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The role of uncertainties in the design of international water treaties: an historical perspective

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Abstract Water is one natural resource whose management is especially susceptible to uncertainties, many of which are being exasperated by climate change. Some of these uncertainties originate from knowledge deficits in physical conditions while others relate to behavioral and social variability related to water supply and use. However, to our knowledge no quantitative analysis of how uncertainties have been translated into transboundary water treaty structures exists. The present paper partially fills this gap through an examination of how uncertainty has been reflected in basin specific transboundary treaties and how that reflection has changed over the last century. While we could identify only minor trends in the frequency with which uncertainties are mentioned in treaties, we did find two clear patterns in the strategies adopted to deal with them. First, treaties seem to adopt a portfolio approach that spreads the dangers of uncertainty by concurrently including several management strategies simultaneously. Second, there is a trend towards more open-ended strategies in recent decades, rather than hard codification of rules as had earlier been more common.

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1 Introduction

As resource scarcity grows, the need for resource management becomes increasingly important. To assist with the management process, societies have often turned to science to provide a basis for decision making and policy formulation (Song and M'Gonigle 2001; Shackley and Wynne 1996). Systematic, scientific investigation has been credited with providing the certainty required for sound sustainable resource planning and policies (Van Asselt and Rotmans 2002) supporting stable political outcomes (Grundmann 2007).

However, there is now growing recognition of the complexity of natural systems and a better understanding that our knowledge of them and our ability to predict their future change will never be complete. This has resulted in what has come to be known as a 'skeptical crisis' (Funtowicz and Ravetz 1993) in which the limits of certainty are recognized. This skepticism arises around our ability to develop complete knowledge of systems' behavior. The distinction between uncertainty and risk is in this context crucial. Risk is in its neoclassical economic definition consistent with complete knowledge, as it can be calculated by multiplying the value of possible outcomes with their corresponding probabilities. By contrast, uncertainty is incompatible with complete knowledge, as either the probabilities of the outcomes or the potential outcomes themselves are unknown (Knight 1921). However, even if the probabilities are known, people tend to act upon their perceived risks rather than the actual probabilities of the occurrence of particular outcomes (Beck 1999; Freudenburg 1988). This suggests that the interpretation and the understanding of the material world surrounding us might be a more important driving force of human behavior than the knowledge of "scientific facts".

While an inability to develop certainty and to assess the real risks of natural resource system operation could be used as an argument for inaction, the answer to the "crisis" is in fact in the design of management systems that can address the multiple uncertainties which will always exist (Berkes 2007; Gunderson and Light 2006; Cutter 2003). This is especially the case for combating climate change, a problem which requires adoption of robust decision-making procedures (Lempert 2002; Lempert et al. 2003) that seek to identify strategies which perform well across a wide range of possible impacts and a wide range of plausible probability density functions (Keller et al. 2008). Failure to implement such systems can result in delays to practical responses, policies and legislation to environmental problems (Yearly 1996; O'Riordan 1992).

Water is one natural resource whose management is especially susceptible to uncertainties (UNEP 2006). These uncertainties can originate from a variety of sources. Some relate to knowledge deficits in physical conditions including water availability, connections between surface and groundwater, and ecosystem vulnerability to water shortage or quality change (Newig et al. 2005; Pahl-Wostl and Jeffrey 2007). Available climate change scenarios indicate that these uncertainties will be increasing over time as extreme weather events and natural hazards, such as flooding, heat waves and cyclones become more frequent, and the geographic and temporal clustering of precipitation patterns shifts (IPCC 2007). Other uncertainties relate to behavioral and social variability related to water supply and use and are often connected to factors beyond the water sector including income growth, global grain production (Hoekstra and Hung 2005) or energy policy (De Fraiture

et al. 2008). Thus, there is little wonder that water management problems have been said to defy absolute solution (Adler 1998) and whose governance instead requires considerations of multiple users and sectors, each subject to differing change processes operating at different spatial scales.

Further increasing uncertainty around water outcomes is the fact that water's natural boundaries are often inconsistent with those of the bureaucratic and political systems on which management institutions and resource control are based. As a result, successful management often requires cooperation across boundaries if it is to reduce the uncertainties mentioned above and facilitate effectiveness and efficiency in water resources planning and policy. At the international level, codification of this cooperation is reflected in a large body of basin specific water treaties and agreements. The growth of these agreements and the large role they play in transboundary water management has triggered studies to trace the factors that affect their design and effectiveness. A few such examples include examinations of ambiguity incorporated within agreements (Fischhendler 2008a), the degree of flexibility in treaty design (Drieschova et al. 2008; Kistin and Ashton 2008) and the influence of international law on treaty language (Conca et al. 2006). However, to our knowledge no quantitative analysis of how risks and uncertainties have been translated into transboundary water treaty structures and language is available in the literature to date. This gap is especially critical in combating climate induced change as it is clear that for internationally shared resources both mitigation and adaptation are facilitated by creating international environmental agreements that can address the multiple uncertainties concerning its causes and effects.

The present paper partially fills this gap through an examination of how uncertainty has been reflected in basin specific transboundary treaties and how that reflection has changed over the last century. To do this, a rudimentary model is first developed to typify the various sources of uncertainty related to transboundary water governance and the potential strategies available to address them. The body of transboundary water law is analyzed to highlight how these strategies have been accommodated in actual practice. A time series analysis is then used to show how strategies have changed over time and suggest whether the change is related to an increased understanding of uncertainty or rather a secular change in the issues addressed in transboundary water treaties. The results are used to provide insights into the role of uncertainty management in transboundary water policy, in particular in connection with climate change, and highlight additional key gaps in our understanding.

2 Sources of uncertainties surrounding international waters and responses

The role of uncertainty in international cooperation in general has long been recognized (Keohane 1984; Winham 1977; Zartman and Berman 1982) as has the influence of uncertainty on the design of international institutions (Koremenos et al. 2001; Victor et al. 1998). More recent work has addressed the role of uncertainty for environmental governance in particular (e.g. Adger and Vincent 2005; Litfin 1994). In the following section we build on these earlier works to develop a rudimentary model of the ways in which uncertainty impacts treaty design. While the model is developed for the specific case of international water treaties, it can be generalized

to agreements dealing with the allocation and management of other natural resources as well.

