated among
425 actors who lack the power to enforce their views on each other. Monitoring in a
426 transboundary water governance context is one vehicle for knowledge co-production
427 because it also situates assessment, reflection, and learning in specific empirical contexts.
428 Along the Danube River, information sharing, exchange, and harmonization have been
429 primary objectives of the International Commission for the Protection of the Danube
430 River (ICPDR) from its inception in the early-1990s (ICPDR 2007). Such efforts feed
431 into the Danube River Basin Management Plan, which outlines concrete measures to be
432 implemented by the year 2015 to improve environmental conditions (Weller and Popovici
433 2011). Demonstrating improvements in ecological conditions and coordinating among the
434 diverse institutions involved in managing the Danube prove challenging (Gerlak 2004).
435 However, the information collected provides: (i) a solid foundation of agreed-upon data
436 which simplifies the process of developing management plans, and (ii) consistent
437 reporting on achievements and remaining challenges in restoring water quality

438 throughout the basin to better guide decision makers on policy measures (Schmeier 2014).

439

440 *Engage boundary organizations and informal networks*

441

442 Boundary organizations work at the interface of governmental and non-governmental

443 spheres, and typically are the formal bodies that mediate interactions (e.g., about values,

444 purposes, strategies) among social actors (Guston 2004; Crona and Parker 2012).

445 Evidence from different environmental policy and governance settings indicates that

446 these organizations can serve as clearing houses for information, foster conflict resolution,

447 and, where supported by legislation, build the legitimacy and credibility needed to

448 encourage behavioral change (Cash et al. 2003; Huitema and Turnhout 2009; Crona and

449 Parker 2012). To achieve these potential benefits, however, boundary organizations

450 require cultivation, experience and involvement from stakeholders at higher and lower

451 levels of governance. Where boundary organizations do not exist, or where they are

452 ineffective, informal networks of scientists, policy makers, and community members can

453 sometimes fill gaps (Huitema and Meijerink 2009). In these settings informal networks

454 may emerge that can institutionalize science-policy processes longer-term. Informal

455 networks can utilize scientific information and local knowledge to help work around

456 political resistance, entrenched approaches, or attachments to the old ways of doing

457 things. In turn, such networks can catalyze demonstration projects at smaller scales (e.g.,

458 demonstration projects or sites within a transboundary context), and subsequently

459 communicate lessons learned to a broader policy context (Roux et al. 2006).

460

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

477

478 More formal, government-led river basin organizations such as the Mekong River
479 Commission or the Orange-Senqu River Commission also can serve as a type of
480 boundary organization. These organizations can have specific responsibilities to link
481 scientists, donor agencies, policy makers and communities vertically and horizontally,
482 and as a result, they can function as key nodes in the development of more tightly-
483 coupled networks of scientists, policy makers and civil society actors (e.g., industry,

484 community organizations) seeking to be engaged in decision making. In the Orange-
485 Senqu River Basin, the Orange-Senqu River Commission facilitates information
486 gathering and sharing within the four basin nation states. However, it cannot fully resolve
487 the differences in scientific and technical capacity between basin states which result in
488 challenges providing timely and accurate data. The Mekong River Commission
489 encourages data and information exchange regarding hydrology, biodiversity and
490 fisheries in the form of State of the Basin Reports. It builds technical capacity (as well as
491 institutional and social capacity), through its Flood Management and Mitigation Program
492 and Initiative on Sustainable Hydropower, which supports adaptation to future stressors
493 (Heikkila et al. 2013). However, like the Orange-Senqu, limited capacity in some states
494 is a challenge for data acquisition. Furthermore, boundary organizations must contend
495 with issues of data sharing with non-member states, as in the case of the Mekong River
496 Commission and its interaction with upstream China. The Mekong River Commission
497 has its strengths and weaknesses depending on different programmatic areas (Heikkila et
498 al. 2013), and identifying areas with strong or weak organizational capacity will be
499 important.

500

501 **Conclusion**

502

503 Blueprints for effective science-policy processes in transboundary water governance
504 settings do not exist because, as in water governance generally, problems and solutions
505 are complex and context specific (Ingram 2013). Nonetheless, it is possible to identify
506 conditions that are likely to increase the chances of success based on international

507 experiences. We have done so here using transboundary water governance examples but
508 recognize the value of engaging with a wide range of practitioners and scholars in diverse
509 settings to further reflect upon and build an evidence base of the conditions for effective
510 science-policy processes.

511

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

519

520 Recent experiences in the vast transboundary Mackenzie Basin in Canada reflect many of
521 the conditions and lessons outlined in this policy perspective (see Box 1), with the cases
522 in Table 1 offering supporting examples. As previously noted, science-policy interactions
523 often reflect unequal relations of power between nation states (or sub-national
524 jurisdictions, such as is the case in the Mackenzie Basin). In some contexts, deliberative
525 approaches in political arenas can create new spaces for actors to engage on difficult
526 issues and build trust (Dore 2014). However, efforts to further science-policy interactions
527 in the Mackenzie Basin are complicated by more than jurisdictional differences in power.
528 There are vested industry interests associated with oil sands production and pressure to
529 engage with new technologies (e.g., fracking) that can subvert local deliberative

530 processes, transboundary governance and multi-scale efforts to institutionalize science-
531 policy interactions. These circumstances do not imply that efforts to foster science-policy
532 interactions will fail, and there are in fact many innovative efforts taking place in the
533 Mackenzie Basin (See Box 1). However, they do make the task all that more challenging.

