Proceedings from the GWP workshop:

Assessing water security with appropriate indicators

Global Water Partnership

www.gwp.org

Global Water Partnership (GWP), Global Secretariat, PO Box 24177, SE-104 51 Stockholm, Sweden
Phone: +46 8 1213 86 00, Fax: +46 8 1213 86 04, Email: gwp@gwp.org

About Global Water Partnership

The Global Water Partnership (GWP) vision is for a water secure world.

Our mission is to advance governance and management of water resources for sustainable and equitable development.

GWP is an international network that was created in 1996 to foster the implementation of integrated water resources management: the coordinated development and management of water, land, and related resources in order to maximise economic and social welfare without compromising the sustainability of ecosystems and the environment.

The Network is open to all organisations which recognise the principles of integrated water resources management endorsed by the Network. It includes states, government institutions (national, regional, and local), intergovernmental organisations, international and national non-governmental organisations, academic and research institutions, private sector companies, and service providers in the public sector.

The Network has 13 Regional Water Partnerships, 84 Country Water Partnerships, and 3,000 Partners located in 172 countries.

The papers in this publication were presented in a workshop organised by the GWP Technical Committee in November 2012. Opinions expressed do not imply endorsement by GWP.

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PO Box 24177, 104 51 Stockholm, SWEDEN
Visitor's address: Linnégatan 87D
Email: gwp@gwp.org
Websites: www.gwp.org, www.gwptoolbox.org

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Foreword

Water security is crucial to achieving sustainable and inclusive growth. A water secure world harnesses the productive power of water and minimises its destructive force. It is a world where every person has enough safe, affordable, clean water to lead a healthy and productive life. It is a world where communities are protected from floods, droughts, landslides, erosion, and water borne diseases. Water security promotes environmental protection as well as social justice, and addresses the consequences of poor water management. This is the Global Water Partnership's (GWP's) vision and, over the past 20 years, researchers and practitioners have sought to understand the economic, social, and environmental implications of increasing water security and what this means in practice. Strategic decision-making in the water sector has always been challenging. Climate change increases this complexity and forces us to question established approaches to dealing with future uncertainty.

So, can we quantify and measure water security? If so, what do we measure? Indeed, what can we measure? Should we be seeking absolute measures of security or indicators that enable us to compare and assess change and improvements? These are key questions to which policy-makers, who are responsible for making well-informed decisions and investments in national and regional development, seek answers.

In November 2012 the GWP Technical Committee organised a two-day consultation comprising 26 experts to address these issues. This publication provides a synthesis of this workshop together with the papers presented by the various experts to provide decision-makers with the most up-to-date information, ideas, and approaches being taken to quantify and measure water security.

The workshop addressed a number of questions:

- The scope of water security – how far to go beyond the immediate water sector?
- How to quantify water security?
- What are the relevant objectives, dimensions, and indicators?
- How to use quantified water security indicators?
- Can we compare the water security of different countries, basins, and cities?
- How do we track and evaluate progress over time for a country, basin, and city?
- At what scales can and should water security be assessed (regional, national, basin, and city) and how can these assessments be linked?
- What is/are good frameworks to determine useful indicators?
- Which indicators can be used for which purpose and at what scale?

The set of seven papers presented in this publication represent a wide range of approaches to the subject. They contribute to an increasingly urgent decision-making problem on water management and hopefully will inspire the current debate on water resource's management indicators in the context of the post-2015 Sustainable Development Goals process.

I owe my deepest thanks to the authors: Henrique Chavez (University of Brasilia), Jonathan Lautze and Herath Manthrithilake (IWMI), Roger Calow and Nathaniel Mason (ODI), Ian Makin (ADB), Gemma Dunn (University of British Columbia), Bárbara Willaarts (Water Observatory, Botin Foundation), and Jeroen Warner (Wageningen University).

I am grateful to Peter Rogers, GWP Senior Adviser. This publication has benefited enormously from his contribution to the synthesis summarising the papers as well as our discussions at the Expert Consultation.

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Dr Mohamed Ait Kadi
Chair, GWP Technical Committee

Synthesis

'We cannot plan what we do not measure!' is a remark that cropped up several times in the collection of papers presented at the workshop. Another remark from the UN Commission for Sustainable Development is – 'We measure what we value, and value what we measure'. There is a large difference between these two slogans, which are fundamental issues in measurement applications. The first is action oriented; the second is descriptive. Even though the first slogan allows for some qualitative measures, the second implies a much broader definition of values and their qualitative measures. There are some pitfalls, however. Does it imply that if we cannot measure some attribute of value then we do not value that attribute? The first slogan also has the drawback of forcing us to rely upon lagging indicators measured by past history – how can we reliably measure the future?

Part of the problem of creating and using indicators for water security, or any other type of resource scarcity, is that many indicators do not specify what the goals of the indicator are and mix a variety of input, output, and state of the resource variables to define the index. Contributors to Wikipedia[1] provide an excellent framework for characterising the possible use of key performance indicators (KPI) in business and industry. The focus is on the 'objective use' of the indicator; an indicator has to be directed towards some management control or assessment action.

To define any objective performance indicator a set of values, based on measurement, has to be selected. Sets of raw values are fed into systems, which are called indicators, for summarising the information. Indicators, identifiable and marked as possible candidates for KPIs, can be summarised into the following sub-categories:

- **Quantitative** indicators can be presented as numbers.
- **Qualitative** indicators cannot be presented as numbers.
- **Leading** indicators can predict the outcomes of a process.
- **Lagging** indicators present the successes or failures *post hoc*.
- **Input** indicators measure the amount of resources consumed while generating the outcome.
- **Process** indicators represent the efficiency or the productivity of the process.
- **Output** indicators reflect the outcomes or results of the process activities.
- **Practical** indicators interface with existing institutional processes.
- **Directional** indicators specify whether or not an organisation is improving.
- **Actionable** indicators are sufficiently under an organisation's control to effect change.
- **Financial** indicators are used in performance measurement and when looking at an operating index.

KPIs, in practical terms and for strategic development, are objectives to be targeted that will add the most value to the management institution. They are ways to periodically assess the performances of organisations, business units, and their divisions, departments, and employees. Accordingly, KPIs are most commonly defined in a way that is understandable, meaningful, and measurable. They are rarely defined in a way that their fulfilment would be hampered by factors seen as non-controllable by the organisations or individuals responsible. From this long list of categories of indicators, we in the 'water business' have several to choose from. The set of seven papers presented in this publication represent a wide range of approaches to the subject.

[1] http://en.wikipedia.org/wiki/Performance_indicator

Creating indices to measure various aspects of water resource use have been in vogue for over a century. Starting with the qualitative comparisons of stream biota of the River Seine at Paris in the 1880s and the development of biochemical oxygen demand measures (an operationally defined number) in the UK in the early 1900s, various aspects of water quality were developed, particularly emphasising dimensions of public health and sanitation. In the 1960s there was renewed concern with environmental rather than public health and this led to a huge outpouring of studies promoting indices of environmental quality. Recently, the emphasis has shifted towards water resources development and water security given the increasing demands placed upon water resources in the face of climate change.

Originally, single indicator measures were largely used to assess stream quality for human use. For example, the amount of dissolved oxygen in a given river was the measure of how much organic (and faecal) pollution was getting into the river. This was relatively easy to measure by simple laboratory techniques and became a basis for many studies on riverine water pollution management. With the industrial revolution, more and different types of chemicals were finding their way into the streams, and so the indices attempted to measure multiple impacts and combine them into single-valued indicators. Again, it was a relatively simple task to apply bench chemical analysis to determine the amounts of pollutants entering the stream. But how is it possible to aggregate the individual measures of the chemical effects to create single-valued functions? Since most of the 20th century's treatment options to control pollution were limited to oxidizing the oxygen-demanding organic waste streams, a simple univariate indicator – biochemical oxygen demand (BOD) – was adequate. Later, as toxics chemicals entered the waste stream much more complex multivariate indicators were needed to characterise stream quality.

Recent shifts towards water security have required economic and ecosystem concerns to be added to defining indices. Moreover, the largest consumer of water by far in most countries is irrigated agriculture. As the global population has rapidly increased, the spectre of diminishing water supplies available for food production, industry, and households has become a salient concern. This has led to a search for indicators of water resource security.

The following summarises the findings of the seven papers presented at the workshop.

1 Assessing water security with appropriate indicators: challenges and recommendations

Henrique Chaves, University of Brasilia

Based on the author's experiences in Brazil, this paper reviews the guidelines and generic requirements for developing a robust water security indicator/index for river basins and provides insights for its future application. A meaningful water security indicator needs to be integrated with other key resources and processes, and incorporate cause-effect relationships. These would include the 'pressure-state-response' approach – climate and people pressures; water quantity and quality; and state and societal responses, including the extent to which an integrated approach to water management is being planned and put into practice.

Sound principles and targets are needed to develop the indicator variables and scores, reflecting current knowledge and aspirational values. In order to have widespread use, information needs to be aggregated so that indicators are dimensionless or normalised (in a range from 0 to 1 or 0 to 10), to facilitate understanding and their contribution to the decision-making process. The indicator equation or model also needs to have a linear structure so that the risk of error propagation is minimal. The appropriate selection of spatial and temporal scales is also important, and, from a water management perspective, the river basin is the recommended spatial unit. A temporal interval of four to five years is recommended for best results. Once the water security indicators are developed they must go through a validation process, using a wide range of basins and scenarios, before their final application.

2 Water security: old concepts, new package, what value?

Jonathan Lautze and Herath Manthrithilake, International Water Management Institute

The authors recognise the advantages of translating water security into numerical terms to encourage clarity and establish a common understanding of a concept around which there currently exists substantial ambiguity. This can help to foster discussion and debate on scales and thresholds for evaluating the presence, absence, or degree of water security. It may also assess the extent to which water security is being achieved on-the-ground in different locations. The authors focus their attention on 46 countries in the Asia-Pacific region where there are diverse water resource and development conditions and, importantly, where data are readily available for analysis. They offer a set of five indicators which they combine into one water security index:

- **Basic needs** – proportion of the population with sustainable access to an improved water source (data source WHO)
- **Food production** – the extent to which water is available and harnessed for agricultural production (data source: FAO AQUASTAT). Note industry and energy production were excluded because agriculture dominates water use in the region
- **Environmental flows** – proportion of renewable water resources available in excess of environmental water requirements (data source: Smakhtin et al.)
- **Risk management** – the extent to which countries are buffered from the effects of rainfall variability through large dam storage (data source: International Commission on Large Dams (ICOLD), FAO AQUATSTAT)
- **Independence** – the extent to which countries are safe and secure from external changes or shocks (date source: Water Resources Institute (WRI)).

The indicators were chosen for their simplicity. The analysis produced few surprises when the results were compared to local knowledge. But the authors see a primary benefit in measuring relative rather than absolute water security – comparing one country to another and one time period with another.

Agriculture dominates water use in the Asia-Pacific region, but focusing on water productivity, as is often the case, is only one means of improving production. The indicator thus addresses water availability and how it is harnessed – increasing storage for example, may be more urgent in areas of economic water scarcity. Groundwater storage is largely ignored, mainly because of the lack of data. The authors also recognise that working to improve one indicator is likely to adversely affect the others and combining them into just one number for overall water security begs the question – does this 'hide' deficiencies in one or more sectors? Myanmar and Bhutan, for example, scored high overall water security values in the analysis because the abundance of internally generated water resources are sufficient to buoy up their scores. These results are at odds with the perception that water security is tied to economic development. There is also a question mark over one indicator describing a national picture when water is in fact managed at a basin level and particularly when basins cross national borders and must take account of transboundary cooperation agreements. The authors suggest that if the first question asked when a single water security index is presented is, "What are the constituents that make up this index?" it is questionable whether such an index has any real value.

Water security clearly requires an integrated approach while recognising and accepting that trade-offs may be needed between the different water-using sectors. Do the indicators add value? Yes, if they highlight critical areas for improvement. They can be a spur for development, but they can also engender confusion if not well defined, and inflate expectations.

3 Which way now? Supporting decisions for climate compatible development in the water sector

Roger Calow, Head of Programme, Water Policy and Nathaniel Mason, Research Officer, ODI, UK

This paper reminds us of how challenging and complex strategic decision-making is in the water sector, how climate change adds to this complexity, and how we are being forced to think again about finding new ways of dealing with future uncertainty. The authors argue that complex problems can only be resolved if both research and policy communities work together. They describe 'boundary work' as a means of enabling people from very different backgrounds and experience to explore the key issues collaboratively and they cite examples of how this is being done in both climate compatible development and water resources planning.

'Boundary work' provides a starting point to frame and approach multi-dimensional and complex problems. The first requirement is a unifying concept and terminology that can be used by different groups with a degree of common meaning. An example is 'climate compatible development', which is now widely accepted as the concept for communicating climate change development, adaptation, and mitigation across sector boundaries. In the water sector, 'water security' is becoming an accepted boundary concept; it has intuitive appeal and can inspire synergy among the many and competitive users of water. 'Integrated water resources management' (IWRM) has experienced a similar broad appeal. The trick, the authors say, is to find sufficient commonality of understanding, while maintaining respect for the additional value which different perspectives bring.

A second requirement is devices and methods that help to make sense of the water world and enable rather than prevent evidence-based decision-making. This is where indicators come into play, together with simulation models, and decision support frameworks. Indicators tend to be heuristic, and political and water specialists need to focus on those indicators which tell the most compelling story to other sectors if they are to encourage water-smart investments. 'We measure what we value, and value what we measure' (UN, 2001).

Indicators are useful for consolidating and processing data, but they should be fit-for-purpose, err on the side of simplicity, be tailored to specific needs rather than be multi-dimensional and conceal underlying trends, and accompanied by a clear expression of the uncertainty inherent in any metric. Some indicators, such as the mortality risk index (MRI), are well established, but other water-related risks, such as drought, are strongly shaped by socio-economic and institutional factors and are in their infancy. The authors suggest five pillars of water security where indicators are needed – water availability and access, risk and variability, equity and livelihoods, ecosystems and biodiversity, and institutions and actors. They emphasise that good indicators and other sophisticated tools depend on reliable and timely data, without which they have little value – something which is often overlooked in the rush to develop ever better and more sophisticated tools. Acquiring data is time consuming, expensive, and there are few shortcuts.

Finally, investment in process is absolutely critical – setting the rules of engagement for the concepts and objectives so that the pieces of the puzzle can come together. This is inherently a political process.

4 Indicators for assessing national water security – Asia Water Development Outlook 2013

Ian Makin et al., Asian Development Bank

This paper focuses on national and regional measures of water security, rather than individual basins. Its foundation is the substantial and comprehensive assessment of water security and the development of key indicators undertaken by the Asian Development Bank – the Asian Water Development Outlook (AWDO) 2013. This study highlights the importance of water management issues in 49 countries across the Asia and Pacific region and the threat from many sources – population growth, urbanisation, increasing water pollution, over-abstraction of groundwater, water-related disasters, and climate change. Its main objective was to establish a means of measuring water security based on the premise that ‘we cannot manage what we do not measure’. AWDO 2013 provides a robust, pragmatic, and readily understood framework for assessing water security. It offers five key indicators which represent the inherent tensions among the different water uses as water resources come under increasing stress. These, when aggregated, provide an indicator of national and regional water security. The indicators (referred to as dimensions) are seen as the means of measuring the outcomes of integrated water resources management. They provide a baseline for analysing trends and the effects of policies and reforms that can be monitored and reported to stakeholders and offer a new way for leaders to look at the strengths and weaknesses of water resources management and service delivery. They also indicate the direction and priority for increasing investment, improving governance, and expanding capacity in the water sector.

The paper adds detail to AWDO 2013 with a description of the data requirements, data sources, and computational methods used. The five indicators describe:

- **Household water security** – based on WHO/UNICEF data on access to water and sanitation
- **Economic water security** – a composite indicator bringing together agriculture, industry, and energy
- **Urban water security** – based on the concept of ‘water sensitive cities’ (cities in transition to a more sustainable water future) and brings together water supply, wastewater treatment, and urban flooding
- **Environmental water security** – addresses river basin health
- **Resilience to water-related disasters** – addresses risk, vulnerability, and the capacity to cope.

Although the indicators were developed with Asia’s water challenges in mind, the authors argue that they are generic in nature and can be applied worldwide. They demonstrate this by calculating the key indicators and a national water security index for 13 countries selected from Africa, the Americas, and Europe as well as 7 countries in Asia.

The makeup of each indicator is complex and boiling down the many factors into five representative key dimensions requires skill and judgement, so the authors discuss the strengths and weaknesses in their approach. The household security indicator for example, is strengthened by regularly updated national statistics on access to water supply and sanitation which has strong support from WHO/UNICEF. But reliable and regular data on quality and sustainability of the services are lacking and relies on disability-adjusted life year (DALY) health data as a proxy.

5 Water security indicators: the Canadian experience

Gemma Dunn et al., University of British Columbia

This paper draws upon a major research project to develop a water security framework as a tool for improving governance for watersheds in Canada. This is in contrast to others who seek to develop national or regional indicators. Indeed the authors describe the challenge of developing and applying indicators at the watershed level that were originally designed for national or regional application and question their relevance and sensitivity for use at a community level and for including socio-economic considerations.

The authors are concerned that environmental indicators are having limited influence on policy decisions and the slow pace at which indicators are released, combined with accessibility challenges, continues to inhibit their influence on policy cycles. This poor link between the development of indicators and decision-making is further exacerbated by two underlying factors: 1) the limited or absent interaction between indicator designers and decision-makers when indicators are developed; and 2) the limited availability and utility of indicators to decision-makers once the indicators have been developed. The utility of indicators is greatly enhanced when the 'end-users' are engaged throughout the development process. In addition to addressing the needs of end-users, evaluation and feedback are also critical stages that ensure an indicator continues to achieve its purpose. The indicator development cycle is – design, implement, evaluate!

The authors define watershed water security as: 'sustainable access on a watershed basis to adequate quantities of water of acceptable quality to ensure human and ecosystem health'. This encompasses a broad range of potential impacts, rather than focusing on one narrow set of water-related concerns.

Key considerations are identified for measuring and assessing water security, relevant to selecting indicators and/or developing user-friendly application/implementation assessment frameworks. These include: the need for stakeholder participation, scalar issues (specifically local scale assessment), data considerations, multivariate analyses, governance tools, and incorporating risk. Moreover, the research findings highlight the importance of a broad and integrative approach to water quality and quantity, which incorporates human health and aquatic ecosystem health. They specifically suggest that the assessment of the current water security status needs to be combined with the assessment of risks, and the results incorporated into an adaptive governance framework, which formalises a flexible 'learning-by-doing' approach that can respond to changing conditions.

6 Water framework directive experiences in Spain

Bárbara Willaarts et al., Water Observatory, Botin Foundation

The paper offers insights into Spain's experiences in meeting the requirements of Europe's Water Framework Directive (WFD), which is essentially a set of key environmental indicators describing the health of Europe's aquatic ecosystems. WFD enables nations to identify areas of concern and take appropriate measures to improve them. The Directive provides a common policy framework for European Union member states to tackle the problems of water quality deterioration, loss of aquatic ecosystem functionality, and increasing water scarcity. It recognises that improving aquatic ecosystems will be essential if EU nations are to guarantee access to sufficient water resources in the future for people, for farming and industry, and for the environment.

The paper's findings relate to experiences in Spain and the challenges that country faces in meeting the requirements of the WFD. Before WFD, Spain did not have a monitoring network in place to track the ecological status of surface water bodies. But since then, it has made significant efforts to gather the data and information to comply with the requirements and to meet the timetable set by the EU, though important gaps still exist. The information available suggests that Spain's surface water bodies have poor ecological status, probably driven by multiple factors depending on geographical context. But River Basin Management Plans only provide overall ecological status indicators and so it is not easy to establish a clear causal relationship between specific pressures and the resulting impacts. This may hinder the steps to identify and deal with the causes. From a water quality perspective, the lack of information prevents a complete diagnosis of the real status of surface water bodies. The great number of priority substances added to the list also does not make this task easy. Other countries in Europe face similar challenges.

7 Fairness and flooding: assessing the distributional impact of flood intervention

Jeroen Warner, Wageningen University

Flooding is still an under-exposed aspect of water security. It can be both a blessing – it brings useful floodwater for growing food and producing fish – and a curse – too much puts people and assets in danger, often in the same place but at different times. Floods bring tensions at system and personal levels, and threats to security are not always distributed fairly and uniformly in a catchment when controlling flooding in one area produces flooding elsewhere in the system – who wins and who loses? So is flood protection a responsibility of government or is it left to individuals bearing in mind their limited ability to cope with the causes of flooding, which may be well beyond their immediate control? Should farm land, which may be vital for food security and rural livelihoods, be flooded in order to protect urban dwellers? Should we enable more people to provide their perception of flood security? People do not always see themselves as vulnerable and even though they are fully aware of the risks, they do not always see floods as 'disasters' – contrast people in the Netherlands, who see flooding as a disaster, with people in developing countries, where flooding is a 'part of daily life' and where people have adjusted their lives to 'accommodate' it.

This paper offers many such insights into the complexity of dealing with flooding security and indeed measuring it. The author focuses on the ethical concerns, such as equity, and offers the 'Gini coefficient' which measures inequality among a set of values – zero measures perfect equality and one measures maximum inequality. He shows that this was useful in measuring how well countries or regions do comparatively in spreading water availability and access – the 'water Gini'. So the question is, Is there a 'flood Gini' which would measure the redistribution of actual and perceived security as a result of water development policies, interventions, and projects to control flooding among the key stakeholder groups?

Recommendations

Table 1 summarises the attempts made by the authors to provide a wide range of possible indicator types and areas of concern to water security. It is apparent that some papers (1 and 3 above) are more quantitative and cover wider areas of concern than others. Some papers emphasise the conceptual framework and the construction of overall indices (1, 2, 3, 4, and 6). Surprisingly only one paper (2) strongly urged stakeholder participation in the process. Even though resilience, risk management, and climate change were included in four of the papers, none focused on the problems of multi-collinearity among the various components of the indices. Some papers noted the strong correlation between economic variables like GDP and the water security indexes. One surprise was that only two papers urged that an integrated approach to water resources management be a major component of any water security index.

All the numerical indices suggested, or included, some way of adding the separate components into overall indicators using some sort of weighting scheme. This is one of the major weak points of any index construction. One highly regarded approach to this problem is the use of a 'dashboard' indicator. This is analogous to the dashboard of an automobile, where the driver is presented with as many as seven highly correlated indicators, such as speed, gasoline level, engine revolutions, and engine oil temperature and pressure. The driver has to monitor these indicators of the security of his automobile while at the same time changing gear, steering, and keeping an eye on outside threats of collision. In learning to drive, the driver has learned to assess the relative importance of each of these variables in keeping the automobile functioning safely.

How can the dashboard analogy help in devising indicators of water security? First, keep the separately chosen components as simple as possible (one variable if possible). Second, avoid redundancy by eliminating highly correlated variables. Third, keep the number of 'gauges' on the dashboard to a minimum – seven is far too many.

Apart from the issue of the weighting of the components, this set of papers does raise enough issues about the relevance, use, and above all, the construction of what may be helpful tools for policy-makers in dealing with the process of integrating water resources management.

Table 1 A summary of water security indicators and areas of concern

Indicators	Chaves	Lautze	Mason	Makin	Dunn	Willaarts	Warner
Paper number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Quantitative indicators	X	X		X		X	X
Qualitative indicators	X	X		X		X	X
Leading indicators							
Lagging indicators	X	X		X		X	
Input indicators		X					
Process indicators		X	X				X
Output indicators				X			
Practical indicators		X		X		X	
Directional indicators							
Actionable indicators				X			
Financial indicators				X			X
Areas of concern							
Domestic		X		X		X	
Industry				X			
Agriculture		X		X			
Urban uses		X		X			X
Water quality				X			
Water quantity		X		X			X
Energy			X				
Ecosystem		X				X	
Climate			X				X
Resilience		X		X			
Risk management		X	X	X			
IWRM					X	X	
National	X				X	X	
Regional							
Stakeholder participation					X		
Conceptual framework	X	X	X	X	X		
Overall index		X		X			

1. Assessing water security with appropriate indicators: challenges and recommendations

Author: Henrique M.L. Chaves, EFL-School of Technology, University of Brasilia-UnB, Brazil.

Email: hchaves@unb.br

Abstract

This paper reviews the guidelines and requirements for developing robust water security indicators/indices and provides insights for their future application. A meaningful water security indicator needs to be integrated with other key resources and processes and incorporate cause-effect relationships, such as the 'pressure-state-response' approach. Sound principles and targets are needed to develop the indicator variables and scores, reflecting current knowledge, and aspirational values. In order to have widespread use, information needs to be aggregated so that the indicators are dimensionless or normalised. This will help them and their contributions to decision-making processes to be understood. The indicator equation or model also needs to have a linear structure so that the risk of error propagation is minimal. The appropriate selection of spatial and temporal scales is also important, and, from a water-management perspective, the river basin is the recommended spatial unit. A temporal interval of four to five years is recommended for best results. Once the water security indicators are developed they must go through a validation process, using a wide range of basins and scenarios, before their final application.

1.1 Introduction

According to Gilbert (2010), about 80 percent of the world's population lives in areas with threats to water security. Water security is defined as 'the reliable availability of an acceptable quantity and quality of water for health, livelihoods, and production, coupled with an acceptable level of water-related risks' (Grey and Sadoff, 2007).

UN Water (UN Water, 2013) aims to provide good quality water for all and has searched for coherent and reliable information on key water-related trends and management issues, based on a sound and reliable set of key indicators with proper monitoring and reporting systems.

A great challenge, however, is that data on water security and other water-related issues are usually lacking, unreliable, incomplete, or inconsistent. Additionally, the mere collection of data is not enough. It must be analysed and converted into information and knowledge, then shared widely within and between countries and stakeholders to focus attention on water problems at all scales (WWAP, 2013a).

An example is the WWAP list of water indicators (WWAP, 2013a). It includes 51 different variables, involving 11 topics and 6 categories, which could be applicable to data-rich basins and countries, but they are of little use in the majority of the world's data-scarce regions and basins, particularly those where water security is an issue.

Considering these challenges and limitations, this paper reviews the requirements and guidelines for developing a robust water security indicator/index and provides insights for their future application.

1.2 Indicators and indices

Indicators (from the Latin *indicare* – to show, point out) are tools that provide information about something (Mitchell, 1996). They communicate or inform about the progress of a process toward a goal, such as sustainable development, but also indicate a trend about a phenomenon and evolution in management performance (Hammond et al., 1995).

Depending on the level of aggregation, primary data can be consolidated in indicators and indices (Figure 1). The large amount of original data sits at the bottom of the pyramid, providing a limited basis for the decision-making process. As we move up in the pyramid, information is condensed into indicators and indices, which are more useful for managing and controlling.

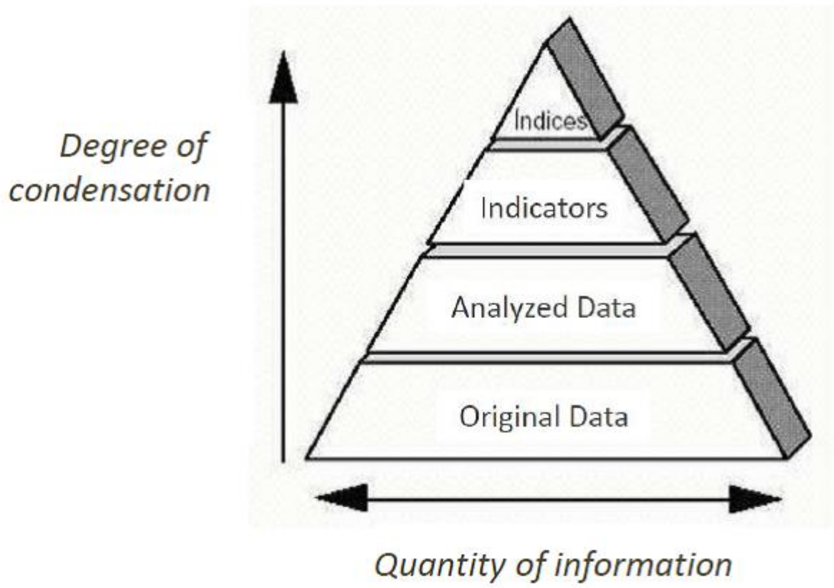

Figure 1 Consolidation of original data into indicators and indices
Adapted from Shields et al., 2002

Contrary to the original data, indicators and indices are usually single-valued, dimensionless numbers, which aggregate different sources of information and reflect the overall score of a given process or phenomenon, in a given period. Examples are the Human Development Index (HDI) (UNDP, 2010) and the Watershed Sustainability Index (WSI) (Chaves and Alipaz, 2007), the range of which lies between 0 and 1.

Care is needed when selecting the variables and the type of aggregation equation leading to the indicators and indices to avoid pitfalls, such as multi-co-linearity between variables (Netter et al., 1985), and correlation with other existing indicators. An example of the latter is the (undesired) high correlation (r^2 = 0.92) existing between the HDI and GDP per capita, which could render the indicator innocuous and/or redundant.

1.3 Desired characteristics of indicators and indices

Desired indicators and indices are those that aggregate or simplify relevant information, allowing for the identification of important trends and phenomena, and communicating them in a neat way to users and decision-makers (Gallopín, 1997). Additionally, the original data need to be available, comprehensible, credible, relevant, and universal (HTCF, 2003).

The number of variables used in computing sound indicators has to be sufficiently large to span the complexity of the problem/process being assessed, but small enough to be easily obtained and managed by the users and decision-makers. The current version of HDI, used worldwide, has only three sub-indicators and four variables (UNDP, 2010).

Indices with more than 20 sub-indicators and variables, such as the Environmental Sustainability Index (ESI) (Esty et al., 2005), are applicable only to data-rich areas (Chaves & Alipaz, 2007). If a universal water security indicator is sought, a reduced number of variables must be used.

If equations are used to aggregate variables in a single indicator, their structure needs to be mathematically robust, such that the uncertainties inherent in the original data do not propagate severely to the output (Chaves & Nearing, 1991). Structures involving multiplication, exponential, and power functions tend to exacerbate input uncertainty. Additive-type structures, on the other hand, tend to cancel out or reduce the errors in the output (Harr, 1987).

1.4 Integration with other resources and processes

The development of a sound and robust water security indicator/index will only be accomplished if the water resource is adequately integrated with other key resources, such as land (Falkenmark and Lundqvist, 1998), natural vegetation (Chaves and Alipaz, 2007), population (Sullivan, 2002), and climate (WWAP, 2013b). This is because of the strong interconnectivity of water with these resources and processes (Lang and Armour, 1980).

Although complex, these interconnections can be incorporated with sub-indicators, encompassing the different resources/processes in such a way that they are treated more or less independently (Wischmeier, 1976).

In the case of land and natural vegetation, the better they are conserved, the better preserved is the water cycle (Hunsaker and Levine, 1995), thus increasing water security. The same occurs with societal pressures and responses, whose actions could either lead to water conservation, through sound management (Falkenmark and Lundqvist, 1998), or to societal collapse, when adequate water management is disregarded (Diamond, 2005).

Climate and climate variability/change is another key issue in any attempt to establish a sound water security indicator, since the hydrological cycle is highly climate-dependent (Held and Soden, 2006).

1.5 'Pressure-state-response' approach

In order to adequately incorporate the dynamics of the different environmental, climatic, and societal pressures and feedbacks affecting water security, an appropriate water security indicator should include some form of the *Pressure-State-Response* (P-S-R) approach (OECD, 1993) (Figure 2).

Appropriate sub-indicators/variables could incorporate the P-S-R process in such a way that acquisition, process, and presentation of information are at the same time simple and transparent, showing existing cause-effect relationships. This approach could be appropriate for climate and climate variability/changes.

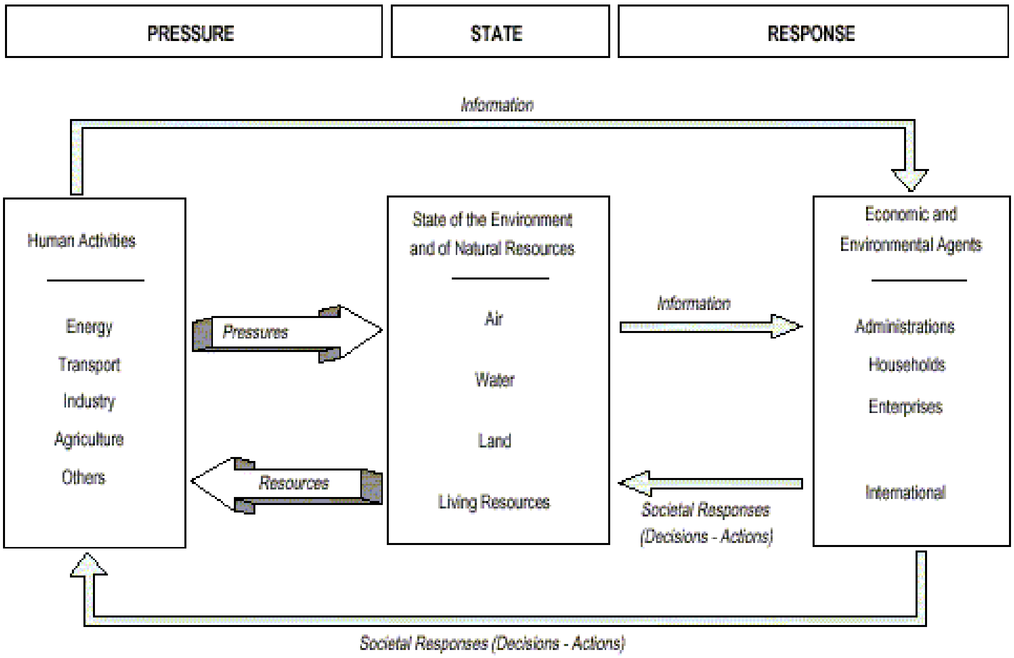

Figure 2 OECD's pressure-state-response approach (OECD, 1993)

1.6 Principles and targets

In the absence of a full understanding of the processes leading to water security, some principles can guide the development of a robust indicator. These are i) the precautionary principle (Foster et al., 2000) and ii) adaptive management (Walters, 1986).

Additionally, the targets for water security, which would guide the establishment of ranges and scores of indicator variables, need to be aspirational, since there are no real examples of a fully water secure basin. In the absence of more concrete targets, the water-related Millennium Development Goals (WWAP, 2013b) would be a starting point.

1.7 Spatial and temporal scales

Another important aspect in the development of robust indicators and indices is the selection of spatial and temporal scales. In the case of water security indicators, hydrologic science has long identified that the river basin is the ideal *locus* for research, planning, and management, allowing for a thorough application of hydrologic systems' concepts, including mass and energy balances (Chow et al., 1988).

Therefore, if meaningful and robust water security indicators and indices are sought, the river basin should be the spatial unit. The river basin size could be selected based on the indicator objectives. It is known, however, that it is easier to identify cause-effect relationships at the sub-basin level (area < 2,500 km^2) (Schueler, 1995). If, however, larger basins are to be analysed, they could be subdivided into sub-basins of suitable size.

The temporal scale for indicators and indices should reflect the intended objectives. However, periods between a month and a year are too short to detect significant changes, and periods longer than 10 years tend to be too long to observe important ongoing changes. Thus, a temporal scale of four to five years is usually suitable for most indices.

1.8 Presenting the results

Another important issue for robust indicators, including water security ones, is the presentation of the results. Even if single-valued, dimensionless numbers are used to express the indicator outcome, providing additional information about the steps leading to its computation is helpful. In the case of HDI, its three sub-indicators are often analysed along with the overall HDI, in order to identify existing bottlenecks which can facilitate future intervention strategies.

In more complex indicators and indices, comprising more variables, a spreadsheet is often useful to identify bottlenecks (low scores). Those water security index variables whose scores lie below the overall index output (mean) are considered critical for overall basin sustainability, and should be prioritised for future interventions (Chaves and Alipaz, 2007).

The advantage of the periodic and continuous calculation of indicators and indices is that decision-makers are able to identify their improvement or deterioration over the years, plotting a time series of the resulting scores.

1.9 Potential variables for water security indicators

The selection of potential variables and/or sub-indicators to develop a water security indicator should meet the criteria of relevance, availability, credibility, universality, and statistical independence. Additionally, they should consider the water quantity and quality aspects (*state*) of the basin, the main driving processes (climate and human *pressures*) affecting them, and existing (or lacking) societal *responses*.

Water quantity (availability) should account for both surface and groundwater sources and equity of distribution among water users (including the environment). Per capita figures of availability are often preferred over absolute volumes, since they are more useful and comparable (Falkenmark and Widstrand, 1992).

Water quality should be relevant and reflect universal water pollution/contamination measures, such as the 5-day biochemical oxygen demand of wastewater (BOD5), and chemical concentrations, such as nitrate. The basin water footprint, particularly related to *grey water*, is another useful sub-indicator for water quality, which is universal and easily quantifiable (Hoekstra et al., 2011).