It is possible to distinguish between two types of uncertainties affecting the need for international water treaties, their design and eventual effectiveness, those exogenous to agreements and those endogenous to agreement creation. Exogenous uncertainties can be divided into two categories. *Exogenous resource uncertainties* refer to perceived uncertainties related to the material nature of shared water resources. They can originate from uncertainties around variability in water quality and quantity, or from uncertainty in the vulnerability of resource systems. The possible occurrence of drought and flood is an example of the former while the general lack of knowledge about the impact of climate change on basin ecosystems is an example of the latter.

Another set of exogenous uncertainties results from the social surrounding and the global system into which states, and their agreements, are embedded. These *exogenous background uncertainties* include uncertainties about internal politics, such as the possibility of changing domestic coalitions which can translate into different national interests and therefore changing state behavior. Other exogenous background uncertainties can be found in the domain of international relations where alliance politics can lead to the eventuality of war in the extreme case; alternatively market fluctuations as for example price shocks on the food market can impact demand for grain and therefore water (Hoekstra and Hung 2005). In cases where states have not developed "dependable expectations of peaceful change" (Adler 1998: 170) and common norms and belief structures, background uncertainties can make states feel a need to prepare for worst case scenarios rather than manage for most likely outcomes.

For internationally shared resources, if equitable rules governing use are not secured through agreement, there is a danger that exogenous resource and background uncertainties will be manifested in overuse, degradation, and even conflict. Indeed, we are now aware of a few cases where unilateral development of a river has caused conflict between basin riparians (Gruen 2000; Ratner 2003). Uncertainties are likely to increase under the case of what O'Brien and Leichenko (2000) termed "double exposure", the potential for physical changes to simultaneously interact with social change to affect livelihood outcomes and development opportunities. In the context of this paper, double exposure is the occurrence of both exogenous resource and background uncertainties. For example, in the case of the Nile River, uncertainties over future flow regimes due to changes in rainfall and land cover combine with political uncertainties over Egypt's possible reactions to upstream water development.

Yet, the creation of an agreement to address resource and background uncertainties can itself create new uncertainties, uncertainties endogenous to the agreement design. This *induced endogenous uncertainty* can manifest itself as uncertainty about the implementation of a treaty by one or more parties, uncertainty about the validity and/or interpretation of collected data, or uncertainty about treaty finance. The presence of both resource and background uncertainties can also exacerbate the impact of endogenous uncertainties. For example, a continuous drought coupled with deteriorating political relations in the case of Israel and Jordan was found to turn the constructive ambiguity in their water treaty to destructive (Fischhendler 2008b) by allowing the uncertainty in the agreement to affect the entire peace relations between the two sides.

Obviously endogenous uncertainties cannot exist without the creation of an agreement. Thus there is a general trade-off between the management of exogenous uncertainties and the manufacture of endogenous uncertainties through the management process. For example, when states try to deal with flow variability in water sharing agreements by basing allocations on percentages of river flows, uncertainty about treaty implementation can arise if insufficient data about the hydrological flow are available or if these data are or could be disputed by either party. Many of the disputes around the Ganges Water Treaty signed between Bangladesh and India in 1996 (Salman and Uprety 2002) can be attributed to this scenario.

The presence of and the interplay between exogenous resource uncertainty, exogenous background uncertainty and induced endogenous uncertainty creates three significant dangers of uncertainty for riparians. These are the dangers of resource degradation, water scarcity and of an inequitable distribution of the resource. The consideration of these dangers of uncertainty among other things impact on the treaty design, which in turn affects the likelihood of treaty ratification and effectiveness.

Four generic strategies can be identified for addressing exogenous uncertainty in international water agreements and the endogenous uncertainties they create. The first is to ignore them. One means of *ignoring uncertainty* in agreements is to eliminate any use of language acknowledging uncertainty. For example, a treaty establishing fixed water allocations between two countries may be drafted to ignore the obvious possibility that flows will vary from year to year. Uncertainty, formally acknowledged or not, may also be ignored by failing to include mechanisms for its management. For example, an agreement may not specify water deliveries under low flow conditions or may not refer to the allocation of water between parties at all, but rather focus on the gains from cooperation, such as through joint development of hydropower.

At the other extreme, agreements may aim for a *complete contracts approach* (Simon 1981; Hart and Moore 1988) focused on reducing the implications of uncertainty. Under a complete contracts approach, agreements specify each party's obligations under all potential scenarios that may arise out of uncertainty, leaving no space for ambiguity in treaty interpretation or performance. In other words, the agreement includes provisions such as monitoring frameworks, escape clauses for unexpected conditions, and binding arbitration mechanisms which describe fully the actions possible no matter how uncertainty eventually materializes.

In between these extremes are two additional strategies. In what might be called an *uncertainty minimization strategy*, agreements attempt to reduce either the implications of uncertainty or its core causes. An assumption behind this strategy is that uncertainty reduction can produce social benefits especially in relation to the effects of climate change (Yohe 1996; Nordhaus and Popp 1997). In the realm of transboundary water management, such agreements can adopt mechanisms such as data exchange or technology transfer to increase understanding of natural systems or can facilitate the creation of shared hydrologic models to predict water resources futures and provide a platform for building and understanding possible future scenarios (Courtney 2003; Van Asselt and Rotmans 2002).

Finally, agreements can use an *open-ended strategy*. The premise behind this approach is that uncertainty is stochastic and thus inevitable. The solution is hence to either adopt a risk avoidance tactic by prescribing precautionary policies to limit activities (O'Riordan and Jordan 1995; Dratwa 2002; Mayer et al. 2002) or to leave

room for change by including flexibility and adaptability to the design of management systems (Pahl-Wostl and Jeffrey 2007). Agreements using this strategy may include provisions for consultation, a broadening of cooperation, mutual assistance, indirect allocation, or include a reliance on the ambiguous language of international law. They may also include the option for the sequential construction of regimes over time rather than immediate finalization. The emphasis of the open ended approach is on procedures while the emphasis in complete contracts approach and uncertainty minimization approaches are on clear rules.