534

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

550

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559

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

Transboundary basin	Key issues, successes and challenges
<p>Colorado Drainage area: 640,000 km² River length: 2,334 km Average annual natural* flow: 641 m³/s Average annual actual flow, measured at the southern international border: 75.3 m³/s Population: 40 million Jurisdictions: 10 (international)</p>	<p><u>Issues</u></p> <ul style="list-style-type: none"> • Over-allocation, anticipated increased duration and severity of drought, growing population and demand for water <p><u>Successes</u></p> <ul style="list-style-type: none"> • Emerging <i>network</i> 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 <i>knowledge</i> and opportunities for <i>learning</i> among different actors <p><u>Challenges</u></p> <ul style="list-style-type: none"> • 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 <i>power</i>
<p>Mackenzie Drainage area: 1.8 million km² River length: 4,241 km Average annual flow: 9910 m³/s Population: 397,000 Jurisdictions: 7 (sub-national)</p>	<p><u>Issues</u></p> <ul style="list-style-type: none"> • 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 <p><u>Successes</u></p> <ul style="list-style-type: none"> • 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 <i>knowledge</i> in decision making • Innovative measures to create <i>positive conditions early on</i> for decision making processes by embedding credible scientists on land and water boards <p><u>Challenges</u></p> <ul style="list-style-type: none"> • 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
<p>Mekong Drainage area: 760,000 km² Average annual flow: 14,500 m³/s</p>	<p><u>Issues</u></p> <ul style="list-style-type: none"> • 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

<p>River length: 4,909 km Population: 70 million Jurisdictions: 6 (international)</p>	<p><u>Successes</u></p> <ul style="list-style-type: none"> • Emergence of civil society-based <i>network</i> 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 <i>boundary organization</i> – i.e., connecting actors through <i>shadow</i> networks <p><u>Challenges</u></p> <ul style="list-style-type: none"> • Capacity building for the development of different kinds of <i>knowledge</i> held by various stakeholders and ways to include them in the decision-making process – <i>science as one input</i> 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 <i>initial conditions</i> needed for collaboration among science, policy and community actors
<p>Murray-Darling Drainage area: 1,064,469 km² Average annual natural* flow: 409 m³/s Average annual actual flow: 161 m³/s River length: Darling 2,740km Murray 2,530 km Population: 2.1 million Jurisdictions: 5 (sub-national)</p>	<p><u>Issues</u></p> <ul style="list-style-type: none"> • 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 <p><u>Successes</u></p> <ul style="list-style-type: none"> • Institutionalization of environmental flows and Federal and State offices of an Office of Environmental Water Holder help create <i>initial conditions for better decisions</i> over the longer term • Scientific input into the Water Basin Plan and evaluative reviews conducted by the former National Water Commission illustrates effective <i>learning</i> 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 <i>science is ultimately one input</i> • Trading of water rights and/or allocations has expanded economic opportunity for irrigators and increase options for environmental buyback <p><u>Challenges</u></p> <ul style="list-style-type: none"> • 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 <i>network</i> 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 <i>initial conditions</i> 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 <i>learning</i> through change

<p>Orange-Senqu Drainage area: 896,368 km² Average annual flow: 364 m³/s River length: 2,200 km Population: 19 million Jurisdictions: 5 (international)</p>	<p><u>Issues</u></p> <ul style="list-style-type: none"> • 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 <p><u>Successes</u></p> <ul style="list-style-type: none"> • Institutionalized body (Orange-Senqu River Commission: ORASECOM) established in 2000 which has the potential to serve as <i>boundary organization</i> 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 <i>knowledge</i> needed to measure key ecological components and function as a baseline against future 5-year surveys <p><u>Challenges</u></p> <ul style="list-style-type: none"> • 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 <i>learning</i> and efforts to build vertical and horizontal <i>networks</i>
<p>Danube Drainage area: 801,463 km² Average annual flow: 6,550 m³/s River length: 2,857 km Population: 82 million Jurisdictions: 19 (international)</p>	<p><u>Issues</u></p> <ul style="list-style-type: none"> • Pollution, flood protection / prevention and ecological rehabilitation (e.g., delta) <p><u>Successes</u></p> <ul style="list-style-type: none"> • Long-standing and institutionalized <i>boundary organization</i> (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 <i>knowledge co-production</i> and <i>learning</i> <p><u>Challenges</u></p> <ul style="list-style-type: none"> • Demonstrating improvements in ecological conditions remains a challenge reflecting need communicate story of success <i>beyond the science</i> • Coordination among diverse institutions in region because of various capacity and organizational issues undermines network of actors and constrains establishment of <i>conditions</i> 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

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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.

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