The ongoing *pressures* of climatic variability/change can be incorporated using indicators such as the risk of droughts/floods. Human-related pressures include measures of over-population and urban sprawl over floodplains. The ratio of natural vegetation to human developed areas, easily obtained from satellite images, could be an indicator of watershed integrity and is strongly related to water quality and water quantity (Chaves et al., 2012).

Finally, the extent to which integrated water resources management (IWRM) is being planned and put into practice (*response*) could be considered. This would include measures of flood control and storage structures, water-use licensing and charging, demand management, and water re-use, all of which reflect the effectiveness of an integrated approach.

Ideally, a water security indicator will have no more than 12 to 15 variables and sub-indicators. Finally, it is important that when aggregating information, equal weight is given to all variables, since their relative importance to water security is generally unknown. This follows from the principle of maximum entropy (Jaynes, 1957). Additionally, the use of equal weights in hydrological, environmental, and socio-economic variables could reduce the frequent conflicts between indicator users with different backgrounds. Based on the arguments raised in this paper we propose a possible form for a robust water security indicator:

WS = *f*[W(p,s,r); R(p,s,r); M(p,s,r)] [1]

where: WS = water security indicator (0-1), *f* is a linear, additive function; W is an integrated water quantity and quality sub-indicator score (dimensionless); R is an integrated key resource sub-indicator score (land, vegetation, population) (dimensionless); M is the basin management sub-indicator score (dimensionless); p, s, r are pressure-state-response variables (different units).

A minimum of nine variables would be required, which is more than enough to span the water security spectrum. The aggregation of the P-S-R variables, with different units, in the dimensionless W-R-M sub-indicator scores could be made through a simple look-up table.

The selection of P-S-R variable ranges and sub-indicator scores could be made by using different case studies (river basins and scenarios), with a wide range of water security levels, as well as previously established targets. That would guarantee that the selected ranges and scores are meaningful and universal.

The highest sub-indicator scores would be set so that they represent aspirational values of the p-s-r variables. If these values are not known then the precautionary principle should be used, providing for higher standards of the W-R-M sub-indicators.

In order to facilitate the computation of the WS indicator, a spreadsheet could be used, where the rows would be the W-R-M sub-indicators, and the columns the P-S-R variables.

Given that the sub-indicators in equation [1] resemble the widely known IWRM acronym, the question to ask is, “Where is the missing ‘I’”? The answer lies in the *integration* of information of the W-R-M sub-indicators, provided by the function *f*.

1.10 Validation of the water security indicator

Once the water security indicator is developed it will need to go through sensitivity analysis and validation stages (Bockstaller and Girardin, 2003), using data from well-known pilot basins. Multidisciplinary specialists would then evaluate the indicator performance under different climate, economic, water use, and management scenarios, to assess the sensitivity/range and meaningfulness of the indicator scores (McCuen and Snyder, 1986).

1.11 Conclusions

This paper has reviewed the challenges and requirements leading to the development of a robust water security indicator – it must be simple and universal and its variables must be relevant, available, credible, and statistically independent.

The indicator needs to be integrated with other key resources and processes, and incorporate cause-effect relationships, such as the P-S-R approach. Sound principles and targets are needed to develop the indicator variables and scores, reflecting the current knowledge and aspirational values.

In order to have widespread use, information needs to be aggregated so that the indicators are dimensionless or normalised (in a range from 0 to 1 or 0 to 10), in order to facilitate understanding and their contribution to the decision-making process. The indicator equation or model also needs to have a linear structure so that the risk of error propagation is minimal.

The appropriate selection of spatial and temporal scales is also important and from a water-management perspective the river basin is recommended as the spatial unit. A temporal interval of four to five years is recommended for best results.

Once the water security indicators are developed they must go through sensitivity analysis and validation processes, using a wide range of basins and scenarios, before their final application.

References

Bockstaller, C. and Girardin, P. (2003) How to validate environmental indicators. *Agricultural Systems* **76**: 639–653.

Chaves, H.M.L. and Alipaz, S. (2007) An integrated indicator based on basin hydrology, environment, life and policy: the watershed sustainability index. *Water Resources Management* **21**(5): 883–895.

Chaves, H.M.L. and Nearing, M.A. (1991) Uncertainty analysis of the WEPP soil erosion model. *Transactions of the American Society of Agricultural Engineers* **34**:2437–2444.

Chaves, H.M.L., Camelo, A.P., and Mendes, R.M. (2012) Groundwater discharge as affected by land-use change in small catchments: a hydrologic and economic case study in central Brazil. pp. 49–62. In: Climate *Change Effects on Groundwater Resources* (Treide, I.H. Ed.). CRC Press, New York, NY, USA.

Chow, V.T., Maidment, D.R., and Mays, L.W. (1988) *Applied Hydrology*. McGraw-Hill, New York, NY, USA.

Diamond, J. (2005) *Collapse – How Societies Choose to Fail or to Succeed*. Penguin, New York, NY, USA.

Esty, D.C., Levy, A.M., Srebotnjak, T., and Sherbinin, A. (2005) *Environmental Sustainability Index: Benchmarking National Environmental Stewardship*. Yale Center for Environmental Law and Policy, Yale University, New Haven, CT, USA.

Falkenmark, M. and Widstrand, C. (1992) *Population and Water Resources: a Delicate Balance*. Population Bulletin, Population Reference Bureau, Washington, DC, USA.

Falkenmark, M. and Lundqvist, J. (1998) Towards water security: political determination and human adaptation crucial. *Natural Resources Forum* **21**(1): 37–51.

Foster, K.R., Vecchia, P., and Repacholi, M.H. (2000) Science and the precautionary principle. *Science* **288**(5468): 979–981.

Gallopín, G.C. (1997) Indicators and their use: information for decision-making. Part 1: Introduction. pp. 13–27. In: Sustainability Indicators: a Report on the Project on Indicators of Sustainable Development (Moldan, B., Billharz, S., and Maltravers, R. Eds). J. Wiley, Chichester, UK.

Gilbert, N. (2010) Balancing water supply and wildlife. *Nature* (published online). http://www.nature.com/news/2010/100929/full/news.2010.505.html

Habitat Conservation Trust Fund (HTCF). (2003) Mission *Creek Sustainable Watershed Indicators Workbook*. HTCF, Victoria, BC, Canada.

Hammond, A., Adriaanse, A., Rodenburg, E., Bryant, D., and Woodward, R. (1995) *Environmental Indicators: a Systematic Approach to Measuring and Reporting on Environmental Policy Performance in the Context of Sustainable Development*. World Resources Institute, Washington, DC, USA.

Harr, M.E. (1987) *Reliability-based Design in Civil Engineering*. McGraw-Hill, New York, NY, USA.

Held, I.M. and Soden, B.J. (2006) Robust responses of the hydrological cycle to global warming. *Journal of Climate* **19**:5686–5695.

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M., and Mekonnen, M.M. (2011) *The Water Footprint Assessment Manual: Setting the Global Standard*. Earthscan, London, UK.

Hunsaker, C.T. and Levine, D.A. (1995) Hierarchical approaches to the study of water quality in rivers. *BioScience* **45**:193–203.

Jaynes, E.T. (1957) Information theory and statistical mechanics, II. Physical Review, **108**(2): 171–190.

Lang, R. and Armour, A. (1980) *Environmental Planning Resource Book*. Environment Canada, Ottawa, ONT, Canada.

McCuen, R.H. and Snyder, W.H. (1986). *Hydrologic Modeling: Statistical Methods and Applications*. Prentice-Hall, New York, NY, USA.

Mitchell, G. (1996) Problems and fundamentals of sustainable development indicators. *Sustainable Development* **4**(1):1–11.

Netter, J., Wasserman, W., and Kutner, M.H. (1985) Applied Linear Statistical Models: Regression, Analysis of Variance, and Experimental Designs. R. Irwin, Homewood, CA, USA.

Organisation for Economic Development and Co-operation (OECD). (1993) OECD core set of indicators for environmental performance reviews. Environment Monographs No. 83. OECD, Paris, France.

Organisation for Economic Development and Co-operation (OECD). (2003) Environmental indicators: development, measurement and use. Reference paper. OECD, Paris, France.

Schueler, T. (1995) *Site Planning for Urban Stream Protection*. Metropolitan Washington Council of Governments. Washington, DC, USA.

Shields, D., Solar, S., and Martin, W. (2002) The role of values and objectives in communicating indicators of sustainability. *Ecological Indicator* **2**(1-2): 149–160.

Sullivan, C. (2002) Calculating a water poverty index. *World Development* **30**(7): 1195–1210.

United Nations Development Programme (UNDP). (2010) Human Development Report 20th Anniversary Edition. Available at: http://hdr.undp.org/en/reports/global/hdr2010/chapters/

United Nations Water (UN Water). (2013) Available at: http://www.unwater.org/TFindicators.html, downloaded on February 10, 2014.

Walters, C. (1986) *Adaptive Management of Renewable Resources*. Macmillan, New York, NY, USA.

Wischmeier, W. (1976) Use and misuse of the universal soil loss equation. *Journal of Soil and Water Conservation* **31**(1):5–9.

World Water Assessment Programme (WWAP). (2013a) Indicators. Available at: http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/indicators/

World Water Assessment Programme (WWAP). (2013b). Water for the Millennium Development Goals. Available at: http://www.unesco.org/new/fileadmin/MULTIMEDIA/HQ/SC/pdf/WWAP_Water_and_MDGs.pdf

2. Water security: old concepts, new package, what value?[1]

Authors: Jonathan Lautze and Herath Manthrithilake. International Water Management Institute, Battaramulla, Sri Lanka.

Email: j.lautze@cgiar.org and h.manthrithilake@cgiar.org

Abstract

The term water security has infiltrated prominent discourse in the international water and development communities, but achieving it is often viewed as a new water sector target. Despite the elevated status that the concept has increasingly acquired, the understanding of the term is murky and quantifying it is rare. To promote a more tangible understanding of the concept, the authors have developed an index for evaluating water security at the country level. The index comprises indicators in the five components considered to be critical to the concept: (i) basic needs, (ii) agricultural production, (iii) the environment, (iv) risk management, and (v) independence. Achieving water security in these components can be considered necessary, but insufficient criteria, for measuring the achievement of security in related areas, such as health, livelihoods, and industry. After populating the indicators with data from Asia-Pacific countries, the results are interpreted and the viability of the method is discussed. This effort comprises an important first step in quantifying and assessing water security across countries, which should spur a more concrete understanding of the term and discussion of its added value.

2.1 Introduction

Water security has assumed an increasingly prominent position in the international water and development communities in recent years. Staff at the World Bank have explained that water security is critical for growth and development (Grey and Connors, 2009; Grey and Sadoff, 2007). The importance of water security for the sustainable development of countries like China has been recognised nationally (Chen, 2004; Cheng et al., 2004; Liu et al., 2007). Water security has been at the heart of high profile negotiations on a Cooperative Framework Agreement in the Nile Basin (WaterLink, 2010). Finally, academia (Briscoe, 2009, Cook and Bakker, 2012; Sinha, 2009; Tarlok and Wouters, 2009; University of East Anglia, 2009; Vörösmarty et al., 2010; Zeitoun, 2011;) and other development actors (Asia Society, 2009; Asian Development Bank, 2007; Biswas and Seetharam, 2008; FAO, 2000; Swaminathan, 2001) have also placed prominent emphasis on the concept[2].

Despite the elevated status that the term has increasingly acquired in policy documents and development discourse, the concept of water security remains largely un-quantified. While there may be advantages to leaving the concept as a qualitative theoretical ideal, there are, simultaneously, several benefits to translating water security into numerical terms. First, it can encourage clarity and common understanding of a concept around which there currently exists substantial ambiguity. Second, it can help to foster discussion and debate on scales and thresholds for evaluating the presence, absence or degree of water security. Third, it can help to assess the extent to which the concept is really being achieved on the ground in different locations.

[1] Reprinted with kind permission from *Natural Resources Forum* **36:** 76–87 (2012).

[2] We acknowledge that some of these documents feature the language of water security prominently yet use the term quite loosely.

This paper presents an index that quantifies water security at the country level in order to encourage a more concrete understanding of the term. An initial section (Section 2) reviews the definitions of water security and identifies five components that provide a conceptual framework for assessment – basic needs, agricultural production, the environment, risk management, and independence. The conceptual framework is then translated into a set of numerical indicators (Section 3), which are populated with data from 46 countries in the Asia-Pacific region to generate a set of results (Section 4). The Asia-Pacific was selected because of its great diversity of water resources' conditions and economic development levels, and because of the extent of the available data. Finally, key issues revealed through undertaking this approach are examined (Section 5), and the viability of the approach, as well as the added value of water security as a concept, are discussed (Section 6).

2.2 Conceptual framework

As water security is a fairly new concept, definitions of the term are evolving. Reviewing four key definitions of the term suggests that the meaning of water security has grown somewhat more expansive since its initial use to include a more explicit focus on agriculture and food production, the adverse impacts of water, and national security. The Global Water Partnership (GWP) (2000) first defined water security simply as an overarching goal where *"… every person has access to enough safe water at affordable cost to lead a clean, healthy and productive life, while ensuring the environment is protected and enhanced."* Swaminathan (2001) then stated that water security "*… involves the availability of water in adequate quantity and quality in perpetuity to meet domestic, agricultural, industrial and ecosystem needs.*" Cheng et al. (2004) subsequently defined water security to include access to safe water at affordable cost to enable healthy living and food production, while ensuring the water environment is protected and water-related disasters, such as droughts and floods, are prevented. Finally, Grey and Sadoff's (2007) more recent definition of water security is focused on "*… the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies.*"

Despite some differences, these definitions have several common strands. The first is a focus on access to potable water for basic human needs or domestic use. A second relates to providing water for productive activities – presumably production of agriculture, food, and industrial goods, as specified in some definitions. A third is the focus on environmental conservation or protection. A fourth strand, common at least to the latter two definitions, is preventing water-related disasters. A final element worth noting relates to Grey and Sadoff's (2007) broader treatment of risk, which strongly suggests including issues related to water for national security or independence.

Based on the four common strands and the final element specific to Grey and Sadoff (2007), a conceptual framework is proposed that contains five components – basic needs, agricultural production, the environment, risk management, and independence. Note the second component was confined to agricultural production, which encompasses food production, but excludes other areas that may plausibly be subsumed within this component, such as industry and energy. This was because agriculture is the largest productive use of water, and because water was considered either too peripheral to the outcomes of other activities. With industry, for example, water is but one input among many, and different levels of industrial output are most likely associated with factors other than different levels of water security. As for energy, while some countries rely on hydropower as a critical source of energy, other countries satisfy all their energy requirements without making use of hydropower[3]. Gauging water security related to hydropower in a cross-country fashion, therefore, is severely constrained by the non-essentiality of hydropower for energy production. Finally, while there may be a more direct connection in the case of water for cooling after electricity generation, there were insufficient national-level data on this and so it was not considered[4].

These five components can be treated as important in enabling many of the outcomes linked to water security, such as adequate food consumption, healthy people, economic development, and environmental conservation. However, achieving security in these areas is a function of much more than water security. For example, while water security can imply that economies are buffered from droughts and floods, this does not mean that economies will be resilient from other shocks, such as those related to global financial crises. Similarly, while water security implies sufficient agricultural production to feed a community or country, the selection of crops that satisfy nutritional needs and the distribution and provision of those crops in a time-appropriate manner may not fall within the parameters of water security – this is food security. As such, water security can be considered but one contributor to the security of other areas, such as food and the environment. Ultimate security in these areas, however, relies on factors over and above those specific to water security.

2.3 Methods

To assess water security for basic needs, agricultural production, the environment, risk management, and independence, data were used from a combination of recent sources (e.g., FAO AQUASTAT, 2007; WHO, 2009; WRI, 2009). The methods used to assess water security in each of the five components of the framework are discussed below and summarised in Table 1. A quintile-based approach was used for each component, whereby countries were ranked according to their performance, divided into five quintiles that were approximately equal in size, and assigned a score depending on the quintile into which they fell.

2.4 Water security for basic needs

To assess the degree to which countries have achieved water security for the basic needs of their populations, we used data from the World Health Organization (WHO, 2009) on the proportion of populations with sustainable access (within 1 km) to an improved water source (household connections, public standpipes, boreholes, protected dug wells, protected springs, and rainwater collection). The results for countries were ranked according to the proportion of their population with sustainable access to an improved water source and divided into five groups of roughly equal size. A score, between 1 and 5, was assigned to each group with 5 indicating a greater proportion of the country's population having sustainable access to an improved water source, and 1 indicating a smaller proportion having sustainable access.

[3] One option in considering water security for energy is to stratify countries according to the degree to which hydropower contributes to their energy production. In the subset of countries in which hydropower satisfies a major portion of the energy requirements, a supplemental indicator could be used to gauge water security for energy.
[4] The quantities of biofuel and desalinated water produced are two other areas that may be considered in any future analysis. At present, however, their use would appear to be too limited in most countries to justify incorporation into an assessment framework.

Table 1 Calculating water security

<table>
<tr><th colspan="5">Overall water security = A + B + C + D + E</th></tr>
<tr><th>Component</th><th>Definition</th><th colspan="2">Scoring system</th><th>Source</th></tr>
<tr><td>A = Basic household needs</td><td>Proportion of population with sustainable access to an improved water source</td><td colspan="2">High proportion of population with access to improved water source = 5, to low proportion of population with access to improved water source =1</td><td>WHO, 2009</td></tr>
<tr><td rowspan="3">B = Food production</td><td rowspan="3">The extent to which water is available and harnessed for agricultural production</td><td colspan="2">Water security for agricultural production = (a + b)/2</td><td rowspan="3">FAO AQUASTAT, 2007</td></tr>
<tr><td>a. Water availability (RWR/person)</td><td>From low availability = 1 to high availability = 5</td></tr>
<tr><td>b. Water use (withdrawal/person)</td><td>From low withdrawal = 1 to high withdrawal = 5</td></tr>
<tr><td>C = Environmental flows</td><td>Proportion of renewable water resources (RWR) available in excess of environmental water requirement (EWR). That is, [RWR – (environmental water requirement + withdrawn water)]/RWR×100</td><td colspan="2">High proportion above EWR = 5, to low proportion above EWR = 1</td><td>Converted from Smakhtin et al., 2004</td></tr>
<tr><td rowspan="3">D = Risk management</td><td rowspan="3">Risk management measures the extent to which countries are buffered from the effects of rainfall variability through large dam storage</td><td colspan="2">Risk management = (a + b)/2</td><td rowspan="3">ICOLD, 2003; FAO AQUASTAT, 2007; Mitchell et al., 2002</td></tr>
<tr><td>a. Inter-annual coefficient of variation (CV)</td><td>From low CV = 5, to high CV = 1</td></tr>
<tr><td>b. Storage</td><td>From high storage = 5, to low storage = 1</td></tr>
<tr><td>E = Independence</td><td>Independence measures the extent to which the country's water and food supplies are safe and secure from external changes or shocks</td><td colspan="2">From low dependence on external waters = 5 to high dependence = 1</td><td>WRI, 2009</td></tr>
</table>

2.5 Water security for agricultural production

The degree to which water security for agricultural production is achieved in a country was treated as a composite of two sub-indicators: i) water availability per capita and ii) water withdrawal per capita. Data for both sub-indicators were obtained from FAO AQUASTAT (2007). Water availability per capita (i.e. renewable water resources/person) provides an indication of the total water available for agricultural production. It is particularly relevant to rainfed agriculture in a country, but it also provides an indication of the potential for irrigation. Given that greater water availability enables more rainfed agriculture and represents a greater potential for irrigation, greater water availability per capita can be associated with greater water security for agricultural production. Water withdrawal per capita provides an indication of how much control a country possesses over its water resources. Given that agriculture is the primary user of water in virtually every country in Asia, accounting for more than 80 percent of water use, greater control of water can be associated with greater water security for agricultural production.

For each of the two sub-indicators (water availability per capita and water withdrawal per capita), countries were ranked and divided into five groups. A score, between 1 and 5, was then assigned to each group. For the first sub-indicator, a score of 5 reflects greater water availability per capita, and a score of 1 indicates less water availability per capita. For the second sub-indicator, a score of 5 indicates greater water withdrawal per capita and a score of 1 indicates less water withdrawal per capita. Results in each of the two sub-components were then averaged. Therefore, 5 represents greater water security for agricultural production in a country, and 1 represents less water security.

2.6 Water security for the environment

The degree to which water security for the environment is achieved in a country was considered to be the extent to which environmental water requirements (EWRs) are satisfied. Clearly, achieving sufficient quantities of water for environmental needs captures only part of the picture, as it is also important that water for the environment be of appropriate quality. Nonetheless, since country-level data on water quality were not widely available, the focus was solely on water quantity.

To assess the country-level water security for environmental flows, we determined the proportion of water not withdrawn in excess of the EWR. To calculate this, we subtracted the amount of water withdrawn and the EWR from a country's renewable water resources (RWRs) (converted from Smakhtin et al., 2004). The remaining amount was then divided by the country's RWR[5]. Countries were ranked, divided into 5 groups, and a score of 1 through to 5 was applied to each group – 5 indicates a greater proportion of water available in excess of the EWRs and 1 indicates a smaller proportion.

2.7 Water security for risk management

Many essential activities in countries are vulnerable to fluctuations in rainfall and storing water constitutes a viable method to mitigate the effects of these fluctuations. Water security for risk management was considered to be the extent to which the water storage capacities are in place to offset a country's level of inter-annual rainfall variability. This indicator contains two sub-components. A first sub-component consists of the proportion of RWRs stored in each country. This is, calculated by dividing the storage capacity in large dam reservoirs (ICOLD, 2003) by the country's RWRs (FAO AQUASTAT, 2007). Large dams are admittedly but one storage option, as there are indeed other ways to store water, such as in the ground, soil, and behind small dams (IWMI, 2009; Taylor, 2009). Nonetheless, accessible data across countries are only available for water storage

[5] In other words, the proportion in excess of EWR = [RWR − (EWR + withdrawn water)]/RWRx100

behind large dams. Countries were stratified into five groups depending on the proportion of their RWRs stored, with higher storage levels scoring greater than lower storage levels.

The second sub-indicator focused on inter-annual rainfall variability, for which we used country-level data on the inter-annual rainfall coefficient of variation (Mitchell et al., 2002). Countries were divided into five groups according to the degree of inter-annual rainfall variability, with lower rainfall variability scoring greater than higher rainfall variability.

To develop an aggregate score for risk management, each country's scores in the two sub-components were averaged. A scale of 1 to 5 was used. Scores towards 5 indicate greater water security for risk management (i.e., more storage, less variability). Scores towards 1 indicate less water security (i.e., less storage, more variability).

2.8 Water security for independence

A country's national security is tied to the degree to which it is capable of satisfying its own water needs through internal means. Water security for independence was considered to be the proportion of a country's water resources that is generated internally. To determine this we used the dependency ratio (WRI, 2009). Countries were categorised on a five point scale such that a score of 5 indicates that a country is largely reliant on its own water resources and 1 indicates a heavy reliance on external waters.

2.9 Overall water security index

To generate a score for the overall water security, the results for each of the five components were summed, producing a 25 point scale (Table 1). Just as the 5-point scales indicate the degree of water security achieved in individual components, the broader score on a 25 point scale indicates the degree of overall water security in a particular country. In Figure 1, therefore, scores for each of the components is on a 5 point scale, and the overall maximum that can be achieved by a country in all five components is 25 points. A high score indicates greater water security, and a low score indicates the opposite.

2.10 Results

Comparing the strength of the overall water security scores across countries reveals substantial dispersion, with scores ranging from less than 10 to greater than 20 (Figure 1). Noticeably, even in those countries that appear quite water secure, there still exist weak spots. Australia's overall level of water security is high, but the risk management component is mediocre. Similarly, Japan is limited by its poor score for the environment, and Malaysia needs to improve water security for environment and independence. In water insecure countries, such as Cambodia and Afghanistan, weak spots are apparent in at least four of the five components.

Some results for overall water security defy the perception that water security is tied to economic development (Figure 2). Myanmar, Bhutan, and the Kyrgyz Republic are among those with the greatest level of overall water security. These countries are all water endowed, with much of their water resources generated internally, and with less alteration to the environment than many other countries. Hence their scores in certain components may have sufficed to buoy these countries' scores.

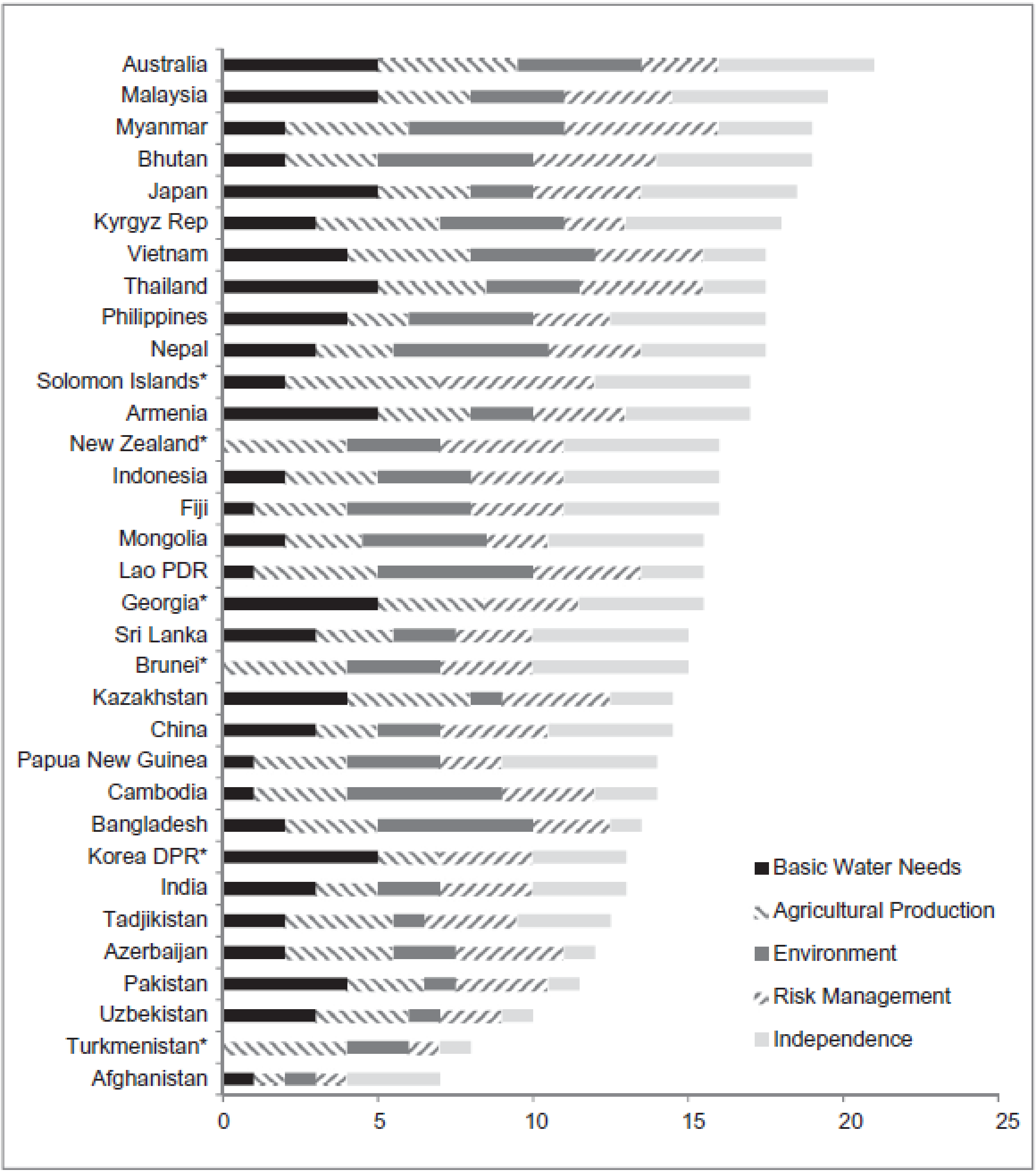

Figure 1 Water security in the Asia-Pacific, ordered from greatest to least water secure; * indicates that data are available for only four rather than all five components; countries with data for less than four components are not displayed (Source: authors' calculations)

A review of the scores for individual water security components reveals results that could be largely predicted based on levels of economic development, but there are a few surprises (Figure 1). High scoring countries like Australia, Georgia, and Malaysia are among the more developed in the Asia-Pacific region or are former Soviet Republics. Low scoring countries like Afghanistan, Cambodia, and Fiji are among the least developed in the region or are small island states. Overall, these results yield few surprises and could be said to be largely aligned with expectations.

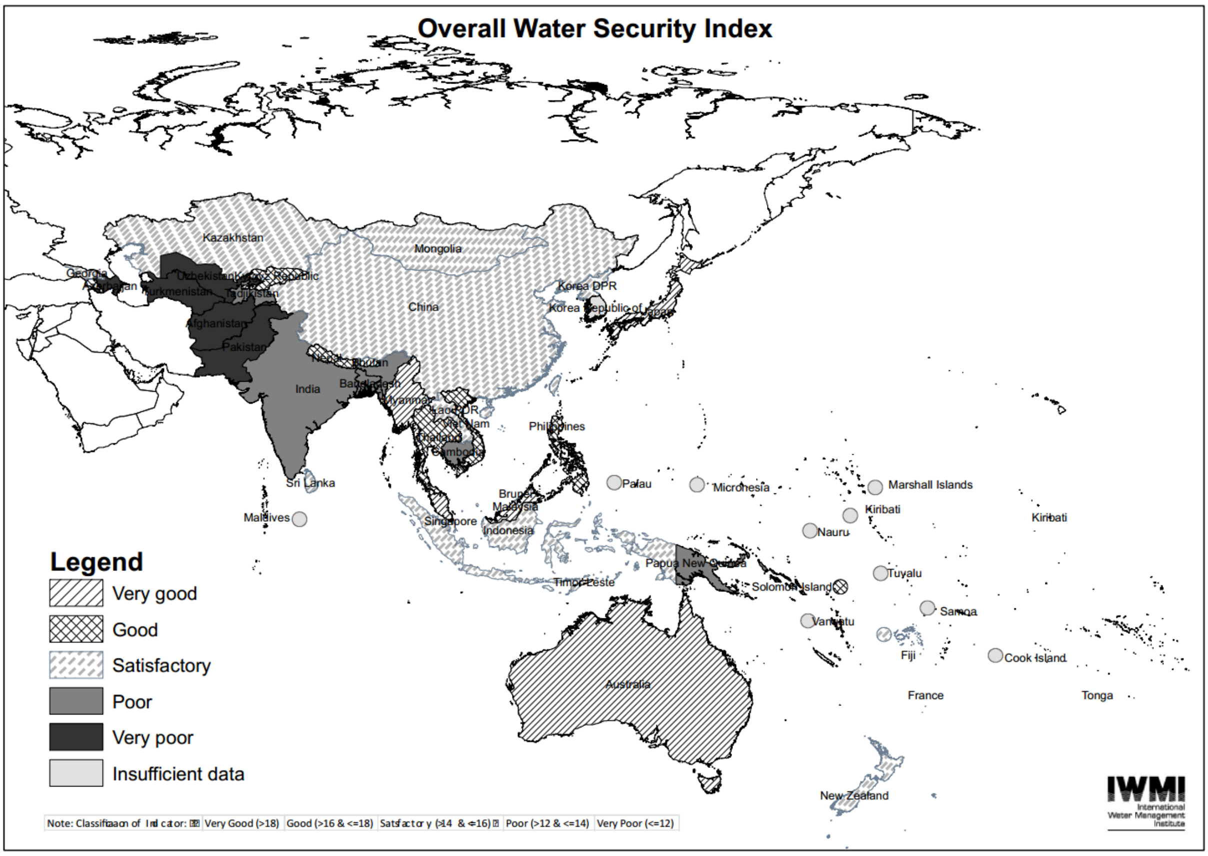

Figure 2 Overall water security index (Source: authors’ calculations, IWMI)

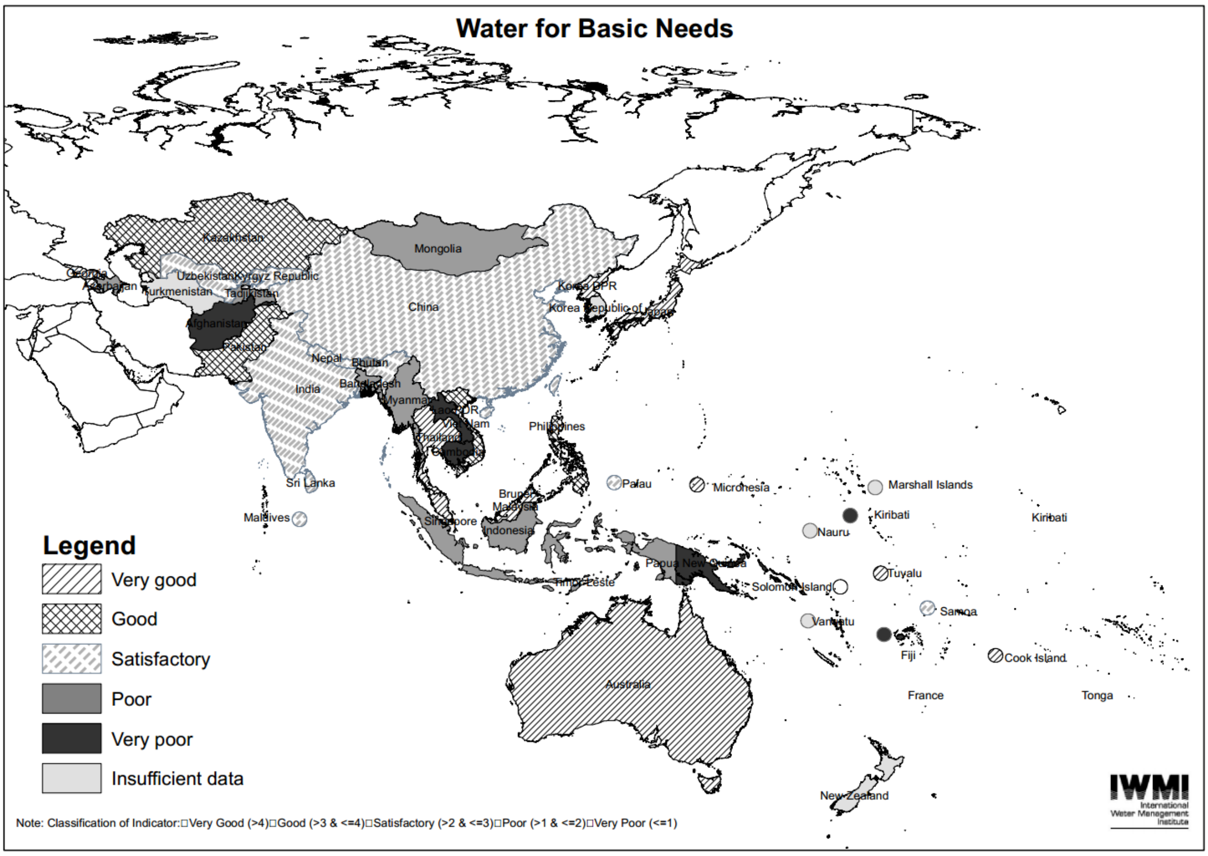

Figure 3 Water security for basic needs (Source: authors’ calculations, IWMI)

Results related to water security for agricultural production were somewhat less aligned with levels of economic development (Figure 4). Kazakhstan, the Kyrgyz Republic, Lao People's Democratic Republic (PDR), Myanmar, Turkmenistan, and Viet Nam, for example, were among countries that scored fairly high. The Korean Republic and Singapore, in contrast, scored fairly low. In the first group the results reflect the high mean quantities of RWRs per person and the levels of withdrawal per person, and highlight the potential for greater agricultural production. The second group has low per capita water availability and low water withdrawal per person.