The process through which uncertainties enter into treaty formation and translate into design strategies is shown in Fig. 1. Exogenous background uncertainties and exogenous resource uncertainties create the preconditions for a particular treaty design. During the negotiation process the parties do, however, also have to take into account the existence of induced endogenous uncertainties (Koremenos et al. 2001). On the other hand those induced endogenous uncertainties only materialize once a given treaty design is in place. As shown in Fig. 1, a given treaty design adopts either one or a combination of the four uncertainty management strategies discussed above, though possibly via an iterative path as negotiations and outcomes become evident.

Clearly the particular strategy taken will depend on a variety of factors including the overall relations between basin riparians, the overall package of issues to be negotiated, and the level of contention and political sensitivity of the issues. In addition, the likelihood of any particular strategy being used can be hypothesized to be a

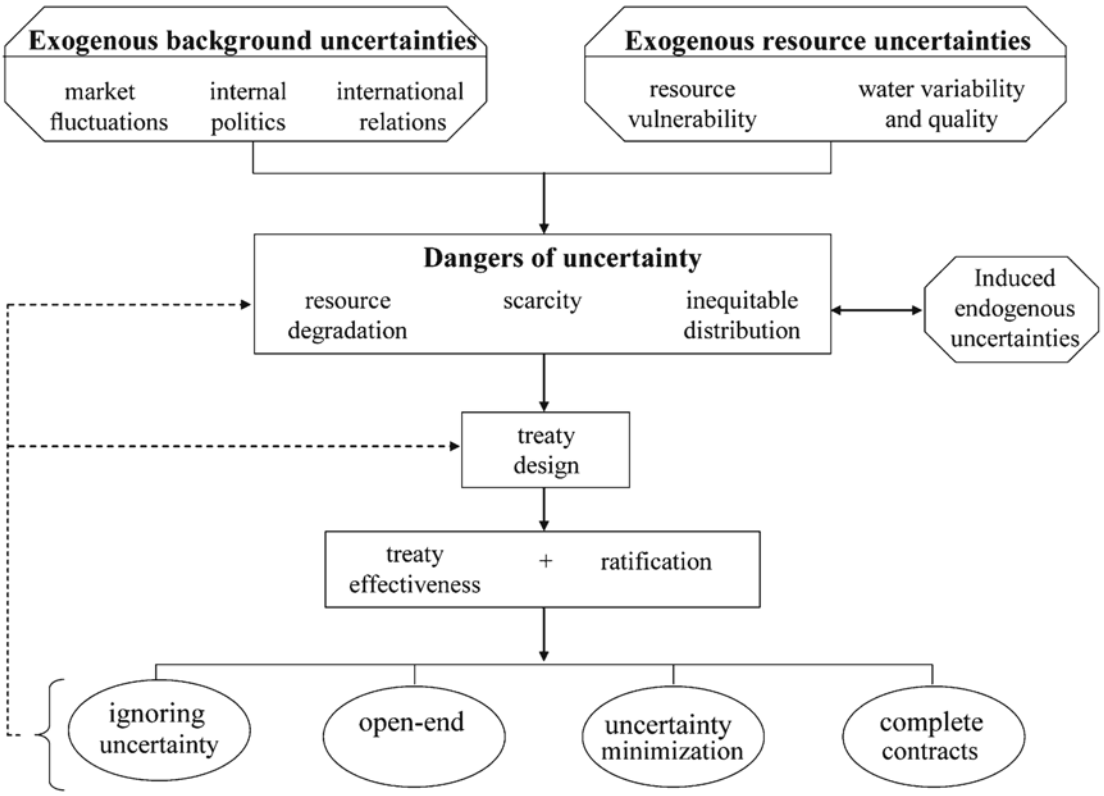

Fig. 1 Uncertainty in transboundary water treaty design and implementation: a conceptual framework

function of time and place. As our understanding of both exogenous uncertainties and the functioning of treaties change, our understanding of how uncertainty should be approached in agreements may change as well. Similarly, the use of any particular strategy likely depends on the nature of the basin at a particular point in time. Early in basin history the focus may be on development, later on joint management. The key uncertainties to be addressed vary in each circumstance as do the most appropriate strategies for their management.

3 Methodology

That uncertainty is a factor in treaty formation is clear. How it has actually been dealt with in agreement practice, and how that practice has changed over time, is much less obvious. To ascertain if and how transboundary water treaties have addressed uncertainty, a content analysis of available transboundary water treaties was undertaken. For the analysis, a treaty is considered to be "an international agreement concluded between States in written form and governed by international law, whether embodied in a single instrument or in two or more related instruments and whatever its particular designation" (United Nations 1969: Article 2). This definition highlights the need to group agreement texts according to lineage, i.e. consider original agreements along with later amendments and protocols as single instruments for analysis.

Building on an earlier Hamner and Wolf (1998: 158) distinction, documents selected in the analysis were limited to those transboundary water treaties which governed rivers, lakes or aquifers which crossed international borders and focus on "water as a scarce or consumable resource, a quantity to be managed, or an ecosystem to be improved or maintained" rather than those which deal "only with boundaries, navigation or fishing rights" (Hamner and Wolf 1998: 158). Most importantly, this meant that agreements which focused only on navigation, border delineation and fishing rights (as distinct from water as a provider of habitat for fish) were excluded. In addition, the analysis was limited to agreements focusing explicitly on specific basins. Under this limitation, "global" agreements such as the 1997 UN Convention on the Law of the Non-navigational Uses of International Watercourses which lay out principles for water governance but do not apply those principles to actual water bodies are excluded.

The recently expanded Transboundary Freshwater Dispute Database (TFDD) is the most comprehensive source of transboundary water agreements that meet the criteria. The updated version of the database had available full or substantial texts of 303 agreements meeting these definitions and criteria. Because of the low frequency of agreement formation before the twentieth century, we limited our sample for analysis to the 289 agreements signed after 1900. The agreements were read and the content analyzed first for reference to uncertainty management and second for inclusion of mechanisms potentially consistent with uncertainty management. These mechanisms were identified based on a reading of the existing literature on water treaty structures (Wouters et al. 2005; Young 1999), and insights gained from reading actual agreements. Each of the identified mechanisms was then classified according to its relation with the four uncertainty management strategies elaborated above.

For assessments of how uncertainty management has changed over time, each agreement in a lineage (original agreement plus later amendments and protocols)

was classified according to the signature date of the original agreement. The alternative approach would have been to classify each agreement according to the date of its final amendment or protocol. Either approach has conceptual advantages and drawbacks. While choosing one approach over the other clearly changes the precise image of temporal treaty development, actual differences in results were minor and did not change the overall picture.