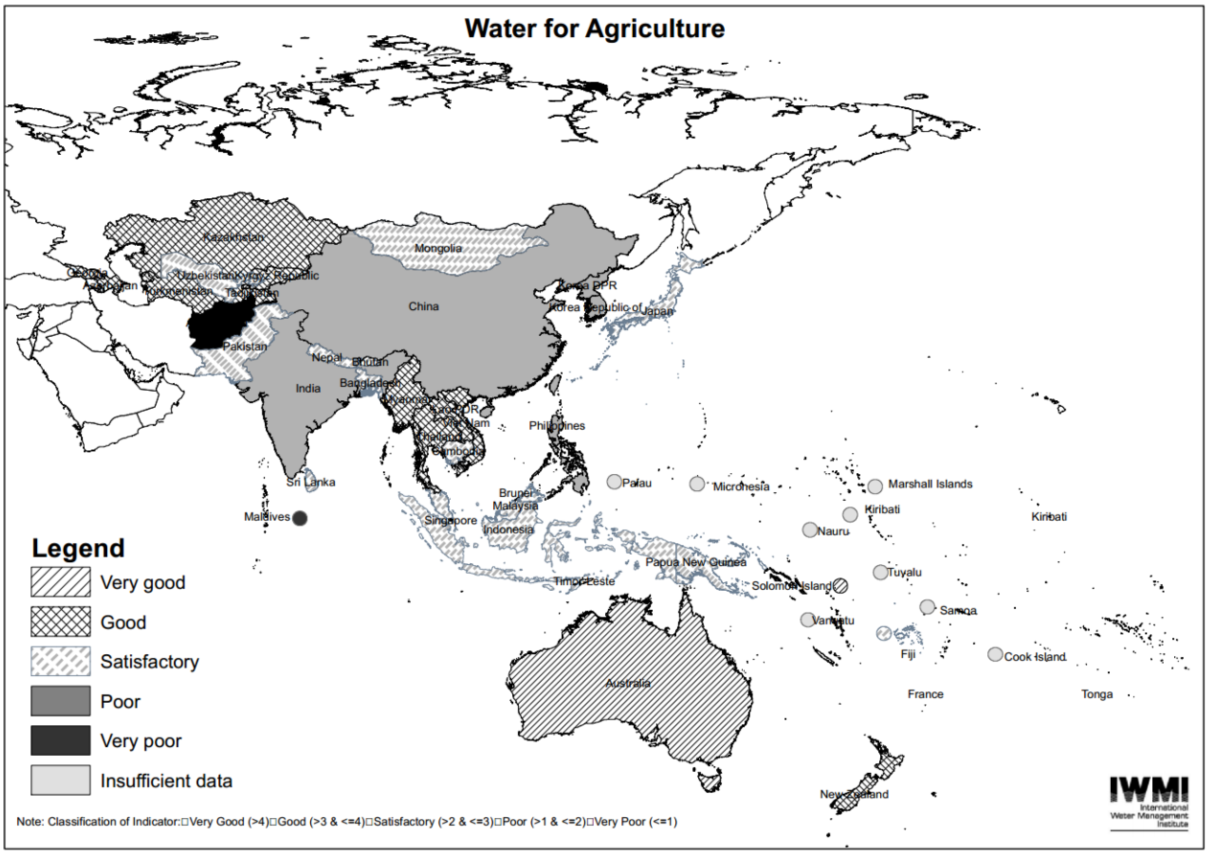

Figure 4 Water security for agricultural production (Source: authors' calculations, IWMI)

Results for water security for the environment (Figure 5) indicate that Southeast Asian countries are relatively strong and Central Asian countries are somewhat weak. High scoring countries, such as Bangladesh, Cambodia, Lao PDR, Myanmar, and Nepal, are concentrated in conditions of somewhat low levels of water resources development. Low scoring countries, such as Kazakhstan, Pakistan, Tajikistan, and Uzbekistan, are concentrated in countries with higher levels of water resources development.

Many of the high scoring countries in water security for risk management, such as Bhutan, New Zealand, and Singapore, are predicted to be effectively managing water-related risk (Figure 6). Low scoring countries, such as Myanmar, Solomon Islands, and Vanuatu appear to be less effective at managing risk. However, scores in some countries may appear deceptively high because of the effect of one storage infrastructure on a small water resources base. Countries scoring low in water security for risk management are mainly those with lower levels of economic development.

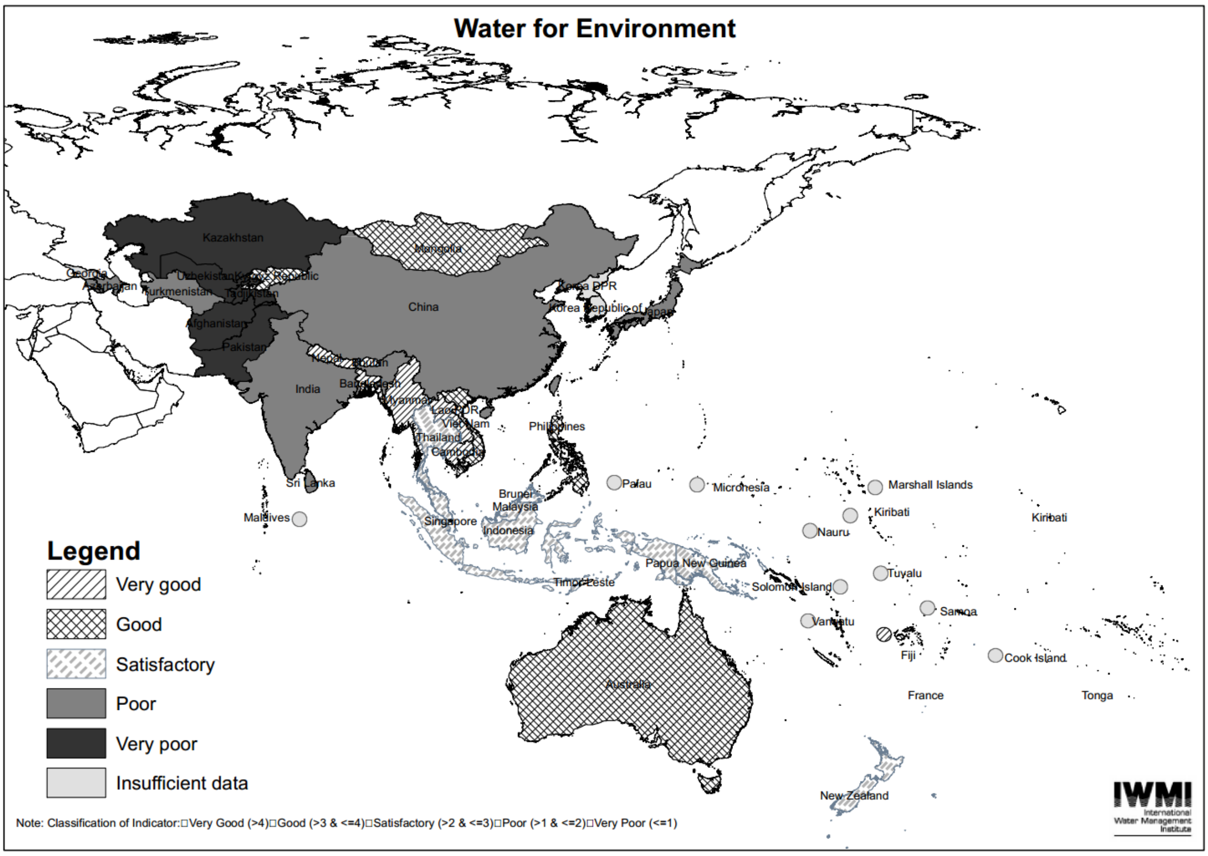

Figure 5 Water security for the environment (Source: authors' calculations, IWMI)

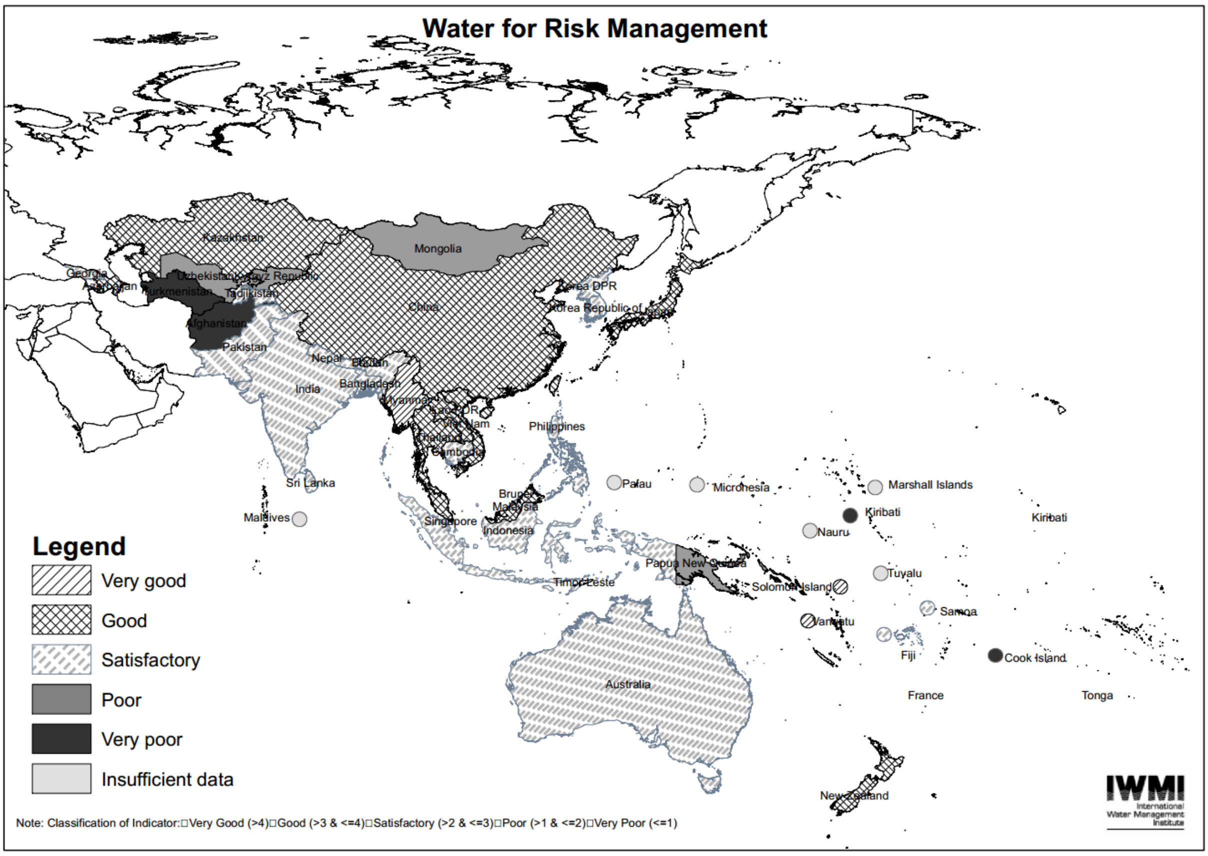

Figure 6 Water security for risk management (Source: authors' calculations, IWMI)

A review of the results for the final component in the assessment framework, water security for independence, yields few surprises (Figure 7). Countries that are islands and located upstream in river basins fare better than downstream nations. Countries such as Australia are more water secure by virtue of their geographic position while other countries, like Bangladesh, are fairly insecure because of their heavy reliance on inflows from upstream countries.

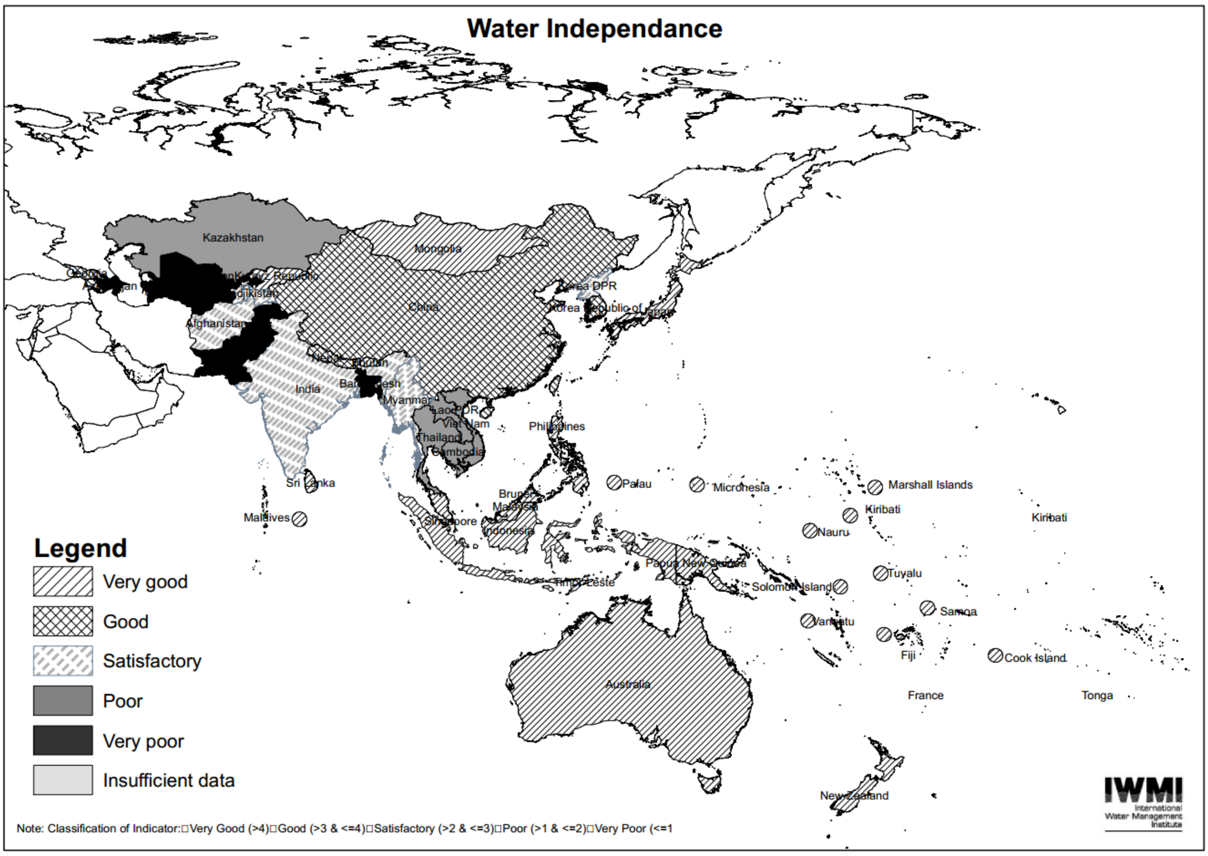

Figure 7 Water security for independence (Source: authors' calculations, IWMI)

2.11 Discussion

Five key components of water security were identified and translated into numerical indicators and were applied across the countries of the Asia-Pacific region. While the results might generate few surprises if presented in the countries, given the local knowledge which may already exist on water sector strengths and weaknesses, a primary benefit of applying a water security framework, such as this, is to understand how water secure countries are in relation to one another. A secondary benefit, if the framework is re-applied in the future, is monitoring the rate and direction of change in water security to enable comparison over time.

An important goal was to identify some of the key issues inherent in assessing water security in order to spur a more concrete discussion on what the concept truly means. One fundamental issue raised by the methods employed relates to assessment of relative vs. absolute water security. It is apparent that the approach used here assessed only relative water security, but either approach has advantages and limitations. Assessing relative water security allows for the reality that there is not necessarily an ideal state of water security and that notions of good water security will be in constant evolution and implicitly affected by known reference points (e.g., on the ground conditions in the countries). Treating notions of good water security as relative, however, fails to reflect the situation that the best levels of water security on the ground may still be poor. In contrast, while evaluation of absolute water security enables assessment of countries according to more standardised thresholds, identifying such thresholds would be no easy task, and might be derived from practical country-level experiences anyway. Further, the use of absolute indicators could imply the existence of an ideal state of water security, which is debatable.

Whatever the case, another issue is the scale at which water security is assessed. While country-level assessment has its advantages, in particular for international donors who typically transfer development funds to national governments, evaluation of water security conditions at the country level is inconsistent with the fact that water management is often conducted at a basin-level. In some countries, all basins fall within national borders, such that a country-level water security score can be considered an aggregation of water security in specific basins. However, many other countries contain basins that cross borders, which may confound the results determined at a country level. A particular country may have insufficient storage on its own territory to mitigate the effects of rainfall variability, for example, but may be able to rely on the storage capacities of an upstream neighbour. Similarly, while a country may generate too little water internally to satisfy its national security needs, inflow from an upstream country may be sufficiently assured through an international agreement.

In light of the confounding nature of transboundary waters on the country-level evaluation of water security, one way to improve the assessment framework is to include the existence and functions of transboundary water agreements. If a country relies on external waters, but such waters are assured through a treaty, for example, that country is clearly in a more water secure position than an analogous country without a treaty (Sadoff et al., 2008). To capture this nuance, the amount of water assured by a provision in an international treaty could be added to that which a country generates internally. Although there are cases when treaty provisions are not honoured, implying water assured through treaty is not as secure as that produced internally, consideration of transboundary treaties would nonetheless help to reflect the reality that water management is often undertaken at the basin-level, even in the context of transboundary waters.

A third issue relates to conceptualising water security for agricultural production. There was a temptation to make use of conventional indicators in agricultural water management, such as water productivity and the related sub-indicators of efficiency or yield per unit of evapotranspiration. The approach used however, measured water availability and use that enable agriculture and food production. While improving water productivity is clearly a way to increase agricultural production, it is simply one means of improving agricultural production, and may not be essential. In areas of economic water scarcity, for example, greater storage may be needed more urgently than improved productivity (Molden et al., 2010).

A fourth issue relates to including water storage behind large dams and excluding other forms of storage, such as groundwater and soil moisture. While obviously our analysis would have been strengthened by including all forms of storage, national data simply do not exist. These data constraints may have biased the analysis in favour of those countries that focus on large dam storage and have somewhat under-estimated the water security in countries that make more effective use of groundwater and soil water to buffer themselves from the effects of rainfall variability.

A final point relates to aggregating the five components into an overall water security index. While it is possible to perform well in all components, performing well in one component may adversely affect performance in other components, and vice versa. In particular, achieving higher levels of water security for agricultural production and risk management may require higher levels of water storage and use, which may decrease water available for the environment. Conversely, ensuring ample water for the environment may constrain scores in water security for agricultural production and risk management.

2.12 Conclusion

The development and application of the approach described in the paper has helped clarify the notion of water security and prompts at least two overarching suggestions for reaching a more common understanding of the meaning and utility of the concept. A first suggestion is to move beyond qualitative definitions to make a list, or finite set of criteria, on which water security is determined and evaluated. While the criteria used here may not be perfect, we believe they mark a valuable step towards arriving at a clear meaning of the concept. A second suggestion is to clearly distinguish between means and ends. This is analogous to the need to disentangle the common conflation of processes and outcomes in the context of water governance (Lautze et al., 2011). Interpreting water security could benefit from a clear focus on the ends of water security, not the means to water security nor the ends beyond water security.

Interestingly, given the current ambiguity associated with the concept, it is ironic that so much importance is attached to it. In high profile negotiations over a comprehensive water management agreement for the Nile Basin, water security was considered the paramount issue on which negotiations have stalled for many years (WaterLink, 2010). Yet why should governments agree to such a concept if a set of its key elements have not been clearly defined and hold the potential to undermine their positions if more exhaustively outlined at a subsequent point? Conversely, what is the point of agreeing to a concept that can ultimately be interpreted in multiple ways in the future?

In terms of the added value of introducing the concept of water security, the results are mixed. While focusing on five priority issues related to water management is important, the benefits of bundling these five issues under the umbrella of a new water indicator are not immediately apparent. On the contrary, with the steady stream of new concepts flowing into the water sector (e.g., integrated water resources management (IWRM), water governance, and hydro-politics), there may be confusion, scepticism, and even fatigue associated with introducing another new term that is supposed to bring benefits for water managers, but which is not yet well defined.

Although there is a lack of a clear, widely-accepted meaning for a water security indicator, there may be benefits to leaving the terms vague. If water security is de-shrouded to reveal that it is simply a package of five criteria that have already been used for decades, for example, the need for packaging may be questioned and the topic may lose some of its allure.

From a practical perspective, the need to aggregate the five components in the assessment framework into an overall score is questionable, for at least two reasons. First, presenting an overall score for a country almost immediately triggers interest in identifying the specific areas that explain such overall scores. Second, the overall water security score provides little direct guidance to a country given all the information compressed into one value. The presentation of the results at a component-level, in comparison, provides indicators which explain water security performance and this, in turn, provides a basis for recommending improvements.

References

Asian Development Bank (ADB). (2007) Asia water development outlook achieving water security for Asia. Available at: http://www.adb.org/Documents/Books/AWDO/2007/awdo.pdf

Asia Society. (2009) Leadership group on water security in Asia. Progress report (June). Asia Pacific Water Forum. Available at: http://www.apwf.org/archive/documents/5th_GC/3-17_Asia_Society_concrete_initiative_report.pdf

Biswas, A. and Seetharam, K. (2008) Achieving water security for Asia, *International Journal of Water Resources Development* **24**(1): 145–176.

Briscoe, J. (2009) Harvard water initiative: science technology and policy for water security. Available at: http://www.johnbriscoe.seas.harvard.edu/research/Harvard%20University%20Water%20Security%20Initiative%2020090609.pdf

Chen, S. (2004) Differentiating and analysing the concept of water security. *China Water Resources* **17**(13).

Cheng, J., Yang, X., Wei, C., and Zhao, W. (2004) Discussing water security. *China Water Resources* **1**: 21–23.

Cook, C. and Bakker, K. (2012) Water security: debating an emerging paradigm. *Global Environmental Change* **22**: 94–102.

Food and Agricultural Organization of the United Nations (FAO). (2000) *New Dimensions in Water Security.* FAO Land and Water Development Division. Rome, Italy.

FAO AQUASTAT. (2007) AQUASTAT Database. Available at: http://www.fao.org/nr/water/aquastat/data/query/index.html.

Global Water Partnership (GWP). (2000) *Towards Water Security: A Framework for Action*. GWP, Stockholm, Sweden.

Grey, D. and Connors, G. (2009) The water security imperative: we must and can do more. Stockholm World Water Week. Available at: http://www.worldwaterweek.org/documents/WWW_PDF/Resources/2009_19wed/0903_Grey_Connors_The_Water_Security_Imperative_FINAL_PRESS.PDF

Grey, D. and Sadoff, C. (2007) Sink or swim? Water security for growth and development. *Water Policy* **9**: 545–571.

International Commission on Large Dams (ICOLD). (2003) *World Register of Large Dams*. ICOLD, Paris, France.

International Water Management Institute (IWMI). (2009) *Flexible Water Storage Options: for Adaptation to Climate Change*. IWMI Water Policy Brief 31. IWMI, Colombo, Sri Lanka.

Lautze, J., De Silva, S., Giordano, M., and Sanford, L. (2011) Putting the cart before the horse: IWRM and water governance. *Natural Resources Forum* **35**(1): 1–8.

Liu, B., Mei, X., Li, Yu, and Yang, Y. (2007) The connotation and extension of agricultural water resources security. *Agricultural Sciences in China* **6**(1): 11–16.

Maplecroft 2011. Water Security Risk. Maplecroft. U.K. Available online: http://maplecroft.com/about/news/water_security.html

Mitchell, T.D., Hulme, M., and New, M. (2002) Climate data for political areas. *Area* **34**: 109–112.

Molden, D., Lautze, J., Shah, T., Bin, D., Giordano, M., and Sanford, L. (2010) Growing enough food without enough water – second best solutions show the way. *International Journal of Water Resources Development* **26**(2): 249–263.

Sadoff, C., Greiber, T., Smith, M., and Bergkamp, G. (2008) Share – *Managing Water Across Boundaries*. International Union for Conservation of Nature and Natural Resources, Gland, Switzerland.

Sinha, U. (2009) The why and what of water security. *Strategic Analysis* **33**(4): 470.

Smakhtin, V., Revenga, C., and Döll, P. (2004) A pilot global assessment of environmental water requirements and scarcity. *Water International* **29**(3):307–317.

Swaminathan, M. (2001) Ecology and equity: key determinants of sustainable water security. *Water Science and Technology* **43**: 35–44.

Tarlock, A. and Wouters, P. (2009) Reframing the water security dialogue. *Journal of Water Law* B: 53–60.

Taylor, R. (2009) Rethinking water scarcity: the role of storage. *Transactions of the American Geophysical Union* **90**(28): 237–238.

University of East Anglia. (2009) Shaping policy through dialogue. Water Security Research Centre. Available at: http://www.uea.ac.uk/watersecurity.

Vörösmarty, C., McIntyre, P.B., Gessmer, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S., Sullivan, C., Liermann, C., and Davies, P. (2010) Global threats to human water security and river biodiversity. *Nature* **467**: 555–561.

WaterLink. (2010) Nile Basin initiative deadlock. Available at: http://www.waterlink-international.com/news/id1230-Nile_Basin_Initiative_Deadlock.html

World Health Organization (WHO). (2009). World health statistics 2009 Available at: http://www.who.int/whosis/whostat/2009/en/index.html

World Resources Institute (WRI). (2009) Earth trends environmental information searchable database. Available at: http://earthtrends.wri.org/#

Zeitoun, M. (2011) The global web of national water security. *Global Policy* **11**: 1–11.

3. Which way now? Supporting decisions for climate compatible development in the water sector[1]

Authors: Nathaniel Mason and Roger Calow, ODI Water Policy Programme[2]

Abstract

Strategic decision-making in the water sector has always been immensely challenging. Climate change magnifies the complexity of managing water resources and forces us to question old approaches for dealing with future uncertainty. Supporting decision-making in this space is not simply a matter of providing the right concepts and tools. It calls for different ways of working in which those providing analysis and research, as well as those with the executive power over resources and how they are spent, can ask questions and collaboratively explore the answers.

This paper presents a brief survey of the various ways in which strategic decisions in the water sector can be aided in pursuit of climate compatible development – a 'triple win' across adaptation, mitigation, and development. Drawing on social science theory for tackling complex real-world problems, we argue that a number of elements are needed.

First, a unifying concept should be framed, allowing for sufficient common understanding, but with enough leeway for different perspectives to be valid.

Second, when it comes to evolving devices to make these expansive concepts operational, certain caveats are necessary: (i) indicators can be useful to consolidate and process data, but should be simple, explicit about uncertainty, and tailored to the context, (ii) simulation models of hydrological systems under climate change are better used to explore multiple possible futures than to predict a single future, and (iii) frameworks and methodologies for decision-making can help structure the problem and identify options that perform 'well enough' over these multiple possible futures.

Third, as much, if not more, attention should be paid to the political elements of any decision space, such as capacity, incentives, trust, and power, as to the technical tools and methods for structuring and breaking down the problem.

3.1 Climate change – water management's complexity magnifier

Institutions charged with managing water resources have never had it easy. They are tasked with designing and implementing strategies to ensure accessibility, availability, and quality of a resource which is critical to survival and many productive processes. The resource is costly both to confine and transport. Risks arise from the uses that water is put to (e.g. pollution), as well as the natural environment (e.g. extreme weather events). The 'decision space' for those involved in water management can, consequently, be characterised as complex. It is marked by a high degree of uncertainty, has the potential for dispute about goals and how these should be achieved, and features a large number of different actors, both public and private, working to different agendas (Hummelbrunner and Jones, 2013) – a reason why it is pointless to refer to any homogeneous class

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of 'water managers'. Water management's complexity arises with respect to both biophysical and socio-economic systems and processes (Box 1).

Box 1 Water management and complexity

An example of the complex space in which actors with water management responsibilities need to operate is presented by the explosion in groundwater abstraction in parts of India. The combined effect of energy subsidies, access to cheap borehole technology, and other agronomic advances permitted an abrupt increase in groundwater abstraction by many small farmers. Initially unpredictable, and hence difficult to control, the economic opportunities have created a positive feedback loop, encouraging new entrants to the groundwater economy, resulting in rapid increases in living standards for many farmers. The political importance of this group has increased with their economic significance, making it harder to achieve a settlement which could tackle the perverse incentives encouraging over-abstraction, such as subsidies for energy.

Meanwhile, the groundwater resources in question are depleted, but at varying rates because of the complex interaction of surface and subsurface flows, as well as variations in demand. A shorter-term feedback loop is also apparent in the effect of seasonal climate variation on demand for irrigation water, since hot, dry years are likely to increase groundwater pumping. The system as a whole is ultimately adaptive (another property of complex systems) since where it becomes uneconomic to pump groundwater, activity will eventually cease. But the threat to multiple livelihoods which this would entail means that those whose core business is water management cannot act alone. To be genuinely adaptive, in a sense that considers the welfare of individuals as well as the system as a whole, they have to act alongside other agents – for example, in a broader socio-economic development strategy in which the 'groundwater economy' is a stepping stone to a more diversified and less water-intensive livelihood system.

Source: draws on Hummelbrunner and Jones, 2013; Ramalingam et al., 2008; Shah et al., 2003.

Climate change magnifies the complexity of managing water resources (World Bank, 2010). Most obviously, there are the impacts of climate change on hydrological variability and uncertainty. Climate change presents particular challenges to the conventional water management paradigm of 'stationarity'. This essentially assumes that, while hydrological variables (such as annual flood peak) are known to fluctuate, they do so within certain bounds that can be delineated with reasonable certainty from analysis of historical records. Stationarity has been a useful concept, allowing planning in the face of uncertainty. It is deeply embedded in the development and management of water resources, particularly in the engineering community. Exceptions, or instances of 'non-stationarity', were factored into the paradigm to some extent, and methods are available to engineers to factor in 'human disturbances' arising from physical interventions, such as channels, drainage, and land-use change. Anthropogenic climate change and internal, low-frequency variability within the climate system (such as the Atlantic multi-decadal oscillation) are also acknowledged, but were, until recent decades, often assumed to be of such a magnitude that they would not challenge the fundamental assumption of stationarity (Milly et al., 2008).

More recently, the prospects of stationarity in the face of climate change were questioned more closely. Certainly, evolved water management systems have a number of mechanisms, such as designing infrastructure with additional headroom and systems of variable water rights, to cope with non-stationarity. At broad scales of time and space there is some degree of scientific consensus around the direction, pace, and magnitude of changes to climate, and what this might mean for hydrology. For example, Working Group I of the 5th Assessment of the Intergovernmental Panel on Climate Change (IPCC) states that, "It is *virtually certain* that changes of average precipitation in a much warmer world will not be uniform, with some regions experiencing increases, and others with decreases or not much change at all. The high latitudes are *likely* to experience greater amounts of precipitation. Many mid-latitude arid and semi-arid regions will *likely* experience less precipitation." (Stocker et al., 2013).

But confidence around climate change is low across whole regions, including much of sub-Saharan Africa and South Asia; regions where the 'hard' (infrastructure) and 'soft' (institutional) capacity to cope with non-stationarity are historically lower. While climate models are now more sophisticated, there is no substantial convergence in the projections of changes to precipitation and extremes by the general and regional circulation models (GCMs and RCMs; the global- and regional-scale climate models). That models agree is, moreover, no guarantee that they are more trustworthy (Weaver et al., 2013).

The extent, and even direction, of change in the expected mean and variation of key water-related variables is unclear. Catchment-scale hydrological models can be linked up to GCMs and RCMs, to project the impacts of climate change on hydrology. The extensive studies to date provide important first-principles, e.g. that catchment-level hydrological responses to climate change are likely to depend on existing geological and hydrogeological characteristics, and the existing climate regime. However, the outcomes for studies in the same catchment can differ, given the variations in both the climate and hydrological models used. Key components in the water cycle, in particular how climate change will affect the interaction of surface and ground water by changing the timing and intensity of precipitation, as well as effects on water quality, remain poorly understood.

As a result it remains difficult for a water manager operating at the catchment or basin scale to make evidence-based decisions in relation to climate change risks, even in contexts of high technical and managerial capacity (Conway, 2013).

The possibility for climate change to introduce new feedback loops and emergent phenomena also make it a 'complexity magnifier' for the water sector. If rainfall does become less frequent and more intense, as is projected for several global regions, rainfed farming is likely to become more risky, providing incentives for the development of irrigation and increasing the demand for ground and surface water in some areas. Unless measures are taken to improve built and natural water storage, the increased 'flashiness' of runoff will, meanwhile, make the job of capturing water for such purposes as irrigation more difficult (Calow et al., 2011). In its fourth assessment, the IPCC argued that overall water stress, in terms of per capita availability of renewable fresh water, is likely to be reduced at the global average level. This will be because anticipated increases in runoff will be concentrated in populous areas of the world (eastern and south-eastern Asia). But a meaningful reduction in water stress will only occur in such areas if society is able to capture and effectively use that water (Bates et al., 2008). In terms of its effect on water management strategies, climate change, therefore, interacts with other drivers and concerns (e.g. population growth, patterns of demand, national food security agendas, and availability of agricultural land). It is not, therefore, the 'only game in town' – a point returned to later in this paper. But the interactions among drivers make it even harder to discern the impacts of climate change on hydrology and the water management decision space, even where confidence can be placed in emissions scenarios and the circulation models.

One further important way in which climate change increases the complexity of water resources management is in introducing mitigation as a policy driver. The water sector is not exempt from the need to decarbonise. Storing, pumping, treating, and heating water can all be energy intensive activities and how that energy is generated is increasingly a consideration (WEF, 2009). For example, in China, groundwater pumping for irrigation alone was estimated to contribute just over one half of one percent of the country's greenhouse gas emissions (Wang et al., 2012). At the same time, certain changes in the energy mix, driven by the climate change mitigation imperative, can have significant impacts on hydrology, including hydropower installations and the conversion of land to grow water-intensive biofuels (ODI et al., 2012). Therefore, while the actors and institutions charged with managing water are increasingly tasked with leading climate adaptation efforts, the mitigation dimension cannot be ignored.

3.2 Decision-making in the face of complexity

This paper approaches a number of heuristic and decision-making aids for ‘climate compatible development’ (CCD) in the water sector. The aim is not to present a toolkit. Discussion is purposefully kept general, considering such broad classes as indicators, conceptual models, simulation models, and analytical frameworks, while emphasising the fact that ultimately getting the process right can be more important than using a particular tool.

In each case, examples are brought to bear from recent grey and academic literature to identify both the potential for, and limitations of, supporting more informed and actionable decisions in the water management space, with CCD as an overarching objective.

To structure the narrative, this paper uses the notion of ‘boundary work’, which has emerged from a number of schools of thought, including sustainability science and trans-disciplinarity. Boundary work is, broadly, a way of working to tackle complex problems that require the collaboration of research and policy communities. Within the overall process of boundary work, certain core components can be identified (paraphrased from Mollinga, 2010):

- Boundary concepts: terminology that can be used by different disciplines and interest groups with a degree of common meaning, while acknowledging the different contribution of each. Boundary concepts can provide a starting point to frame and approach multidimensional, complex problems.
- Boundary objects: devices and methods that allow us to approach complex problems and overcome dilemmas, including uncertainty and nonlinearity, which might otherwise prevent evidence-based decisions or paralyse the decision-making process altogether.
- Boundary settings: finally, and most importantly, the underlying rules of engagement, or institutions, within which boundary concepts and objects are to be ‘fruitfully developed and effectively put to work’.

The following sections therefore address, in turn, a selection of boundary concepts, objects, and settings for CCD in the water sector.

3.3 Boundary concepts – finding common language

A term already referred to, and gaining increasing prominence in policy and academic debates, provides the first boundary concept – CCD (Figure 1). The Climate and Development Knowledge Network (CDKN) evolved this boundary concept, which provides a common point of reference for development, mitigation, and adaptation communities. CDKN defines CCD as ‘development that minimises the harm caused by climate impacts, while maximising the many human development opportunities presented by a low emissions, more resilient, future’.

The coincidence of development, adaptation, and mitigation is presented in the figure as optimal, producing a ‘triple win’. The terminology describes the coincidence of two of these objectives and provides other boundary concepts – low-carbon development (mitigation with development); cobenefits (adaptation alongside mitigation); or climate resilient development (development with built-in adaptation).

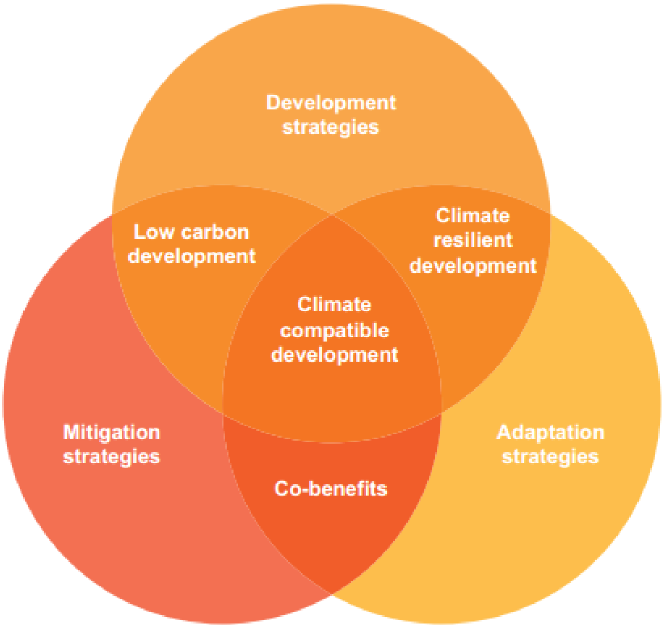

Figure 1 Climate compatible development
Source: Mitchell and Maxwell, 2010

Another boundary concept, increasingly used as a catch-all for the objectives of water management, is 'water security'. Numerous definitions of water security have, and continue to be proposed. UN agencies collaborating under the UN Water umbrella have agreed a definition which emphasises society's management capacity and is, therefore, fit-for-purpose in this paper:

"… the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability." (UN Water, 2013, p. vi)

The two boundary concepts of CCD and water security are, moreover, compatible. Because water is essential to health and livelihoods, water security is a development imperative. Since many climate change impacts will be felt through water, climate adaptation and water security are closely interlinked. And, as noted, the mitigation imperative has a number of implications for water security – changing patterns of water demand associated with a changing energy mix and the need to decarbonise water treatment and pumping.