The combined outcome of the static and temporal analyses provide a basis for discussing the frequency with which strategies have been used and how their use has changed over time. It also provides a basis for analyzing if and how multiple strategies can be used within a single agreement.

4 Results

To produce the overall results, we first analysed the frequency with which the concrete uncertainties identified in our model (Fig. 1) were mentioned in treaty texts and how the frequency of such inclusions has changed in the course of the last century. In a second step we identified the mechanisms employed to deal with uncertainties and classified them according to the uncertainty management strategies described above. Finally, we searched for possible trends in the employment of those strategies.

4.1 Uncertainty language in treaty texts

As highlighted above, there are a number of uncertainties that any particular transboundary governance structure might address or which it must face in operation. A first question is the extent to which these uncertainties are formally addressed in treaties and which particular uncertainties receive the most attention. In the content analysis we aimed to stay as close as possible to the original language of treaty texts in order to preserve as accurately as possible the intentions and the perspectives of negotiators, while at the same time summarizing the findings quantitatively. Hence the categories identified in treaty texts slightly differ from our theoretical model (see Fig. 1), but they are nonetheless translatable to the categories developed in our model.

We found that almost two-thirds of all sampled agreements (65.7%) explicitly mention uncertainties in some form. As shown in Table 1, of those uncertainties mentioned, exogenous resource uncertainties were most common, with uncertainty surrounding flows dominant. Other exogenous resource uncertainties explicitly mentioned included scientific uncertainty and general environmental uncertainty. For example the Agreement between Portugal, Mozambique and South Africa relative to the Cahora Bassa Project signed in 1984 states in article 2 that "any overwhelming occurrence of nature which could not reasonably have been foreseen or guarded against" is a force majeure. Article 12 then states that the parties shall review the situation and agree on measures to be taken in case force majeure occurs. General environmental uncertainty encompasses the whole category of exogenous resource uncertainties; the language employed is vague and ambiguous. As such it cannot be clearly attributed to resource vulnerability or water variability and quality. Scientific uncertainty can also be linked to resource variability as well as water variability and

Table 1 Uncertainty language in transboundary water agreements, 1900–2007

Nature of uncertainty	% of sample which mentioned
Exogenous resource uncertainty	
Flow variability	49%
General environmental	13%
Scientific	4%
Explicit climate change uncertainty	0.69%
Exogenous background uncertainty	
International relations	8%
Demand uncertainty	4%
Induced endogenous uncertainty	
Treaty implementation	7%
Data	1%
Treaty finance	6%
Treaty effectiveness	4%
Treaty created infrastructure	18%

quality. However, the emphasis is put on a lack of knowledge, which can be alleviated by undertaking further scientific research.

Climate change as a source of exogenous resource uncertainties has been mentioned in only two treaties, the Convention for the Establishment of the Lake Victoria Fisheries Convention signed between Tanzania and Kenya in 1994 and the Convention on the status of the Volta River and the Establishment of Volta Basin Authority signed in 2007 by Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali, Togo. The preamble of the Convention of the Volta River states for instance that "there is continuous degradation of the natural resources of the Volta basin, especially its water resources, as a result of climate change and variations of the past decades, on the one hand, and by the negative impacts of the human activities carried out throughout the basin on the other hand".

The only exogenous background uncertainties referred to in agreements are uncertain international relations and demand uncertainty, issues mentioned in 35 (12%) agreements. As an example of uncertainty about the development of international relations, the Convention for the Management of the Hydraulic Power of the Rhone signed between France and Switzerland in 1913 states in article 9 that the two governments explicitly reserve for themselves the freedom to undertake any measures necessary for their national defense. An example of a demand uncertainty is inherent in the Exchange of notes between the government of the USA and the government of Canada constituting an agreement regarding the development of certain portions of the Great Lakes- St. Lawrence Basin project signed on the 7th of November 1940. The agreement states that "there is apprehension in both countries over the possibility of a power shortage; these apprehensions have been heightened by the necessity for increased supplies of power in consequence of Canada's war effort and of the major national defense effort in the United States". While in this case demand uncertainty is related to the uncertain international environment, in other cases it can be related to internal politics or to market fluctuations; in fact most treaties remain ambiguous on the reasons for demand uncertainty. Endogenous uncertainties referred to in treaties include uncertainty about financial operation, regime effectiveness, treaty implementation, shared data and infrastructure. For

example the Convention between Mexico and the US on the Distribution of Water signed in 1906 states in article 2 that in case of serious accident to the irrigation system, the water delivered to the Mexican canal shall be diminished in the same proportion as the water available to the US.

Of the agreements which mention uncertainty, more than 60% mention only one form of uncertainty. Another 19% mention two different forms of uncertainty and the remaining 21% mention three or more. One, the Convention on the Protection of the Rhine signed in 1998, mentions six uncertainties related to variability, general environmental uncertainty, scientific uncertainty, uncertainty about treaty implementation, about treaty effectiveness and infrastructural uncertainty.

For most types of uncertainties, we could not identify a visible trend in the frequency with which they were mentioned in treaties across time (Table 2). The three exceptions are general environmental uncertainty, which experienced a marked increase from the period of 1900–1949, when it was mentioned in only 2% of the treaties, to the period of 1990–2007, when it was mentioned in 24%. Secondly infrastructural uncertainty rose from 10% in the 1900–1949 to 28% in 1990–2007. Finally, the mentioning of uncertain international relations declined from 17% in 1900–1949 to 4% in 1990–2007.

4.2 Uncertainty management mechanisms

While more than a third of all treaties sampled do not explicitly refer to any uncertainty, this does not necessarily mean that these treaties ignore uncertainty. In fact there are many mechanisms which can be built into agreement frameworks without explicit mention of uncertainty, but nonetheless providing a potential method for uncertainty management. In total, 26 mechanisms with a potential role in uncertainty management were identified in the sample treaties. Table 3 provides a list of these mechanisms and classifies them according to the four uncertainty management strategies outlined earlier in the paper. Detailed definitions used to identify each mechanism and the rationale for associating each with a particular strategy are given in the Appendix.