While both water security and CCD appeal intuitively, they do not necessarily tell us how their ambitious ideals are to be achieved. Comparison with integrated water resources management (IWRM) shows how difficult it is to make operational a holistic, integrative concept. Recent monitoring on the implementation of IWRM suggests slow progress for many countries in developing the institutions and processes required. It also reveals the difficulty in identifying meaningful outcome measures and monitoring progress towards these, which applies to many broadly defined, integrative agendas (UN Water, 2012).

In practice, it is extremely challenging to achieve the 'triple win' implicit in CCD, or to increase water security for one set of interests without jeopardising the water security of others. The concepts aspire to synergy, but reality often presents trade-offs, with objectives that are frequently in tension. Similarly, the expansive nature of both concepts means that they pull in numerous interests making the task of reconciling perspectives and identifying the preferred path among future options still harder.

Investments and strategies may produce adaptation, mitigation, and development benefits for some, but rarely are they free of costs, either in the terms of the same 'win' (e.g. adaptation for some, increased vulnerability for others) or in corresponding 'wins' (e.g. adaptation at the cost of mitigation). An impounding dam designed to provide flood management, water for irrigation, and clean energy may, on the face of it, seem an ideal investment for water security and CCD. But looking a little deeper, trade-offs are readily apparent:

- Development benefits for downstream farmers who receive water for irrigation need to be set against the adaptation costs for populations dependent on wetland ecosystem services, which may be compromised by a loss of seasonal flow-spikes that regulate biotic processes.
- At the same time, buffering spikes in flows can provide an adaptation benefit, by reducing flood risks for those immediately downstream. But this may, in turn, need to be set against a mitigation cost (compared to other clean energy options) in terms of high levels of embedded carbon, deforestation, and on-going methane emissions associated with the growth and die-back of vegetation with changing dam levels.
- Meanwhile, the mitigation benefit (compared to fossil fuel installations) needs to be set against the development cost to displaced local people if an upstream valley is flooded, or to neighbouring communities if they are bypassed by power lines which travel hundreds of miles away to major cities.

This said, defining a holistic concept like CCD or water security is a critical first step towards establishing a common language, within which other components of 'boundary work' – the boundary objects and settings discussed below – can operate. Boundary concepts can thus help to articulate where interests meet as well as where they divide. They can help stimulate dialogue between different constituencies; and encourage collaboration around a common agenda.

3.4 Boundary objects – tools for sense-making

There is evidently a need for methods and devices to help systematise our understanding of messy situations and make them easier to navigate – referred to here as 'boundary objects'. The idea that we can develop aids to help us extract, interpret, and communicate decision-relevant information is an appealing one, and generates a thriving market for research. There are, however, imperfections in that market (Box 2), and concrete examples of the application of climate models providing a make-or-break input into large-scale water investment decisions, are rare (Weaver et al., 2013). Therefore, a note of caution must be sounded. There are unlikely to be tools and methods to allow all stakeholders to come to a fully unified, holistic understanding of a complex problem, or to agree with absolute certainty on 'the best option'. Boundary objects can help us make sense of the world, but not to make *perfect* sense.

This section briefly reviews three categories of boundary objects of relevance to CCD and water security – indicators, simulation models, and frameworks. Examples of each are considered with the objective of pointing out the core principles, which may increase their usefulness in applications to real-world problems. A key premise underlying the argument throughout, and picked up particularly in relation to decision-support frameworks, is that decisions should rarely be made on the basis of the signal provided by a single device or methodology (even if they are sometimes justified on the basis of the signal that best conforms to the users preconceptions). Adaptability and compatibility are therefore important.

Box 2 A profusion of tools, but limited demand?

Recent research has identified over 137 tools for climate risk management (in a broad sense, including process methodologies) of relevance to the water sector. Across the identified tools, functions, and outputs follow similar common sense principles. So does the large number of tools reflect demand?

In part the large number of tools arises because of the need to design for a particular scale, or socio-economic or biophysical context. The proliferation also illustrates a strong interest in tools for decision support by the development community at large – notably the donors who fund them. Evidence of user demand for them is, however, mixed, particularly in the developing world. While a few tools see a great deal of use, many of the others are rarely updated and have few search engine/social media hits. Where there is latent user demand for tools it might be expected that this could stimulate the development of more 'for profit' tools. This greater competition would identify more clear favourites and eliminate the less useful competitors in favour of a few adaptable and straightforward tools. Again, this has generally not been observed to be the case.

Source: Doczi, 2014.

3.4.1 Indicators

Indicators are often assumed to be a pre-requisite for evidence-based decision-making, argued by proponents to be 'indispensable tools for informing and orienting policy-making, comparing situations and measuring performance' (Molle and Mollinga, 2003, p. 529). And yet the development and use of indicators is a highly political process, open to biases and distortions. Political and financial capital can accrue around the issues and trends that we measure with indicators, in turn providing incentives to each interest-group to promote their 'pet variable' for inclusion. This temptation is especially strong where indicators are associated with targets. Multidimensional indicators attempt to capture multiple variables (and thus multiple interests) combining them using mathematical functions and weightings, often based on expert judgement. But such indicators often constitute an 'information iceberg', whereby the quality of the underlying data, and how it is assembled, remain largely hidden from view for the user (Jessinghaus, 1999, in Molle and Mollinga, 2003).

When it comes to formulating fit-for-purpose indicators for CCD, two additional points can be emphasised, both essentially about communication.

First, CCD is a concept which increases the imperative to communicate across sector and discipline boundaries. At the same time, such boundaries exist for good reason, helping to structure realms of responsibility and focus expertise. In practical terms, then, the pragmatic response is to develop indicators according to the needs of the specific user, rather than all-purpose, multidimensional indicators, which attempt to capture everything, but mean nothing. For water managers, this can mean thinking through the strategic imperatives which decision-makers in other sectors face, and helping them construct water-relevant indicators accordingly (Box 3).

Box 3 Framing water-relevant indicators in the energy sector

A project to develop a shortlist of indicators for strategic decision-making in the energy sectors of Cameroon and Togo illustrates the strategic integration of water-related indicators alongside other considerations. The framework, TIPEE (Traitement de l'Information pour des Politiques Énergétiques favorisant l'Écodéveloppement), comprises 24 indicators that are relevant to different strategic imperatives for energy planners.

From a CCD perspective, these imperatives include increasing access to affordable energy (development), reducing greenhouse gas emissions (mitigation), and ensuring that infrastructure is resilient to climate change (adaptation).

Water-related considerations, therefore, enter the framework in terms of the risk presented to power infrastructure. Three indicators within the set of 24 TIPEE indicators focus on the vulnerability of renewable and non-renewable power generation and transmission systems to climatic variation and extremes:

- vulnerability of power plants (and refineries if applicable) to flooding
- vulnerability of renewable energy systems to climatic variations
- length of transmission lines/distribution networks threatened by extreme weather events.

Other indicators in the framework track a range of other considerations, including access and affordability of energy for households and the emissions associated with power generation and deforestation.

This is not to say that quantifying the vulnerability of infrastructure to water-related climate risks is a simple matter (as explained further below). Rather, it says that water specialists need to focus on those issues, and indicators, which tell the most compelling story to other sectors if they are to encourage water-smart investments.

Source: Helio International, 2012.

The second point to emphasise is that indicators, in attempting to communicate what we know, often conceal what we do not know. The effect of climate change as a complexity magnifier for water management increases the need to be explicit about the uncertainties inherent in any metric.

In some cases this can be attempted quantitatively. Where sufficient data are available on historic and future trends, for example from an ensemble of GCMs, metrics of the risk of extreme hydrological events can be constructed on a probabilistic basis. Formally, risk metrics are often understood to require integrating information on the likelihood of an event of given magnitude, the population or assets exposed to such an event, and the capacity to anticipate and recover. These three constituent components of risk – often referred to as hazard, vulnerability, and exposure – can all be separately computed using measured and modelled data. Such exercises can yield complex multidimensional indices for hydrological extremes, such as floods. Such exercises are exemplified by the mortality risk index (MRI) developed for the Global Assessment Report on Disaster Risk Reduction (Peduzzi et al., 2010). The MRI assembles modelled population exposure, statistical analyses of past extreme events to assess vulnerability, and geographical information system (GIS) data on hazards at a 1 km x 1 km grid resolution. For other water-related risks, such as drought, however, where the hazard itself may be more strongly shaped by socio-economic and institutional factors, methodologies are in their infancy (UNISDR, 2011).

Furthermore such probabilistic, quantitative expressions of risk do not get round the issue of more fundamental uncertainties, relating both to the availability and quality of the underlying data and in the dynamics of the systems being characterised. As a result, numerous assumptions must be made. This does not mean that multidimensional indicators of risk are not useful in certain applications, for example as communication devices where a risk index is mapped over time across a geographical territory to identify areas where risk mitigation resources should be targeted. Models, too, will play their part, as the next section explores.

But it does mean that the need to confront uncertainties remains. The desire to justify a course of action militates against frank admission of the significant gaps in our knowledge and understanding. Those making decisions rarely request the caveats and analysts can be loath to provide them. Nonetheless, even where a rigorous probabilistic estimate is not possible, supplying a qualitative statement of confidence alongside a given metric may actually increase its utility (Box 4).

Box 4 How the IPCC qualitatively handles uncertainty

For its 5th Assessment the IPCC requires its authors to include qualitative expressions of confidence in their findings, 'based on the type, amount, quality, and consistency of evidence (e.g., mechanistic understanding, theory, data, models, and expert judgement) and the degree of agreement', as well as quantitative, probabilistic expressions of uncertainty where the data are statistically sufficient. Guidelines for how to calibrate the language for qualitative expressions of uncertainty do not remove inherent subjectivity, but at least provide a consistent framework for approaching this thorny issue. Importantly, the guidelines also permit authors to make statements of fact, without uncertainty qualifiers, where the evidence and understanding are judged to be overwhelming.

Source: Mastrandrea et al., 2010.

3.4.2 Simulation models

As implied in the discussion on indicators, simulation modelling of climate change and climate change impacts is heavy with assumptions. This does not make the use of such models as decision support tools redundant, but it does imply that their primary purpose may need to be revisited. Whatever the temptation to use models to frame a single future for which the optimal investment or strategy can be found, their predictive ability is questionable. Instead, modelling may be better used to increase the range of futures we are capable of understanding.

Those who are not directly involved in the preparation of technically complex climate and hydrological models may perceive an apparently binary choice: to 'leave it to the experts' and place full trust in model outputs; or to dismiss the outputs as a hubristic attempt to schematise and stratify an unknowable future.

As ever, a better course may lie somewhere between the two extremes. Comprehending the strengths, limitations, and assumptions implicit in any model is vital. Doing so requires transparency on the part of the modellers and a spirit of inquiry on the part of model users. Although this is an area of considerable academic debate, recent discussion would imply that several broad caveats on climate-hydrology modelling are currently valid:

- 'Downscaling' global and regional climate model outputs to scales at which most hydrological phenomena are experienced, and water management decisions made (e.g. river catchments or basins) is extensively attempted. But different methodologies are more or less appropriate depending on context (Conway, 2013). Uncertainties inherent in the 'parent' model, for example a RCM, are retained through downscaling and may be amplified (Pielke and Wilby, 2012).

- Just as increasing the resolution of a climate-driven hydrological model can potentially amplify uncertainties, so too does the addition of more geophysical phenomena, which may themselves be only partially understood (for example the effect of aerosols, land-use change, and ice-sheet dynamics). The more 'realistic' the model, in the sense of the more observed phenomena it tries to integrate, the greater the number of assumptions introduced (Weaver et al., 2013).
- Over periods in excess of around two decades, the future extent of anthropogenic climate change becomes a critical consideration (Weaver et al., 2013). The uncertainty in how society will respond to climate change, to be manifested in terms of emissions, land-use change, and even activities such as geo-engineering, is usually addressed using scenarios. But the inherent unpredictability of social systems and human behaviour mean the fundamental assumptions implicit to each scenario are of critical importance, and need to be transparently reflected alongside a given climate-driven hydrological model output. Moreover, clear reference to the role of anthropogenic emissions in driving future uncertainty can help reinforce the CCD concept – underscoring the fact that, to improve prospects for development and reduce the adaptation hurdle, mitigation is critical across all sectors.

At the same time, incremental improvements in model 'skill' are regularly occurring (how well the model performs against observed data). Conway (2013) identifies a number of advances in hydrological modelling more generally, for instance, greater understanding of large-scale changes in groundwater storage using satellite data, and the hydrological effects of major weather patterns, such as the El-Niño southern oscillation. Assessing the skill of multi-decadal climate models is, however, difficult because the timeframes involved make it hard to compare model outputs with observations (Weaver et al., 2013).

Despite such developments, however, the role of climate models in strategic decision-making remains contentious, even as it continues to be demanded:

"… a kind of cognitive dissonance infuses discussions of the social value of climate modelling. On one hand, we recognize that the climate system is almost unimaginably complex and the challenges of modelling it are enormous. On the other hand, we tell ourselves that we urgently need the predictions that only models can supply". (Weaver et al., 2013, p. 43).

In the face of this conundrum it may be that what is needed is a shift in expectations on the demand side (the model users) rather than an exponential improvement in predictive ability on the supply side (the modellers). To do so would, ultimately, involve acceptance that climate models are not actually predictive tools at all, but rather exploratory devices. As such, models can help us to identify plausible bounds to the range of possible futures and where outputs are unexpected, can re-orient our thinking about that range of possibility (important in the context of extreme events).

At the limit, however, some critics of using climate models for strategic decisions argue that they can only ever identify a subset of possible future climate risks (Pielke and Wilby, 2012). This implies that, within a reoriented decision-making paradigm, models are not the only exploratory devices to bring to the table – an issue prominent in the emerging decision-support frameworks discussed in the next section.

3.4.3 Frameworks

On the basis of the above discussion, there is a need for frameworks for decision-making that permit models (alongside other tools) to be used in an exploratory, rather than predictive manner.

The idea that capital investment and other strategic decisions should be robust to different future outcomes is not a new one. The concept of using sensitivity testing in conventional cost-benefit analysis is one example – key variables are changed to stress-test whether the initially identified option remains the preferred one.

But sensitivity analysis is often 'treated as an afterthought' in conventional cost-benefit analysis (GWP and AMCOW, 2012, p. 23). The end goal is still to identify a single *optimal* option, which necessarily implies there is high confidence about the future context in which an investment or strategy is expected to perform. Alternative frameworks for approaching decisions under significant uncertainty give greater emphasis to alternative visions of the future. 'Robust decision-making' (RDM) for example, requires those approaching a given problem to first frame a range of plausible futures. In the case of climate planning in the water sector, this range of futures might be defined according to different levels of temperature change and rainfall. The emphasis is then placed on identifying the option that performs best under the widest range of plausible futures, rather than the option that performs optimally for a single future. Finally, remaining vulnerabilities for the preferred option and potential ways to manage these are identified in an iterative process. At each stage, climate models may be used, for example, to derive probabilities for different visions of the future at the first stage (although without assuming there is a single model, with a single probability distribution for a future event or change). Or the models may be used to examine how the option in question performs against these different future visions at the second and third stages (Weaver et al., 2013).

RDM does not necessitate the use of significant volumes of quantitative data, or modelling. The basic procedures can also be applied using qualitative data, or combinations of quantitative and qualitative data from multiple sources. These include, for example, historic records (including ancient history and the 'paleo record', as well as more recent metered information) and qualitative estimates from stakeholders, as well as modelling. This potential was used to promote RDM for use in contexts where information and availability of appropriate expert capacity may be constrained (AGWA, 2012), though it is notable that most applications of RDM thus far have been in developed country contexts (e.g. Brown et al., 2011; Dessai and Hulme, 2007). RDM does not in and of itself, therefore, obviate the need for a careful and closely supported process – the subject of the next and penultimate section.

A further area in which RDM could be further evolved for CCD applications in the water sector is the mitigation dimension. For example, a government department evaluating the option of investment in an impounding dam using an RDM framework might, from the development and adaptation perspective, seek to consider how different future climates would affect water levels upstream and downstream of the dam, and the consequent implications for flood control, irrigation assurance, and hydropower generation. But a full, CCD-oriented application might also consider how those different climate futures would affect the mitigation benefits offered by the dam, for instance where fluctuating water levels increase methane emissions as vegetation repeatedly grows and is inundated on the reservoir's banks.

3.5 Boundary settings – where it comes together

Decision support is not a product, for instance an index, tool, or framework, or even a package of such products. Instead, decision support is better understood as a process (Weaver et al., 2013).

Within this process the technical pieces in the puzzle, such as toolkits and methodologies, may be difficult to design, but an even greater challenge lies in finding their ‘fit’. This challenge is inherently political, requiring an understanding of capacity, incentives, trust, and power.

Getting the process right is an arduous business. The way the world and knowledge about it is commonly structured means that the division between decision-maker and decision-supporter runs deep. Technical experts are expected to provide analysis and evidence, while others are entrusted with resources and the executive power to decide how these are spent. There are sensible reasons for this – for programme managers, policy-makers, and investors, being able to understand a lot of different information is often more valuable than being an expert in a single field. But if this is the case, there is often room for greater reflexivity and dialogue across the divide – a process in which knowledge can be exchanged and questions asked, and answered, by both the party responsible for making the decision and those who provide analysis and advice. Creating this kind of process is time consuming and requires a substantial investment in developing trust and respect between stakeholders. There is plenty of theory about how this should work. An example is the concept of ‘trans-disciplinarity’ whereby disciplinary experts, such as climatologists, hydrologists, economists, and biologists collaborate with practitioners, such as government agents, farmers, and business representatives to tackle a ‘socially relevant’ problem (Hirsch Hadorn et al., 2008).

But it is probably fair to say that such ideal processes are still the exception, rather than the norm, for how large public spending decisions, such as water management investments, are made in developed and developing countries alike. In developing countries especially, perceived and real resource constraints can mean a reluctance to invest in and support process and capacity development. Given that much of the funding for CCD is likely to come in the form of climate finance from international development partners, it is especially important not only that process and capacity are supported, but that this is done in a context-sensitive manner, and on the basis of need (Box 5).

Box 5 Understanding capacity needs for strategic water planning

In 2012, GWP and CDKN made an important contribution to the area of long-term planning for the water sector under climate uncertainties, by supporting the publication of a *Strategic Framework for Water Security and Climate Resilient Development* on behalf of the African Ministers’ Council on Water (AMCOW). But the framework is, ultimately, a ‘boundary object’, providing tools and methodologies across a number of policy briefs and a detailed technical background document, as well as the main framework document.

The organisations concerned recognise that, to make this framework operationally useful, significant investment in capacity development and a closely supported process will be necessary, and that this must be assembled and targeted on the basis of need.

As a result, a programme of capacity development is being developed for eight African countries participating in the Water and Climate Development Programme (WACDEP) – Burundi, Rwanda, Burkina Faso, Ghana, Cameroon, Tunisia, Zimbabwe, and Mozambique. The capacity development work commences not with blueprint training modules, but with a two-phase assessment of demand, with a view to tailoring the support to key stakeholders – government planners across various ministries, including economic planning, energy and agriculture besides water; as well as representatives of regional organisations, such as regional economic communities and river basin organisations.

Source: GWP, 2013; GWP and AMCOW, 2012.

To succeed, such processes require dedication from all concerned, and a willingness to look outside the comfort-zone which many establish within their disciplinary niche, to appreciate that different kinds of knowledge and ways of making sense of the world, may be valid. Trust and relationships need to be built, implying an important role for neutral agents who can encourage all – expert and non-expert alike – to challenge their own preconceptions about what is the 'right answer' for a given problem. Informal ways to interact and learn, ordinarily excluded from the serious business of strategic planning, may come into their own (Box 6).

Box 6 Serious fun: Gaming for experiential learning around climate challenges

A group of researchers from the Red Cross and Red Crescent Climate Centre and partners have developed a series of participatory games for community-based climate adaptation. Their efforts start from the premise that there is a psychological tendency to place more emphasis on the risks of action than those associated with action, and to avoid decision-making in situations where losses, or trade-offs, appear inevitable. They argue that stakeholders can be encouraged to act on climate change where a 'perception of shared knowledge' can be fostered. While conventional learning and communication, such as media and formal education, may help build this shared knowledge, the researchers argue that it is neither as effective, nor as a rapid, as experiential learning in which our decisions have tangible consequences.

Experiential learning opportunities arising from real-life adaptation decisions, or inaction, are likely to be costly (for example, crop failure due to insufficient investment in forecasting capacity). In response, the researchers designed a range of games to replicate the key features of various complex climate adaptation challenges, giving participants the opportunity to engage, cognitively and emotionally, with the consequences of climate adaptation decisions.

In one example developed for Nicaragua and Guatemala, participants play as upstream or downstream subsistence farmers, given the option to plant crops, cut down trees, or plant trees on their land. Each option yields different returns in terms of income and altering flood risk. Flood and drought risks are meanwhile simulated using dice, with a climate change dimension introduced by the game facilitator after a period of initial play, by changing the odds of extreme rainfall occurrences. Players take part as individuals, and as part of a 'team' constituting the upstream or downstream community – winners are those that hold the most resources at the end of the game; players are 'out' if they run out of funds, and are told they must 'migrate to the city' to find work.

A core learning objective is for the game participants to develop an understanding of the role of ecosystem services in mitigating hydrological risk, and payments for ecosystem services as a mechanism for collectively managing these risks. At a certain point in the game, deforestation by upstream farmers starts to increase the odds of flood risk for downstream farmers. Downstream farmers have better land and thus usually amass resources quicker, while their upstream colleagues may find it more profitable to cut down trees than plant crops. Facilitated in the right way, participants can discover for themselves that a more beneficial option for both parties may be for downstream farmers to compensate upstream farmers in exchange for not cutting down trees.

Experiential learning through games is appealing and innovative. But it is also relatively new in strategic decision-making in relation to climate change. Game design is highly complex, requiring internally coherent rules while also giving participants access to new insights about complex problems and accurately depicting social, environmental, and economic systems, albeit simplistically. Effective facilitation of games is also demanding. The researchers acknowledge these challenges and are working to develop training for game facilitators, as well as improved monitoring and evaluation, to assess whether and how experiential learning through games affects people's real-life decision-making.

Source: Bachofen et al., 2013; Suarez et al., 2012.

The incentives to 'get things done' add to a perception that time and resources spent on process, rather than results, is wasted. These incentives arise for politicians wanting to see visible water infrastructure built within their term of office or for the project manager required to spend an allocated budget within a funding cycle. Indeed, where climate change is perceived to be an immediate and pressing threat, it may arise for the entire water management community. But it is worth remembering that big decisions, whatever the process used, invariably take a long time and use up a lot of resources. The urgency to address climate change is somewhat harder to dispute, but it is important not to lose sight of the fact that other things are important (why 'development' is such an important part of CCD). As noted at the start of this paper, water management is already a tough task. When it comes to making big decisions about big issues, then investment in process, in capacity, and mutual understanding is rarely wasted effort.

3.6 Conclusions and recommendations

The gap in all of the above is arguably data to generate the raw impulses that underlie the signals provided by a decision-support system. No matter what the quality of the concepts, tools, and processes provided to those making strategic decisions, there is a need for data which are relevant to the time and spatial scale in question, available in a timely manner, and reliable. In the rush to develop ever better and more sophisticated decision support, data are easily overlooked. Acquiring it is time consuming and expensive, and there are few shortcuts. Hydrological and hydro-meteorological monitoring capacity has deteriorated across much of the world (WWAP, 2012) and while remote-sensing can help fill the resulting gap, for some variables it does not yet remove the need for ground-truthing.

This last caveat aside, the observations in this paper point to various ways in which data and information can be better managed to inform decisions under uncertainty:

- Concepts like CCD and water security can help provide a common language and a unifying objective for different communities. The trick is to find sufficient commonality of understanding, while maintaining respect for the additional value that different perspectives bring.
- In practice, making such abstract concepts as CCD and water security operational requires devices to manage the huge volumes of information which are needed to characterise any complex problem. But certain principles need to be kept in mind in how they are designed and used.
    - Indicators need to be fit-for-purpose. It may be more practically useful to develop a number of simple indicators, tailored to the particular needs of different users and uses, rather than to design multidimensional indicators that amalgamate all key variables, but conceal underlying trends. A further key consideration is to ensure that indicators communicate what we do not know, as much as what we do. Qualitative and, where possible, quantitative statements of uncertainty can be helpful when presenting a given index.
    - Simulation models of climatic and hydrological systems are better used as exploratory devices, to increase our capacity to understand multiple futures and outcomes, including potential unexpected events, than as predictors of any single future.
    - Frameworks for decision-making can be reoriented away from an emphasis on designing an optimal solution for a single future, judged 'most-likely', to locating the option that is most robust to a wide range of futures. Multiple sources and types of information can be brought in to characterise those different visions of the future, the likely performance of decision options across those futures, and the

effectiveness of different ways to reduce the remaining vulnerabilities of the preferred, robust option.

- Beyond tools for compartmentalising, reducing, and reframing information, decision support under uncertainty needs to offer new ways of working. Skilful facilitation and tailored capacity development are required to equip individual actors with the right skills and expertise and also help them exchange and learn from one another. Novel methods, such as gaming, may yet be more valuable than conventional, unidirectional forms of learning and communication, to help participants explore a problem collaboratively and relate their decisions and actions to material consequences.

References

Alliance for Global Water Adaptation (AGWA). (2012) Resilient infrastructure, institutions, and information. Integrating climate adaptation in water management decisions through the AGWA decision support system (DSS). Available at: http://www.unece.org/fileadmin/DAM/env/water/meetings/Core_group_pilots/3rd_meeting_2013/presentations/AGWA_DSS_brief_2013ii20.pdf

Bachofen, C., Suarez, P., Steenbergen, M., and Grist, N. (2013) Can games help people manage the climate risks they face? The participatory design of educational games. Climate and Development Knowledge Network (CKDN) Working paper. CKDN, London, UK.

Bates, B., Kundzewicz, Z., Wu, S., and Palutikof, J. (2008) Climate change and water. Technical paper of the Intergovernmental Panel on Climate Change (IPCC). IPCC Secretariat, Geneva, Switzerland.

Brown, C., Werick, W., Leger, W., and Fay, D. (2011) A decision analytic approach to managing climate risks: application to the Upper Great Lakes. *Journal of the American Water Resources Association*, **2**(47): 524–534.

Calow, R., Bonsor, H., Jones, L., O'Meally, S., MacDonald, A., and Kaur, N. (2011) Climate change, water resources, and WASH. Scoping study. Overseas Development Institute, London, UK.

Conway, D. (2013, forthcoming) Water security in a changing climate. pp. 80–100. In: *Water Security: Principles, Perspectives and Practices* (Lankford, B.A., Bakker, K., Zeitoun, M., and Conway, D. Eds). Earthscan, London, UK.

Dessai, S. and Hulme, M. (2007) Assessing the robustness of adaptation decisions to climate change uncertainties: a case study on water resources management in the East of England. *Global Environmental Change*, **17**: 59–72.

Doczi, J. (2014) Managing climate risk for the water sector in an uncertain world: tools and decision support. In: *Climate Change and Water Resources (*Shrestha, S., Babel, M.S., and Prasad Pandey, V. Eds). CRC Press, Boca Raton, FL, USA.

Global Water Partnership and African Ministers Council on Water (GWP and AMCOW). (2012) *Water Security and Climate Resilient Development: Strategic Framework*. GWP, Stockholm, Sweden and AMCOW, Abuja, Nigeria.

Helio International. (2012) Guide pour les décideurs énergétiques: choisir l'écodéveloppement. Helio International, Paris, France.

Hirsch Hadorn, G., Hoffmann-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., Wiesmann, U., and Zemp, E. (Eds). (2008). *Handbook of Transdisciplinary Research.* Springer Science + Business media BV, Dordrecht, Netherlands.

Hummelbrunner, R. and Jones, H. (2013) A guide for planning and strategy development in the face of complexity. Overseas Development Institute (ODI) background note. ODI, London, UK.

Mastrandrea, M.D., Field, C.B., Stocker, T.F., Edenhofer, O., Ebi, K.L., Frame, D.J., Held, H., Kriegler, E., Mach, K.J., Matschoss, P.R., Plattner, G-K., Yohe, G.W., and Zwiers, F.W. (2010): *Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties*. Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland.

Milly, P., Betancourt, J., Falkenmark, M., Hirsch, R.M., Kundzewicz, Z.W., Lettenmaier, D.P., and Stouffer, R.J. (2008) Stationarity is dead: whither water management? *Science*, **319**: 573–574.

Mitchell, T. and Maxwell, S. (2010) *Defining Climate Compatible Development*. Climate and Development Knowledge Network, London, UK.

Molle, F. and Mollinga, P. (2003) Water poverty indicators: conceptual problems and policy issues. *Water Policy* **5**: 529–544.

Mollinga, P.P. (2010) Boundary work and the complexity of natural resources management. *Crop Science*, **50**(Supplement 1): S-1–S-9.

Overseas Development Institute, Deutsches Institut für Entwicklungspolitik, and European Centre for Development Policy Management (ODI, DIE and ECDPM). (2012) *Confronting Scarcity: Managing Water, Energy and Land for Inclusive and Sustainable Growth*. European Report on Development 2011/12. European Union, Brussels, Belgium.

Peduzzi, P., Chatenoux, B., de Bono, H., de Bono, A., Deichmann, U., Guiliani, G., Herold, C., Kalsnes, B., Kluser, S., Løvholt, F., Lyon, B., Maskrey, A., Mouton, F., Nadim, F., and Smebye, H. (2010) The global risk analysis for the 2009 Global Assessment Report on Disaster Risk Reduction., International Disaster and Risk Conference (IDRC), Davos 2010, 30 May–3 June 2010. On-line conference proceedings, IDRC, Davos.

Pielke, R.A., and Wilby, R.L. (2012) 'Regional climate downscaling: what's the point?' *Eos, Transactions American Geophysical Union*, **93**(5): 52–53.

Ramalingam, B., Jones, H., Reba, T., and Young, J. (2008) *Exploring the Science of Complexity: Ideas and Implications for Development and Humanitarian Efforts.* ODI: London, UK.

Shah, T., Deb Roy, A., Qureshi, A.S., and Wang, J. (2003) Sustaining Asia's groundwater boom: an overview of issues and evidence. *Natural Resources Forum*, **27**: 130–140.

Suarez, P., Mendler de Suarez, J., Koelle, B., and Boykoff, M. (2012) Serious fun: scaling up community based adaptation through experiential learning. Working paper. Available at: http://cdkn.org/wp-content/uploads/2012/02/Red-Cross-paper-2.pdf

Stocker, T., Dahe, Q., and Plattner, G.K. (2013) Climate Change 2013: The Physical Science Basis. Final draft (7 June 2013) of the IPCC WGI Fifth Assessment Report. Intergovernmental Panel on Climate Change, Geneva, Switzerland.

United Nations Environment Programme (UNEP). (2012) *The UN-Water Status Report on the Application of Integrated Approaches to Water Resources Management.* UNEP, Nairobi, Kenya.

United Nations Office for Disaster Risk Reduction (UNISDR). (2011) *Global Assessment Report on Disaster Risk Reduction*. UNISDR, Geneva, Switzerland.

UN Water. (2013) Water security and the global water agenda. UN Water analytical brief. United Nations University Institute for Water, Environment and Health, Hamilton, ON, Canada.

Wang, J., Rothausen, S.G.A., Conway, D., Zhang, L., Xiong, W., Holman, I.P., and Li, Y. (2012) China's water–energy nexus: greenhouse-gas emissions from groundwater use for agriculture. *Environmental Research Letters* **7**(1): 014035 doi:10.1088/1748-9326/7/1/014035

Weaver, C.P., Lempert, R.J., Brown, C., Hall, J.A., Revell, D., and Sarewitz, D. (2013) Improving the contribution of climate model information to decision making: the value and demands of robust decision frameworks. *Wiley Interdisciplinary Reviews: Climate Change* **4**(1): 39–60.

World Bank. (2010) *Sustaining Water for All in a Changing Climate*. World Bank Group implementation progress report. World Bank, Washington, DC, USA.

World Economic Forum (WEF). (2009) *Energy Vision Update 2009: Thirsty Energy: Water and Energy in the 21st Century.* WEF, Geneva, Switzerland.

World Water Assessment Programme (WWAP). (2012) *The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk,* WWAP, UNESCO, Paris, France.

4. Indicators for assessing national water security: Asia Water Development Outlook 2013

Authors: Ian W Makin, Wouter Lincklaen Arriens, and Narciso Prudente, Asian Development Bank[1]

Abstract

The Asian Water Development Outlook (ADWO) 2013 (ADB 2013) presents a framework for the assessment of water security in five key dimensions:

- household water security
- economic water security
- urban water security
- environmental water security
- resilience to water-related disasters.

Measuring the status of water security in five dimensions represents the inherent tension among water uses that emerge as water resources come under increasing stress from competing water use sectors. The AWDO indicators framework may also be used for measuring the outcome of integrated water resources management (IWRM). This paper sets out the data requirements, data sources, and computational methods used in the 2013 edition of AWDO. Initial assessments of the national water security index for 20 countries, including 7 countries listed in the AWDO 2013 report and 13 selected from Africa, the Americas, and Europe.

4.1 Introduction

Water security is both an increasing concern and an urgent need for sustainable development in Asia and the Pacific. An increasing frequency of floods and droughts, uncontrolled releases of pollutants to rivers and lakes, and high levels of political dialogue about climate change impacts have brought water issues to the notice of the public across the region. Expanding populations need more water for drinking, hygiene, and food production. Expanding economies demand an increased energy supply, which in turn relies on access to more water. Most of the industries that are driving economic growth across the region require reliable supplies of freshwater in some part of their process. At the same time, as communities become wealthier, demand for the protection of ecosystems increases. The competing demands for water resources for these different uses make integrated water resources management (IWRM) essential to enable provision of secure water services.

The Asian Water Development Outlook (AWDO) was created by the Asia-Pacific Water Forum (APWF) and Asian Development Bank (ADB) to highlight important water management issues. The first edition (ADB, 2007) was to inform leaders meeting in the first Asia-Pacific Water Summit in Beppu, Japan (ADB, 2007, APWF, 2007). The inaugural edition underlined the need to address water security with a broader perspective than traditional sector-focused approaches. It highlighted governance as a common factor that has constrained efforts to increase water security in Asia and the Pacific. The report was well received by leaders, practitioners, and the media and was translated

[1] The views expressed in this paper are those of the authors and do not necessarily reflect the views and policies of the Asian Development Bank (ADB), its Board of Governors, the governments they represent, or the views and policies of the Asia-Pacific Water Forum (APWF).

into four languages. In response to its two key messages and the Beppu summit, APWF and ADB set out to prepare a second edition (ADB, 2013) to answer the implicit challenge facing the leaders at the Beppu summit, namely that *we cannot manage what we do not measure*.

AWDO 2013 (ADB, 2013) introduced the quantitative measurement of water security and lays a foundation for the measurement of progress towards a water-secure future for the people of Asia and the Pacific. The country-based findings, rankings, and key messages in the report indicate directions and priorities for increased investment, improved governance, and expanded capacity building. They also provide a baseline for the analysis of trends and the impact of policies and reforms that can be monitored and reported to stakeholders through future AWDO editions.

As a foundation to guide development of an analytical framework, the team crafted a shared vision of water security, as follows:

Societies can enjoy water security when they successfully manage their water resources and services to:

- satisfy household water and sanitation needs in all communities
- support productive economies in agriculture, industry, and energy
- develop vibrant, liveable cities and towns
- restore healthy rivers and ecosystems
- build resilient communities that can adapt to change.

This shared vision provided the basis for a broad definition of water security. By measuring water security in five dimensions the indicators provide leaders with new ways to look at the strengths and weaknesses of water resources management and service delivery.