Table 2 Changes in types of uncertainty mentioned in transboundary water agreements, 1900–2007

	1900–1949	1950–1969	1970–1989	1990–2007
Exogenous resource uncertainties				
Flow variability	44%	56%	41%	51%
General environmental uncertainty	2%	6%	19%	24%
Scientific uncertainty	4%	1%	6%	6%
Explicit climate change uncertainty	0%	0%	0%	3%
Exogenous background uncertainties				
International relations	17%	4%	7%	4%
Induced endogenous uncertainties				
Implementation uncertainty	6%	7%	6%	7%
Data uncertainty	2%	0%	0%	1%
Financial uncertainty	6%	6%	7%	4%
Effectiveness uncertainty	4%	1%	7%	4%
Infrastructural uncertainty	10%	13%	15%	28%

Table 3 Percentage of transboundary water agreements employing potential uncertainty management mechanisms, organized by strategy (blanks indicate no use)

	Uncertainty management strategy			
	Ignoring	Complete contracts	Reducing	Open ended
Substantive rules				
Allocation related				
Fixed allocation	5.5			
Variable allocation		17.3		
Vague allocation mechanisms				11.1
Allocation of polluting rights			3.1	
Variability management			27.0	
Variable water or hydropower needs		8.7		
Local needs consideration		17.3		
Equity or sustainability				30.8
Infrastructure related				
Right to construct		12.5		
Ban on particular constructions			12.1	
Compensation		17.0		
Change related				
Alternative scenarios use		18.7		
Model building for future prediction			10.0	
Treaty does not serve as precedence				4.2
Establishment of national programs to support agreement		12.8		
Procedural rules				
Technical or financial cooperation			47.4	
Information exchange			39.4	
Agreement finance		51.2		
Consultations				20.1
Prior notification/consultation				17.0
Prior consent		14.5		
Amendment mechanism				27.7
Institutional mechanisms				
Joint Commission				58.8
Stakeholder participation		6.6		
Means of dispute resolution				
Legal means		30.4		
Diplomatic means				39.4
Monitoring		29.1		

For presentation purposes, the mechanisms are grouped following the legal assessment model of Wouters et al. (2005). In that model, substantive rules establish the "material rights and obligations of the parties"; procedural rules "provide the means through which substantive rules are implemented"; institutional mechanisms lead to the creation of a body to implement certain agreement elements; means of dispute resolution are procedures the parties can or have to follow when disputes arise; and lastly monitoring mechanisms serve to verify that the parties follow the agreement or that the objectives of the agreement are met.

Two findings from the table are worth additional analysis here. The first is that mechanisms consistent with a strategy to ignore uncertainties do not appear from an analysis of treaty content. Indeed, a strategy to ignore uncertainty almost by

definition involves inaction rather than action. The one exception may be in water allocation agreements. There is no question that water availability will vary. Any agreement which has provisions for water allocation and whose regulations are based on fixed allocations almost certainly ignored flow uncertainty as a strategy. Within our sample, 98 agreements dealt with allocation but only 16 made allocations based on fixed quantities. However, even in these cases there is no way to know for certain if the use of fixed allocation rules is truly part of a strategy, due to insufficient knowledge by negotiators of hydrology, or resulting from a perception that the impact of ignoring possible flow variability was minimal. For most other cases, it is unclear which uncertainties were even considered in agreement formation and therefore even more difficult to identify a connection between mechanisms which are or are not included in the agreements and a strategy of ignoring uncertainty.

The second finding, perhaps less immediately obvious from the table, is that any particular agreement can and likely does have multiple mechanisms which may or may not be associated with just one of the identified strategies. In fact, we found that the average agreement includes 6.3 different mechanisms. These mechanisms corresponded with an average of 2.5 different strategies. Only 11% of agreements had mechanisms consistent with only one strategy and the remaining 79% had mechanisms consistent with two or three different strategies. The remaining 10% included all four strategies.

4.3 Temporal evolution of uncertainty management strategies

As already mentioned, explicit reference to uncertainty language in treaties does not appear to have changed substantially over the last 100 years. However, the way treaties are structured to handle uncertainty has. As shown in Fig. 2, the average number of mechanisms per treaty has increased fairly consistently since the early twentieth century, at least suggesting that treaties have become more complex as have codified options for uncertainty management. Similarly, the average number of uncertainty strategies associated with each treaty has also increased in the second half of the twentieth century, rising from around two per treaty before 1950 to almost three by the end of the period.

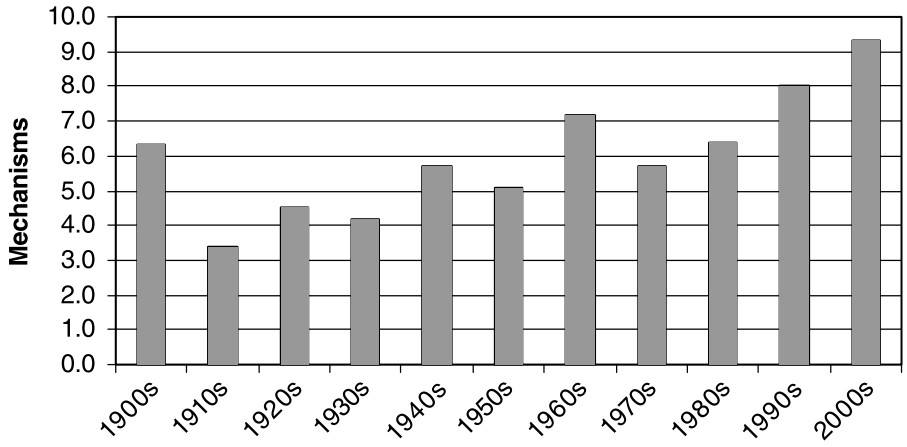

Fig. 2 Average number of uncertainty mechanisms per treaty

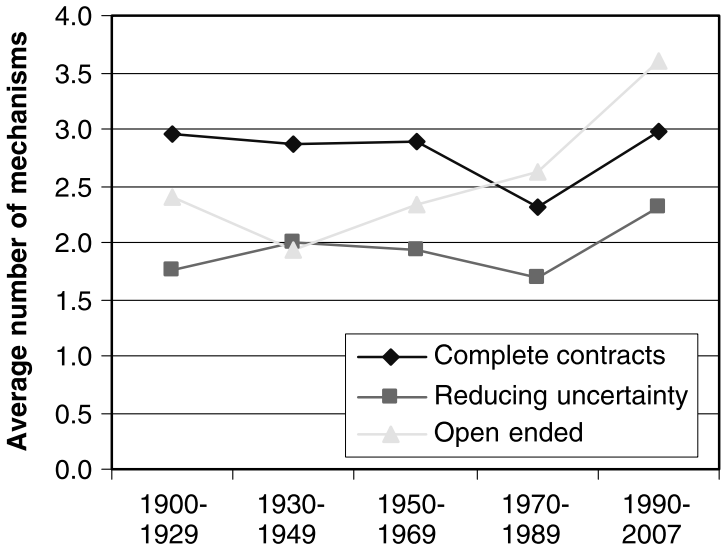

Fig. 3 Change in the composition of uncertainty management strategies over time (average number of mechanisms per treaty)

While there was a general change in treaty complexity, it did not manifest itself proportionately across strategies. As shown in Fig. 3, there has been a sharp increase in the use of mechanisms associated with the open-ended strategy, while the complete contracts approach decreased somewhat to the 1970s, before increasing in frequency again. The reducing uncertainty strategy does not manifest any marked changes, except for a slight increase in its use since the 1970s.

To understand the drivers of this change, it is useful to look back again at changes in the use of particular mechanisms. The increase in open-ended approaches can be attributed to simultaneous increases in the use of mechanisms to establish joint management institutions and the conceptually related employment of mechanisms to encourage consultation between parties and increase communication through prior notification of activities. An increase in mechanisms requiring considerations of equity or sustainability, as opposed to strict water allocations, also contributed to the increase in the frequency of the strategy. The lesser rise in uncertainty reduction strategies is due almost entirely to increased deployment of data exchange mechanisms. Changes in the use of complete contracts approaches cannot be attributed to secular changes in any particular mechanism but are rather the result of rises and declines in the use of a variety of different mechanisms.

5 Discussion

Uncertainty is common to transboundary environmental problems, especially water. Yet, the water treaties examined here are in fact characterized by relative infrequency in reference to any form of uncertainty. Even less frequent are treaties which concurrently make explicit reference to the multiple uncertainties any transboundary water management regime must face or to the difficulties resulting from climate change. At the same time, all treaties include multiple mechanisms which are or could be used to manage various sources of uncertainty. Indeed, the strategies employed by negotiators to deal with uncertainty often appear to develop quite organically in an emergent process, although qualitative research would be more appropriate to shed further light on this issue. Nevertheless, it is obvious that treaty negotiations

are a political process usually reflecting a compromise which has been reached in an emergent, evolving, and indirect series of negotiations and interactions. Yet, even if the process is an evolving one, the fact that we could identify a trend in treaty content suggests that our findings identify some structural limitations of what negotiators can accomplish under real life constrains. The findings relating to the question of how scientific uncertainty has historically been dealt with in water treaties, can also show us what to expect from treaty design under conditions of ongoing climate change, the currently most important source of uncertainty.

The contrast between infrequency of uncertainty language but frequent use of potential uncertainty management mechanisms could be explained by the social relationship between scientists and those whom they advise—policy makers (Shackley and Wynne 1996; Jasanoff 1987). While scientists tend to stress the unknown, policy makers must provide certainty and concrete deliverables (Dabelko 2005; Fogel 2005), in particular because they have to meet the expectations of their domestic constituencies (Putnam 1988). This two-level game implies that politicians might avoid uncertainty language in treaties to ensure domestic support while at the same time including mechanisms to address anticipated uncertainties. The result, consistent with our findings, can be a minimization of explicit references to uncertainty in treaty texts with concurrent development of mechanisms and strategies with potential uncertainty management implications, although these mechanisms are not explicitly described as climate change related. This suggests that international water treaties might in fact provide a feasible way of dealing with increasing uncertainty and climate change, even though it might not appear so on first sight. This is especially the case in more contemporary water treaties that include multiple strategies for dealing with uncertainty as discussed below. Yet is it is important to note that the ability to accommodate climate change is not only a function of appropriate treaty language but also of the ability of the treaty to evolve and to resolve future conflicts. Evaluating the real life performance of the treaties is beyond the scope of this paper. Consistent with our findings, Fogel (2005) points out that many IPCC (Intergovernmental Panel on Climate Change) reports purposefully avoid discussing the numerous scientific uncertainties inherent in the analysis so as to project authority and confidence. Quite interestingly this communication strategy stands in contrast to the IPCC's explicit mandate to manage climate change uncertainties.

Further, we could not identify any marked changes in the temporal development of uncertainty language employed in treaties with the exception of an increase in references to infrastructural uncertainty since the 1980s and general environmental uncertainty since the 1960s. The former coincides with a water-specific trend, namely the growing distrust of huge hydropower projects while the latter might partially be explained by a more general societal trend, the expanding concerns over the environment.

Although uncertainties are not mentioned more frequently in later agreements than they are in earlier ones, both an increased average number of mechanisms per treaty and the incorporation of several strategies within individual treaties may signal increased perceptions of uncertainty. More specifically in relation to the individual uncertainty management approaches, we identified a shift to open-ended strategies. A possible advantage of the open-ended strategy is that it provides a better response to irreversible natural and social processes (Henry 1974), tends to speed up the negotiations (Fischhendler 2008a) and provides flexibility useful in meeting

new conditions (Athias and Saussier 2008). The need for a strategy that provides flexibility and adaptability is in line with the growing recognition that for cases of bounded rationality, policymakers must be equipped with mechanisms which allow them to learn and improve policies over time. It also seems to represent a feasible option for dealing with the uncertain nature of climate change as our knowledge of the phenomenon increases over time due to improved scientific understanding and an accumulation of experiences on its effects.

Yet, Fig. 3 indicates that the growing use of open-ended strategies has not resulted in a tradeoff between the open-ended and complete contracts approaches. In fact we have seen a marked increase in the use of reducing uncertainty strategies and the complete contracts approach in the last two decades. This could be partially connected to a rising awareness of the uncertainties resulting from climate change. In fact, the three strategies are increasingly being employed simultaneously. The fact that one does not come at the expense of the other strengthens our finding for the need to create treaties that are able to address uncertainty by choosing a set of mechanisms that belong to a variety of all four strategies identified. The resurgence of the complete contracts approach in the 1990s, despite a simultaneous rise in open-ended strategies, can be explained by the tension that exists between the high transaction costs related to its employment versus the contribution of this strategy to compliance (Hart 1995).