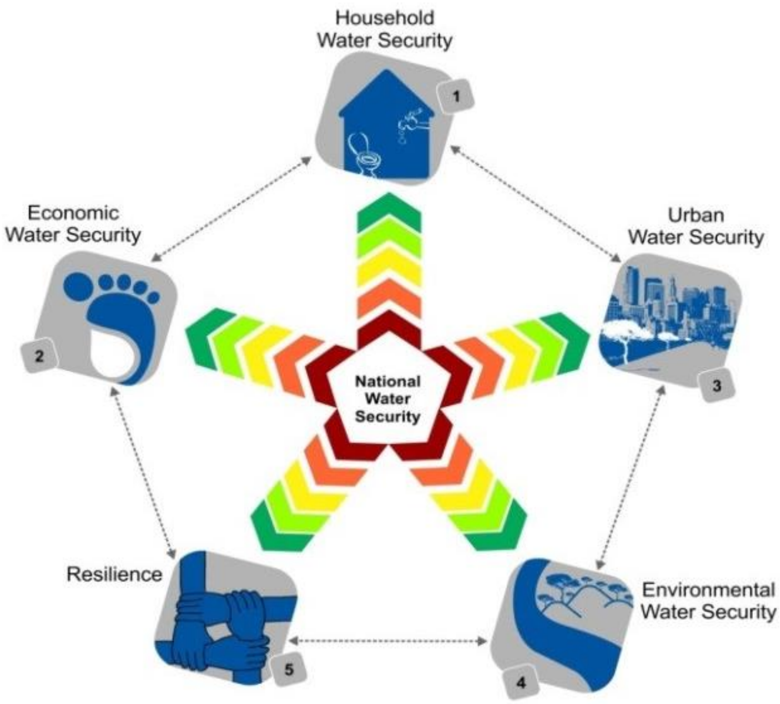

Figure 1 Water security framework of five interdependent key dimensions

Table 1 National water security index for selected countries (AWDO, 2013)

Country	KD1	KD2	KD3	KD4	KD5	Total	National water security indicator	Index
Australia	5	3	4	4	5	21	4.20	4
Brazil	3	3	3	3	3	15	3.00	3
Bulgaria	5	3	2	1	3	14	2.80	3
Cambodia	1	<u>2</u>	1	2	1	7	1.40	1
Canada	5	3	3	5	5	21	4.20	4
China, People's Republic of	3	<u>3</u>	2	2	2	12	2.40	2
Egypt	4	3	2	1	3	13	2.60	2
Ethiopia	1	3	2	3	2	11	2.20	2
Georgia	3	<u>2</u>	2	2	3	12	2.40	2
Kyrgyz Republic	3	3	2	2	1	11	2.20	2
Mexico	3	3	2	2	3	13	2.60	2
Morocco	3	3	2	1	3	12	2.40	2
Mozambique	1	3	2	3	2	11	2.20	2
Nepal	1	3	1	2	3	10	2.00	2
Pakistan	1	<u>3</u>	1	1	1	7	1.40	1
Poland	5	3	2	1	3	14	2.80	3
Slovakia	5	3	2	<u>***1***</u>	3	14	2.80	3
Spain	5	3	3	1	4	16	3.20	3
Tanzania	1	4	2	3	2	12	2.40	2
Uruguay	5	3	3	3	4	18	3.60	3

Notes: KD – key dimension; KD1 – Household water security; KD2 – Economic water security; KD3 – Urban water security; KD4 – Environmental water security; KD5 – Resilience. Numbers shown in <u>***underlined bold italic***</u> type indicate a rating from expert opinion (no data available). Results for KD2 shown <u>underlined</u> indicate where the assessment has changed from the earlier AWDO 2013 publication as a result of the exclusion of the resilience sub-indicator due to lack of comparable data for countries outside Asia and the Pacific region.

4.2 Measuring water security

4.2.1 KD1 – Household water security[2]

Household water security is the foundation and cornerstone of what happens in households in rural and urban areas. Providing all people with reliable, safe water and sanitation services is an urgent goal reflected by the inclusion of specific targets for both in the Millennium Development Goals (MDGs). Household water security is essential for eradicating poverty and supporting economic development. KD1 measures domestic water security at the household level.

[2] The description of the KD1 indicators is based on work undertaken by Le Huu Ti and Ermina Sokou of UNESCAP for AWDO 2013. Further details are available on the background DVD for AWDO 2013 – in preparation.

4.2.1.1 Definition

KD1 builds on existing indicators using the WHO/UNICEF Joint Monitoring Programme (2012) data for estimates of access to water and sanitation. Unfortunately, existing data sets do not measure the quality or sustainability of water supply and sanitation services. KD1 uses disability-adjusted life year (DALY)[3] as a proxy estimate of the sustainability of access to water and sanitation (water quality) and of human and environmental health outcomes.

KD1 provides an assessment of the extent to which countries are satisfying their household water and sanitation needs and improving hygiene for public health in all communities. It is a composite of three sub-indices (i) access to a piped water supply (%), (ii) access to improved sanitation (%), and (iii) hygiene (age-standardised DALYs per 100,000 people for the incidence of diarrhoea).

To assess the degree of household water security for each country, the data are categorised on a five point scale (Table 2) corresponding to progressively improving security in each sub-dimension (access to piped water, access to sanitation, DALYs).

Table 2 Categorisation matrix – household water security

Piped water access		Access to sanitation		Hygiene		Household water security	
%	Category	%	Category	DALY	Category	Indicator	Index
0	1	0	1	0	5	0	1
60	2	60	2	100	4	4	2
70	3	70	3	200	3	7	3
80	4	80	4	500	2	13	4
90	5	90	5	760	1	14	5

Note: Household water security indicator represents a composite of the of the three categories of piped water access, access to sanitation, and hygiene.

4.2.1.2 Strengths and weaknesses

This indicator’s strength is the regular updating of the national statistics on access to water supply and sanitation services, with strong support and oversight by WHO/UNICEF Joint Monitoring Programme partners. However, the lack of quantitative estimates of quality and sustainability of those services makes it necessary to include the DALY information as a proxy. Estimates of DALY are updated less frequently than the water supply and sanitation data.

4.2.1.3 Results

The data for the household water security indicators are the most readily available as the data are closely linked to on-going monitoring of progress towards achieving the MDGs. The results for a sample of 20 countries, including seven previously reported (ADB, 2013) are shown in Table 3.

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[3] DALY is defined as the age-standardised disability-adjusted life years per 100,000 inhabitants caused by diarrhoea. This is a measure of an overall disease burden, expressed as the number of years lost through poor health, disability, or early death.

Table 3 KD1 – household water security index

Country	Piped water access	Piped water index	Sanitation access	Sanitation index	DALY	DALY index	Indicator	Index
Australia	***90%***	5	100%	5	30	5	15	5
Brazil	92%	5	79%	3	532	2	10	3
Bulgaria		***4***	100%	5	45	5	14	5
Cambodia	17%	***1***	31%	1	2,170	1	3	1
Canada		4	100%	5	34	5	14	5
China, People's Republic of	68%	2	64%	2	324	3	7	3
Egypt	96%	5	95%	5	454	3	13	4
Ethiopia	8%	1	21%	1	3219	1	3	1
Georgia	73%	3	95%	5	597	2	10	3
Kyrgyz Republic	53%	1	93%	5	905	1	7	3
Mexico	89%	4	85%	4	209	3	11	3
Morocco	60%	2	70%	3	512	2	7	3
Mozambique	8%	1	18%	1	1766	1	3	1
Nepal	18%	1	31%	1	1,345	1	3	1
Pakistan	36%	1	48%	1	1,072	1	3	1
Poland	98%	5	96%	5	43	5	15	5
Slovakia		***4***	100%	5	35	5	14	5
Spain	99%	5	100%	5	31	5	15	5
Tanzania	8%	1	10%	1	2,084	1	3	1
Uruguay	98%	5	100%	5	126	4	14	5

Notes: DALY – age-standardised disability-adjusted life years – is a measure of the diarrheal incidence per 100,000 people. Numbers shown in ***underlined bold italic*** type indicate a rating from expert opinion (no data available).

4.2.2 KD2 – Productive economies[4]

Water is an essential input to grow food and fibre, for many industrial processes, and to generate the energy required by society. The use of water in these sectors is increasingly recognised as closely related and can no longer be addressed in isolation from each other. Debate about the water-food-energy nexus has begun to raise general awareness about the critical interactions among water uses to support economic activities. Economic water security measures the productive use of water to sustain economic growth in the food production, industry, and energy sectors of the economy.

4.2.2.1 Definition

To assess water use in the agriculture, industry, and energy sectors, data were used from a combination of sources (e.g. FAO, 2007, 2013; WRI, 2009). The indicators are aggregates of multiple sub-indicators, defined to highlight key aspects of water security in a particular sector as described in the following sections.

Water is essential for agricultural production and agriculture uses the largest proportion. Three components were considered to characterise water use and to estimate the degree of water security in productive agricultural economies; namely:

- resilience
- agricultural dependency
- efficiency of use.

Each component includes multiple sub-components. To develop a score for each component, the sub-component rankings were aggregated such that a 10 point scale was achieved.[5] If there were two sub-indicators, rankings were simply added. If there were three sub-indicators, rankings were added and the sum was multiplied by 2/3. The overall score for water security for agriculture was determined by averaging the scores in the three individual components.

4.2.2.2 Resilience

Resilience refers to the ability of a country to cope with the adverse effects of rainfall variability. Recognising that agricultural water use is vulnerable to rainfall variability[6] and that water storage constitutes a viable method to mitigate the effects of that variability, a first indicator focuses on these two key issues. We first determined the proportion of renewable water resources stored in each country by dividing the quantity stored in large dam reservoirs (ICOLD, 2003) by the country's renewable water resources (FAO, 2007). Only one storage option, large dam storage, provided the most accessible data across countries, therefore it was used in this analysis. Countries were stratified into five groups depending on the proportion of their renewable water resources that they store, with larger storage levels scoring higher than lower ones. For rainfall variability, we used country-level data on the inter- and intra-annual rainfall coefficient of variation obtained from the Tyndall

[4] The description of the KD2 indicators is based on work undertaken by H. Manthrithilake and J. Lautze, of the IWMI, and T. Facon and L. Whiting, of the FAO, for AWDO 2013. (ADB 2013).

[5] In the original definition of the agricultural water security indicator a quintile approach was adopted which divided the countries into five groups of roughly equal size to categorise countries into one of five ranks in each sub-component. In AWDO 2013 countries were assessed in water security stages on the basis of computed indicator values and categorisation bands.

[6] Other water uses are vulnerable to rainfall variability as well. Given the greater role of water in agriculture and that agriculture, after the environment, is usually the residual water user, agriculture can be considered particularly vulnerable.

Centre (2005). The degree of inter- and intra-annual rainfall variability were each also divided into five groups, with lower rainfall variability scoring higher than larger rainfall variability.

Table 4 Resilience assessment matrix

Storage		Inter-annual rainfall		Intra-annual rainfall	
Proportion of MARR (%)	**Indicator**	**CV**	**Indicator**	**CV**	**Indicator**
	A		B		C
0	1	0	5	0	5
3	2	0.025	4	0.20	4
5	3	0.050	3	0.40	3
20	4	0.100	2	0.60	2
50	5	0.150	1	0.75	1

Note: MARR – mean annual renewable resource; Resilience = 2*(A+B+C)/3.

In the preparation of this paper we were not able to obtain a reliable data set to enable computation of this sub-indicator. Therefore, a sensitivity test was made to examine excluding the sub-indicator, using the 39 countries reported in the AWDO 2013 report. This revealed that ignoring the resilience indicator reduced the estimated KD2 index by one unit for four of the seven of the countries of the original AWDO data set. However, the overall national water security index did not change as a result of the exclusion of the resilience sub-indicator. Therefore for the purposes of this paper, this sub-indicator has been ignored in the results presented.

4.2.2.3 Agricultural dependency

Recognising that a greater dependence on water and goods from outside a country can leave it more insecure, this indicator assesses i) the proportion of a country's water emanating from outside its boundaries and ii) the degree of consumption of agricultural goods (translated into units of water) relative to the amount of water withdrawn for agriculture in a country.[7] To determine the proportion of water emanating from outside a country, we used the dependency ratio (FAO, 2007). To determine consumption of agricultural goods relative to agricultural water withdrawal in a country, we used water footprint (Hoekstra and Chapagain, 2008) data and divided by agricultural water withdrawals. A higher number indicates greater reliance on agricultural imports, and a lower number indicates greater domestic agricultural production relative to consumption. A five point scale was then applied – countries withdrawing an amount of water that is close to the amount necessary for the agricultural goods that they consume were rated 5, while countries that appear heavily dependent on imports were rated 1.

Table 5 Matrix for the assessment of agricultural dependency

External water dependency	Agricultural consumption independence

[7] An alternative way to conceptualise this is as the net virtual water consumed/withdrawn water. All water is for agriculture in this equation.

Proportion of external RWR (%)	Indicator[a]	Agricultural footprint	Indicator[b]
0	5	<1	1
20	4	1	2
40	3	9	3
60	2	20	4
90	1	60	5

Note: Agricultural water security = a + b; RWR – renewable water resources.

4.2.2.4 Agricultural use efficiency

This defines a function of agricultural water productivity, the proportion of arable land irrigated, and the rainfall. To characterise the productivity of water use in irrigated agriculture, we considered the dollar value per unit of water in agriculture, the proportion of each country's arable land that is irrigated, and a country's level of rainfall on an annual basis. To determine agricultural water productivity, we first divided each country's agricultural gross domestic product (GDP) (UNESCAP, 2009) by the cubic kilometres of water withdrawn for agricultural use each year. This was placed on a five point scale, where 5 represents a high value generated per unit of water and 1 represents a low value. As agricultural GDP includes production from non-irrigated agriculture, which does not necessarily require water withdrawal, we determined the proportion of arable land irrigated. The areas of irrigated and arable land were obtained from the ResourceSTAT database (FAO, 2007), and the proportion determined by simple division. A five point classification system was then applied, where 5 indicates that a high proportion of a country's arable land is irrigated, and 1 indicates a low fraction irrigated. The classification system is illustrated in Table 6.

Table 6 Agricultural water use efficiency matrix

Agricultural water productivity		Arable land irrigated	
$M/km^3	Indicator[a]	Proportion (%)	Indicator[b]
0	1	0	1
100	2	20	2
200	3	30	3
350	4	45	4
1,000	5	60	5

Notes: $M/km^3 – US$ million per cubic kilometre of water use. Use efficiency = a + b.

4.2.2.5 Assessing industrial water use

Similar measures were applied to industrial water use. However, the number of indicators used for industry was much smaller than for agriculture. The reduced number of indicators reflects both the reduced proportion of water claimed by industrial uses in countries as well as the relative dearth of data related to water and industry. Our water-industry indicator is the composite of two sub-indicators. The first focuses on water productivity in industry, and the second on consumption of industrial goods (in terms of units of water) relative to water withdrawn for industry.[8] To calculate water productivity, we divided the financial value generated for industrial goods in each country (UNESCAP, 2009) by the amount of water withdrawn for industry in that country (FAO, 2007). Values were classified on a five point scale, where 5 represents a greater financial value per unit of water, and 1 is a lower financial value. To determine the ratio of the consumption of industrial goods to industrial withdrawal, we divided the quantity of water used to produce the industrial goods consumed in a country (Hoekstra and Chapagain. 2008, Water Footprint Network, no date) by the amount of water withdrawn for industry. A five point scale was then applied; a value of 5 being assigned to countries producing close to what they consume, and a value of 1 being assigned to countries who appear heavily dependent on imports.

Table 7 Water security in industry matrix

Industrial water productivity		Industrial consumption	
$M/km³	**Indicator[a]**	**Industrial footprint**	**Indicator[b]**
0	1	0	1
2,100	2	0.6	2
5,500	3	1.0	3
20,000	4	1.75	4
50,000	5	2.0	5

Notes: $M/km³ – US$ million per cubic kilometre of water use. Water security in industry = a + b.

4.2.2.6 Assessing water use for energy

Given the direct linkages between water, hydropower, and energy supply in a country and data constraints related to water use for cooling, we used an energy indicator directly focused on hydropower. The two sub-indicators focused on the proportion of a country's technically exploitable hydropower capability that has been tapped and the relative contribution of hydropower to a country's energy supply. The proportion of technically exploitable hydropower capability currently used was calculated by dividing the amount of electricity currently generated by the technically exploitable potential (WEC, 2007). The result was ranked on a five point scale, where 5 indicates a relatively low percent tapped, and 1 indicates a relatively high percent. It is important to note that even though a country may have a large proportion of its hydropower potential untapped, not all of that potential can be sustainably developed. Further, as highlighted below among our caveats, it must be acknowledged that extraneous factors, such as population density, play a critical role in spurring the development of a country's hydropower resources. The contribution of hydropower to a country's energy supply relative to other sources was obtained from the International Energy Agency (IEA, 2009). A five point classification scale was used – 5 for higher contributions of hydropower to overall energy supply, to 1 for a lower contribution of hydropower to overall energy

[8] An alternative way to conceptualise this is as the net virtual water consumed/withdrawn water. All water is for industry in this equation.

supply. Scores for each sub-indicator were added to produce an aggregate score for hydropower. A score of 10 indicates that hydropower makes a relatively large contribution to a country's energy use and there is still large potential to tap new hydropower sources. A score of 2 indicates that hydropower makes only a relatively small contribution to a country's energy use and there is little additional potential to develop new sources of hydropower.

Table 8 Water security for energy production matrix

Hydropower potential		Hydropower dependency	
Proportion developed (%)	**Indicator[a]**	**Proportion of energy use (%)**	**Indicator[b]**
0 ≤ 1.5	5	0 ≤ 4.0	1
1.5 ≤ 8.0	4	4.0 ≤ 8.0	2
8.0 ≤ 14.3	3	8.0 ≤ 17.0	3
14.3 ≤ 30.0	2	17.0 ≤ 50.0	4
> 30.0	1	> 50	5

Note: Use efficiency = a + b.

4.2.2.7 Overall productive economies index

To determine an overall productive economies index, results for each of the three sectors were summed, producing a 30-point scale. In Table 9 below, therefore, the score for each of the sectors is on a 10 point scale, and the overall maximum that can be achieved by a country for all three sectors is 30 points. Just as the scales of 1 through 10 indicate an increasingly effective use of water for productive economies in a particular sector, so the broader score on a 30-point scale characterises an increasingly effective water use for productive economies in all three sectors (on aggregate). A higher score indicates more effective water management for productive economies.

The economic water security index measures how countries are ensuring the productive use of water to sustain their economic growth in food production, industry, and energy. The International Water Management Institute (IWMI) and FAO were involved in developing sub-indices for each of the three sectors, using three main indicators that characterise water security. Each sub-index is evaluated on a ten point scale, with 1 being insecure and 10 being secure. The mean of the scores for each sub-index gives the total economic water security of the country's economy. The maximum score for the index is 30 (10 points for each of the three sub-indices that make up the index). A factor for resilience is incorporated into each of these sub-indices to indicate the intra- and inter-annual rainfall variability and water resources storage.

Table 9 Results: KD2 – economic water security index

Country	Agriculture	Industry	Energy	Indicator	Index
Australia	4.33	4.67	4.00	13.00	3
Brazil	5.33	4.67	6.00	16.00	3
Bulgaria	4.89	2.89	4.44	12.22	3

Cambodia	2.67	3.56	5.11	11.33	2
Canada	5.22	4.22	5.78	15.22	3
China, People's Republic of	5.67	5.56	5.78	17.00	3
Egypt	5.78	5.78	4.89	16.44	3
Ethiopia	4.78	4.44	7.56	16.78	3
Georgia	5.00	-	6.22	11.22	2
Kyrgyz Republic	4.67	4.00	6.67	15.33	3
Mexico	5.89	4.89	4.44	15.22	3
Morocco	5.44	5.11	5.56	16.11	3
Mozambique	4.22	4.89	5.78	14.89	3
Nepal	5.00	3.56	6.44	15.00	3
Pakistan	4.67	6.22	6.44	17.33	3
Poland	4.67	4.00	3.33	12.00	3
Slovakia	3.44	4.44	4.22	12.11	3
Spain	6.11	5.11	4.89	16.11	3
Tanzania	5.44	5.11	7.56	18.11	4
Uruguay	4.33	4.67	5.33	14.33	3

Notes: Expert opinion was used to estimate values for countries with insufficient data to compute the sub-indicators. In this table, all countries have been assessed without the rainfall resilience index included, as data for this sub-indicator could not be obtained for countries outside the Asia-Pacific region. This resulted in the indices for Cambodia, People's Republic of China, Georgia, and Pakistan being reduced by one unit. Additional data collation will be required to obtain the data for the resilience sub-indicator.

4.2.3 KD3 – Urban water security (liveable cities)[9]

Water plays an increasingly vital role in achieving sustainable, liveable cities (Water Services Association of Australia, 2011). According to the ADB Water Operational Plan 2011–2020 (ADB, 2011), growing cities in Asia need more water supply and improved sanitation to sustain the urban economy, livelihoods, and overall quality of city life.

Over 50 percent of the world's population now lives in cities. In Asia and the Pacific, about 43 percent of the population currently lives in urban areas, having risen by 29 percent over the past 20 years; a more rapid increase than in any other region (UNESCAP, 2010). After a century of transformation from agrarian rural societies to urban centres, and the creation of the world's largest number of megacities, Asia's cities have become important economic drivers. The urban water security indicators measure the creation of better water management and services to support vibrant and liveable water-sensitive cities.

[9] The description of the KD3 indicators is based on work undertaken by Eva Abal and Mark Pascoe, of the International Water Centre, Brisbane, and Phang Tsang Wing, of Public Utilities Board, Singapore, for AWDO 2013. Further details are available on the background DVD for AWDO 2013 – in preparation.

Water resources are often viewed as renewable and limitless, with little or no recognition that watershed use, surface water and groundwater quality, rainfall, climate, hydrology, and geography are inextricably linked with biodiversity, human health, liveability, and sustainable economic prosperity. The idea that we need to invest in cleaning up our water resources and that it is a real cost to the community is relatively new and continues to shift as cities and towns continue to pursue sustainability. Thus, as cities pursue increasing states of sustainability a paradigm shift is required from managing waterways as a source of water to managing waterways for future generations.

4.2.3.1 A framework for water-sensitive cities

A water-sensitive city is defined as one that integrates water supply, sewage, storm-water, and the built environment; a city that respects the value of urban waterways; and a city where citizens value water and the role it plays in sustaining the economy, environment, and society (Brown et al., 2009).

In Australia, researchers and practitioners have traced the changing function of water resources and the socio-political drivers as cities pursue increasing states of sustainability. The term *water-sensitive cites* was coined as an expression to describe a city transitioning to a more sustainable water future (Figure 2). Brown et al., (2009) revealed that the early stages of transition – which they call a water supply city, a sewered city, or a drained city – were logical expansions of the services provided by governments. For instance, governments levied a tax on behalf of communities, with an implicit promise to provide a cheap and unlimited water supply and, ultimately, public health protection, through sewage and drainage services. The pollution of water, over-extraction, and over-allocation were considered an acceptable cost to the public.

4.2.3.2 Definition of indicators

In alignment with the rationale for using the first three steps of the water-sensitive cities framework, the urban water security index is a composite of three sub-indices addressing water supply coverage, wastewater treatment, and urban flooding.

PROPORTION OF URBAN WATER SUPPLY COVERAGE (WATER SUPPLY CITY)

The proportion of urban water supply coverage is the most fundamental indicator of a city's water security. The majority of data for this indicator was sourced from the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (2012). In addition, data was obtained directly by the Public Utilities Board, Singapore through a survey of water resource boards in selected cities. This is only a proxy indicator for a water supply city because it does reflect other factors, such as availability of the water source, quality of potable water supplied, sustainability of services, pricing, and equity of service delivery. The indicator value for urban water supply is assessed, based on the proportion of the urban population provided with piped water services, from the assessment matrix presented in Table 10.

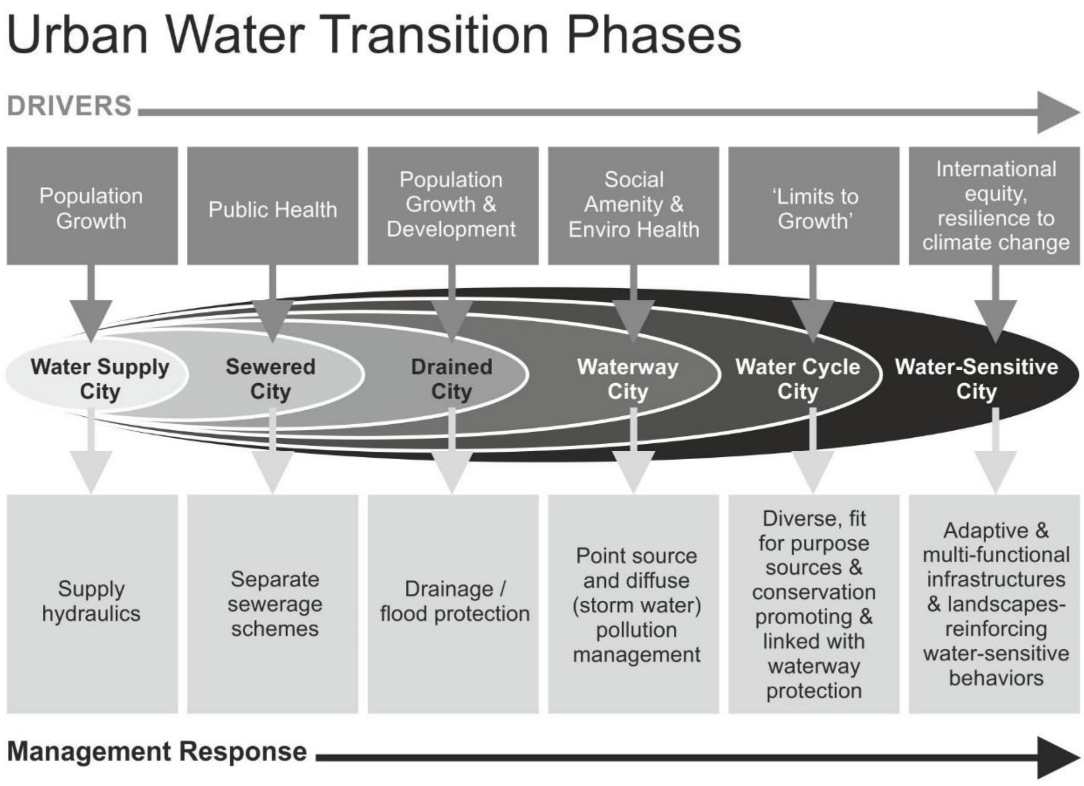


Figure 2 Water-sensitive cities framework
Source: Brown et al., 2009

PROPORTION OF WASTEWATER TREATED (SEWERED CITY)

The available literature indicates that, although indicators of the proportion of land area (or population) with sewerage coverage are available, these may not provide adequate insight into the extent of wastewater treatment. The definition of sewerage coverage varies, including: (i) sewerage coverage, in which wastewater is conveyed by pipe to specified (mostly centralised) treatment facilities of greater or lesser sophistication; (ii) on-site treatment; and (iii) more advanced wastewater treatment plants in some countries. A number of different formulations for estimating the 'Sewered city' concept were tested; however the most readily available and robust data set for the proportion of wastewater was chosen. Data were obtained from FAO AQUASTAT (FAO, 2013).

Table 10 Water supply and wastewater treatment assessment matrix

Coverage (%)	Urban water supply indicator	Wastewater treatment indicator
0%	1	1
60%	2	2
70%	3	3
80%	4	4
90%	5	5

EXTENT OF URBAN FLOODING (DRAINED CITY)

This indicator was available only for countries, rather than for cities, and is a proxy for the extent of the drainage infrastructure and flood protection within cities. It is expressed as the monetary damage brought about by flood and storm incidents in a country, compared with its urban population's vulnerability to such incidents.[10]

The 'Drained city' indicator was assessed from the reported extents of flood damage (US$/year) standardised to per capita loss as a proportion of per capita GDP. The urban flooding indicator is assessed based on the standardised loss estimate as shown in Table 11.

Table 11 Urban flood damage assessment matrix

Standardised loss (Percent per capita GDP/year)	Urban flood damage indicator
0.0	5
0.5	4
6.0	3
10.0	2
14.0	1

An initial value for urban water security is estimated as the sum of the indicators Table 10 and Table 11. This value is modified by multiplying by the urbanisation correction factor (Table 12) and scaled by dividing by 5.

Table 12 Urbanisation Correction Factor

Urbanisation rate (%/year)	Urbanisation correction factor
−2	1.0
2	0.9
3	0.8

The national river basin health index is used as a proxy indicator for likely urban river management by adding a further correction factor to the initial urban water security indicator value. The urban river management factor was assessed as zero (0) for a river basin health index value less than three and as unity (1) for an index value of three and above. The urban water security index is assessed as shown in Table 13.

[10] Data for assessment of urban water security were obtained from the UNESCAP (2012) data from 2000–2011. The author used UNESCAP 2009 for flood and storm data. But the UNESCAP website indicates their data source for natural disaster indicators is EM-DAT.

Table 13 Urban water security index assessment matrix

Urban water security indicator	Urban water security index
x < 1.8	1
1.8 ≤ x < 2.8	2
2.8 ≤ x < 3.8	3
≤ x < 4.8	4
4.8 ≤ x	5

4.2.3.3 Results

The urban water security index is a composite of three sub-indices and adjustment factors representing urban growth rate and river basin health:

- urban water supply (%)
- wastewater treated (%)
- drainage (measured as the extent of economic damage caused by floods and storms)
- adjustment factors for urban growth rate and river health.

Table 14 KD3 – urban water security index

Countries	Piped urban water supply access	Water supply index	Waste water treatment	Waste water index	Flood-storm damage loss (US$/ capita)	Drainage index	Indicator	Urban factor	River health index	Index
Australia	100%	5	96%	5	338.76	4	14	1.0	1	4
Brazil	96%	5	15%	1	15.22	5	11	1.0	0	3
Bulgaria	98%	5	42%	1	86.08	4	10	1.0	0	2
Cambodia	63%	2	9%	1	56.14	2	5	0.8	0	1
Canada	100%	5	77%	3	47.72	5	13	1.0	1	3
China, People's Republic of	95%	5	58%	1	119.58	4	10	0.9	0	2
Egypt	100%	5	47%	1	0.00	5	11	0.9	0	2
Ethiopia	46%	1	0%	1	0.67	5	7	0.8	1	2
Georgia	92%	5	74%	3	0.95	5	13	1.0	0	2
Kyrgyz Republic	89%	4	48%	1	1.46	5	10	1.0	0	2
Mexico	93%	5	11%	1	146.64	4	10	1.0	0	2
Morocco	89%	4	11%	1	10.91	5	10	0.9	0	2
Mozambique	19%	1	3%	1	73.15	3	5	0.8	1	2
Nepal	53%	1	12%	1	13.87	4	6	0.8	0	1
Pakistan	58%	1	34%	1	36.43	4	6	0.8	0	1
Poland	99%	5	60%	2	40.69	5	12	1.0	0	2
Slovakia	95%	5	54%	1	130.59	4	10	1.0	0	2
Spain	99%	5	87%	4	71.82	5	14	1.0	0	3
Tanzania	22%	1	1%	1	0.00	5	7	0.8	1	2
Uruguay	98%	5	14%	1	22.58	5	11	1.0	1	3

Note: Expert opinion was used to estimate the values for countries with insufficient data to compute the sub-indicators.

4.2.4 KD4 – Environmental water security[11]

4.2.4.1 River basin health

Rivers provide multiple goods and services that support human activities. However, it is only over the past 150 years or so that the delicate balance between people and rivers has begun to change significantly when communities and industries began to treat rivers as agents of economic and social opportunity, waiting to be altered and used. Many rivers are now vulnerable to pressures from pollution, diminished flows, watershed deterioration, and increasing populations and industrial activities. The uneven distribution of water resources over time and space, and the way human activity is affecting that distribution today, are fundamental sources of water crises in many parts of the world (Vörösmarty, 2008).

Asia's environment and precious natural resources have suffered greatly from decades of neglect as governments across the region prioritised rapid economic growth over environmental objectives. Asia's leaders are now starting to 'green' their economies as a broader focus on sustainable development and inclusive growth gains ground. The environmental water security indicator assesses the health of rivers and measures progress on restoring rivers and ecosystems to health on a national and regional scale. The sustainability of development and improved lives depends on these natural resources. There is a need to manage water resources and services more effectively while simultaneously halting further degradation and restoring rivers to health.

4.2.4.2 Calculating the river basin health indicators

The analysis of the river health index (RHI) is based on the 2010 study (Vörösmarty, 2008) of biodiversity threats (BD threats) to rivers, including 23 separate input drivers representing four types of threat to river biodiversity. The RHI is calculated, as the reciprocal of the BD threat index, as a measure of river health relative to biodiversity. All data used in the BD threat and RHI analyses were developed by Vörösmarty et al. (2010) using a 0.5° grid cell size. A total of 23 input drivers relevant to BD threat analysis are organised into four themes – watershed disturbance, pollution, water resource management, and biotic factors.

These groupings reflect different threat pathways from anthropogenic forcing. A three-stage process is used to convert the input driver values into standardised driver scores, which are then aggregated to give the BD threat index. This conversion process enables accounting for downstream propagation of threats, normalisation for downstream changes in discharge, and expresses all drivers on a common scale. The three steps are as follows:

- Threat levels associated with each driver are routed down river corridors (Fekete et al., 2001) to reflect downstream accumulations of threat resulting from the propagation of stressors along flow paths within the basin.
- Routed driver values are normalised by grid-cell-specific discharge ($\bar{Q}_i$) to account for dilution of stressors as water flow increases or decreases downstream.
- Normalised driver scores for all grid cells with active flow are standardised on a continuous zero to 1 scale based on a cumulative distribution function. This rescaling procedure replaces each raw driver score with its percentile within the frequency distribution of scores across all grid cells, placing all drivers on the same numerical scale.

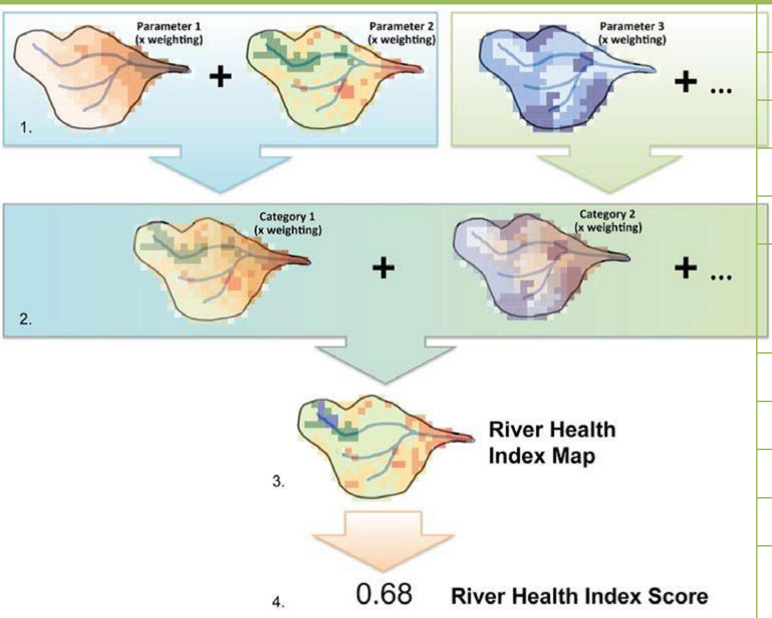
[11] The description of the KD4 indicators is based on work undertaken by Eva Abal, of the International Water Centre, Brisbane, for AWDO 2013. Further details are available on the background DVD for AWDO 2013 – in preparation.

All drivers are assessed for each theme for computation of the index of aggregate incident BD threat, with weights assigned to indicate the relative magnitude of the threat posed. Each driver is assigned a weight relative to the other drivers in the same theme (collectively summing to 1), and each theme is assigned a weight relative to all other themes (also collectively summing to 1). Where no score can be calculated for a particular driver in a grid cell (e.g. in the case of cropland in grid cells with no agricultural land use), it was set at zero to reflect a presumed lack of threat. The weights for drivers and themes are listed in Appendix 1.

The weights used in these analyses are taken from the expert opinions of eight authors, collectively representing a wide range of disciplinary expertise (river ecology, civil engineering, environmental economics, hydrology, water resource assessment) and work experience on most continents (north and south America, western and eastern Europe, Africa, southeast Asia, Australia). A longer description of the computation scheme for each driver is given in Appendix 1.

4.2.4.3 Results

Table 15 KD4 – environmental water security



Country	River health input data, processed in GIS spatial analysis	Indicator	Index
Australia		0.59	4
Brazil		0.51	3
Bulgaria		0.10	1
Cambodia		0.29	2
Canada		0.72	5
China, People's Republic of		0.26	2
Egypt		0.18	1
Ethiopia		0.37	3
Cambodia		0.29	2
Georgia		0.26	2
Kyrgyz Republic		-	***2***
Mexico		0.22	2
Morocco		0.16	1
Mozambique		0.47	***3***
Nepal		0.26	2
Pakistan		0.12	1
Poland		0.10	1
Slovakia		-	***1***
Spain		0.08	1
Tanzania		0.41	3
Uruguay		0.41	3

Note: Expert opinion was used to estimate values for countries with insufficient data to compute the sub-indicators. Numbers shown in ***underlined bold italic*** type indicate a rating from expert opinion (no data available).

The RHI measures:

- pressures/threats to river systems from watershed disturbances and pollution
- vulnerability/resilience to alterations to natural flows by water infrastructure development and biological factors. This may be intrinsic (vulnerability of river/river basin to pressures) or extrinsic (level of degradation of ecosystems).

4.2.5 KD5 – resilience to water-related hazards[12]

Recent global figures show that the number of water-related disasters is increasing – 2,831 were reported globally from 2000 to 2008 (Centre for Research on the Epidemiology of Disasters, 2010). Furthermore, over 80 percent of deaths resulting from natural disasters are attributed to water-related disasters affecting millions of people, especially the poor. Water-related disasters, therefore, represent a major impediment to the achievement of human security, poverty eradication, and sustainable socio-economic development.

The region's growing prosperity has involved unprecedented changes in economic activity, urbanisation, diets, trade, culture, and communication. It has also brought increasing levels of uncertainty and risk from climate variability and change. The security of communities in Asia and the Pacific with respect to these changes, and especially to water-related disaster risks, is assessed through the indicator of resilience to water-related disasters. The building of resilient communities that can adapt to change and are able to reduce risk from natural disasters related to water must be accelerated to minimise the impact of future disasters.

There is an increasingly global consensus on the importance of water-related risk management. Management requires quantification of water-related disaster losses at a finer temporal and spatial resolution than is currently available for the analysis of trends. Such analysis will provide estimates of vulnerability and resilience and allow assessment of the effectiveness of mitigation policies and investments. For AWDO 2013, the indicators of resilience to water-related disasters (KD5) use measures of each country's level of hazard, exposure, vulnerability, and coping capacity to estimate the resilience index. The complexity of assessment of water-related disasters is such that the computations of the resilience indicators are the most complex in the AWDO water security index.

4.2.5.1 Definition of indicators

Evaluation of water-related disaster risk requires an understanding of hazard, vulnerability, exposure, and coping capacity (Box 1). Risk is the probability of harmful consequences or expected losses (e.g. deaths, injuries, or damage to property, livelihoods, economic activity, or the environment) resulting from interactions between natural or human-induced hazards and conditions in the community. The strengthening of coping capacities usually builds resilience to natural and human-induced hazards. A combination of hazard, vulnerability, exposure, and coping capacity constitutes the risk faced by a population. Therefore, a basic concept of disaster risk (R) is formulated as described below.

Disaster risk (R) is defined as an indicator of expected disaster damage per capita, taking into account the likelihood of occurrence and likely severity. Likelihood of occurrence is not measured by

[12] The description of the KD5 indicators is based on work undertaken by Yoshiyuki Imamura and Yoganath Adikari of the International Centre for Water Hazard and Risk Management (ICHARM) and Madhav Karki and Hua Ouyang of the International Centre for Integrated Mountain Development (ICIMOD) for AWDO 2013. Further details are available on the background DVD for AWDO 2013 – in preparation.

a strict joint probability of hazard occurrence and vulnerability, but by a statistical average of hazardous phenomena, such as an area's average daily maximum precipitation.

Box 1 Framing water-relevant indicators in the energy sector

- A hazard is a potentially damaging physical event, phenomenon, or human activity that may cause the loss of life, injury, property damage, social or economic disruption, or environmental degradation.
- Vulnerability comprises the physical, social, economic, and environmental factors or processes that increase a community's susceptibility to the effects of hazards.
- Exposure comprises the people, property, systems, or other elements present in the area affected by a hazard.
- Capacities are the means by which people or organisations use available resources and abilities to face adverse consequences of hazards that could lead to a disaster. In general, this involves managing resources, both in normal times and during crises or adverse conditions.

Disaster risk is therefore expressed by:

$R = \Sigma\mathrm{HtLoss}(Ht^\wedge, Vt)$

where Ht is hazard type, $Ht^\wedge$ is an indicator of extreme statistics of hazard type Ht, Vt is vulnerability to hazard type Ht, and Loss is an indicator of expected loss per capita from $Ht^\wedge$ and Vt.

The disaster risk indicator provides a means of comparing target cells, regions, or nations and is not an assessment of the absolute level of risk.

DEVELOPMENT OF THE RESILIENCE INDICATOR

Disaster risk is the product of hazard (H) and vulnerability (V):

$R = H \times V$

Vulnerability is a function of exposure (E), basic vulnerability (V_B), and coping capacity (C), where coping capacity can reduce vulnerability by, at most, the total of exposure and basic vulnerability and is expressed as:

$V = (E + V_B)(1 - C/C_{\mathrm{MAX}})$

where $V_B = 0$ if $E = 0$ and C_{MAX} is the hypothetical maximum coping capacity.

This expression implies that with no coping capacity ($C = 0$), the vulnerability is a sum of exposure and vulnerability ($E + V_B$), and that with full coping capacity ($C = C_{\mathrm{MAX}}$), vulnerability can be fully compensated for, becoming $V = 0$.

If exposure is zero, then basic vulnerability should also be zero ($E = 0$, $V_B = 0$). Although the relation is not explicit in this formula, it is obvious that if there are no people or assets in the hazard zone then there is no vulnerability.

Coping capacity is considered in terms of hard coping capacity (C_H), achieved through structural means, and soft coping capacity (C_S) the result of non-structural means:

$$C = C_H + C_S$$

Coping capacity can be further divided into direct coping capacity (*D*) and indirect coping capacity (*I*). Direct capacity includes actions and means specifically designed for disaster risk reduction (e.g. distribution of flood forecasts by mobile phones), whereas indirect capacity is assessed from other societal factors (e.g. mobile phone availability). The distinction of direct and indirect capacities applies both for soft coping capacity and hard coping capacity. The coping capacity can then be expressed as follows:

$$C_S = C_S D + C_S I$$

$$C_H = C_H D + C_H I$$

$$C = C_H + C_S = (C_H I + C_S I) + (C_H D + C_S D)$$

These distinctions are important because, although direct capacity can be improved through the efforts of disaster managers, indirect capacity is beyond the efforts of disaster managers. Even if there is little direct capacity ($C_H D + C_S D$), there remains much that can be done to reduce disaster risk. If there is already much direct capacity, then there is little that disaster managers can do in the way of disaster risk reduction. The ratio $(C_H D + C_S D)/C_{MAX}$ is an indicator of direct disaster management capacity and may be called the manageable capacity ratio.

C_{MAX} is the maximum coping capacity available to compensate for all of the vulnerabilities of a given society. This is a hypothetical concept and can be replaced by the maximum coping capacity available, multiplied by expectations. An arbitrary factor of 1.5 was selected and applied to the maximum coping capacity presently available (C_{MCPA}).

$$C_{MAX} = 1.5 \times (C_{MCPA})$$

Each sub-indicator (H, E, V_B, C_S, and C_H) is estimated by a sum of selected base factors whose number may be arbitrary, as in the case of hazard: $H = (F_1 + F_2 + \ldots + F_{KH})(K_{MAX}/K_H)$, where K_{MAX} is the maximum number of sub-indicator factors and K_H is the number of sub-indicators for the class of hazard.

The average operation of dividing by K_{MAX} standardises the different numbers of indicators selected for each indicator. Each factor and indicator is standardised into [0, 1], such as:

$$H1 = (\log F_1 i - \log F_{1MIN})/(\log F_{1MAX} - \log F_{1MIN})$$

where $F_1 i$ indicates the F_1 value of target cell, region, or nation i and F_{1MIN} and F_{1MAX} indicate the minimum and maximum value of F_1 among all cells, regions, or nations. The logarithm is used to adjust the differences of values in multiple orders of any base indicators.

The resilience indicator (Res) is defined as a reciprocal of vulnerability:

$$Res = 1/V = 1/(E + V_B)(1 - C/C_{MAX})$$

4.2.5.2 Procedure to compute resilience indicator

The resilience indicators are estimated for (i) floods and windstorms, (ii) droughts, and (iii) storm surge and coastal flooding. For each type of water-related disaster risk, the resilience indicator is computed by:

Select factors:

Hazard = F_{H1}, F_{H2}, ..., F_{KH};

Exposure = F_{E1}, F_{E2}, ...

Basic vulnerability = F_{VB1}, . . .

Standardise the factors:

$F_1 = (\log F_1 i - \log F_{1\text{MIN}})/(\log F_{1\text{MAX}} - \log F_{1\text{MIN}})$

Calculate the value of sub-indicators *H, E,* V_B*, and C* as an average of the standardised basic indicators:

$H = (F_{H1} + F_{H2} + \ldots + F_{KH})\ (K_{\text{MAX}}/K_H)$

Note that if $E = 0$, then $V_B = 0$.

Estimate C_{MAX} (AWDO assumes maximum observed capacity, $C_{\text{MCPA,}}$ is 66 percent of the maximum achievable – hence the application of a factor of 1.5 to estimate C_{MAX}):

C_{MAX} = 1.5 x Maximum value of present capacity (C)

Calculate disaster risk:

$R = H(E + V_B)(1 - C/C_{\text{MAX}})$ (1)

Calculate resilience:

$\text{Res} = 1/(E + V_B)(1 - C/C_{\text{MAX}})$ (2)

Resilience (equation. 2) is the inverse of risk (equation. 1) with the exclusion of the factor for hazard (H). The factors considered in the computation of the indicators are summarised in Appendix 2.

A country's coping capacity, exposure, and basic vulnerability to water-related hazards shape its resilience. Countries with more economic power have better coping capacity because they are more developed and because citizens are better informed or warned about the hazards to which they are exposed and are, therefore, less vulnerable. These countries are more capable of recovering from the shock of a disaster. However, coping capacity is not always enough to shape resilience. Theoretically, even if coping capacity is high, there is a possibility that resilience is not. For instance, the country may have high vulnerability or exposure, such as densely populated, low-elevation coastal zones.

Although countries with less advanced economies may be exposed, vulnerable, and have lower coping capacity than wealthy countries, a country with low population density and thus low exposure, may be more resilient. Resilience is dependent on factors including population, individual economic capacity, population density, disaster mitigation infrastructure and organisation, economic growth, and effective governance. These factors combine to support sustainable development and poverty reduction.

The estimate of national water-related disaster resilience is computed from the sum of standardised [0, 1] resilience estimates for (i) floods and windstorms, (ii) droughts, and (iii) storm surge and coastal flooding (equation. 2) translated to an index as shown in Table 16.

Table 16 Resilience to water-related disaster index assessment matrix

Sum of standardised resilience indicators	Water-related resilience index
x ≤ 0.5	1
0.5 ≤ x < 1.0	2
≤ x < 2.0	3
2.0 ≤ x < 2.5	4
2.5 ≤ x	5

Table 17 KD5 – hazard and vulnerability indicators (risk index)

Country	Hazard	Exposure	Vulnerability	Hard capacity	Soft capacity	Indicator	Risk index
Australia	8.14	3.64	0.98	9.67	13.31	5.94	0.15
Brazil	8.51	6.37	4.36	11.09	10.77	15.72	0.20
Bulgaria	6.03	4.23	3.49	9.51	12.09	8.06	0.10
Cambodia	3.49	10.24	11.44	7.47	6.55	17.45	0.43
Canada	9.35	2.93	0.77	10.98	11.83	5.84	0.08
China, People's Republic of	7.68	6.85	5.32	10.52	11.18	16.19	0.40
Egypt	6.19	10.18	4.76	10.03	8.52	18.57	0.24
Ethiopia	6.29	8.84	9.84	1.18	2.83	36.83	0.47
Georgia	3.10	2.22	4.68	9.54	10.22	3.96	0.10
Kyrgyz Republic	3.75	3.38	5.06	5.34	5.82	10.00	0.25
Mexico	12.52	7.68	4.97	11.84	10.93	25.60	0.33
Morocco	8.56	7.83	5.02	7.94	9.16	22.46	0.29
Mozambique	10.64	11.61	13.99	3.91	2.52	77.75	1.00
Nepal	3.19	8.15	7.12	5.29	2.66	17.92	0.44
Pakistan	6.23	9.24	8.29	9.90	4.71	25.51	0.63
Poland	8.77	6.10	2.38	11.43	11.13	12.16	0.16
Slovakia	4.01	5.91	3.27	12.17	11.32	6.70	0.09
Spain	8.83	7.49	1.72	15.61	12.54	9.81	0.13
Tanzania	7.49	11.22	12.24	5.26	5.13	44.27	0.57
Uruguay	6.36	4.27	1.28	10.41	11.16	6.04	0.08

4.2.5.3 Results

The water-related disaster resilience index is a composite of sub-indices based on type of hazard (floods/windstorms, drought, and storm surges/coastal floods), measuring:

- exposure (population density, growth rate)
- basic population vulnerability (poverty rate, land use)
- a country's hard coping capacities (e.g. telecommunications development level)
- a country's soft coping capacities (e.g. literacy rate)

Table 18 KD5 – resilience to water-related hazards

Country	Flood indicator	Drought indicator	Coastal indicator	Indicator	Index
Australia	1.03	1.37	1.49	3.00	5
Brazil	0.67	0.66	0.28	1.61	3
Bulgaria	0.88	0.74	0.32	1.94	3
Cambodia	0.20	0.20	0.19	0.34	1
Canada	0.97	1.00	1.00	2.97	5
China, People's Republic of	0.44	0.43	0.48	0.75	2
Egypt	0.60	0.49	0.09	1.18	3
Ethiopia	0.30	0.25	0.14	0.69	2
Georgia	0.77	1.63	0.68	1.22	3
Kyrgyz Republic	0.39	0.36	-	0.38	1
Mexico	0.68	0.57	0.26	1.52	3
Morocco	0.55	0.48	0.19	1.21	3
Mozambique	0.29	0.27	0.08	0.64	2
Nepal	0.18	0.09	-	0.20	1
Pakistan	0.24	0.16	0.25	0.41	1
Poland	0.72	0.64	0.43	1.78	3
Slovakia	0.77	0.68	0.36	1.81	3
Spain	0.97	0.83	0.44	2.44	4
Tanzania	0.35	0.29	0.09	0.73	2
Uruguay	1.00	0.84	0.48	2.31	4

Note: Expert opinion was used to estimate values for countries with insufficient data to compute the sub-indicators.

4.3 Future perspectives and challenges

In the international debate that has followed the Rio+20 Conference (United Nations, 2012), water has been recognised as a key component of sustainable development and poverty reduction. The Rio+20 conference launched efforts to develop proposals for post 2015 sustainable development goals (SDGs) to succeed the existing MDGs. There is considerable interest to ensure that the SDGs include specific water resource management targets, in addition to the goal of universal access to safe water supply and sanitation.

The water security concepts, presented in this paper, can provide a generic framework that would allow measurement of the outcome of IWRM. The AWDO water security framework is based on data that are, in the main, already monitored as part of the international efforts to assess progress against the MDGs. The framework and associated scale-relevant indicators will enable the evaluation of progress towards a water-secure future with application at local, river basin, and national scales.

IWRM is recognised as a process of adaptive management designed to enable resource managers to resolve the tensions inherent between water users that become increasingly significant as total water use is approached and, in many cases, exceeds the capacity of the resources. However, because IWRM is a process it is difficult to directly measure the status of IWRM, and in fact attempts to do so may lead to IWRM becoming a goal rather than a means to the desired end, namely water security. By assessing water security at the appropriate spatial scale, the outcome of the IWRM process can be measured and progress towards increased water security can be assessed.

The AWDO national water security index was applied to assess water security in a representative selection of 20 countries. Figure 3 illustrates that, although there is a trend of higher water security with higher water availability, per capita water availability is not a good indicator of national water security.

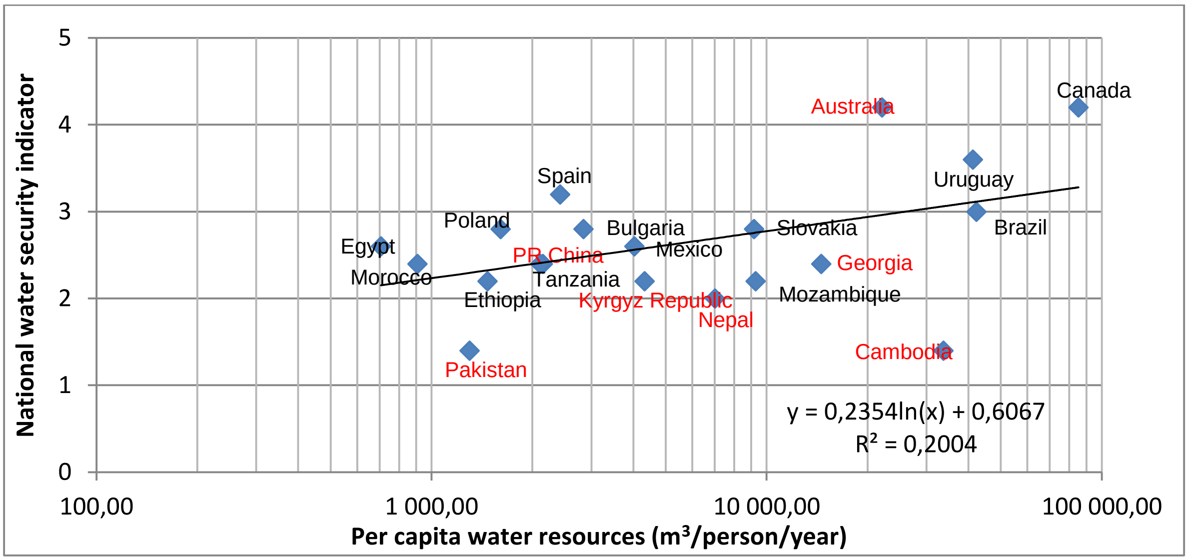


Figure 3 National water security index against per capita water resources

Figure 4 illustrates the distribution of national water security and GDP (2009 US$) which suggests that GDP and national water security are more closely related than simple per capita water availability.

Figure 5 shows that national water security is relatively well correlated with observed governance indicators; consistent with the observation in the first edition of AWDO (ADB, 2007) that future water scarcity will more likely to arise from poor governance rather than water resource limitations.

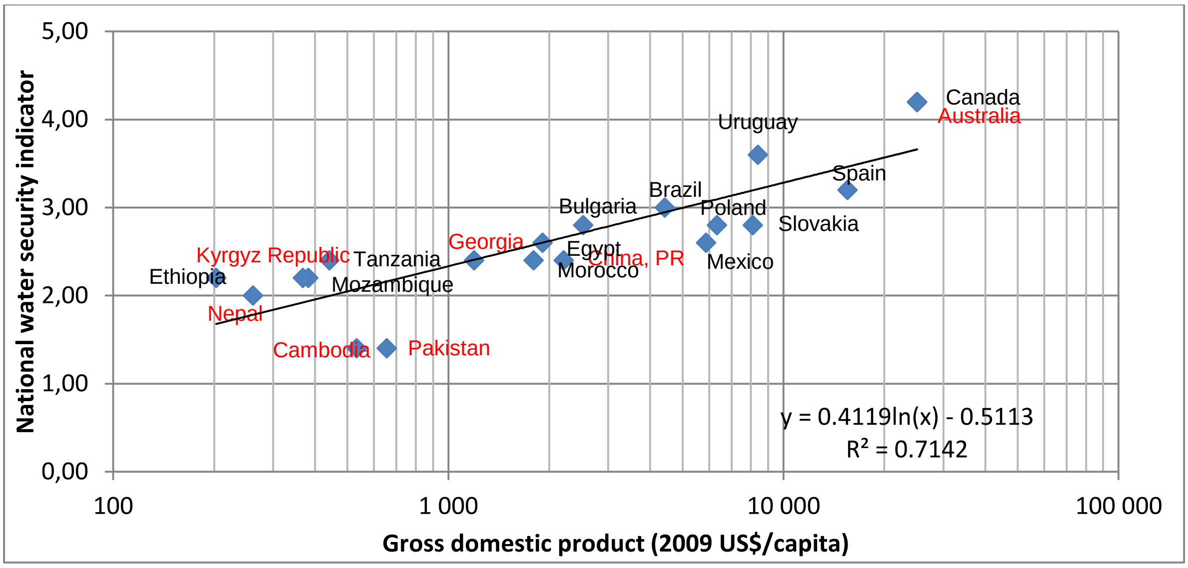


Figure 4 National water security index against per capita GDP (2009 US$)

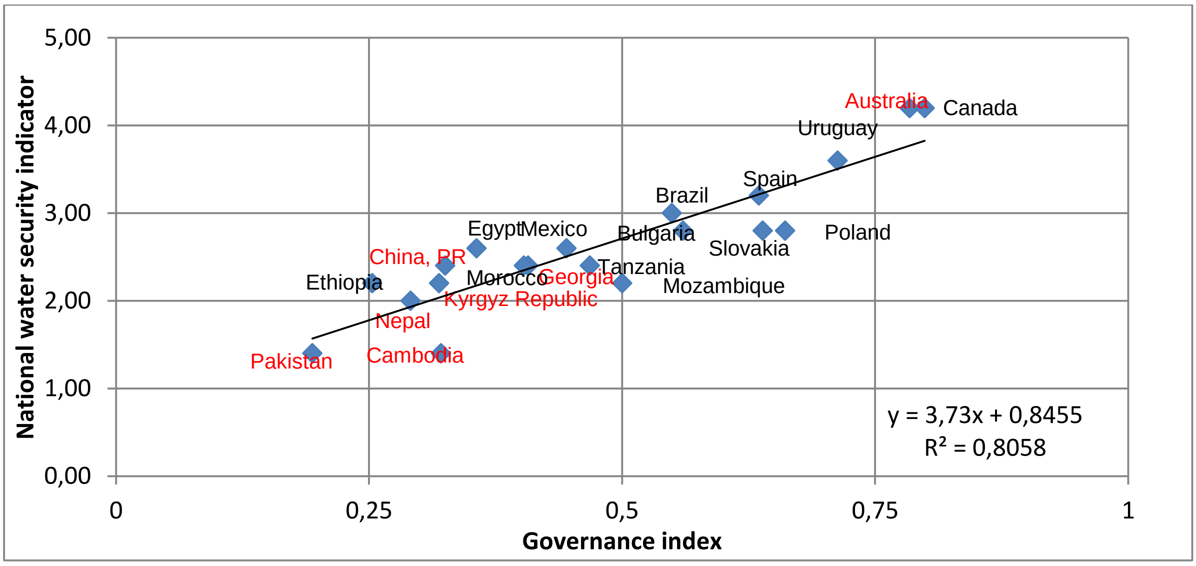


Figure 5 National water security index against governance index

Although the AWDO 2013 water security framework and indicators have provided a viable toolset for evaluation of national water security in the five dimensions defined by AWDO, the work is not yet complete. The indicator families will benefit from further research and testing to confirm the stability and sensitivity of the indices. The Asia and Pacific Centre for Water Security (APCWS) at Tsinghua University, Beijing will lead this research to test the robustness of the AWDO indicators in advance of the next edition of the AWDO, with early results expected to be available by the 7th World Water Forum in Daegu, Korea in April 2015. The authors are aware of a number of research efforts that are seeking to build on the AWDO framework in regions outside the original focus of AWDO. These initiatives, and others still to emerge, will enable national leaders and their water sector professionals to measure progress towards a water-secure world that results from investments in necessary infrastructure, management systems and public awareness.

References

Asian Development Bank (ADB). (2007) *Asian Water Development Outlook 2007*. ADB, Manila, Philippines.

Asian Development Bank (ADB). (2011) *Water Operational Plan 2011-2020*. ADB, Manila, Philippines.

Asian Development Bank (ADB). (2013) *Asian Water Development Outlook 2013*. ADB, Manila, Philippines.

Asia-Pacific Water Forum. (2007) First Asia-Pacific water summit: message from Beppu. Asia-Pacific Water Forum, Manila, Philippines.

Brown, R., Keath, N., and Wong, T. (2009) Urban water management in cities: historical, current and future regimes. *Water Science and Technology* **59**(5):847–55.

Centre for Research on the Epidemiology of Disasters. (2010) EM-DAT International Disaster Database. Available at: http://www.emdat.be

Fekete, B., Vörösmarty, C., and Lammers, R. (2001) Scaling gridded river networks for macroscale hydrology: development, analysis, and control of error. *Water Resources Research* **37**(7): 1955–1967.

Food and Agriculture Organization of the United Nations (FAO). (2007) ResourceSTAT database. Available at: http://faostat.fao.org/site/377/default.aspx

Food and Agriculture Organization of the United Nations (FAO). (2013) AQUASTAT database – FAO. Available at: http://www.fao.org/nr/water/aquastat/main/index.stm

Hoekstra, A. and Chapagain, A. (2008) *Globalization of Water: Sharing the Planet's Freshwater Resources.* Blackwell Publishing, Oxford, UK.

International Commission on Large Dams (ICOLD). (2003) *World Register of Large Dams.* ICOLD, Paris, France.

International Energy Agency (IEA). (2009) Statistics by country/region. Available at: http://www.iea.org/stats/index.asp

Tyndall Centre for Climate Change Research. (2005) *Coefficient of Variation Data.* Tyndall Centre for Climate Change Research, Norwich, UK.

United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP). (2009) Annual core indicators online database. Available at: http://www.unescap.org/publications/detail.asp?id=1333

United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP). (2010) *Statistical Yearbook for Asia and the Pacific 2009*. UNESCAP, Bangkok, Thailand.

United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP). (2011) *Statistical Yearbook for Asia and the Pacific 2011*. UNESCAP, Bangkok, Thailand. Available at: http://www.unescap.org/stat/data/syb2011/I-People/Urbanization.asp

United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP). (2012) *Statistical Yearbook for Asia and the Pacific 2012*. UNESCAP, Bangkok Thailand. Available at: http://www.unescap.org/stat/data/syb2012/

United Nations. (2012) The future we want. Outcome document. UN Conference on Sustainable Development. Available at: http://www.uncsd2012.org/content/documents/727The%20Future%20We%20Want%2019%20June%201230pm.pdf

Vörösmarty, C.J. (2008) *Water for a Crowded Planet: an Emerging Global Challenge for Earth System Science and Technology*. Taylor and Francis, London, UK.

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., and Gidden, S. (2010) Global threats to human water security and river biodiversity. *Nature* **467**: 555–561.

Water Footprint Network (WFN). (no date) Water footprints indicators. Available at: http://www.waterfootprint.org/?page=files/WaterStat-NationalWaterFootprints

Water Services Association of Australia (WSAA). (2011) A sustainable future for the urban water industry. Melbourne: Water Services Association of Australia.

World Energy Council (WEC). (2007) *Survey of Energy Resources: Hydropower.* WEC, London, UK.

World Health Organization and United Nations Children's Fund (WHO/UNICEF). (2012) *Progress on Drinking Water and Sanitation – 2012 Update.* WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation, New York, NY, USA.

World Resources Institute (WRI). (2009) EarthTrends environmental information database. Available at: http://earthtrends.wri.org/#

Appendix 1: Description of drivers and thematic groupings in the river basin health index[13]

The following descriptions summarise how the biodiversity threat (BD threat) indicators were computed by Vörösmarty et al. (2010) to form the basis for the AWDO 2013 river basin health index. A summary of the weightings factor for each driver and thematic grouping is given in the table at the end of this Appendix.

Theme 1: Watershed disturbance – captures the local-scale effect of land-use change and poor stewardship within drainage basins. Drivers include conversion to cropland (Driver 1), construction of impervious surfaces (Driver 2), destruction of riparian zones (Driver 3), and disconnection of wetlands from rivers (Driver 4).

Theme 2: Pollution – encompasses a broad suite of pollutants with well-documented direct or indirect negative effects on water resources and biodiversity. Drivers include salinisation (Driver 5), anthropogenic nitrogen loading (Driver 6), anthropogenic phosphorus loading (Driver 7), anthropogenic mercury deposition (Driver 8), pesticide loading (Driver 9), total suspended solids (Driver 10), organic loading, expressed as biochemical oxygen demand (Driver 11), potential acidification (Driver 12), and thermal impact (Driver 13).

Theme 3: Water resource management – includes a variety of ways in which humans have altered the quantity of water available to society. Drivers include the dam density within drainage basins (Driver 14), river network fragmentation by dams (Driver 15), relative water consumption (Driver 16), water stress (Driver 17), available water relative to cropland area (Driver 18), and changes in residence time within river networks (Driver 19).

Theme 4: Biotic factors – captures the local and spatially distributed impacts of changing the biota of river ecosystems. Humans have affected riverine fauna in many ways, but global data sets documenting such changes are largely unavailable. Here, we focus on three categories of impact: the introduction of non-native species, fishing, and aquaculture. Specific drivers include the proportion of non-native fish species (Driver 20), number of non-native fish species (Driver 21), fishing pressure (Driver 22), and aquaculture (Driver 23).

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[13] This annex is abstracted from the background paper prepared by Dr. Eva Abal, International Water Centre Knowledge Hub, describing the analysis of the river basin health index. Available on the DVD accompanying AWDO 2013 – in preparation. Further information is also available at: http://www.nature.com/nature/journal/v467/n7315/extref/nature09440-s1.pdf

Appendix 2: Data requirements and assessment period for KD5

Components of the floods and windstorm indicator

Sub-indicator	Factor	Year/period of data
Hazard	1. Maximum weekly average precipitation (mm)	2002 to 2009
	2. Cyclone proneness (hits and magnitude)	1998 to 2007
	3. Frequency (> 100 mm/day rainfall)	2002 to 2009
Exposure	1. Population density	Population: 2005 Land area: 2000
	2. Urban population growth rate	1985, 2005
	3. Population growth rate	1985, 2005
Vulnerability	1. Governance (likelihood of corruption)	2009
	2. Proportion of the population below US$1/day consumption	2005
	3. Net official development assistance as percent of gross net income	2005
	4. Deforestation rate	1990, 2005
	5. Infant mortality rate (per 1,000 live births)	2009
Hard coping capacity	1. Potential investment density (GDP per area)	GDP: 2005 Land area: 2000
	2. Total reservoir capacity per area	Total reservoir capacity: 2009 Land area: 2000
Soft coping capacity	1. Literacy ratio	2008
	2. Education (enrolment ratio)	2007
	3. Information (television receivers per 1,000 inhabitants)	1997
	4. Information (mobile phone subscriptions)	2010
	5. Economic growth (gross domestic saving)	2010

Components of drought indicator

Sub-indicator	Factor	Year/period of data
Hazard	1. Number of consecutive dry days (<5 mm rainfall)	2002 to 2009
	2. Dryland as a proportion of total area	1999
Exposure	1. Population density	Population: 2005 Land area: 2000
	2. Urban population growth rate	1985, 2005
	3. Population growth rate	1985, 2005
Vulnerability	1. Governance (likelihood of corruption)	2009
	2. Proportion of the population below US$1/day consumption	2005
	3. Net official development assistance as a proportion of gross net income	2005
	4. Agriculture gross production per GDP (%)	2005
	5. Infant mortality rate (per 1,000 live births)	2009
Hard coping capacity	1. Potential investment density (GDP per area)	GDP: 2005 Land area: 2000
	2. Total reservoir capacity per capita	Total reservoir capacity: 2009 Population: 2005
Soft coping capacity	1. Literacy ratio	2008
	2. Education (enrolment ratio)	2007
	3. Information (television receivers per 1,000 inhabitants)	1997
	4. Information (mobile phone subscriptions)	2010
	5. Economic growth (gross domestic saving)	2010

Components of storm surge/coastal flooding indicator

Sub-indicator	Factor	Year/period of data
Hazard	1. Cyclone susceptibility (hits and magnitude)	1998 to 2007
	2. Coastline length/land area	Coastline length: 2000 Land area: 2000
Exposure	1. Population density	Population: 2005, Land area: 2000
	2. Proportion of the population in lowland areas (below 10 m) (%)	2000
	3. Population growth rate	1985, 2005
Vulnerability	1. Governance (likelihood of corruption)	2009
	2. Proportion of population below US$1/day consumption	2005
	3. Net official development assistance as a proportion of gross net income	2005
	4. Infant mortality rate (per 1,000 live births)	2009
Hard coping capacity	1. Potential investment density (GDP per area)	GDP: 2005 Land area: 2000
	2. Infrastructure (paved road density)	2008
Soft coping capacity	1. Literacy ratio	2008
	2. Education (enrolment ratio)	2007
	3. Information (television receivers per 1,000 inhabitants)	1997
	4. Information (mobile phone subscriptions)	2010
	5. Economic growth (gross domestic savings)	2010

5. Water security indicators: the Canadian experience

Authors: Gemma Dunn[1], Karen Bakker[2], Emma Norman[3], Diana Allen[4], Christina Cook[5], Rafael Cavalcanti de Albuquerque[6], and Mike Simpson[7]

Abstract

This paper draws upon a four-year research project, which developed a water security framework as a tool for improved governance for watersheds in Canada. Key considerations are identified for measuring and assessing water security, relevant to selecting indicators and/or developing user-friendly application/implementation assessment frameworks. These considerations include: the need for stakeholder participation, scalar issues (specifically local-scale assessment), data considerations, multivariate analyses, governance tools, and incorporating risk. Moreover, our research findings highlight the importance of a broad and integrative approach to water quality and quantity, which incorporates human health and aquatic ecosystem health. The assessment of current water security status needs to be combined with the assessment of risks, and the results incorporated into an adaptive governance framework, which formalises a flexible 'learning by doing' approach that can respond to changing conditions.

5.1 Introduction

Indicators have proliferated rapidly over the past few decades, both in Canada and abroad. However, while many environmental indicators have been developed, their uptake is limited. Furthermore, environmental indicators are having limited influence on policy decisions. A wide range of indicators to assess and measure freshwater-related issues at multiple scales have been developed (Chaves and Alipaz, 2007; Falkenmark and Lundqvist, 1998; Falkenmark et al., 1989; Gleick, 1990; Heap et al., 1998; Meigh et al., 1998; OECD, 2002, 2008; PRI, 2007; Raskin et al., 1997; Sullivan and Meigh, 2007). However, relatively little progress has been made in the systematic application of indicator assessment methods or the translation of the results into changes in water use, governance, and policy (Falkenmark, 2007; UN WWAP, 2006). In Canada, for example, environmental statistics are generally not as timely as their economic and social cousins (Statistics Canada, 2009 p. 4). Typically, most Canadian federal level (and some provincial) indicator reports are released between two and five years after the data period they refer to. The slow pace at which indicators are released, combined with accessibility challenges, continues to inhibit their influence on policy cycles. This poor link between the development of indicators and decision-making is further exacerbated by two underlying factors: 1) the limited or absent interaction between indicator designers and decision-makers when indicators are developed; and 2) the limited availability and utility of indicators to decision-makers once the indicators are developed.

The key characteristics of a good indicator include: easy to access, easy to understand, timely (driven largely by data availability), relevance (including scale), credible, transparent, accurate, and enabling informed decision-making. The utility of indicators is greatly enhanced when the 'end-users' are

[1] Program on Water Governance, University of British Columbia, Vancouver, BC, Canada V6T 1Z4.
[2] Department of Geography and Program on Water Governance, University of British Columbia, Vancouver, BC, Canada V6T 1Z2.
[3] Department of Social Sciences, Michigan Technological University, Houghton, MI 49931, USA.
[4] Department of Earth Sciences, Simon Fraser University, Burnaby, BC, Canada V5A 1S6.
[5] Geography Department, Hebrew University of Jerusalem, Jerusalem, 91905 Israel.
[6] Schlumberger Water Services, Rio de Janeiro, Brazil.
[7] Department of Earth Sciences, Simon Fraser University, Burnaby, BC, Canada V5A 1S6.

engaged throughout the development process (Dunn, 2012; Dunn and Bakker, 2009, 2011; Norman et al., 2012). Different end-users have different needs as illustrated in Table 1.

Table 1 Target audiences and their indicator need

Target audience	Indicator needs
Technical experts and science advisors	Raw data Highly detailed and complex indicators Emphasis on scientific validity and system complexity
Policy-makers, decision-makers and resource managers	Indicators directly related to: • policy objectives • evaluation criteria • target values
General public and media	Reduced set of indicators Easy to understand Represent issue of direct concern

Source: (adapted) Environment Canada and Canada Mortgage & Housing Corporation, Guidelines for the Development of Sustainability Indicators, August 2001 (Dunn and Bakker, 2009).

In addition to addressing the needs of end-users, evaluation and feedback are also critical stages that ensure an indicator continues to achieve its purpose. In Canada however, indicator projects typically only go through one cycle with no feedback mechanism to re-evaluate whether or not the scope was met.

5.2 Inventory of freshwater-related indicators

Canada's constitutional division of powers has resulted in one of the most decentralised approaches to water (and environmental) governance (Bakker and Cook, 2011; Harrison, 1996; Saunders and Wenig, 2007). There are a myriad of government agencies at the federal, provincial, and municipal levels that engage in some way in the management of water resources. Responsibility for water resource management is highly complex as it is shared not just vertically between all three levels of government, but also horizontally, involving multiple government agencies, public authorities, and other actors (Bakker and Cook, 2011; Furlong and Bakker, 2011; Saunders and Wenig, 2007).

Currently in Canada, no central location or repository exists for freshwater-related indicators and their associated data, with no coordinated approach to their development. In 2008, the Program on Water Governance conducted an inventory of all freshwater-related indicators. A total of 365 indicators were identified, 295 of which were developed at federal, provincial, and regional (large-scale watershed) levels. A further 70 indicators were developed at community level (small-scale watershed). This inventory did not include any of the 50 bilateral agreements to which Canada is committed, which require information sharing and progress reports, nor did it include any international indicators (Dunn and Bakker, 2009, 2011).