However the shift to open-ended strategies in water treaties may also reflect the changing water paradigm (Gleick 2003; Pahl-Wostl et al. 2006), which is leading away from water development towards management, as has already been identified by Mostert (2003). This water specific shift may itself be partly a reflection of more broad based changes in societal perceptions of the potential risks of previously favored "hard path" radical infrastructural interventions in the environment and the tendency towards adoption of "soft path" managerial and governance solutions to ecological problems. The change may be related to the growing use of the precautionary principle, a guide to action under conditions of uncertainty (Young 2001: 16).

In order to shed light on whether the change can be attributed to a changing water paradigm, of which uncertainty management is a part, we used Young (1999) to classify each of the sampled agreements according to its function: Regulatory, Procedural, Programmatic, or Generative. Regulatory agreements are those which proscribe or prescribe action (e.g. water allocation or control of pollution). Procedural agreements are those which provide frameworks for regular, collective decision making (e.g. joint water management committees). Programmatic agreements provide rules for pooling or generating resources for project development (e.g. construction and operation of dams). Finally, generative agreements develop new social practices (e.g. establishing principles such as "no significant harm").

Figure 4 shows how the prevalence of treaty purposes has changed over time. We can see that regulatory agreements have decreased when comparing the pre-1950 with the post-1950 period. This can partly be in line with the low peak in the complete contracts strategy in the 1980s. The second trend is an increase in procedural and especially in generative agreements, which is in line with an increase in open-ended strategies.

The initial trigger behind this shift away from development towards management in water treaties may be partly a function of geography. In Europe and North America, many rivers became fully or even over developed in the post-war period. As

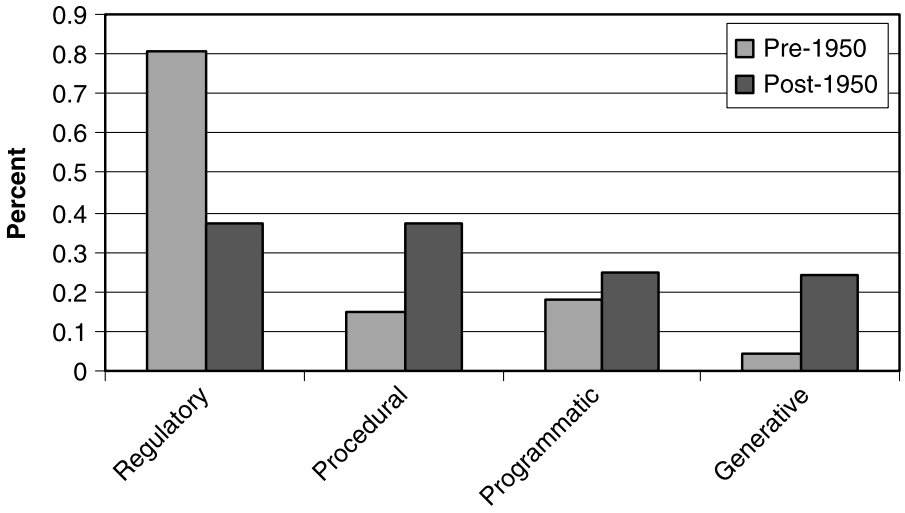

Fig. 4 Changes in transboundary water treaty purposes over time

a result, the focus of water management problems began to shift from hard solutions (e.g. infrastructure development) to soft solutions (e.g. demand management and sustainability) as previously mentioned.

Uncertainty may then be one of the aspects contributing to this shift away from development towards management in water treaties, but it is embedded in the larger context described above. The prior goal of economic growth via industrialization, with the development of water resources as one small part of this larger endeavor, may have itself been closely tied to the notion of the rational man and the idea of unlimited scientific progress. The discursive shift towards an objective of sustainable growth linked in particular to an understanding of the environmental limits and risks inherent in prior practices connects with a more careful management approach in the governance of the water resource. The precautionary principle, which is to guide action under conditions of uncertainty, is then both a product of and one of the driving forces behind the historical trends we identify.

Litfin (2003: 55) writes: "The precautionary principle, for instance, is finding its way into both domestic and international environmental law. While the precautionary principle does not pose any significant challenge to scientific rationality, it takes a more skeptical stance with regard to instrumental reason and, most importantly, adopts an attitude of humility that is contrary to that of secularism. This increased sense of humility represents a more holistic orientation to science and technology, one that decentres humanity to some extent and acknowledges our inability to grasp the complexity of human nature". A focus on integrated water resource management bears this holism already in its title and the softer, management-like approach towards governing water we see develop might indicate the skepticism towards instrumental reason Litfin is talking about.

6 Conclusion

Reliable information on the cause and effect of problems is of critical importance in environmental regime formation (Dimitrov 2003). Yet, incomplete knowledge

exists around all environmental issues (Tol 2005), a fact which has found substantial discussion in recent years as related to climate change and its multiple sources of uncertainty such as carbon cycle uncertainty (e.g. Prentice et al. 2001) and thresholds for ecological process (e.g. Keller et al. 2008). Thus, while uncertainty has been studied in climate change policy, the aim of this paper was to uncover how uncertainty language and strategies for uncertainty management have appeared in treaty language and structure, a topic less studied. The hope was that the outcome could provide insights for future treaty architects on barriers and opportunities for negotiating uncertainty language, language believed to be a problem in generating environmental policy, in particular in connection with the increasing relevance of climate change (Shackley and Wynne 1996; Lahsen 2007).