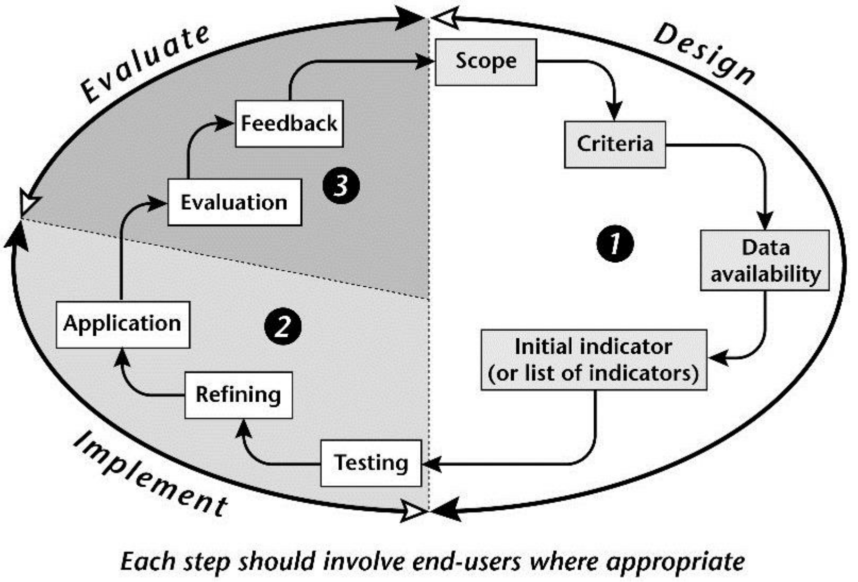

Figure 1 The indicator development cycle; design, implement, evaluate
Source: Dunn and Bakker, 2009

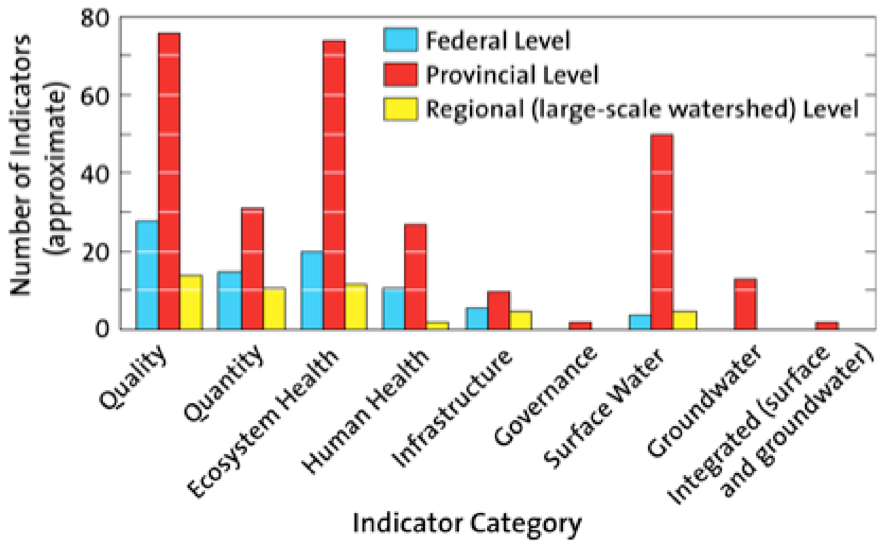

Figure 2 Types of freshwater-related indicators in Canada (March 2009)
Source: Dunn and Bakker, 2009, 2011

Once compiled, the inventory was analysed using five broad categories of water research and management – water quantity, water quality, ecosystem health, human health, infrastructure, and governance (Figure 2). This categorisation was chosen as it aligned closely with our initial project research areas. There are, however, obvious caveats to this categorisation approach, such as overlaps between groups (for example an indicator for level of wastewater treatment could be an indicator of human health or pollution in waterways).

In summary we found that of the 365 indicators:

- The majority measure water quality; relatively few focus on water quantity.
- There are significantly more ecosystem health indicators than human health indicators. Contaminant specific indicators (e.g. levels of nitrogen) are more common.
- Surface water indicators dominate; there are few groundwater indicators.

- There are only a handful of integrated (surface *and* groundwater) indicators.
- Water supply and demand indicators are largely disconnected; few indicators examine demand *in relation to* supply. Most indicators measure *either* demand *or* supply, more often demand.
- Infrastructure indicators are limited in number and in scope. The main focus is usually population served or level of wastewater treatment; few indicators reflect the condition of the supply infrastructure.
- Governance indicators are sparse and poorly developed. Two types of governance indicator exist: 1) *Governance rules:* the legal, constitutional, regulatory environment and 2) *Governance outcomes:* existence or absence of specific agencies. The latter is the most common governance indicator and the type found in Canada.

Overall, we found that indicators are narrowly focused and do not enable decision-makers to effectively assess and mediate between conflicting demands for water or negative land–water management practices. Moreover, our research identified three key issues, which we explore in more detail below: 1) lack of a shared definition of water security; 2) the limited number of user-friendly water security assessment tools; and 3) the need for risk to be incorporated into the water security assessment.

5.2.1 Defining water security

Water security has gained increasing attention over the past five years as evidenced by the increasing use of the term 'water security' and related research activity (Figure 3). Despite growing research interest, no common definition of water security exists. Multiple definitions are available from a wide range of disciplines including environmental studies (Schindler, 2001); hydrology (Döll et al., 2003); public health (Hrudey et al., 2003); multidisciplinary (Vörösmarty et al., 2010); and environmental sciences (Ashton, 2002), and are applied at varying scales (Cook and Bakker, 2012). The term is used to cover a range of potential threats to freshwater (Bakker, 2012), including:

- *Threats to drinking water supply systems* (e.g. via contamination and human impacts on aquatic ecosystems (GWP, 2000) or terrorist attacks (ODNI, 2012)), implying the need for enhanced monitoring and emergency preparedness.
- *Threats to economic growth and human livelihoods* from water-related hazards (e.g. floods and droughts), water stress, and water scarcity, notably with respect to food security (Scozzari and Mansouri, 2011) and energy security (Cook and Bakker, 2012), implying the need for both technological innovation and water conservation (UNEP, 2009).
- *Threats to biodiversity and water-related ecosystem service*s given increased absolute and per capita water consumption and growing agricultural water demands, leading to increased consumption of ecosystem services and biodiversity loss (Vörösmarty et al., 2010; WEF, 2011). This implies the need to move beyond an anthropocentric focus to jointly manage water for human and ecosystem needs, particularly given the possibility of 'tipping points' in critical socio-ecological systems (WWAP, 2012).
- *Increased hydrological variability* in the context of climate change (notably the increased amplitude and frequency of droughts and floods, or hydrological 'shocks'). This implies the need to develop innovative strategies for dealing with uncertainty (Nuzzo, 2006), which move 'beyond infrastructure' (Rockström et al., 2009) to include governance and social learning as key strategies for more effective water management (Gleick, 2000).

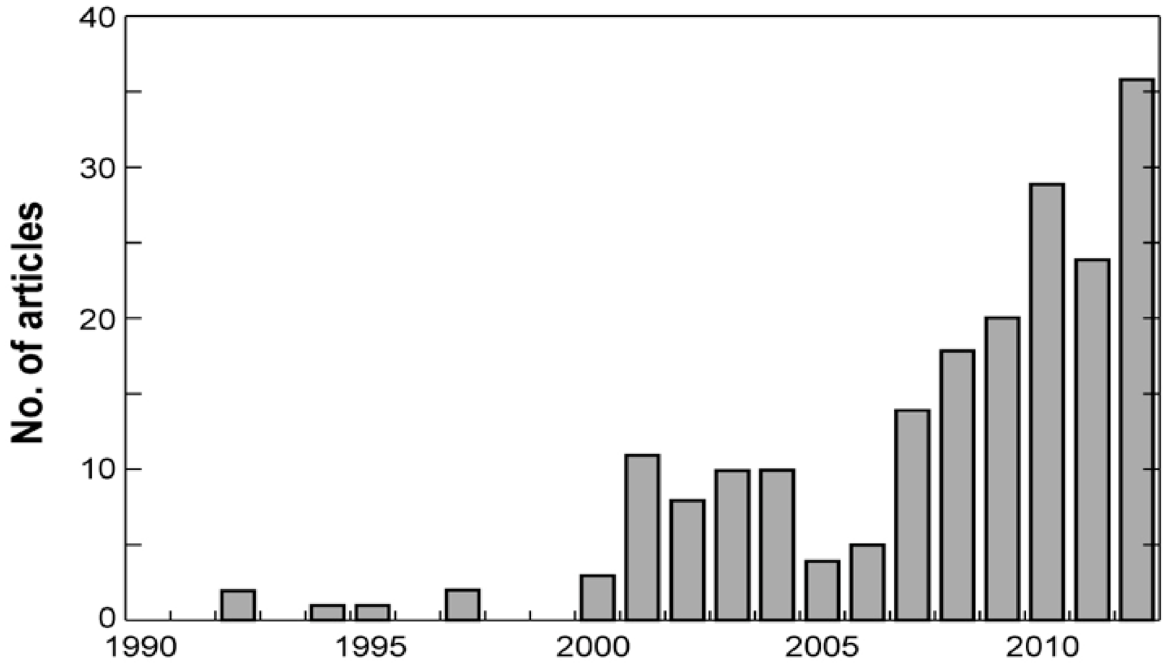

Figure 3 Articles in academic literature containing the term water security (1990–2012)
Source: Cook and Bakker, 2012

Water security incorporates and extends the key aspects of the integrated water resources management (IWRM) paradigm (WRI, 2005), notably in its emphasis on the linkages between sectors, and between ecosystem and human health (GWP, 2000; Vörösmarty et al., 2010). The innovative aspect of water security research stems from its focus on identifying, anticipating, and responding to water-related shocks, threats, and tipping points in the context of limited predictability. This is allied with a conceptual focus on a triad of inter-related concepts – vulnerability, risk, and resilience – which highlight the importance of adaptive management (Bakker, 2012). The inclusion of local stakeholders in integrated assessment is recommended (Sabatier et al., 2005), particularly in the analysis of complex issues and unstructured problems, such as freshwater resources (Jasanoff, 2004). Moreover, there is a recognised need to couple scientific assessment with governance practices (Braden et al., 2009; Brown et al., 2012; Sullivan and Meigh, 2007; van der Keur et al., 2010; Wagener et al., 2010).

Accordingly, our research project recommended that water security assessment adopt a broad approach, examining quality and quantity (including climate change and allocation), aquatic ecosystem health, human health, risk, and adaptive governance. For our project we defined water sustainability as: '*sustainable access on a watershed basis to adequate quantities of water of acceptable quality to ensure human and ecosystem health'.* This broad definition situates water security at the nexus between human health and ecosystem health in terms of water quality and water quantity and allows for the analysis of the multiple stressors that contribute to water insecurity.

This definition encompasses a broad range of potential outcomes, rather than focusing on one narrow set of water-related concerns. It allows for an integrated assessment of the synergistic interactions between (for example) water quantity and water quality, and between (aquatic) ecosystem health and human health. It implies the need to integrate consideration of stressors as well as impacts (or effects) on hydrological systems. Lastly, our definition is goal-oriented in terms of specific thresholds for water quality and quantity monitoring and enforcement.

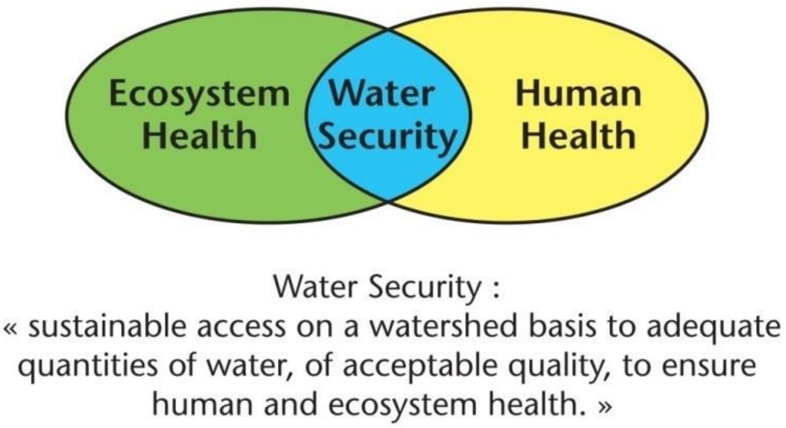

Figure 4 Defining water security for this project

5.3 Assessing water security

There are five important considerations when selecting indicators or developing user-friendly tools to assess water security: 1) multivariate analyses, 2) appropriate scale, 3) stakeholder participation, 4) data availability, and 5) adaptive governance.

5.3.1 Multivariate analyses

Threats to water are ubiquitous, including (but not limited to) population growth, climate change, land-use activities, and aging infrastructure, all of which affect water quality and quantity. Narrow governance approaches (for example the single variable, single indicator studies that predominate in the literature) fail to link water quality and quantity, both in terms of human health and aquatic ecosystem health, and hinder the ability of communities to achieve water security. Furthermore, inadequate assessment of status and risk hinder long-term plans for communities to achieve water security. In short, water security assessment requires a broad integrated pro-active approach; including water quality and water quantity-related variables as they pertain to aquatic ecosystems and human health.

5.3.2 Scale

The issue of scale poses an ongoing challenge in water security assessment and governance, particularly given the spatial mismatch between administrative boundaries and flow resources. A number of agencies have developed water-related indicators at a variety of scales (international, national, regional, provincial, and local). Understanding the scale for which an indicator was developed is an important consideration. Currently, indicators are often site-specific, or framed for a specific scale that may not be transferable to other scales (e.g. national or international level indicators may not be sensitive enough to identify water issues at a local level). While wider scale assessment models have made progress in addressing complex water security issues (Vörösmarty et al., 2010), these indicators are rarely commensurate at a scale that is meaningful at a community level. It is important to consider how accessible existing relevant indicators are (e.g., will the developer share the index formula or calculator?) and whether existing indicators can be adapted to suit the water security assessment needs. Our research highlighted the challenge of developing and applying indicators originally designed for national or regional application; whether these can be sensitive enough for use at a community level and whether they include socio-economic considerations (Cook and Bakker, 2012; Dunn, 2012; Norman et al., 2012). We advocate focusing on long-term assessment at the local scale, which concurs with the findings of PRI (2007), and which suggests that assessment processes should be conducted (and data employed) at scales commensurate with governance decision-making scales. Focusing on local-scale assessment and multi-stakeholder participation enables communities to determine the appropriate indicators based on available resources in combination with long-term assessment, reporting, and community goals.

5.3.3 Stakeholder participation

The inclusion of stakeholders, particularly end-users, is an important component in the design and development of an integrated assessment method. Focusing on local-scale assessment and multi-stakeholder participation enables communities to determine the appropriate indicators based on available resources in combination with long-term assessment, reporting, and community goals. They can provide valuable local knowledge, access to data sources, and long-term commitments to adaptive planning. For our research, end-user participation supported the design and development of the user-friendly assessment method. Participatory methods, through multi-stakeholder involvement, were used in the indicator selection and data identification processes (see Norman et al., 2012).

5.3.4 Data

Data play a fundamental role in the development of indicators (Bouleau et al., 2009; PRI, 2007; UNEP, 2003) and water security assessment. In Canada, freshwater-related data are collected by federal, provincial, and municipal government agencies as well as by a variety of non-governmental agencies and community-based or special interest organisations. Data concerns include gaps in monitoring networks, limited data availability, the absence of standardised data collection protocols, inconsistencies in existing data, and limited institutional capacity to collect, access or assess data (Bond et al., 2005; Brennin, 2007; CESD, 2010; NRTEE, 201). Specific challenges experienced in Canada include:

- practical challenges i.e. institutional capacity to collect (or access) and assess data (including financial and staff capacity)
- data sharing: facilitating coordination of access and exchange of data among existing water-related networks
- comparability of data, which can be impeded in the absence of standardised data collection protocols
- limited data availability, particularly groundwater
- available data may be unsuitable for the indicator of choice (e.g. not collected sufficiently frequently, or a different/incomplete set of variables collected). 'Retrofitting' previously collected data to match pre-determined indicators can be difficult and inefficient.

Once the variables (i.e. parameters) to be assessed are identified, the standards, baselines or benchmarks against which they are to be compared also need to be chosen (local, provincial, national, or international). A particular challenge can be in determining comparable parameters of ecosystem health. Unlike 'human health' there are no widely established parameters of 'ecosystem health' (Norman et al., 2012). The issues of data and scale are also important considerations when linking assessment with policy.

5.3.5 Adaptive governance

The results of the water security status and risk assessment need to be incorporated into governance practices. An adaptive management approach, whereby policies in resource management are considered fluid rather than fixed, and have built-in networks for change depending on outcomes, is also needed for water security assessment. Governance is central to this, providing concrete outputs that can be incorporated into water decision-making processes to improve aspects of insecurity. This approach reflects ongoing calls for integrating governance in indicator assessment along with the need for individual and community engagement (Delanty, 2002; Denhardt and Denhardt, 2007).

5.4 Incorporating risk

Indicators are static, presenting a snapshot in time of the current status. If they are applied routinely they can be compared against a baseline to see if changes (positive or negative) are occurring over time. However, risk or future status is not included. An important element of water security is the likelihood that the quality and/or quantity of a water source may deteriorate in some way and have some consequences for human or ecosystem health (Dunn, 2012). The risk to water quality and quantity, associated with current land-use practices, changes in land use, climate change, or changes in water demand, can be evaluated by considering these various stressors. Moreover, this information should be incorporated into an adaptive governance framework so decision-making processes can improve aspects of insecurity. Although risk principles and methodologies are well documented for natural disasters, such as landslides and earthquakes (Birkmann, 2006), comprehensive risk assessments are seldom applied to water-related issues. Our water security risk assessment (WSRA) framework considers the hydrologic components of the watershed (surface water and groundwater) and the quality and quantity of these water sources (Simpson et al., 2012). The framework is based on the principles of a risk assessment methodology and considers the hydrologic components of the watershed (surface water and groundwater), together or separately, depending on the driving issues and practicalities (e.g. data availability, knowledge). The WSRA also considers water quality and quantity, together or separately, for similar reasons.

The risk assessment framework itself provides spatial indicators of risk by mapping attributes of the built and natural environments, ideally, at a watershed scale. These include:

- the intrinsic susceptibility of the source, the natural water supply
- natural and anthropogenic pathways for water movement (e.g. low topography leading directly to streams and wells as conduits)
- the hazard threat (either in terms of natural or anthropogenic contamination or threats from the over use of water).

The framework incorporates some measure of probability or likelihood of occurrence, such as a spill, entry of agricultural contaminants into an aquifer or surface watercourse, or reduction in water quantity resulting from climate change. The uncertainty of these events must be taken into consideration. In addition, the framework incorporates some measure of consequence or loss, such as socio-economic hardship related to having to seek a replacement water source, human health, or aquatic ecosystem health.

The risk assessment may be used in a general way (encompassing a range of contaminants) or tailored to a specific contaminant of concern. In a tailored assessment of water quality, the assessment would be focused on a particular contaminant (e.g. chemical or pathogen) to determine:

the susceptibility of the system, the presence of pathways, the hazard threats, and the loss or consequence, all relative to that contaminant alone.

Water quality risk assessments include susceptibility (vulnerability assessment), hazard inventory (e.g. threat of contamination) and potential consequences (such as economic loss if people get sick from a contaminated water supply). Water quantity risk assessments can present more challenges in that projections are also necessary, in addition to current supply and demand data, to determine how their ratio might change in the future. While projections for future use can be made, a supply assessment is more difficult because of natural climate variability and climate change. Indeed, climate change and variability are wild cards that can, potentially, affect both water quantity and quality.

5.5 Conclusions

Our research findings suggest the importance of a broad and integrative approach to water quality and quantity, which incorporates human health and aquatic ecosystem health. We specifically suggest that the assessment of the current water security status needs to be combined with the assessment of risks, and the results incorporated into an adaptive governance framework, which formalises a flexible 'learning by doing' approach that can respond to changing conditions. In facilitating this integration the concept of water security is worthy of consideration for both research and policy strategies in support of sustainable water governance.

5.6 Acknowledgements

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[8] See references marked *

References

Ashton, P.J. (2002) Avoiding conflicts over Africa's water resources. *Ambio* **31**: 236–242.

*Bakker, K. (2012) Water security: research challenges and opportunities. *Science* **33**(6097): 914–915. 2.

Bakker, K. and Cook, C. (2011) Water governance in Canada: innovation in the context of fragmentation. *International Journal of Water Resources Development* **27**(2): 275–289.

Birkmann, J. (2006) Measuring vulnerability to promote disaster-resilient societies: Conceptual frameworks and definitions. pp. 9–54 In: *Measuring Vulnerability to Natural Hazards Towards Disaster Resilient Societies* (Birkmann, J. Ed.). United Nations University Press, Tokyo, Japan.

Bond, W., O'Farrell, D., Ironside G., Buckland, B., and Smith, R. (2005) Current status, trends, and perceptions regarding environmental indicators and state of the environment reporting in Canada. Background paper to an Environmental Indicators and State of the Environment Reporting Strategy, 2004–2009. Gatineau, Quebec. Knowledge Integration Strategies Division, Environment Canada. Available at: http://www.ec.gc.ca/soer-ree/English/documents/bg_paper1_e.cfm

Bouleau, G., Argillier, C., Souchon, Y., Bathélémy, C., and Babut M. (2009) How ecological indicators construction reveals social changes – the case of the lakes and rivers in France. Ecological Indicators 9(6): 1198-1205.

Braden, J.B., Brown, D.G., Dozier, J., Gober, P., Hughes, S.M., Maidment, D.R., Schneider, S.L., Schultz, P.W., Shortle, J.S., Swallow, St. K., and Werner, C.M. (2009) Social science in a water observing system. *Water Resources Research* **45**. doi:10.1029/2009WR008216.

Brennin, R. (2007) Linking indicator information to the policy process for sustainable development. Lessons learned from relevant international examples. A report prepared for the Strategic Information Integration Directorate, Environment Canada.

Brown, A., Medd, W., and Anderson, B. (2012). Incorporating social science in water assessment practices. Developing novel approaches to tracking domestic water demand under uncertainty – a reflection on the "upscaling" of social science approaches in the United Kingdom. Water Resources Management.

Commissioner of the Environment and Sustainable Development (CESD). (2010) Report of the Commissioner of the Environment and Sustainable Development to the House of Commons Fall 2010. The Commissioner's Perspective Main Points. Chapters 1 to 3 and Appendix. Office of the Auditor General of Canada, Ottawa, ON, Canada.

Chaves, H.M.L. and Alipaz, S. (2007) An integrated indicator based on basin hydrology, environment, life, and policy: the watershed sustainability index. *Water Resources Management* **21**(5):883–895.

*Cook, C. and Bakker, K. (2012) Water security: debating an emerging paradigm. *Global Environmental Change* **22**(1): 94–102.

Delanty, G. (2002) Knowledge as communication: a review of literature on method and theory in social science. *International Journal of Social Research Methodology* **5**(1):83–90.

Denhardt, J. and Denhardt, R. (2007) *The New Public Service: Serving Not Steering*. ME Sharpe Inc, Armonk, NY, USA.

Döll P., Kaspar, F., and Lehner, B. (2003) A global hydrological model for deriving water availability indicators; model tuning and validation. *Journal of Hydrology* **270:** 105–134.

*Dunn, G. (Ed.) (2012) *Water Security Guidance Document*. UBC Program on Water Governance, Vancouver, BC, Canada.

*Dunn, G. and Bakker, K. (2011) Fresh water-related indicators in Canada: an inventory and analysis. *Canadian Water Resources Journal* **36**(2): 135–148. 4.

*Dunn, G. and Bakker, K. (2009) *Canadian Approaches to Assessing Water Security: an Inventory of Indicators (Policy Report)*. UBC Program on Water Governance, Vancouver, BC, Canada.

Falkenmark, M. (2007) Shift in thinking to address the 21st century hunger gap. *Water Resources Management* **21**(1): 3–18.

Falkenmark, M., Lundqvist, J., Widstrand, C. (1989) Macro-scale water scarcity requires micro-scale approaches– aspects of vulnerability in semi-arid development. *Natural Resources Forum* **13**(4):258–267.

Falkenmark, M. and Lundqvist, J. (1998) Towards water security: political determination and human adaptation crucial. *Natural Resources Forum* **22**(1):37–51.

Furlong, K. and Bakker, K. (2011) Governance and sustainability at a municipal scale: the challenge of water conservation. *Canadian Public Policy* **37**(2), 219–237.

Gleick, P.H. (2000) The changing water paradigm: a look at twenty-first century water resources development. *Water International* **25**(1): 127–138.

Gleick, P.H. (1990) Vulnerability of water systems. pp. 223–240. In: *Climate Change and US Water Resources* (Waggoner, P.E. Ed.). Wiley, New York, NY, USA.

Global Water Partnership (GWP). (2000) *Towards Water Security: A Framework for Action*. GWP, Stockholm, Sweden.

Harrison K. (1996) *Passing the Buck: Federalism and Canadian Environmental Policy*. UBC Press, Vancouver, BC, Canada.

Heap, C., Kemp-Benedict, E., and Raskin, P. (1998) *Conventional Worlds: Technical Description of Bending the Curve Scenarios.* Polestar series report. Stockholm Environmental Institute, Boston, MA, USA.

Hrudey, S.E., Payment, P., Huck, P.M., Gillham, R.W., and Hrudey, E.J. (2003) A fatal waterborne disease epidemic in Walkerton, Ontario: comparison with other waterborne outbreaks in the developed world. *Water Science and Technology* **47**(3): 7–14.

Jasanoff, S. (2004) Science and citizenship: a new synergy. *Science Public Policy* **31**(2):90–94.

Meigh, J., McKenzie, A., Austin, B., Bradford, R., and Reynard, N. (1998). Assessment of global water resources–phase II. Estimates of Present and Future Water Availability in Eastern and Southern Africa. DID Report 9814. Institute of Hydrology, Wallingford, UK.

National Round Table on the Environment and the Economy (NRTEE). (2010) *Changing Currents: Water Sustainability and the Future of Canada's Natural Resource Sectors*. NTREE, Ottawa, ON. Canada.

*Norman, E., Dunn, G., Bakker, K., Allen, D., and Cavalcanti de Albuquerque, R. (2012) Water security assessment: integrating governance and freshwater indicators. *Water Resources Management* 27: 535–551. DOI: 10.1007/s11269-012-0200-4

Nuzzo, J.B. (2006) The biological threat to U.S. water supplies: toward a national water security policy. *Biosecurity and Bioterrorism* **4**(2): 147–159.

Office of the Director of National Intelligence (ODNI). (2012) *Global Water Security*. ODNI, Washington, DC, USA.

Organisation of Economic Co-operation and Development (OECD). (2002) *Aggregated Environmental Indices: Review of Aggregation Methodologies in Use.* OECD, Paris, France.

Organisation of Economic Co-operation and Development (OECD). (2008) *Handbook on Constructing Composite Indicators: Methodology and User Guide.* OECD, Paris, France.

Policy Research Institute (PRI). (2007) *Canadian Water Sustainability Index (CWSI): Project Report.* PRI, Ottawa, ON, Canada.

Raskin, P., Gleick, P., Kirshen, P., Pontius, G., and Strzepek, K. (1997) *Water Futures: Assessment of Long-Range Patterns and Problems. Comprehensive Assessment of the Freshwater Resources of the World*. Stockholm Environmental Institute, Stockholm, Sweden.

Rockström J. et al., (2009) A safe operating space for humanity. *Nature* **461**: 472–475.

Sabatier, P., Focht, W., Lubell, M., Trachtenberg, Z., Vedlitz, A., and Matlock, M. (2005) *Swimming Upstream: Collaborative Approaches to Watershed Management*. MIT Press, Cambridge, MA, USA.

Saunders, O.J. and Wenig, M.M. (2007) Whose water? Canadian water management and the challenges of jurisdictional fragmentation. pp. 119–142. In: *Eau Canada* (Bakker, K. Ed.). UBC Press, Vancouver, BC, Canada.

Schindler, D.W. (2001) The cumulative effects of climate warming and other human stresses on Canadian freshwaters in the new millennium. *Canadian Journal of Fisheries and Aquatic Sciences* **58**:18–29.

Scozzari, A. and El Mansouri, B. (2011) *Water Security in the Mediterranean Region*. NATO Science for Peace and Security Series, Springer, London, UK.

Simpson, M., Allen, D.M., and Journeay, M. (2012). Water security risk assessment (WSRA) – Part II Section 2. In: *Water Security Guidance Document*. UBC Program on Water Governance, Vancouver, BC, Canada.

Statistics Canada. (2009) *A Framework for Developing Environmental Statistics*. Statistics Canada, Ottawa, ON, Canada.

Sullivan, C. and Meigh, J. (2007) Integration of the biophysical and social sciences using an indicator approach: addressing water problems at different scales. *Water Resources Management* **21**(5):111–128.

United Nations Environment Programme (UNEP). (2009) *Water Security and Ecosystem Services: The Critical Connection*. UNEP, Nairobi, Kenya.

United Nations World Water Assessment Programme (UN WWAP). (2006) *Water a Shared Responsibility*. UNESCO, Paris, France.

United Nations Environment Programme (UNEP). (2003) Environmental indicators. Fourteenth meeting of the Forum of Ministers of the Environment of Latin American and the Caribbean (Nov.2003). Available at: http://www.pnuma.org/forumofministers/14-panama/pan11nfi-EnvironmentalIndicators.pdf

van der Keur, P., Brugnach, M., Dewulf, A., Refsgaard, J.C., Zorilla, P., Poolman, M., Isendahl, N., Raadgever, G.T., Henriksen, H.J., Warmink, J.J., Lamers, M., and Mysiak, J. (2010) Identifying uncertainty guidelines for supporting policy making in water management illustrated for Upper Guadiana and Rhine Basins. *Water Resources Management* **24**(14):3901–3938.

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Reidy, C., Liermann, C.R., and Davies, P.M. (2010) Global threats to human water security and river biodiversity. *Nature*, **467**:551–561. doi:10.1038/nature09440

Wagener, T., Sivapalan, M., Troch, P.A., McGlynn, B.L., Harman, C.J., Gupta, H.V., Kumar, P., Suresh, P., Rao, C., Basu, N.B., and Wilson, J.S. (2010) The future of hydrology: an evolving science for a changing world. *Water Resources Research* **46** W05301, doi:10.1029/2009WR008906

World Economic Forum (WEF). (2011) *Water Security: The Water-Food- Energy-Climate Nexus*. Island Press, Washington, DC, USA.

World Resources Institute (WRI). (2005) *United Nations Millennium Ecosystem Assessment. Ecosystems and Human Well-Being: Wetlands and Water Synthesis*. WRI, Washington, DC, USA.

World Water Assessment Programme (WWAP). (2012) *Managing Water Under Uncertainty and Risk: World Water Assessment Report.* WWAP, Geneva, Switzerland.

6. Water framework directive experiences in Spain

This paper is a synthesis of *Ten years of the Water Framework Directive in Spain: an overview of the ecological and chemical status of surface water bodies* by Bárbara A. Willaarts[1], Mario Ballesteros[2], and Nuria Hernández-Mora[3]. In: *Integrated Water Resources Management in the 21st Century: Revisiting the Paradigm* (Martínez-Santos P., Aldaya M.M., and Llamas M.R. Eds). CRC-Press, Boca Raton, FL, USA. (Forthcoming).

Email: barbara.willaarts@upm.es

Abstract

This paper offers insights into Spain's experiences in implementing the requirements of Europe's Water Framework Directive (WFD), which is essentially a set of key environmental indicators describing the health of Europe's aquatic ecosystems. The WFD enables nations to identify areas of concern and take appropriate measures to improve them. The Directive provides a common policy framework for European Union Member States to tackle the problems of water quality deterioration, loss of aquatic ecosystem functionality, and increasing water scarcity.

Additionally, the paper provides a national overview of the ecological and chemical status of Spain's surface water bodies (SWB). It identifies the country's hotspots in terms of environmental water security challenges, what are the main pressures underpinning the bad status of Spain's SWBs, as well as reviewing the coherence of the evaluation methods used and the challenges ahead.

6.1 Spain and the Water Framework Directive agenda

The development of the European Water Framework Directive (WFD 2000/60/EC) responded to the need for a common, coherent, and integrated policy framework for European Union (EU) Member States in order to effectively tackle the growing problems of water quality deterioration, loss of aquatic ecosystem functionality, and increasing water scarcity throughout Europe. The Directive recognised that addressing these issues is crucial to ensure the mid- and long-term water security of EU countries.

The WFD is legally binding and incorporates the key principles of integrated river basin management. It brings together economic and ecological issues, incorporates stakeholder perspectives into policy-making, and accounts for the interrelationships among water management and other sector policies. WFD works on six-year planning cycles. Its work includes assessing the ecological, chemical, and quantitative status of waters, setting environmental objectives, designing programmes of measures to achieve them, and monitoring progress in preparation for the six-yearly review. During the first planning cycle, the Directive established that river basin management plans (RBMPs) had to be approved in 2009, so that by 2015 all of Europe's waters are expected to have reached 'good' status (Box 1) or adequately justify exceptions to this common goal. While most countries have complied with the WFD's calendar, Spain, Denmark, Greece, and Portugal had not submitted all their RBMPs to the European Commission (EC) as of November 2013.

[1] Water Observatory, Botin Foundation, Madrid, Spain.
[2] Research Centre for the Management of Agricultural and Environmental Risks (CEIGRAM), Technical University Madrid, Madrid, Spain.
[3] A founding member of Fundación Nueva Cultura del Agua (FNCA), Zaragoza, Spain.

Spain's non-compliance with the Commission's deadline derives from a pool of complex factors, largely driven by strong political conflicts emerging around water between different stakeholders groups and regions. Much of these conflicts arise from the fact that the Directive has represented a significant departure from prior water management and planning practices in Spain, moving to a completely different and new approach to water security. Water management at the river basin scale has been a trademark of Spanish water policy since the 1920s and the development of RBMPs has been a legal requirement since the approval of the 1985 Water Act. However, with the transposition of the WFD into Spanish law in 2003, the Spanish water policy, traditionally oriented towards supply augmentation to meet increasing water demands, was forced to shift the focus and prioritise aquatic environment protection.

Data and monitoring requirements, as well as water planning processes to comply with this new Directive's approach, have changed considerably. The new requirements have implied a massive effort to develop the biological, hydromorphological, and chemical data and reference conditions necessary to assess the status of water bodies, thus helping to improve understanding about the health of our surface and groundwater resources.

This paper reviews Spain's experiences in implementing this new approach to water management. Specifically, it provides a national overview of the ecological and chemical status of Spain's surface water bodies (SWB), identifying the country's hotspots in terms of environmental water security challenges. It considers what are the main pressures underpinning the bad status of Spain's SWBs, as well as reviewing the coherence of the evaluation methods used and the challenges ahead. The environmental information used in this paper was extracted from the approved RBMPs and refers to monitoring campaigns undertaken between 2006 and 2009. For those river basin organisations whose RBMP was not approved by December 2012 (the date when this work was completed) we chose to use the planning documents available for public consultation, which include monitoring data of similar periods of time.

Box 1 Definitions of 'good' status for surface water bodies (WFD, 2000)

'High' or 'good' ecological status is achieved when the values of the biological quality elements for the surface water body show low levels of distortion resulting from human activity and deviate only slightly from those normally associated with the surface water body type under undisturbed conditions. If these levels of distortion and deviation become more important, the ecological status will fall to 'moderate', 'poor', or 'bad', depending on the degree of deviation from undisturbed conditions.

'Good' chemical status is recorded when a water body achieves compliance with all the environmental quality standards established in Article 16 (Strategies against pollution of water) and Annex IX (Emission limit values and environmental quality standards) of the Water Framework Directive, and other relevant EU Community legislation setting environmental quality standards. If not, the water body shall be recorded as failing to achieve 'good' chemical status and thus be classified as 'poor' chemical status.

'Good' overall status is achieved when a surface water body reaches a 'high' and a 'good' ecological and chemical status. The overall status of a SWB is ruled by the 'one out, all out principle', meaning that the final score for any kind of status is defined by the worst value among its elements or standards (either ecological or chemical).

6.2 Current picture

Rivers are the most representative SWBs in Spain and have a combined length of over 70,000 km. Yet, almost 9 percent of Spain's rivers are declared as being 'heavily modified' because of their hydromorphological or hydrological alterations. The majority of these are located in the mid southern part of the country and their alterations are very much related to the construction of dams for irrigation or hydropower – which have inverted the river's hydrological regime – or for flood control, or domestic water supply. Lakes and wetlands are spatially less significant SWBs (occupying less than 1,000 km^2), although they have great ecological and socio-economic importance in certain areas of Spain, e.g. the Daimiel and Doñana wetlands. So far, over 15 percent of lakes and wetlands have been declared heavily modified, and again the reasons are related to the development of irrigation systems. Because of the long coast line of the Iberian Peninsula, Spain's coastal waters occupy around 18,000 km and their degree of human modification, i.e. the area of coastal waters that has been heavily modified, is comparatively smaller. Artificial SWBs refers to canals and built dams, which are less representative.