The results were to a certain degree surprising. While we could identify only minor trends in the frequency with which uncertainties are mentioned in treaties and in the types of uncertainties mentioned, we did find two clear patterns in the strategies adopted to deal with them. First, treaties have become more complex in their potential options for the handling of uncertainty, which could suggest that there is indeed a changing perception of risk and a higher appreciation of uncertainty in water negotiations. This is especially visible in the time trend identified for the adoption of portfolio approaches that may spread the risk of uncertainty by concurrently including several strategies to address uncertainty. Second, there is a trend towards more open-ended strategies in recent decades, rather than hard codification of rules as had earlier been more common. We offered two possible rationales for these changes. The first was a broad-based shift in underlying treaty purposes going from development of water resources towards water resources management, with uncertainty management being closely tied to this process but not the only driving force. The second was an increasing realization of the advantages of more open-ended strategies. Regardless of the reason for the change, the uncertainty language employed in treaties and especially the potential mechanisms to solve uncertainties suggest that it is possible to sign treaties even without having solved all uncertainties. In fact the existence of uncertainties might facilitate agreement formation (Young 1994). In sum, since treaty design is a political process, identifying what is missing and what is included in water treaties provides us with insight into what negotiators can and cannot do: They can provide a set of mechanisms and strategies to potentially address climate change, but they are not likely to explicitly attribute these mechanisms, strategies and the treaty language to uncertainties, including climate change.

Our study aimed to provide a broad overall picture of how to conceive of uncertainty management in international water treaties and how it has been dealt with in the past. This has the advantage of providing a general overview of the topic and a description of change. But it also brings with it at least two important limitations. First, the textual survey performed here reveals nothing about the actual intent of negotiators underlying the inclusion of mechanisms into treaty texts. Of particular interest is the relationship between strategies used in bargaining and strategies appearing in final agreements. A second important limitation is our lack of knowledge about actual treaty effectiveness, i.e. how well do the mechanisms we have identified address uncertainty management. While this study provided a first picture into the overall issues, addressing these shortcomings requires a shift in approach towards more nuanced case study.

Appendix

Fixed allocation Mechanisms allocating absolute quantities of water to the riparians. Since a certain degree of flow variation occurs in every basin, these allocation mechanisms clearly ignore the uncertainty of flow variability.

Variable allocation Mechanisms allocating water based on a percentage of flow. Since any agreed variable allocation can be respected under any possible flow condition, the mechanism falls into the complete contracts category.

Vague allocation mechanisms These are allocation mechanisms, which are vague in that they incorporate calluses such as an agreement to consult in case flow variability occurs but are unclear as to how final decisions will be made. They thus fall into the open-ended strategy.

Allocation of polluting rights By setting limits to the pollution of water flows, the parties intend to reduce the uncertainty of water quality.

Variability management These mechanisms include early warning systems or the construction of dams in order to reduce the uncertainty of flow variability and/or alleviate its consequences.

Variable water or hydropower needs These mechanisms allow states to redistribute water flows or hydropower energy in case one of the parties has an excess or a lack of these resources. We categorized them under the rubrique of complete contracts, since they take into account eventualities which are missing in other treaties.

Local needs consideration These mechanisms set aside a guaranteed amount available to communities living in border areas. Since a given amount of water is guaranteed under all circumstances, we grouped them into the category of complete contracts.

Equity or sustainability These mechanisms are inherently vague in that it is not clear what an allocation based on the principles of equity and sustainability means concretely. They were thus grouped in the open ended category.

Right to construct These mechanisms provide a right to one or more parties to the agreement to construct particular types of infrastructure. Since they are oriented towards future opportunities of employing water resource in particular ways, they were placed in the complete contracts category.

Ban on particular constructions These mechanisms forbid the construction of particular infrastructure to one or more parties of a treaty and thus aim at reducing the uncertainty related to potentially undesirable water uses and/or basin developments by one or more of the parties.

Compensation These mechanisms provide a right to the party affected by undesirable developments under the control of other parties to the agreement to obtain

compensation. They were grouped in the complete contracts category, since they employ compensation as a universal mechanism of settlement between the parties.

Alternative scenarios use These mechanisms state that under different circumstances particular issues will be dealt with differently. Since they take changing circumstances into account, we grouped them in the category of complete contracts.

Model building for future prediction These mechanisms aim at reducing the uncertainty of future developments by creating models, which can help to predict future outcomes.

Treaty does not serve as precedence These clauses state that the signed treaty does not serve as a precedence for similar situations which might arise in the future, but which are not directly addressed in the treaty. Since this leaves open how such issues will be addressed, we grouped the mechanism in the open ended strategy.

Establishment of national programs to support agreement These mechanisms oblige the parties to adopt national programs in order to obtain treaty goals, thus making them susceptible to national legislation, where enforcement is considerably higher than in international law. Thus they are grouped with the complete contracts approach.

Technical or financial cooperation By guaranteeing to provide support under extreme conditions, such as for instance floods, or generally to cooperate in order to develop technological solutions to issues such as flow variability, the parties aim at reducing uncertainty.

Information exchange An increase in the availability of information helps to reduce uncertainty.

Agreement finance These mechanisms stipulate rules about the financing of agreements and were grouped in the category of complete contracts, because they clearly specify the financial requirements for meeting the agreement.

Consultations Since consultations do not specify any clear measures which will be adopted in order to alleviate uncertainty, but rather leave the possible solutions open to negotiations between the parties, they were considered an open-ended strategy.

Prior notification/consultation These mechanisms suggest that parties have to notify or consult each other before they realise new water needs, which have hitherto not been agreed upon. Since it is inherently unclear whether a party has a right to the new water uses or whether another party has a right to block any new water uses, we have located these mechanisms in the open-ended category.

Prior consent Prior consent before one of the parties is allowed to realise new water uses was grouped in the Complete contracts category, since they guarantee to the parties of an agreement that no country is allowed to realise water uses unless the other side agrees to them.

Amendment mechanism The inclusion of amendment mechanisms makes the treaty inherently open-ended.

Joint Commission Joint Commissions create an institutional framework for parties to discuss and manage the water resource, but they do not provide any clear rules or procedures to follow. They are thus an open ended strategy.

Stakeholder participation We have grouped stakeholder participation into the complete contracts category, because this mechanism allows stakeholders to participate in water management, thus presumably making the adopted policies less contested at the national level.

Legal means These mechanisms should guarantee an independent solution to any conflict between the parties and were thus grouped in the complete contracts category.

Diplomatic means We grouped these mechanisms in the open-ended category, since it is uncertain whether the parties will be able to reach an agreement to a dispute.

Monitoring Monitoring mechanisms provide a control that the parties respect their obligations from the agreement and thus reinforce the strength of the treaty. They were therefore grouped in the complete contracts category.

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