The environmental assessment conducted within the different river basin districts (RBDs) showed that almost 50 percent of the evaluated SWBs are in poor overall status (that is poor ecological and/or chemical status). Among evaluated lakes, only 18 percent have good overall status, although 50 percent remain unevaluated. Rivers and transitional waters are better, with 50 percent of the evaluated SWBs in good overall status. Coastal waters seem to be in better condition, with more than 75 percent of those evaluated as being in good overall status. Our analysis shows that the main driver determining the poor status of SWBs is poor ecological status, rather than any major chemical problem. The European Environmental Agency 2012 report, *European water- assessment of status and pressures*, indicates that the situation is similar in other European countries. Nevertheless, this information should be carefully interpreted since more than 40 percent of SWBs still lack a full chemical assessment.

6.3 Lessons learned

Spanish river basin authorities have made significant data and information gathering efforts to comply with the requirements of the WFD during this first water planning cycle. They have carried out a detailed assessment of the environmental status of the water bodies. This has improved significantly Spain's knowledge of the ecological and chemical status of its SWBs.

As regards their ecological status, no monitoring network was in place to track the ecological status of SWBs before the WFD. With the enactment of the Directive, a network of 1,533 monitoring stations for rivers and 304 for lakes and wetlands was created. While the development of this network has meant a significant step forward, important monitoring gaps still exist. The lack of reference conditions for many ecological indicators during this initial planning cycle has led to some river basin authorities not including key indicators of ecological conditions (e.g. fish fauna or hydromorphological conditions) in their RBMPs, which, if included, could significantly alter the current overall picture.

The poor ecological status of Spain's SWBs reveals important alterations in the hydrological functionality of aquatic ecosystems, which have been driven by multiple factors depending on the geographical context. Because the majority of RBMPs provide only the overall ecological status, without detailing the results obtained for each indicator (i.e. individual biological, chemical, or hydromorphological assessments), it is not easy to establish a clear causal relationship between pressures (e.g. pollution from urban or industrial areas, highly regulated water bodies, over-extraction of water, or diffuse pollution) and the resulting impacts. Obtaining such information might be helpful in assessing if the programme of measures, elaborated by each RBMP in order to achieve the 'good status' of all water bodies by 2015, is adequate to deal with the actual pressures and impacts occurring in their regions. And if so, to what extent it will effectively contribute to improving the status of those SWBs that have deteriorated.

With respect to the chemical status, there is still a lack of clear information, which prevents there being a complete diagnosis of the real status of the SWBs. In part this is because of the lack of monitoring systems. But it is also because an important number of priority substances and priority hazardous substances were included in the chemical assessment requirements late in the WFD implementation process, thus limiting the options for RBDs to consider them all. As a result, some basins have chosen to perform their assessment without considering all those substances, while others have delayed assessing the chemical status until monitoring options are available. The great number of priority substances that were progressively listed (e.g. emergent contaminants) also poses a major challenge from a water management perspective, particularly the ability of river basin agencies to develop effective programmes of measures, since the management of the programmes lie far beyond their jurisdiction.

Selected references

European Commission (EC). (2012) *River Basin Management Plans: report on the Implementation of the Water Framework Directive (2000/60/EC).* Available at: http://ec.europa.eu/environment/water/water-framework/pdf/COM-2012-670_EN.pdf [Accessed November 2012].

European Environmental Agency (EEA). (2012) *European waters – assessment of status and pressures.* EEA Report No 8/2012. Available at: http://www.eea.europa.eu/publications/european-waters-assessment-2012 [Accessed November 2012].

Water Framework Directive (WFD). (2000) Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0060:EN:NOT [Accessed September 2012].

7. Fairness and flooding: assessing the distributional impact of flood interventions

Author: Jeroen Warner, Social Sciences Group, Wageningen University, Netherlands

Abstract

This paper explores the development of a method for the security impact assessment of water policies and projects. The starting point is that interventions can be expected to redistribute the security positions of key stakeholders in a differential way. An analysis is presented of the redistribution of actual and perceived security as a result of water development policies, interventions, and projects among the key stakeholder groups. By requiring that this distribution be equitable, a normative element is introduced that is well captured by the proxy of the Gini[1] coefficient. This helps us to assess the security externalities of water interventions for both the whole (system at risk) and its parts (vulnerable groups at risk).

7.1 Conceptual exploration

A 'risk management' rather than 'flood defence' approach to flood risk means accepting residual flooding as well as risk differentiation. This brings in ethical issues. While environmental justice literature tends to look at marginalised regions, especially in the global south, equity issues are also relevant for rural middle classes in the Netherlands.

Can we develop a methodology for assessing the security impact of decisions? This promises to open a can of worms. This article investigates some of these worms. In this first section I will explore concepts of security and equity, as applied to floods. I briefly review the Gini index as a possible indicator for security impact.

7.1.1 What is security?

Together with resilience, security is about to become the dominant concept in the international water community. This is a remarkable development, given the young history of water as a security issue. So it is all the more reason to explore its actual meaning and implication.

Security comes from the Latin, *s(in)e cura* – without a worry, without a care. Its everyday meaning however, has become multifarious. For example, the German translation of security, 'Sicherheit', refers to security, safety, and certainty (Bauman, 1999). Insecure: full of doubt and fear. Uncertain: precarious, implying a lack of predictability. Unsafe: full of danger. Translated into the water domain, we want to make sure there is no worry, that we will get a predictable amount of safe-to-use water.

In this paper we not only consider water security as a problem of balance (not too much, not too little resource access), but also one that brings tensions at the system level and at the actor level. This concerns the distribution of security as well as threats to security as the consequence of

[1] The Gini coefficient measures the inequality among values of a frequency distribution. A Gini coefficient of zero expresses perfect equality, where all values are the same (for example, where everyone has an exactly equal amount). A Gini coefficient of one (100 on the percentile scale) expresses maximal inequality among values (for example where only one person has all). However, a value greater than one may occur if some persons have shortages. (Source: Wikipedia).

interventions elsewhere to obtain security for others. In other words, insecurity has ‘external effects’ or ‘externalities’ for water or for policy interventions by others, even with the best of intentions.

7.1.2 Security for whom? Dilemmas of distribution and referents

Security is normally a state concern, an issue of territory and diplomacy. It has taken until the early 1980s to recognise that ‘low politics’ conflicts could become ‘high politics’ (Keohane and Nye 1977). Water security as a state concern can easily clash with human security. Based on the UN Development Programme’s approach (UNDP, 1994), water security is defined as freedom from direct or indirect consequences of a lack of sufficient, clean water. Just as the survival of the whole may not coincide with the survival of the parts, the raison d’états may not necessarily coincide with the interests of its constituency. Critical scholars have noted that making water a state concern may be beneficial, but also harmful to local security. ‘Securitisation’, calling an issue a security issue, lifts it above politics, making it a life or death issue, legitimising extraordinary measures, such as secrecy, violence, blank cheques, and bracketing out democratic decision-making (Buzan et al., 1998). Related to state security, civil rights may be impeded to secure state sovereignty over water. Related to human security, state sovereignty and powers may be compromised to secure water for certain social groups if water security is made operational at the community or individual levels. If water security is augmented by energy security and food security, as proposed in the nexus approach, it risks promoting the ‘securitisation’ of everything, a trend that was criticised in a conference in Sussex, UK (STEPS, December 2012). Instead, we explore an approach that takes security concerns seriously, but considers them less than absolute and part-measurable, provided ethical concerns, such as equity, are observed.

7.1.3 Flood (in)security

Water security is often treated as being synonymous with a certain minimum continual availability of water. Flooding is still under-exposed in debates on water security. As the Associated Programme for Flood Management’s (AFPM) ground-breaking report on Integrated Flood Management (WMO, 2009) notes, floods are an underdeveloped subset of integrated water resources management. Integrated flood management (IFM) seeks to integrate periods of flood and drought, and land and water management. It is not incompatible with existing definitions. For example Sadoff and Grey (2007) include in their definition of water security the words ‘acceptable level’. We can look at this from two ends; making sure people do not have too much or too little water.

Various definitions of water security include minimum standards of quantity and quality and focus on access alone, such as ‘freedom from direct or indirect consequences of a lack of sufficient and clean water’. While water security is primarily couched in terms of availability and access, it excludes safety from flooding. This is less clear as it is concerned with what has not happened, rather than with what could happen.

Floodwater has both the extremes of too little (not enough floodwater to grow food) and too much (destructive flood). In flood terms, water security would be:

- a certainty of enough floodwater (for irrigation, soil flushing, fish reproduction, environmental flow) – covered by water security methods
- enough protection from excess floodwater (safety of people, assets).

This is indeed a fragile balance!

Floods are one of the most destructive natural hazards. In the 1990s, floods killed about 100,000 people world-wide and affected over 1.4 billion people (Jonkman, 2005). The Red Cross annual World Disaster report provides an encouraging trend of ever fewer fatalities, but disasters continue to inflict ever-more economic and social damage on those who survive. Flooding wreaks havoc when it overwhelms the local system, but in manageable doses it is essential to millions of livelihoods. The current Dutch practice of keeping the flood out at any cost is not one that can be adopted by everyone.

Decision-making usually takes account of balancing needs with coping capacity, but does not often take account of balancing security interests. Certain actors often stand to gain while others predictably expect to lose, with uncertain or no compensation. Rather than expecting everyone to look to maximise their interest, as the traditional rational actor might do, we may expect stakeholders to be willing to forego certain security aspects if they believe this is equitable, that is, proportional to the sacrifices made. Of particular importance in this light is the maxim that insecurity should not be disproportionally displaced, offloaded elsewhere in time or space, or create a spurious win-sum that in a wider perspective becomes a zero-sum or even a negative-sum.

7.1.4 What is equity?

Nobel laureate, Amartya Sen (1984), highlighted that equity is not about absolute availability (natural distribution); it is access and entitlements that create crises like famines. This entitlement is an equity issue. Equity is 'the study of fairness in economics'.

Where equity is concerned, geography deals river riparians an unequal hand. 'Upstreamers' are at an advantage over 'downstreamers'. However, inequities are not only natural, but also imposed, where 'strategies which appear to be most technically and economically effective fall far short of being fair from either a vulnerability or equality perspective' (Johnson et al., 2007). It is this imposed inequity that interests us most here. The bulkiness and vulnerability of water to pollution and evaporation means it poses more distribution problems than, say, gas. This puts a heavy responsibility on the design of infrastructure, which may function as 'pipelines of power'. Powerful actors can monopolise structural works to support their or their clientele's political and economic interests. A critical review of equity to support water allocations in the Amu Darya Basin was undertaken by Wegerich (2007).

In economics, unequal distribution is treated as an externality of an intervention, such as an investment. But from a political perspective, this disparity may be intended. If politics is the contest for the allocation of scarce resources (Heywood, 1994), water distribution is almost by nature political and normative. This means the design of the allocation system, both infrastructural (pipes) and institutional (rights), is of prime importance to secure security.

The political economy allocates water to cities over the countryside, and irrigated agriculture over other livelihoods. Some authors (Blaikie et al., 1994) observe that the political economy causes the poor and marginalised to end up in unsafe conditions, making them more vulnerable than the well-off. This is worsened by the fact that poor migrants into cities are often not recognised as citizens, and so they end up without rights and basic services.

Additionally, licensing is not politically neutral, but allocates water away from the legally non-savvy. As a consequence, access disparities between users may be enormous.

7.2 Distribution, equity, and the water Gini

7.2.1 The water Gini

To highlight and remedy these disparities, it makes sense to establish an indicator for how well countries, or regions, do comparatively, in spreading availability and access to water among stakeholders.

Cullis and van Koppen (2007) explored the use of the Gini coefficient, which measures inequality among the values of a frequency distribution. For the Olifants, the Mhlatuze, and the Inkomati catchments in South Africa, they show that reducing the Gini coefficient is relatively straightforward. Rural households could have double the current amount of water if 'large-scale registered users reduced their current irrigation water-use entitlement by 6 percent or the largest ten users reduce their use by 20percent each'.

As a measure for water distribution, the Gini coefficient can be 'displayed graphically as a plot of the distribution of the size fractions of ordered individuals' – the Lorenz curve. If the curve is a straight line, equity is at its maximum. This is not normally the case. The curve usually plots below the 'equity line' and the area between the curve and the equity line is the Gini coefficient.

Deducting registered water use[2] from total water availability shows that '99.5 percent of households in the rural area account for the direct use of only 5 percent of the total estimated water used in the rural areas of the catchment'. Some authors further note that indirect benefits from those not controlling the water should be taken into account. This brings us back to the 'nexus' issue, in which benefits from environmental services may accrue to a target group that is physically removed from where the benefits are generated.

A low Gini coefficient may be preferable where water availability is low and many livelihoods directly depend on water. In highly industrialised and urbanised economies, only a few users directly need water. Not mentioned here is the importance of virtual water (Seekell et al., 2011), which is often believed to reduce inequalities between countries. For Seekell et al. (2011) however 'variability in the internal agricultural footprint is due to the availability of arable land and a suitable climate for growing crops, and not social development factors. Additional variability may be explained by the water-use efficiency'.

Cullis and van Koppen (2007) note that the Gini coefficient is a neat way of picturing inequality, but not inequity. Unlike inequity, inequality is descriptive – some have, or get, more than others. Giving everybody an equal share while needs are obviously different may be inequitable. Political science can come to the rescue here. Total equality (a society without hierarchy) would be unworkable. Inequality is, therefore, a feature of all societies. Legitimacy refers to the social acceptance of power disparity (Beetham, 1991). Inequality may be justifiable e.g. in the light of needs and of legitimate claims (Beetham, 1991). Inequity is an ethical issue; what is unfair and unjust.

7.2.2 A flood Gini

Flood disasters, like other hazards are not 'natural', they are always mediated by social patterns, such as settlement and infrastructural bias. Interventions, such as dams and irrigation systems, are man-made and influence the distribution of benefits and harms. The questions of 'who gains? who

[2] Cullis and van Koppen (2009) note that South Africa does not have a water use database, and that non-registered water use is a significant addition to registered water use.

loses?' guide recent work on water resources by political ecologists and political geographers. 'The challenge of dam projects is that those areas that benefit and those that pay are different places and people' (Beekman, 2002). The work of Scudder and others shows that compensation plans for displacing people rarely work out well.

Flood protection projects tend to have an urban bias. They protect cities by flooding rural or peri-urban areas. These have fewer inhabitants, fewer vulnerable economic assets, and are sacrificed for the benefit of population concentrations.

What would the Gini coefficient mean for floods? Amartya Sen's maxim more or less holds for flood disasters. It is well known that floods do not affect all groups equally. Structural vulnerabilities make socio-economically marginalised groups more harm-prone than others, and smaller crises cause them to cross the tipping point between stable and unstable conditions (the same largely applies for weak infrastructure). The encouraging reverse of the coin is that smaller positive shocks should push weak households back from unstable into stable conditions as well.

It makes little sense to seek flood control in isolation. The world risk index, for example, 'a tool to assess the disaster risk that a society or country is exposed to by external and internal factors', places income distribution as a key factor in susceptibility to harm after a shock, i.e. vulnerability is made operational here as exposure, susceptibility, lack of coping capacities, and a lack of adaptive capacities (Alliance Development Works, 2012).

This indicates great potential for reducing the risk of flood damage by structural and non-structural disaster risk reduction measures. In the flood domain, infrastructure likewise protects some more than others, exaggerating or reducing the disparity in protection.

7.2.3 Displacement, cumulation, and cascade effects

If not well thought through, structural disaster risk reduction interventions can, in practice, function as disaster risk displacement measures. Protecting population concentrations, such as cities, means that isolated households outside these protected areas are more exposed. There are many cases of entirely predictable differential impacts from flood protection projects; e.g. countryside vs. urban, charlands (ephemeral, submersible land) vs. town after embanking the Tangail area in Central Bangladesh for safer food production (Warner, 2011).

The Fukushima disaster dramatically illustrated that disasters can and do cascade. It is common for secondary disasters, such as floods after earthquakes or epidemics after floods, to claim more victims than the primary disaster. They may be reinforced by ageing infrastructure, especially in countries with poor records of public infrastructure maintenance, including the USA (Little, 2012). Some cascades are unexpected flukes, but others are predictable given the tight coupling of vulnerable systems. Unexpected and complex interactions between faults can occur in coupled systems that would be tolerable individually, but destructive in their interrelatedness.

There is a tendency to design according to fail-safe standards, especially in vulnerable systems affecting human health, such as drinking-water systems. The fallacy, of course, is then a false sense of security – the belief that one has indeed reduced risk to zero and can sleep safely. No matter how well-designed, closely coupled systems always have residual risks, as Perrow (1984) cogently showed in his volume Normal Accidents.

In the UK in 2007, after the Midlands flooded, the water had an effect on many more than the 300 people directly affected in the small town of Tewkesbury. Over half a million were affected by the flood when their water supply and sanitation facilities broke down because of vulnerable, closely coupled infrastructure.

7.3 Risk differentiation – how much is a rural citizens' safety worth?

Figure 1 The Netherlands – areas below and above sea level

Since 1960, the Netherlands has built coastal and riverine protection standards on solidarity in the face of floods as a principle, disregarding upstream–downstream dynamics. Collective infrastructure was built or reinforced to safety standards based on hazard, holding out the promise of uniform protection – all dikes were supposed to have the same safety standards. Based on macro-regions, the standards were so absurdly high compared to other deltas, that the residual risk may as well be zero. The safety standards were differentiated by macro-region, area below sea level, 1:100,000, riverine areas 1:3000, and 1:250 in the north. The city of Rotterdam is a low-lying city, located below sea level (Figure 1), and continues to be the powerhouse of the Dutch economy. As it is also best protected, economic logic dictates it attracts even more citizens and assets behind the dikes. After all, a Rotterdam citizen is potentially better protected than an upland citizen. Is a life in the east or north Netherlands worth less than one in Rotterdam? Is a rural life worth less than a metropolitan one?

Figure 2 Controlled flooding area near Nijmegen

Since the mid-1990s, two high-water events served as a wake-up call that the Dutch are not invulnerable to river floods. The Netherlands' flood policy now appears to be considering a more Anglo-Saxon risk management approach, based on cost-benefit and the 'acceptable loss' considerations current in non-flood security domains.

This opens the door to risk differentiation at a much smaller scale, even within polders – compartmentalisation – and for private companies or well-to-do communities to buy additional security (gated communities). It has made space for non-(infra)structural solutions for flood protection, such as controlled flooding. Another option is risk transfer-spreading through insurance. Finally, risks can be reduced by increasing the awareness and resilience of potentially flood-affected people.

An example of this type of ethical conundrum is controlled flooding in the Ooij polder west of the east Netherlands city of Nijmegen near the German border (Figure 2). In 2000, central government designated the polder for controlled flooding to attenuate flood peaks expected to become more frequent and intense as a result of climate variability.

Should upstream rural areas be flooded to save a downstream city?

A local platform emerged to protest against the proposed development, which pushed the issue up to parliament (Roth and Warner, 2007). After enlisting technical advice, the local platform argued that bundling population concentrations may lead to a rise in local groundwater levels which may cause flooding in residences for months. Also the designation as a flood control area meant that no new investment would be allowed, and this would imperil real estate prices. But the key argument inciting protest was an ethical one – does the social contract allow a government to flood an inhabited area to save others?

Complicating the credibility of the protest was an anti-urban bias/rhetoric ('Calimero effect[3]'). Moreover, the most vocal protest did not come from established families, whose attitude reflected

[3] When a party (person, organisation, country) needs to be taken seriously, but is small in size relative to another party, then this is known as the 'Calimero effect'.

the more law-abiding one, but from urbanites, who had immigrated in search of rural peace and quiet and were opposed to any intervention that may disturb it.

7.4 Compensation and commensurability: swapping security externalities?

In the Netherlands there is no flood insurance to speak of and in the above case there was hardly any question of compensation for the upstream sacrifice on behalf of ‘downstreamers’. It was assumed, that in the national interest, ‘upstreamers’, who knew they were first in line for flooding, would be willing to make this sacrifice, even without planning approval. In addition to the flood protection issues, there are also ‘normal accidents’ to consider which arise from sudden failure (especially large, non-modular infrastructural works), where one failure brings knock-on effects for the system as a whole and compromises lives and livelihoods (Perrow, 1984).

Currently the Netherlands are looking to switch to the ‘risk approach’ prevalent in the UK. Cost-benefit considerations are far more pre-eminent and efforts are being made to bring the benefits and risks of prevention (dikes), land-use planning, and crisis management together with the same common denominator.

The UK meanwhile, appears to be shifting to a more solidarity and government role, e.g. protection of less well-off areas. Since the 1960s, the UK has relied on a ‘gentlemen’s agreement’ between insurance companies and central government, leaving government largely out of the equation (Huber, 2005). But this agreement ran out in March 2013. While it might be argued that people should only insure for the risks they take and choices they make, a social-justice perspective requires everyone be insured (O’Neill and O’Neill, 2012). The 2007 floods case referred to above underscores the interconnected nature of the systems carrying the risks faced by the British population. Since 1998 there has been increasing demand for a greater government role to provide security following a series of floods. The Environment Agency (2005) wishes to take a more active role as protector, but it is poorly endowed. Insurers have also forced the government’s hand to invest more in infrastructure.

The physical or economic harm from risk displacement may be compensated for in the same or in another domain of security. For example, costs may be shared between upstreamers and downstreamers. Downstreamers may compensate upstreamers for losses incurred by altering their dam design (Hensengerth et al., 2012). Upstreamers may be paid for storing or diverting water to reduce flood risk for more populous downstream areas.

So if we start from the six sustainable livelihood domains identified by the UK’s Department for International Development (human, natural, social, physical, financial, and political) – which are similar to the five domains of security identified by Buzan et al., (1998) and modified by Warner (2004) (physical, political, environmental, economical, and socio-cultural) – some can complement each other. Security among those domains may, to a degree, be interchangeable. A loss of environmental security (natural capital) may be compensated for by greater economic security (financial).

7.4.1 Expanding security: water-food-energy nexus

While the iconic image of a child drinking from the tap is appealing, drinking water is only a fraction of water demand. Water problems are not generated only in the water sector and their solutions are not necessarily confined to the water sector (Lopez-Gunn et al., 2013). The 2011 Bonn ‘Nexus’ conference (adopted by the UN) sought, with considerable success, to broaden the concept of water security by adding energy and food security. This realisation in principle facilitates the zero-sum negotiation, in which 'I lose when you win'. In theory it facilitates plus-sum package deals – the environmental services that water provides can be enhanced if they do not all have to be produced where they are consumed. 'Virtual water', embedded in food and electricity, can be transported over much larger distances than the bulky and perishable water resource. Moreover, water for hydropower production is non-consumptive and, therefore, in principle, does not take away from its consumptive reuse.

The approach appears to lean heavily on liberal institutionalism[4] in international relations, with its foregrounding of complex interdependence and issue-linkage, enabled by side payments (Dombrowsky, 2009; Klaphake, 2005; Phillips et al., 2006). It largely ignores asymmetries of power and property rights, as well as the 'shadow of the past', which makes deal-making on basins, such as the Nile and Jordan, so cumbersome. Moreover, the spatial displacement of sources and beneficiaries requires giving up sovereignty and in so doing may clash with people's sense of security.

The approach points lead us to the possibility of widening the 'solution space'. However, as Espeland and Stevens (1998) have shown, not all values are commensurable. Cultural, religious, and humanitarian values, for example, cannot be 'sold'. Conflicts over water, such as described by Donahue and Johnson (1998), show that people experience the protection of identity and cultural and natural values as non-negotiable survival (life-and-death) issues.

7.5 Ask the people – security is a state of mind (and habit)

'*Danger is real, but risk is socially constructed*' (Slovic, 1999). '*Security is not a number, it is a feeling*', Huib de Vriend, Professor of Civil Engineering, Delft University, cited in Technisch Weekblad, 27 January 2007.

Another approach that may increase solution space is to acknowledge people's own perceptions of security. Interviews reveal that many people do not see themselves as vulnerable, even though they are fully aware of the risks and they do not always see floods as 'disasters'. This highlights the importance of the 'flood culture' developed by some communities. The governability or manageability of floods can be expressed as the ratio between the challenge and the coping capacity. If people (feel they) can manage, they are more resilient than if they are overwhelmed and at a loss. Disaster, then, denotes a period in which local coping capacity is overwhelmed and the sovereignty of individual or political systems is compromised – the *'cost of erosion of sovereignty*' (Phillips and Jagerskog, 2006).

The sense of what is a disaster is variable, and relates to culture and history. In the Netherlands, which after 1953 invested heavily in infrastructure to prevent coastal flooding ever happening again, any flood is now considered disastrous. In Bangladesh, by contrast, small floods are seen as good, as they provide environmental services, such as irrigation, flushing, and fish breeding environments. Communities that are exposed to flooding every year have adapted to this and may not see floods as dangerous, or even as events: '*aqui no pasa nada*' (nothing going on here).

Authors in the domain of disaster studies (e.g. Bankoff, 2001), have warned against the excesses of enlightenment ideology, labelling the south as dangerous, underdeveloped, and vulnerable. Interviews with local stakeholders reveal that people do not normally label themselves as

[4] Liberal institutionalism is a modern theory of international relations, which claims that international institutions and organisations, such as the United Nations, NATO, and the European Union, can increase and aid cooperation between States. (Source: Wikipedia).

'vulnerable', unless they have learned that they can use it to their advantage (Heijmans, 2012). It may highlight the importance of the 'flood culture' that many communities have developed in the face of recurrent hazard. Therefore, we should be mindful not to impose western views of danger and disaster onto others, by promoting disaster risk reduction and risk management. Placing 'security' on the agenda may make people feel more (unnecessarily?) insecure.

7.5.1 Lived security

Graciela Peters Guarin (Peters Guarin, 2009, Peters Guarin et al., no date) tried to remedy this bias. Peters triangulated vulnerability assessment based on geographical information system maps and door-to-door interviews about the 'manageability' of flooding, in terms of stage (waist deep, knee deep, ankle deep), and its duration in an area in the Philippines. This provided a more sophisticated manageability chart for that community. The results were surprising. People fare much better than predicted by the flood maps. In establishing people's 'flood security', therefore, this triangulation is vital to assess people's real needs.

Taking people seriously is still not common in the disaster risk reduction domain, which is largely a technocratic domain, and has tended to see people as irrational. Floodplains, coasts, and lakes are highly attractive places for settlement. That is, except for those populist groups who lionise local people and celebrate local knowledge and tacit know-how ('metis'). 'Flood culture' provides resilience to normal (not exceptional) floods. There must be a way of sailing in between the Scylla[5] of 'blaming the victim' when things go wrong and the Charybdis of 'celebrating the victim' when things go well. The people are not always wrong; but also they are not always right.

Stakeholders, even those with PhDs, cannot expect to be able to tackle the complexities of flood risk management. Training is needed for effective participation and proper facilitation.

7.6 Security impact analysis: *ex-ante* assessment of the security effect of interventions

When conflict arises over interventions, this is often evidence that consultative steps were skipped or values essential to certain actors were not recognised or taken seriously at the right moment. Too early, and it is too abstract for affected stakeholders (identification of so-called 'search areas'); too late and irreparable investment and sunk costs are incurred. A participatory prior security impact analysis (SIA) based on the five (or six) capitals stands to reason. Placing policies or interventions centre stage, Warner and Meissner (2008) proposed and initiated the development of a methodology for joint (multi-stakeholder) SIA of interventions in the transboundary Okavango delta, southern Africa This would predict and analyse the redistribution of actual and perceived security as a result of water development policies, interventions, and projects among the key stakeholder groups, including assessing their 'security absolutes' (inviolable values) based on textual analysis vs. a 'do-nothing' or 'do-something else' scenario. While that early exercise was an external assessment, progressive insight, such as the above, points us to the importance of an internal ('lived') assessment.

7.6.1 Other challenges

Apart from the negative coupling noted in the section on cascading effects, both floods and interventions may also have intentional and/or non-intentional positive externalities elsewhere, e.g.

[5] Scylla and Charybdis – monsters in Greek mythology that lived on opposite banks of a narrow waterway along which sailors must pass.

an upstream dam may reduce flood risk downstream as is the case for the downstream effects in Syria of Turkish dams. However, if there is neither trust nor a feedback loop of information and decision-making between the riparians, this may not be experienced as a benefit (Warner, 2011). There may also be positive spill-over (known as 'Jacobs externalities', after Jacobs, 1969), leading to mutually reinforcing security.

Problems concern uncertainties about the magnitude of direct and indirect short-term and long-term effects and interventions. Moreover, complicating the development of an indicator is the observation that both water challenges and affected/exposed populations are evolving and variable over time. There will also be interactions between these changes, in a process of co-evolution.

Still with that shortcoming we may advocate the further development of this method.

References

Alliance Development Works. (2012) World risk report. Available at: http://www.nature.org/ourinitiatives/habitats/oceanscoasts/howwework/world-risk-report-2012-pdf.pdf

Bankoff, G. (2001) Rendering the world unsafe: 'vulnerability' as western discourse. *Disasters* **25**(1):19–35.

Bauman, Z. (1999) Freiheit und Sicherheit. Die unvollendete Geschichte einer stürmischen Beziehung. pp. 23–34. In: Die neue Ordnung des Politischen. Die Herausforderungen der Demokratie am Beginn des 21 Jahrhunderts (Anselm, E., Freytag, A., Marschitz, W., und Marte, B. Eds). Campus Verlag, Frankfurt am Main, Germany and New York, NY, USA.

Beekman, G.B. (2002) Social change and water resource planning and development. *International Journal of Water Resources Development* **18**(1): 183–195.

Beetham, D. (1991) *The Legitimation of Power*. MacMillan, Basingstoke. UK.

Blaikie, P., Cannon, T., Davis, I., and Wisner, B. (1994) *At Risk: Natural Hazards, People's Vulnerability, and Disasters.* Routledge, London, UK.

Buzan, B., Waever, O., and de Wilde, J. (1998) Security: A New Framework for Analysis. Lynne Reinner Publishers Inc., London, UK.

Cullis, J. and van Koppen, B. (2007) Applying the Gini coefficient to measure inequality of water use in the Olifants River water management area, South Africa. Research Report 113. International Water Management Institute. (IWMI). Available at: http://www.iwmi.cgiar.org/publications/iwmi_research_reports/pdf/pub113/rr113.pdf

Dombrowsky, I. (2009) Revisiting the potential for benefit-sharing the management of transboundary rivers. *Water Policy* **11**(2):125–140.

Donahue, J.M. and Johnston, B.R. (Eds) (1998) *Water, Culture, and Power, Local Struggles in a Global Context*. Island Press, Washington, DC, USA.

Environment Agency UK. (2005) Addressing Environmental Inequalities: Flood Risk. Science Report: SC020061/SR1. Environment Agency, Bristol, UK.

Espeland, W.N. and Stevens, M.L. (1998) Commensuration as a social process. *Annual Review of Sociology.* **24**: 313–343.

Grey, D. and Sadoff, C. (2007) Sink or swim? Water security for growth and development. *Water policy* **9**: 545–571.

Hensengerth, O., Dombrowsky, I., and Scheumann, W. (2012) Benefit-sharing in dams on Shared Rivers. DIE Discussion paper 2012-6. DIE, Frankfurt am Main, Germany.

Heijmans, A. (2012) Risky encounters. Institutions and interventions in response to recent disasters and conflict. PhD dissertation. Wageningen University, Netherlands.

Heywood, A. (1994) *Political Theory: An Introduction*. Macmillan, Basingstoke, UK.

Huber, M. (2005) Reforming the UK flood insurance regime. The breakdown of a gentleman's agreement, ESRC/LSE, Discussion paper no. 18, Available at: www.lse.ac.uk/collections/CARR/pdf/Disspaper18.pdf

Jacobs, J. (1969) *The Economy of Cities*. Vintage, New York, NY, USA.

Johnson, C., Penning-Rowsell, E., and Parker, D. (2007) Natural and imposed injustices: the challenges in implementing 'fair' flood risk management policy in England. *Geographical Journal* **173**(4): 374–390.

Jonkman, S.N. (2005) Global perspectives on loss of human life caused by floods, *Natural Hazards* **34**: 151–175.

Keohane, R.O. and Nye, J. (1977) Realism and complex interdependence. pp. 20–32. In: *Power and Interdependence*. Third Edition. Longmans, New York, NY, USA**.**

Klaphake, A. (2005) Kooperation an internationalen Flüssen aus ökonomischer Sicht. Das Konzept des Benefit Sharing. Deutscheszed Institut für Entwicklungspolitik, Bonn, Germany.

Little, R. (2012) Case study. Managing the risk of aging infrastructure. Paper prepared for the International Risk Governance Council (IRGC), July.

Lopez-Gunn, E., Willarts, B., Corominas, J., and Llamas, R. (2013) The Spanish water "pressure cooker": threading the interplay between resource resilient water governance outcomes by strengthening the robustness of water governance processes. *International Journal of Water Governance* **1**(1): 1–28.

O'Neill, J. and O'Neill, M. (2012) Social justice and the future of insurance. Available at: http://www.jrf.org.uk/publications/social-justice-flood-insurance

Perrow, C. (1984) Normal Accidents: Living with High-risk Technologies. Princeton University Press, Princeton, NJ, USA.

Peters Guarin, G. (2009) Integrating local knowledge into GIS-based flood risk assessment. The case of Triangulo and Mabolo communities in Naga City. The Philippines. PhD Dissertation. University of Twente, Enschede, Netherlands.

Peters Guarin, G., McCall, M.K., and van Westen, C. (no date) Managing coping strategies and manageability. How participatory GIS can transform local knowledge into better disaster management. Available at: www.abuhrc.org/Publications/Working%20Paper%2022.pdf

Phillips, D.J.H., Daoudy, M., Öjendal, J., Turton, A.R., and McCaffrey, S. (2006) *Trans-boundary Water Cooperation as a Tool for Conflict Prevention and for Broader Benefit-Sharing*. Ministry of Foreign Affairs, Stockholm, Sweden.

Roth, D. and Warner, J. (2007) Flood risk, uncertainty and changing river protection policy In the Netherlands: the case of 'calamity polders'. *Tijdschrift voor Economische en Sociale Geografie* **98**(4): 519–525.

Jägerskog, A. and Phillips, D. (2006). Managing Trans-boundary Waters for Human Development. Human Development Report Office Occasional Paper 2006/9, United Nations Development Programme (UNDP): http://www.unwater.org/downloads/jagerskog_anders.pdf

Seekell, D.A., d'Odorico, P., and Pace, M.L. (2011) Virtual water transfers unlikely to redress inequality in global water use. *Environmental. Research Letters* **6**(2): 024017.

Sen, A.K. (1984), *Resources, Values and Development*, Basil Blackwell, Oxford, UK. Blackwell.

Slovic, P. (1999). Trust, emotion, sex, politics, and science: surveying the risk-assessment battlefield. *Risk Analysis* **19**(4), 689–701.

United Nations Development Programme (UNDP). (1994) *Human Development Report*. Oxford University Press, Oxford, UK and New York, NY, USA.

World Meteorological Organization (WMO). (2009) Integrated flood management. Concept paper WMO-No. 1047. UN Associated Program on Flood Management.

Warner, J., Butterworth, J., Wegerich, K., Mora Vallejo, A., Martinez, G., Gouet, C., and Visscher, J.T. (2009) Corruption risks in water licensing with case studies from Chile and Kazakhstan. Swedish Water House Report 27. SIWI. Available at: http://www.watergovernance.org/documents/WGF/Reports/Corruption_Risks_in_Water_Licensing.pdf

Warner, J.F. and Meissner, R. (2008) The politics of security in the Okavango River Basin: from civil war to saving wetlands (1975-2002) – a preliminary security impact assessment. pp. 252–286. In: *International Water Security: Domestic Threats and Opportunities* (Pachova, N.I., Nakayama, M., and Jansky, L. Eds). United Nations University Press, Tokyo, Japan, New York, NY, USA, and Paris, France.

Warner, J. (2011) *Flood Planning, The Politics of Water Security*. IB Tauris, London, UK.

Warner, Jeroen and Annemiek Verhallen (2004), Multi-Stakeholder Platforms for Integrated Catchment Management: Towards a comparative typology, paper presented at the MOPAN conference, Tilburg, June 2004.

Wegerich, K. (2007) A critical review of the concept of equity to support water allocation at various scales in the Amu Darya basin. *Irrigation and Drainage Systems* **21**(3-4): 185–195.

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Global Water Partnership (GWP), Global Secretariat, PO Box 24177, SE-104 51 Stockholm, Sweden
Phone: +46 8 1213 86 00, Fax: +46 8 1213 86 04, Email: gwp@gwp.org